Futuristic Trends in

Mechanical Engineering

Volume 3, Book 4, 2024, IIP Series

Iterative International Publishers

Futuristic Trends in

MECHANICAL ENGINEERING

Volume 3, Book 4, 2024, IIP Series

Title of the Book: Futuristic Trends in Mechanical Engineering

Edition: Volume 3, Book 4, 2024, IIP Series

Disclaimer

The authors are solely responsible for the contents published in this book. The publisher or editors do not take any responsibility for the same in any manner. Errors, if any, are purely unintentional and readers are requested to communicate such errors to the editors or publishers to avoid discrepancies in future.

ISBN: 978-93-6252-036-4

Publisher, Printed at & Distribution by:

Selfypage Developers Pvt. Ltd.,
Pushpagiri Complex,
Beside SBI Housing Board,
K.M. Road Chikkamagaluru, Karnataka.
Tel.: +91-8861518868
E-mail: info@iipseries.org

IMPRINT: I I P Iterative International Publishers

PREFACE

The primary goal of this book series is to promote research and developmental activities in mechanical engineering. It aims at promoting scientific information exchange among the academicians, researchers, developers, engineers, students, and practitioners working around the world. This book covers the chapters on Advances in Mechanical Engineering. It also focuses on a range of issues but not limited to

1. Strength of Materials and Solid Mechanics
2. Linear Elastic Solutions
3. Elasto-Plastic Solutions
4. Stress Distribution in Real Components
5. Advance Finite Element Modelling
6. Design of Composites
7. Design of Light Alloys
8. Design of Traditional Materials
9. Design of Cast Iron
10. Thermodynamics
11. Heat Transfer
12. Energy Conversion
13. Internal Combustion Engines
14. Fluid Mechanics
15. Fluid Statics
16. Fluid Dynamics
17. Applications for Hydropower Transmission
18. Mechanisms and Machine Design
19. Design Against Fracture
20. Design Against Fatigue
21. Engineering Design and Product Design
22. Computer-aided Design (CAD)
23. Computer-aided Manufacturing (CAM)
24. Instrumentation and Measurement
25. Vibration, Control Theory and Control Engineering
26. Mechatronics and Automation
27. Renewable Energy
28. Additive Manufacturing
29. Manufacturing Engineering, Technology, Processes
30. Marine Engineering
31. Aerospace Engineering

EDITORIAL BOARD MEMBERS

Mr Venkatesh Donekal
Department Of Mechanical Engineering
Ramaiah Institute of Technology
M S R Nagar, Msrit Post, Mathikere
Bangalore-560054, Karnataka State

Sneha
Assistant professor
Siddhartha Educational Academy Group of Institutions
Gollapalli, Tirupati

Dr. G M Swamy
Assistant Professor
Department of Mechanical Engineering
JSSATE, Bangalore

Venkatesh Begori
Professor
Professor of Mechanical Engineering
Vardhaman College of Engineering Kacharam Village
Shamshabad Mandal Rangareddy Dist PIN:501218
Telangana, India

Chitransh Atre
Doctoral Candidate
Project Officer
Department of Applied Mechanics
IIT Madras, IIT Madras
Chennai, pin- 600036, Tamil Nadu

Govindarajulu
Assistant Professor
VIgnan's Foundation for Science
Technology and Research Vadlamudi
Guntur, Andhrapradesh, India

Komal Mohan Garse
Assistant Professor
Department of Mechanical Engineering
Sinhgad College of Engineering
S. No. 44/1, Vadgaon (Budruk)
Off. Sinhgad Road
Pune 411 041.

Dr. S. Balamurugan
Professor And Head
Mechanical Engineering
Mahendra College of Engineering
Attur Main Road, Minnampalli Salem- 636106
Tamilnadu

Dr. Sivasankara Raju R
Associate Professor
Department of Mechanical Engineering
Aditya Institute of Technology and Management
K.Kotturu Tekkali-532201
Andhra Pradesh,India.

Prof. Soumya Ranjan Giri
Principal
Zenith Institute of Science And Technology
NH-16, Pitapalli, Khordha
Odisha, India.

Kanahaiya Lal Ambashtha
Assistant Professor
Faculty of Information Technology
Gopal Narayan Singh University
Sasaram, Bihar, India

CONTENTS

PART 4

PART 1

Futuristic Trends in Mechanical Engineering

Series Id: IIPV3EBS01_G24

Series Editors

Dr Raj Kumar

Ph.D. Assistant Professor

Swami Keshvanand Institute of Technology

Management and Gramothan

Ramnagriya, Jagatpura, Jaipur

Dr Amir Raza Subhani

Ph.D. Assistant Professor

Mechanical engineering Department

Siwan College of engineering and management

Surapur,Siwan, Bihar

Dr. Sachin Ghalme

Ph.D. Associate Professor

Department of Mechanical Engineering

Sandip Institute of Technology and Research Centre

Nashik (MS), Trimbak Road, Nashik

Dr Prakash T

Professor & Head

Department of Mechatronics Engineering

SNS College of Technology

Saravanampatti, Coimbatore - 641035

THE SIGNIFICANCE OF ENTROPY AND THE SECOND LAW OF THERMODYNAMICS: A DISCUSSION

Abstract

The study delves into the scientifically measured properties and laws of thermodynamics, a fundamental branch of physics that explores the transfer of heat and temperature between hot and cool reservoirs. Specifically, the focus of the discussion revolves around the four properties of thermodynamics, also known as measured properties, with a special emphasis on entropy, representing the state of a system characterized by disorder, uncertainty, and randomness. This concept of entropy holds a significant place in understanding the role of heat in our environment, as it always tends to increase.The scientific examination of thermodynamics and its association with entropy as a measure allows for a comprehensive analysis of various aspects. A dynamic effect can be achieved by employing tables about thermodynamics and entropy in evaluating the role of different energy conversion terms. In addition to defining and understanding the nature of these properties, the study explores the laws and equations integral to this field, providing a comprehensive understanding of the topic.By enhancing the effectiveness of the study, researchers can delve deeper into the intricate workings of thermodynamics, uncovering its implications and applications in various domains. This exploration enriches our understanding of the universe and facilitates advancements in energy conversion and utilization, paving the way for sustainable and efficient practices.

Keywords: Thermodynamics; scientific system; entropy; physics; energy conversion

Authors

Raj Kumar
Department of Mechanical Engineering
Swami Keshvanand Institute of Technology Management and Gramothan, Jaipur, India
raj.kumar@skit.ac.in

Kedar Narayan Bairwa
Department of Mechanical Engineering
Regional College for Education Research and Technology, Jaipur, India
bairwame79@gmail.com

I. INTRODUCTION

The second law of thermodynamics is a fundamental principle that states that the entropy of a system either increases or remains constant in any spontaneous process. Simply put, the second law implies that a hot object will naturally cool unless some external action is taken to prevent it. The essence of the second law can be further elucidated by considering the concept of entropy. Entropy can be considered a measure of the disorder or randomness within a system. According to the second law, the overall entropy of a closed system tends to increase over time. This means that as processes occur, the system becomes more disordered or its energy becomes more dispersed.A common example to illustrate this principle is the diffusion of a gas. Suppose a container initially has a high concentration of gas on one side and a low concentration on the other. In that case, the second law dictates that the gas molecules will naturally spread out over time to achieve a more uniform distribution. This increases entropy as the system becomes more disordered. Additionally, the second law of thermodynamics also addresses the issue of heat transfer between different temperature reservoirs. It states that heat cannot spontaneously flow from a lower-temperature reservoir to a higher-temperature one in a cyclic process. This principle is commonly called the Clausius statement of the second law. By understanding and applying the second law of thermodynamics, scientists and engineers can make informed decisions about energy conversion processes and develop technologies that maximize efficiency. It highlights the inherent limitations in certain energy transformations and underscores the importance of considering the directionality of processes in relation to energy flow and entropy change. Overall, the second law of thermodynamics is a fundamental concept that helps us comprehend the behavior of systems and processes regarding energy transfer, disorder, and the irreversibility of certain transformations. Its effective utilization leads to a better understanding of natural phenomena and guides us toward sustainable and efficient practices.

II. OBJECTIVES

The study paper aims to achieve several key objectives, enhancing our understanding of thermodynamics and its fundamental principles. These objectives are as follows:

1. **Evaluating the Role of Entropy as a Measure of Physical Property:** The study seeks to assess its significance as a measure of a system's physical property by delving into the concept of entropy. It aims to explore how entropy quantifies a system's disorder, uncertainty, and randomness, thus providing valuable insights into its behavior.

2. **Elaborating on the Second Law of Thermodynamics:** One of the primary objectives is to explain the second law of thermodynamics comprehensively. By elucidating this law, the study aims to unveil the inherent tendencies of natural processes, particularly how entropy either increases or remains constant in spontaneous processes.

3. **Examining the Energy Conservation Law:** The study also aims to investigate the energy conservation law within the framework of thermodynamics. By analyzing this principle, which states that energy cannot be created or destroyed but only converted from one form to another, the paper seeks to deepen our understanding of energy transformations and their implications.

4. **Analyzing the Role of the Second Law as a Universal Law of Increasing Entropy:** A crucial objective of the study is to highlight the second law of thermodynamics as a universal principle governing the behavior of systems. By exploring how the second law manifests as an overarching law of increasing entropy, the research aims to emphasize its broad applicability and fundamental nature.

5. **Summarizing the Problems of Thermodynamics:** The study also provides a comprehensive overview of the challenges and problems encountered in thermodynamics. By summarizing these issues, such as irreversibility, inefficiencies, and limitations in energy conversions, the paper aims to foster a deeper understanding of the practical and theoretical aspects of thermodynamics.

6. **Understanding the First Two Laws of Thermodynamics:** Lastly, the study aims to comprehend the first two laws of thermodynamics comprehensively. By examining these foundational laws, which pertain to energy conservation and the behavior of heat and work, the research aims to provide a solid foundation for understanding and applying thermodynamic principles.

   By accomplishing these objectives, the study of this paper contributes to advancing the knowledge of thermodynamics, providing valuable insights into the principles that govern energy, entropy, and the behavior of systems. It also highlights the practical implications of these concepts, paving the way for improved energy utilization and the development of sustainable technologies.

III. METHODOLOGY

The study places significant emphasis on the discipline of thermodynamics, aiming to provide authentic and genuine information regarding its laws and properties. To ensure the credibility and reliability of the information presented, a meticulous selection of secondary references from books, articles, and lecture papers has been undertaken [1]. This careful selection ensures that the study offers a concise yet comprehensive overview of thermodynamics, focusing on its immensely important topic and the four fundamental laws that govern it. The study guarantees that reputable sources and scholarly works back the information by relying on these credible sources. This approach adds weight and authority to the study, instilling confidence in the readers regarding the accuracy and validity of the information provided. This article recognizes the paramount importance of thermodynamics as a scientific discipline, acknowledging its wide-ranging implications and applications across various fields. By highlighting the significance of the four laws of thermodynamics, the study underscores their foundational role in understanding and explaining the behavior of energy, heat transfer, and entropy in natural systems.Through this effective approach, the study aims to provide a concise yet highly informative glimpse into the world of thermodynamics, offering readers a valuable and credible resource for exploring this fundamental branch of physics.

IV. LAW OF ENERGY CONSERVATION

Energy conservation is closely associated with preserving momentum, energy, and angular momentum. These fundamental quantities are interconnected and contribute to understanding energy transformations. For instance, the kinetic energy of an object can be utilized to power various processes, such as charging electric vehicles, highlighting the practical application of energy conversion. Traditionally, in classical mechanics, the conservation of mass and energy are treated as separate laws. However, in special relativity, a ground-breaking equation, $E=mc^2$, demonstrates the equivalence of energy and mass. This equation signifies that mass can be considered a form of energy, revealing the deep interplay between the two concepts. The conservation of mass and energy has significant implications across various scientific disciplines; Figure 1 shows the energy interaction in the form of heat and verifies the energy conservation law. From classical mechanics to special relativity, these principles guide our understanding of the fundamental nature of the universe. They provide a framework for comprehending the transformation and preservation of different forms of energy and matter[2,3].

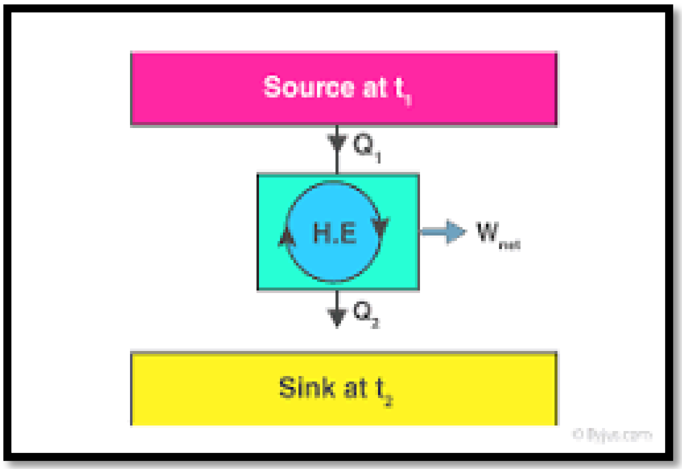


Figure 1: Interaction of heat between source and sink [2]

The scientific system is crucial for accurately characterizing and understanding energy within a given system. It allows us to precisely define the system’s state and is directly linked to that state. Consequently, it becomes essential to continually monitor and analyzeentropy changes, a fundamental property associated with the system. Among the intriguing aspects of thermodynamics are the laws governing heat transfer and temperature, which are measured properties.

V. THERMODYNAMICS AND ITS PROPERTIES AND LAWS

Thermodynamics, a branch of physics, encompasses essential properties such as heat, temperature, volume, and entropy. These properties play a significant role in understanding the behavior of systems. Additionally, thermodynamics is governed by four fundamental laws. Properties in thermodynamics can be classified into various categories based on the material they describe. In a laboratory setting, properties are referred to as measured properties, providing valuable information about the system's characteristics and behavior. Temperature and volume are tangible properties that can be more easily conceptualized. They are commonly used to specify the state of a system. However, entropy, while equally important, is a property that is not as readily visualized. It represents a system's degree of disorder, uncertainty, and randomness. Despite its abstract nature, entropy plays a crucial role in quantifying the behavior and equilibrium of thermodynamic processes. By presenting this information more effectively and readably, we highlight the significance of the properties in thermodynamics and the distinction between the easily visualized properties (heat, temperature, and volume) and the more abstract property of entropy. Laws of Thermodynamics are defined as the fundamental laws of physical quantities. There are 4 laws in the thermodynamics system laws [4]. The laws represent the behaviors of the physically measurable element in any circumstances. The 2nd law of thermodynamics says that in the process of the cyclic, heat cannot be gone from a lower temperature reservoir to a higher temperature reservoir. However, the state of entropy of the universe always increases over time as a system that is isolated [5]. The laws talk about heat, temperature, work, and entropy. This approach allows readers to grasp the importance of each property and understand their role in characterizing and analyzing thermodynamic systems. [6]

VI. THERMODYNAMICS AND THE 2ND LAW

The second law of thermodynamics encompasses two important concepts. First, it states that in a cyclic process, heat cannot spontaneously flow from a lower-temperature reservoir to a higher-temperature reservoir. This principle, known as the Kelvin-Planck statement of the second law, highlights the irreversible nature of heat transfer and the directionality of energy flow. However, the second law goes beyond this specific statement. It also encompasses the notion of the universe's entropy, which always increases over time in an isolated system, as shown in Figures 2 and 3. Entropy can be understood as a measure of the disorder or randomness within a system. The second law recognizes that in natural processes, the overall entropy of the universe tends to increase, leading to a progression toward a state of greater disorder. This increase in entropy is a fundamental characteristic of isolated systems, reflecting the tendency of energy to disperse and become more evenly distributed. It implies that spontaneous processes, left to their own devices, result in a net increase in entropy, contributing to the overall disorder of the system. By presenting these concepts concisely and readably, we can highlight the overarching idea of the second law of thermodynamics. It encapsulates both the restriction on heat transfer between temperature reservoirs in a cyclic process and the general trend of increasing entropy in isolated systems, underscoring the irreversibility and directionality of natural processes.

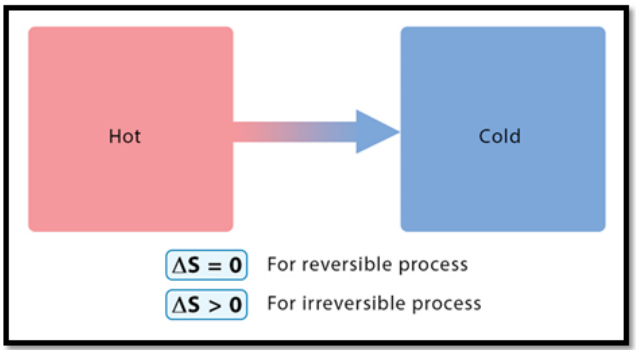


Figure 2: 2nd law of thermodynamics [8]

Moreover, the transfer of heat happens from higher to lower temperatures but never in a spontaneous way in the direction of the reversal [7]. So, one can say that any process is solely impossible to heat transfer from a cooler to an object of hotter.

Reversible (ideal):

$$\Delta S_{univ} = \Delta S_{system} + \Delta S_{surroundings} = 0$$

Irreversible (real, spontaneous):

$$\Delta S_{univ} = \Delta S_{system} + \Delta S_{surroundings} > 0$$

Figure 3: Entropy formula [9]

S is the symbol of the entropy property of thermodynamics. S is used to measure and calculate the equations related to the state of the disorder system [9].

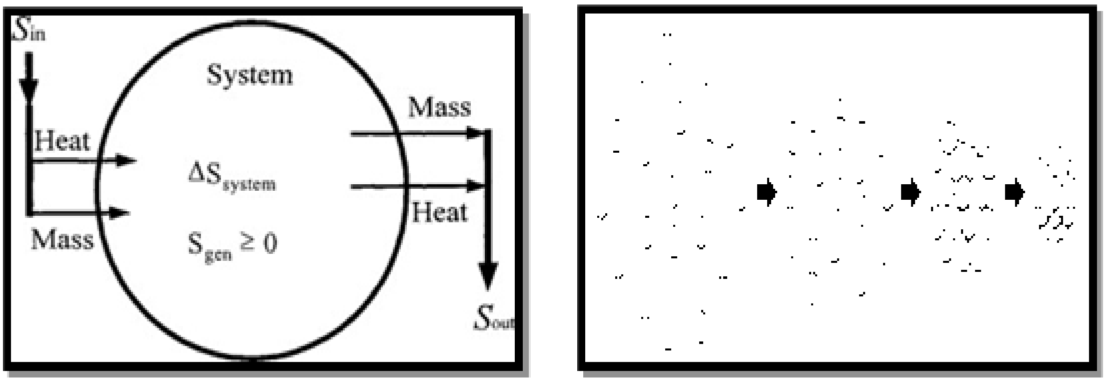
VII. ENTROPY AND PHYSICAL PROPERTY

Entropy, unlike easily visual properties such as temperature, volume, and pressure, is a unique property in thermodynamics. Denoted by the symbol S, entropy is an extensive property in every state of a system, intricately linked to its volume. However, comprehending entropy can be challenging due to its abstract nature and non-conserved characteristics. In thermodynamics, entropy represents the degree of disorder, randomness, and uncertainty within a system as shown in Figures 4 and5. It quantifies the energy distribution within a system and reflects the multiplicity of possible microscopic configurations that correspond to a given macroscopic state. Essentially, entropy measures how many different ways the particles of a system can be arranged while maintaining the same macroscopic properties.

While visualizing entropy directly may be elusive, its significance lies in its role as a fundamental property that influences the behavior of systems. As an extensive property, entropy scales with the size or amount of substance in a system. It can be altered through heat transfer, work, and energy conversion, affecting the overall behavior and equilibrium of the system. By understanding entropy as a property intricately tied to the volume of a system, researchers and practitioners in thermodynamics can analyze and manipulate its values to study and optimize various processes. The careful consideration of entropy enables the evaluation of energy efficiency, the identification of irreversible processes, and the design of efficient energy conversion systems[10,11,12].

Clausius's statement emphasizes that every physical system has a unique entropy associated with its state, representing nature's preference for that particular state. In any process occurring within the system, entropy can only increase; it never decreases. This entropy formulation directly led to the mathematical expression of the second law of thermodynamics.In simpler terms, the change in entropy over time will always be greater than or equal to the change in heat divided by the temperature. Another way to put it is that the change in entropy over time will always be greater than or equal to the initial entropy of the system [13].

Although entropy may not be readily visualized like other thermodynamic properties, it remains a crucial aspect of the discipline. Through its representation as an extensive and non-conserved property denoted by the symbol S, entropy plays a central role in characterizing a system's disorder and energy distribution, offering valuable insights into the behavior and equilibrium of thermodynamic processes.



.

Figure 4: Entropy and disorder [9]

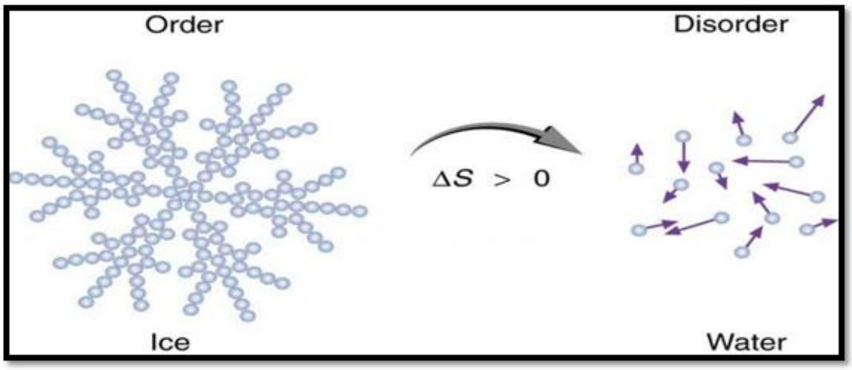


Figure 5: Transferring heat

If the state changes, it is directly associated with entropy's change. It is a state of disorder, uncertainty, and randomness [9,14].

The entropy measurement is based on the Shannon entropy formula, named after Claude Shannon, the "founder" of information theory. The equation H(X) = - P(x) * log2(P(x)) denotes the probability of each conceivable outcome 'x' in the system. In thermodynamics, entropy refers to the number of ways particles can be arranged on a microscopic scale within a system. A lower entropy indicates more order or information, while a higher entropy suggests more disorder. In information theory, entropy measures the amount of information required to encode or send a message, which is useful for recognizing patterns and compressing data effectively. Understanding entropy measurement can provide insights into complex systems and optimize operations in various sectors.Let's consider a mechanical system with a collection of gears with specific teeth arrangements. To understand the organization and performance of this system, we can measure its entropy. We can explore two scenarios to understand this better:Scenario 1: Low Entropy, Suppose the gears in the system are arranged meticulously, with each tooth aligned precisely with its neighboring gear. This arrangement creates a synchronized and highly ordered configuration. In this case, the probability (P(x)) of each specific tooth arrangement 'x' is relatively high, and the Shannon entropy calculation (H(X)) will yield a low value. This low entropy indicates minimal disorder and higher predictability. Such a well-ordered mechanical system ensures efficient power transmission without wastage due to misalignment or friction, making it ideal for smooth mechanical movements.Scenario 2: High EntropyImagine the gears scattered randomly within the system, with no alignment or coordination. The probability (P(x)) of each possible tooth arrangement 'x' is nearly equal, resulting in a uniform distribution. Consequently, the Shannon entropy calculation (H(X)) will produce a high value. This high entropy signifies a high level of disorder and unpredictability in the system's functioning. In such a state, the mechanical system may experience excessive friction, energy loss, and inefficiencies due to misalignments, leading to suboptimal performance.By measuring the entropy of this mechanical system, engineers and designers can identify whether it is operating optimally or requires adjustments to enhance its performance and efficiency. The goal should be to minimize entropy to achieve a well-ordered and smoothly functioning mechanical system [15,16].

So, it is defined as a measure of the propertyand capability of the system specifying the system, as shown in Table 1. Whereas Table 2 concludes the thermodynamic laws and their interaction with entropy.

Table 1: Entropy and a Measured Property

Entropy	**As a measured property**
Visual Aspects	Similar to other parameters like heat and temperature, it cannot be easily visualized.
Related to the state of a system	Directly associated with the state of the system, change with entropy changes.
Measurement property	To, related to system of uncertainly and disorder.

Table 2: Laws of Thermodynamics

Thermodynamics Law	**Relation to Entropy**
Zeroth Law	It is the foundation for defining temperature and establishing thermal equilibrium between systems. Entropy does not directly relate to the Zeroth Law, but it provides a conceptual framework for understanding temperature and its role in determining the direction of heat flow.
First Law	The First Law of Thermodynamics, also known as the Law of Energy Conservation, relates to the total energy of a system. It does not directly pertain to entropy, but it is crucial in understanding energy transfers and the balance between internal energy, heat, and work in a thermodynamic process [6, 14, 17].
Second Law	The Second Law of Thermodynamics is intimately connected to entropy. It states that the entropy of an isolated system either

	increases or remains constant in any spontaneous process. This law establishes the arrow of time, as entropy tends to increase, and serves to measure irreversibility and disorder in natural processes. The Second Law also governs the direction of heat transfer, prohibiting heat flow from a colder object to a hotter object without external intervention [6, 14, 17].
Third Law	The Third Law of Thermodynamics relates to the behavior of entropy at absolute zero temperature (0 Kelvin). It states that the entropy of a perfectly crystalline substance approaches zero as the temperature approaches absolute zero. This law establishes the reference point for measuring entropy and provides insight into the behavior of systems at extremely low temperatures [6,17,18].

VIII. CONCLUSION

This paper extensively explores the significance of entropy as a property of thermodynamics and delves into a detailed discussion of the laws governing these properties. It highlights the vital role of entropy as one of the measured elements in thermodynamics, essential for accurately defining and quantifying various system properties. Furthermore, the study recognizes the central role of entropy in calculating and determining the characteristics of different thermodynamic properties. By incorporating entropy as a key component, the study provides a comprehensive understanding of the measured properties within a laboratory setting. In conclusion, this study emphasizes the utmost importance of entropy and other measured properties in thermodynamics. By recognizing their crucial role, we gain valuable insights into the behavior and characteristics of systems. This enhanced understanding of entropy and other measured properties contributes to advancing scientific knowledge and enables more effective analysis and calculations within the realm of thermodynamics.

REFERENCES

[1] Beretta, G. P. (2020). The fourth law of thermodynamics: steepest entropy ascent. Philosophical Transactions of the Royal Society A, 378(2170), 20190168.
[2] Zhang, L., Bhatti, M. M., Marin, M., & S. Mekheimer, K. (2020). Entropy analysis on the blood flows through anisotropically tapered arteries filled with magnetic zinc-oxide (ZnO) nanoparticles. Entropy, 22(10), 1070.
[3] Ellahi, R., Raza, M., & Akbar, N. S. (2017). Study of peristaltic flow of nanofluid with entropy generation in a porous medium. Journal of Porous Media, 20, 461–478.
[4] Bhatti, M. M., Riaz, A. Z. L. S., Zhang, L., Sait, S. M., &Ellahi, R. (2021). Biologically inspired thermal transport on the rheology of Williamson hydromagneticnanofluid flow with convection: an entropy analysis. Journal of Thermal Analysis and Calorimetry, 144, 2187-2202.
[5] Sagawa, T. (2019). Second law, entropy production, and reversibility in thermodynamics of information. Energy Limits in Computation: A Review of Landauer’s Principle, Theory and Experiments, 101-139.
[6] Khan, M. I., &Alzahrani, F. (2020). The entropy-optimized dissipative flow of Carreau–Yasuda fluid with radiative heat flux and chemical reaction. The European Physical Journal Plus, 135, 1-16.
[7] Wang, R., Wang, C., LU, J., & Jiang, J. (2022). Inelastic thermoelectric transport and fluctuations in mesoscopic systems. Advances in Physics, 7(1), 1-60.
[8] Shan, S., & Zhou, Z. (2019). Second law analysis of spectral radiative transfer and calculation in one-dimensional furnace cases. Entropy, 21(5), 461.

[9] Khan, M. I., Khan, S. A., Hayat, T., &Alsaedi, A. (2019). Entropy optimization in the magneto-hydrodynamic flow of third-grade nanofluid with viscous dissipation and chemical reaction. Iranian Journal of Science and Technology, Transactions A: Science, 43, 2679-2689.
[10] Hayat, T., Khan, S. A., &Alsaedi, A. (2020). Simulation and modeling of entropy-optimized MHD flow of second-grade fluid with dissipation effect. Journal of Materials Research and Technology, 9(5), 11993-12006.
[11] Khan, S. A., Khan, M. I., Hayat, T., &Alsaedi, A. (2020). Darcy-Forchheimer hybrid (MoS2, SiO2) nanofluid flow with entropy generation. Computer Methods and Programs in Biomedicine, 185, 105152.
[12] Ahmad, A., Khan, M. I., H, Tasawar., &Alsaedi, A. (2018). Entropy generation optimization and unsteady squeezing flow of viscous fluid with five different shapes of nanoparticles. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 554, 197-210,
[13] Martin, S. J., Smith, N. A., & Francis, C.D. (2013). Removing the entropy from the definition of entropy: clarifying the relationship between evolution, entropy, and the second law of thermodynamics, Evolution: Education and Outreach, 6, 30, 1-9.
[14] Strasberg, P., & Winter, A. (2021). First and second law of quantum thermodynamics: a consistent derivation based on a microscopic definition of entropy. PRX Quantum, 2(3), 030202.1-030202.26.
[15] Dill, K. A., & Bromberg, S. (2003). Molecular driving forces: statistical thermodynamics in chemistry and biology. New York, NY: Garland Science.
[16] Gemmer, J., &Steinigeweg, R. (2014). Entropy increase in k-step Markovian and consistent dynamics of closed quantum systems, Physical Review E, 89, 042113
[17] Kondepudi, D., &Prigogine, I. (2014). Front Matter. In Modern Thermodynamics, Willey Publication, 1-560.
[18] Chen, Z., Mo, S., & Hu, P. (2008). Recent progress in thermodynamics of radiation—exergy of radiation, effective temperature of photon and entropy constant of the photon. Sci. Chin. Ser., 51, 1096.

EXPLORING USE OF COW URINE FOR EMMISON CONTROL

Abstract

Air pollution is becoming increasingly important for us due to the rising number of petrol and diesel engine vehicles, which is leading to a significant increase in pollution and contributing to global warming. Therefore, it is crucial that we work towards reducing air pollution. The primary objective of this research is to conduct an experimental inquiry aimed at diminishing the release of harmful pollutants, including Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO2), and Nitrous Oxide (NOX), originating from the internal combustion engine of motor vehicles. These noxious emissions stem from the combustion of fuel, contributing to environmental degradation. A promising strategy for mitigating the effluence of these hazardous compounds during the combustion process in vehicular engines involves the utilization of catalytic converters based on noble metals. These catalytic converters effectively transform detrimental CO and HC gases into less harmful byproducts such as CO2 and H2O. Nevertheless, addressing concerns associated with the availability and cost of noble metals prompts the exploration of innovative alternatives. In light of this, a unique approach is proposed, involving the application of natural fluids to curtail emission levels. As an integral part of this research endeavor, various natural liquids, including cow urine, were subjected to pH testing and subsequently introduced into the exhaust system as distinct liquid agents. This research aims to find an alternative and eco-friendly solution to curb automotive emissions and combat air pollution effectively.

Keywords: Air Pollution, Emmision, cow urine, Hydrocarbon, carbon monooxide.

Authors

Mr. Mohnesh Dnyaneshwar Mandhre
PhD Scholar
Department of Mechanical Engineering
Padmashri Dr. Vithalrao Vikhe Patil
Institute of Technology
A.Nagar, India.
mohneshphdwork@gmail.com

Dr. Sachin Ghalme
Associate Professor
Department of Mechanical Engineering
Sandip Institute of Technology and
Research Centre
Nashik, India.
sachin.ghalme@sitrc.org

Mr. Aditya B. Kale
HOD
Department of Mechanical Engineering
Shri Chhatrapti Shivaji Maharaj College
of Engineering
A.Nagar, India.
aditya.kale26@gmail.com

Mr.Amol Klahapure
Assistant Professor
Department of Mechanical Engineering
Shri Chhatrapti Shivaji Maharaj College
of Engineering
A.Nagar, India.
mdmscoea1@gmail.com

I. INTRODUCTION

In the realm of internal combustion engines (IC), the release of noxious gases such as HC, CO, and NOX stems from limitations within the engine's combustion cycle. These emissions are particularly pronounced during idling and deceleration, phases where the engine takes in reduced amounts of air for combustion. This phenomenon is primarily attributed to factors such as inadequate oxygen intake in high air-to-fuel mixtures, elevated temperatures prompting nitrogen-oxygen reactions, the presence of lean mixtures, porous deposits, and oil absorption.These emitted gases exert notable ecological impacts, contributing to concerns like the greenhouse effect, acid rain, and global warming. A multitude of strategies have been devised to mitigate engine emissions, encompassing measures like fuel pretreatment, the integration of renewable resources, and the incorporation of fuel additives. The current project proposes the development of an economical apparatus or model designed to regulate vehicle emissions. This innovative model is designed to be universally applicable across vehicle types and features the utilization of cow urine as an absorbent for harmful gases.The proposed model operates through a mechanism wherein exhaust gases from the engine are exposed to a fine mist of cow urine, dispensed through a nozzle. This interaction between cow urine and exhaust gases leads to a substantial reduction in the concentration of harmful constituents present in the emitted gases. These gases are then allowed to pass to atmosphere. In this experimental work; the objective is to modify the silencer of a two-wheeler to incorporate a natural liquid injection system. The selection of natural liquids for the system will be based on their physical and chemical properties, as well as their availability and cost. The modification of the silencer will be carried out in a manner that does not compromise the performance of the two-wheeler. The natural liquid will be injected into the silencer chamber, where it will blend with the exhaust gases, leading to a reduction in pollutants like carbon monoxide, hydrocarbons, and nitrogen oxides.

II. EXPERIMENTAL PROCEDURE

In this experiment Firstly we need to identify the pollutants emitted by two-wheelers whereas the initial step is to identify the various pollutants that are emitted by two-wheelers. Common pollutants include carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter. Then after studying the properties of natural liquid which having different natural liquids, such as water, cow urine, vegetable oil, and ethanol, have shown potential in reducing emissions from internal combustion engines. The properties of these natural liquids, along with their impact on engine performance, will be thoroughly studied. Lastly modifying the silencer which the silencer or muffler is a critical component of any vehicle designed to reduce engine noise. The modified silencer will be specifically designed to effectively mix the natural liquid with the exhaust gas, thus curbing the pollutants emitted by the engine.

Figure 1 : Experimrnt set up with cow urine

The first step is to design a mixing chamber that will be responsible for blending the natural liquid with the exhaust gas. This design should ensure uniform mixing while maintaining the engine's performance unaffected. Once the modified silencer is ready, it is imperative to conduct experiments to assess its efficiency in reducing emissions. Emissions testing will be performed both before and after installing the modified silencer.

After conducting the experiments, the collected data will be thoroughly analyzed to determine the effectiveness of the modified silencer in reducing emissions. In starting we obtain a standard two-wheeler in good working condition to be used for the experiment.

After that we construct a modified silencer capable of injecting the natural liquid into the exhaust stream of the two-wheeler. This can be achieved by attaching a container of the natural liquid to the silencer and connecting it to a tube leading into the exhaust pipe of the two-wheeler. Select a suitable natural liquid known for its ability to reduce exhaust emissions from internal combustion engines. In this experiment we select cow urine for experiment. But we having options may include a plant-based biofuel or a specially formulated additive designed for emission reduction. After selection of cow urine we set up measurement equipment, such as a gas analyzer, to measure emissions from the two-wheeler with and without the natural liquid injection system. Conduct a baseline test without the modified silencer and the natural liquid injection system to establish the emissions produced under normal conditions. Then install the modified silencer and natural liquid injection system on the two-wheeler and conduct another test under similar conditions as the baseline test. Record emissions measurements and compare them to the baseline results. Analyze the data collected from the tests to assess the effectiveness of the modified silencer and natural liquid injection system in reducing emissions from the two-wheeler. During the testing process, the selected liquids will be introduced into the liquid inlet valve as the flue gas passes through the silencer. The injected liquid will combine with the flue gas, resulting in the discharge of gases. Emission measurements will be taken using a gas analyzer to evaluate the results for each tested liquid.

Upon introducing water into the silencer, a chemical reaction ensues wherein it interacts with carbon monoxide. This interaction prompts the conversion of carbon monoxide into carbon dioxide and hydrogen gas. In a similar fashion, the incorporation of cow urine into the silencer initiates reactions with carbon monoxide, nitrogen oxide, and oxygen. These reactions facilitate the release of carbon dioxide, nitrogen, and water as byproducts. he introduction of water and cow urine into the exhaust system catalyzes transformations within the flue gases confined within the silencer. Consequently, these reactions facilitate the conversion of the original exhaust gases into environmentally benign compounds, including carbon dioxide, nitrogen, and water. This intricate process culminates in the regulated and controlled emission of exhaust gases.

III. RESULT AND DISCUSSION

The test results demonstrate that both the modified silencer and the natural liquid injection system effectively reduce emissions from the two-wheeler. The data gathered from the tests indicates that the combination of the modified silencer and natural liquid injection system significantly reduces the release of harmful gases, such as carbon monoxide and hydrocarbons, which are known to be detrimental to the environment and human health.

The incorporation of natural liquid into the modified silencer proves to be a promising approach for curbing emissions from two-wheelers. It is worth noting that further testing and research may be necessary to develop more advanced and efficient technologies for pollution control from internal combustion engines. Nevertheless, this experimental setup exhibits positive results in reducing emissions from two-wheelers and lays a strong foundation for future research in the field of pollution control.

In conclusion, the modified silencer and natural liquid injection system have the potential to contribute significantly to a cleaner and healthier environment by effectively reducing the emission of harmful gases.

The utilization of cow urine as a means to reduce pollutant particles involves exploiting its inherent properties to catalyze chemical reactions that lead to the transformation of harmful compounds into less harmful or inert substances. Cow urine comprises diverse components with the potential to engage with pollutant particles within exhaust emissions. Notably, cow urine includes ammonia (NH_3) and urea (NH_2CONH_2), both possessing the capability to interact with acidic and detrimental compounds. Ammonia, an alkaline substance naturally found in cow urine, can effectively react with acidic gases like sulfur dioxide (SO_2) and nitrogen oxides (NO_x) that are commonly present in exhaust discharges. The outcomes of these reactions involve the creation of ammonium salts, which exhibit decreased harm potential and can be safely deposited within the environment.

Table 1: Idling Emission

Parameter	Pollutant (as applicable)	Units (as applicable)	Average Reading	
			Before Experiment Set Up	After Experimernt Set Up
Idling Emissions	Carbon Monooxide (CO)	Percentage (%)	0.53	0.48

Parameter	Pollutant (as applicable)	Units (as applicable)	Average Reading	
			Before Experiment Set Up	After Experimernt Set Up
	Hydrocarbon (HC)	ppm	174	81

IV. CONCLUSION

The importance finding emerged from this investigation, can be as follows:

- It can be possible to reduce emission by using natural resources like cow urine.
- If we see result regarding Hydrocarbon it reduce by 50% with cow urine set up.

REFERENCES

[1] N. G. Renganathan, J. Jeyaprakash, and P. Renganathan, “Experimental Investigation on the Performance and Emission Characteristics of a SI Engine with Natural Gasoline and Methanol as Fuel,” International Journal of Engineering and Technology, vol. 3, no. 6, pp. 662–674, 2011.

[2] M.Shakthivel and R. Saravanan, “Experimental Investigation of Performance and Emission Characteristics of Single Cylinder SI Engine Fueled with Bio Diesel Blends,” International Journal of Engineering Science and Technology, vol. 3, no. 3, pp. 2399–2408, 2011.

[3] R. Vijayan and J. Kishore, “Experimental Investigation for Reducing Exhaust Emission in Two Wheeler by Using Nano Fuel Additives as Catalysts,” Proceedings of 2nd International Conference on Advances in Science & Technology, vol. 7, no. 2, pp. 228–234, 2017.

[4] A. Kiran Kumar and B. N. Nagesh, “Experimental Investigation on Pollution Control in Two Stroke SI Engine Using NanoFluids in Modified Silencer,” Proceedings of 2nd International Conference on Advances in Science, Engineering, Technology and Healthcare, vol. 3, no. 3, pp. 156–160, 2015.

[5] R.Saravanan and Chandrasekaran, “Experimental Investigation on the Performance and Emission Characteristics of a Two Stroke SI Engine using Natural Gasoline and Methanol as Fuel,” International Journal of Engineering Research and Technology, vol. 3, no. 2, pp. 2124–2129, 2014.

[6] Mohebi, A., Jafarzadeh, S., Pashae,J. and Shirnezhad, M., "Experimental studying of the effect of egr distribution on the combustion, emissions and performance in a turbocharged di diesel engine", International Journal of Engineering, Transactions A: Basics, Vol. 26, No. 1, (2013)

[7] Kousoulidou, M., Fontaras, G., Ntziachristos, L., Bonnel, P., Samaras, Z. and Dilara, P., "Use of portable emissions measurement system (PEMS) for the development and validation of passenger car emission factors", Atmospheric Environment, Vol. 64, (2013)

[8] Twigg, M.V., "Progress and future challenges in controlling automotive exhaust gas emissions", Applied Catalysis B: Environmental, Vol. 70, No. 1-4, (2007)

[9] Datta, A. and Mandal, B.K., "A comprehensive review of biodiesel as an alternative fuel for compression ignition engine", Renewable and Sustainable Energy Reviews, Vol. 57, (2016)

[10] Ghadikolaei, M.A., "Effect of alcohol blend and fumigation on regulated and unregulated emissions of ic engines—a review", Renewable and Sustainable Energy Reviews, Vol. 57, (2016)

EVALUATING ADDITIVE MANUFACTURING OPTIONS THROUGH TOPSIS METHOD: A COMPREHENSIVE DECISION-MAKING APPROACH

Authors

Dr. Prasanna M Bhagwat
Associate Professor
Mechanical Engineering
Sharad Institute of Technology College of Engineering
Yadrav, Ichalkaranji.

Abstract

In the current competitive landscape, various industries are actively seeking intelligent technologies to maintain competitiveness. These technologies assist research and development teams in clearly expressing ideas and swiftly introducing products to the market while minimizing production timelines and costs. Every additive manufacturing (AM) machine possesses distinct strengths in product fabrication, material utilization, and waste reduction. Key factors such as the costs of machinery and materials hold significant importance and greatly influence the assessment of prototype expenses. The primary considerations in additive manufacturing (AM) are the expenses associated with both machinery and materials. These factors, owing to their distinctive attributes, offer opportunities for cost reduction. Nevertheless, an alternative approach focuses on optimizing the manufacturing process and refining material usage, aiming to effectively lower the overall expenditure related to prototype production.

Research Significance: The research article utilized a multi-criteria decision-making method, TOPSIS, to choose the right material for the product, considering both end user preferences and additive manufacturing (AM). The initial step involves selecting the optimal machine from the available options, considering factors such as cost, precision, material range, and waste. Next, the suitable material is chosen based on respondent's needs. Finally, the key criteria impacting overall additive manufacturing (AM) cost are identified and utilized.

Methodology: TOPSIS helps decision makers select criteria based on respondent expectations. It employs pair wise comparisons using decision maker rankings to choose the right option. A thorough demonstration is presented, fully aligned with respondent needs. The methodology's output can be adjusted based on respondent requirements and machine availability.

Alternative parameters: Vero Black ,Vero White, Tango Black, DurusWhite, TangoPlu, TangoBlackPlus and Vero Clear.

Evaluation parameters: Mixing number, Number of digital materials, Cost, Elongation at break, Tensile strength, Shore hardness, Frequent order and Visual and aesthetic modeling.

Result: Materials were ranked with Vero White as the top choice and DurusWhite as the lowest. TangoBlackPlus ranked second, followed by Vero Clear in third, TangoPlu in fourth, Vero Black in fifth, and Tango Black in sixth. The final outcome assists in selecting suitable equipment and building materials for the prototype, based on respondent criteria.

Keywords: Additive manufacturing, TOPSIS Method, Vero White, Number of digital materials and Frequent order.

I. INTRODUCTION

Rapid prototyping, originating in the 1980s, involves creating 3D objects layer by layer using computer-aided design (CAD). The key benefit of Additive fabrication (AM) is its capability to construct virtually any shape through layer-by-layer fabrication. The STL (STereoLithography or Standard Tessellation Language) file format was introduced by 3D Systems in 1987 and rapidly became a standard in additive manufacturing. It's advantageous as it can be easily generated by all CAD applications.[1] Additive manufacturing (AM) prioritizes sustainability in concept selection, given concerns about pollution and resource scarcity. Sustainability is gaining importance in industrial sectors, allowing the manufacturing industry to achieve economic and social growth without harming the environment. The fourth industrial revolution (Industry 4.0) introduces AM as a smart manufacturing technology. AM is a category of manufacturing technologies that, in contrast to traditional methods, build three-dimensional components by layering materials, contributing to a more sustainable approach. Additive manufacturing is an emerging technique employed by diverse industries, with the potential to reduce environmental impact by minimizing waste and optimizing resource usage [2]. This relatively new manufacturing process enables the creation of intricate shapes rapidly and cost-effectively. Designers, upon realizing this potential, have adopted Design for Additive Manufacturing (DfAM) guidelines. These guidelines facilitate an integrated design approach, empowering product development teams to diminish or eliminate traditional machining constraints. This includes strategies like modular design, standard component utilization, the avoidance of separate fasteners, and minimizing assembly instructions, all aimed at achieving manufacturing parity. [3][4] Various additive manufacturing technologies, including Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA), are available. Additive manufacturing (AM) involves creating parts layer by layer, also known as layered manufacturing. AM is capable of constructing intricate structures more efficiently, with improved material properties. Multi-criterion decision-making (MCDM) problems, alternatively referred to as multi-attribute decision-making problems, pertain to situations where preference decisions are made by evaluating and ranking a limited set of alternatives based on multiple criteria. There are numerous MCDM difficulties in design for conventional manufacturing. This is also true in additive manufacturing (AM) design [7]. AM involves producing less waste during the manufacturing process, as well as the capacity to optimize geometries and manufacture light weight components that reduce material consumption. Furthermore, AM allows for the optimization of process parameters. AM has grown tremendously in popularity in recent years and is now commonly used. It has been motivated by unique properties such as coping with complex geometry, integrated assembly, and providing solutions to challenges encountered in traditional methods. It has certain downsides like as material costs, material availability, high prototype costs, and in some circumstances, real-time functional testing is problematic.[11] Additive Manufacturing (AM) methods have extensive applications in a wide range of industries . Micro fabrication has recently emerged as a viable use. A systematic approach to ranking candidate processes is required in order to identify an appropriate process for Micro fabrication. Many parameters can influence the selection of alternatives during the micro fabrication process. As a result, an approach that takes into consideration all factors is required [12] Nowadays, Additive Manufacturing (AM) is a popular manufacturing technique that introduces a novel approach to making several versions of complicated items with a material range. The key benefits of additive manufacturing include generating complex forms without any additional cost, procedures, or tooling; and decreasing product development cycles, as well as rising demand for customized and personalized items.13] Additive manufacturing, also known as 3D printing, is a new manufacturing technology that involves layering products from digital design files. In contrast to traditional subtractive manufacturing methods, which entail removing material from a solid block, additive manufacturing involves building up material to make the finished thing. In additive manufacturing, a variety of materials such as plastics, metals, ceramics, and even food can be used as "ink" [14]. The process starts with creating a digital 3D model using computer-aided design (CAD) software. This digital model is then divided into thin horizontal layers using slicing software. The physical object is built by the 3D printer, which reads these sliced layers and deposits material one layer at a time. This layer-by-layer approach offers several advantages, including increased design flexibility, reduced waste, and the ability to produce intricate geometries that would be challenging or impossible to achieve through standard manufacturing methods. Aerospace, automotive, healthcare, fashion, architecture, and consumer products have all found applications for additive manufacturing. It's utilized to make prototypes, finished goods, customized things, and even replacement parts. The technology is always evolving, providing new materials, higher precision, and faster production speeds, transforming it into a transformational force in modern manufacturing.[15]

II. MATERIALS AND METHODS

Alternative parameters: VeroBlack ,VeroWhite, TangoBlack, DurusWhite, TangoPlu, TangoBlackPlus and VeroClear.

1. **VeroBlack:** This photopolymer resin is a frequent choice for additive manufacturing techniques like stereolithography (SLA) and digital light processing (DLP) 3D printing. Its distinctive feature lies in its intense black hue and its ability to yield refined surface finishes. This characteristic positions it as an apt selection for fabricating models, prototypes, and functional components characterized by intricate details and a polished, professional aesthetic. Key characteristics of Vero Black resin include its high level of detail reproduction, excellent dimensional stability, and good mechanical properties. It is often chosen for applications where aesthetics and visual appeal are important, such as consumer products, jewelry, automotive components, and architectural models.

2. **VeroWhite:** This particular photopolymer resin is harnessed within additive manufacturing, specifically finding application in technologies like stereolithography (SLA) and digital light processing (DLP) 3D printing. Renowned for its pristine white hue, it excels in generating refined, polished surfaces. This attribute renders it ideal for crafting intricate models, prototypes, and functional components, all of which demand intricate detailing and a polished, professional appearance. One of the key characteristics of VeroWhite resin is its capacity to accurately reproduce intricate details, ensuring that the printed objects closely resemble the intended design. This is particularly advantageous for applications where aesthetics and visual fidelity are important, such as architectural models, consumer products, and medical prototypes. When working with VeroWhite resin, factors such as layer thickness, post-processing techniques, and the intended application should be taken into account to achieve the desired outcomes. Additionally, as with any material, the properties of Vero White resin can vary based on the specific 3D printer and settings used for printing.

3. **TangoBlack :** It refers to a specific type of rubber-like material used in additive manufacturing processes, particularly in technologies like PolyJet 3D printing. This material is characterized by its black color and its ability to replicate the look and feel of rubber, making it suitable for creating flexible and elastomeric parts, prototypes, and products with a range of applications. One of the prominent features of TangoBlack is its flexibility and rubbery texture, which allows for the production of objects with realistic tactile properties. This material is often chosen for applications where parts need to mimic the characteristics of rubber or other flexible materials, such as gaskets, seals, grips, and wearable products.

4. **DurusWhite:** It is a type of material commonly used in additive manufacturing processes, particularly in technologies like PolyJet 3D printing. This material is characterized by its durability and strength, making it suitable for creating robust and rigid parts, prototypes, and products across various industries.One of the standout features of DurusWhite is its high durability, which allows for the production of objects that can withstand mechanical stress and impact. This material is often chosen for applications where structural integrity and strength are important, such as functional prototypes, tooling, and components for engineering and manufacturing. When working with DurusWhite material, considerations such as layer thickness, print orientation, and post-processing methods are crucial to achieve the desired mechanical properties in the printed parts. As with any 3D printing material, the specific characteristics of DurusWhite can vary depending on the printer and settings used.

5. **TangoPlu, TangoBlackPlus :** TangoGray, TangoBlack, TangoPlus, and TangoBlackPlus are PolyJet rubber-like polymers. They provide varying degrees of elastomer characteristics: Shoreline scale VeroClear possesses the necessary characteristics of hardness, elongation at break, tear resistance, and tensile strength to cater to applications demanding non-slip or soft surfaces. These applications span various domains such as consumer electronics, medical devices, and automotive interiors. It finds ideal use in rubber surrounds over molding, soft-touch coatings, and non-slip surfaces. Moreover, it's well-suited for crafting exhibition and communication models, knobs, grips, handles, gaskets, seals, hoses, and footwear.

6. **Vero Clear:** It is a specific kind of photopolymer resin employed in additive manufacturing techniques, notably in technologies such as stereolithography (SLA) and digital light processing (DLP) 3D printing. This resin is known for its transparent and clear appearance, making it suitable for creating parts and prototypes that require optical clarity and visual transparency. Vero Clear resin's capacity to make parts with a smooth and glass-like surface is one of its primary qualities, enabling for the creation of transparent or translucent things with excellent accuracy and detail. This material is often chosen for applications in industries such as optics, design visualization, and consumer products where clear or see-through components are essential.

7. **Evaluation parameters:** Mixing number, Number of digital materials, Cost, Elongation at break, Tensile strength, Shore hardness, Frequent order and Visual and aesthetic modeling.

8. **Mixing number:** In additive manufacturing denotes the practice of blending multiple materials or substances during the 3D printing procedure. This involves creating customized blends of materials to achieve specific properties, colors, or functionalities in the final printed object. Mixing numbers can determine the ratios of different materials used, affecting the characteristics of the printed product. This technique allows for the creation of multi-material objects with varying textures, colors, and mechanical properties, expanding the possibilities for creating complex and versatile 3D printed items.

9. **Number of digital materials:** In additive manufacturing refers to how many different types of materials can be used in a 3D printing process. With advancements in technology, modern 3D printers can work with multiple materials simultaneously. This means that a single 3D print can use different materials to create objects with various colors, textures, and properties. Having a higher number of digital materials available allows for more creativity and customization in creating 3D printed items. It's like having a painter's palette with many colors to choose from, but in this case, it's a 3D printer creating objects with different materials.

10. **Cost:** Cost in additive manufacturing refers to how much it costs to create objects using 3D printing technology. This cost includes various factors, such as the materials used, the time taken to print, energy consumption, maintenance of the 3D printer, and any additional post-processing steps. The cost can vary based on the complexity and size of the object, the type of 3D printer, and the specific materials chosen. Additive manufacturing offers the advantage of creating intricate and customized objects, but it's important to consider the cost factors to make informed decisions about using this technology for different projects.

11. **Elongation at break:** It is an indicator of a material's ductility and pliability. Usually presented as a percentage, it reflects the extent to which a material can stretch or deform under stress until it ultimately fractures. This measurement provides insight into the material's ability to endure elongation before breaking occurs. Elongation at break is a crucial mechanical property to consider when designing and selecting materials for specific applications, as it indicates how well a material can endure strain and deformation without breaking.

12. **Tensile strength :** It refers to the highest level of stress a material can endure under pulling or stretching forces before reaching a point of fracture. This crucial mechanical property aids in gauging a material's resilience when subjected to tensile loads. Typically quantified in units like pounds per square inch (psi) or megapascals (MPa), tensile strength signifies the juncture on a stress-strain graph where a material initiates permanent (plastic) deformation and eventual rupture. In essence, it represents the maximum force a material can withstand per unit area prior to fracturing.

13. **Frequent orders:** It refers to a situation where a particular product or service is requested and purchased on a regular or recurring basis. In this context, customers or clients place orders for the same item or service repeatedly, often due to consistent demand or ongoing needs.Managing frequent orders effectively involves optimizing production, inventory management, and delivery processes to meet the recurring demand

and ensure customer satisfaction. Subscription models, automatic reorder systems, and personalized customer service often play roles in catering to customers who place frequent orders.

14. **Visual and aesthetic modeling:** It refers to the process of creating digital or physical representations of objects, designs, or concepts with a focus on their visual appeal and aesthetics. This type of modeling emphasizes the appearance, form, and overall visual impression of the subject. In various fields, such as art, design, architecture, and product development, visual and aesthetic modeling involves using techniques like 3D modeling software, computer-aided design (CAD), and physical prototyping to bring ideas to life in a visually pleasing way. This can include creating lifelike renderings, sculptures, digital mockups, and prototypes that showcase the design's aesthetics, color schemes, textures, and other visual aspects.

III. TOPSIS METHOD

TOPSIS serves as a commonly employed evaluation technique for addressing Multi-Criteria Decision-Making (MCDM) challenges. Its practical utility spans diverse domains, including assessing company performance, evaluating financial ratios within specific industries, and making informed financial investments in advanced manufacturing systems, among various other applications. However, it has some limitations. The TOPSIS technique, however, has several drawbacks. An important consideration that TOPSIS underscores is the potential for rank reversal to occur. This phenomenon arises when the addition or removal of an option within the decision context leads to a shift in the order of preference for the alternatives. The addition or removal of an option in the process can lead to a phenomenon known as total rank reversal. In such cases, the sequence of preferences is completely inverted, causing the formerly considered superior alternative to become the least favorable. In many cases, such an occurrence would be unacceptable. In MCDM, a variety of options must be analysed and evaluated using a number of criteria. The goal of MCDM is to assist the decision-maker in picking among alternatives. In this sense, practical situations are typically defined by a number of conflicting criteria, and no solution may fulfil all requirements at the same time. As a result, the response is a compromise choice depending on the decision-maker's preferences. TOPSIS operates on the principle that the ultimate solution should be maximally distant from the Negative Ideal Solution (NIS) and closest to the Positive Ideal Solution (PIS). The final ranking is established through a proximity measure.

Step 1: The decision matrix X, which displays how various options perform concerning certain criteria, is created.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2: Weights for the criteria are expressed as

$$w_j = [w_1 \cdots w_n], \quad where\ , \sum_{j=1}^{n}(w_1 \cdots w_n) = 1 \tag{2}$$

Step 3: The matrix x_{ij}'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sqrt[2]{\sum_{i=1}^{m} x_{ij}^2}} \tag{3}$$

The weighted normalized matrix \(N_{ij}\) is computed using the following formula:

$$N_{ij} = w_j \times n_{ij} \tag{4}$$

Step 4: Let's begin by identifying the optimal best and optimal worst values: Here, we must determine whether the influence is "+" or "-." If a column has a "+" impact, the ideal best value for that column is its highest value; if it has a "-" impact, the ideal worst value is its lowest value.

Step 5: Now we need to calculate the difference between each response from the ideal best,

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^+)^2} \qquad for\ i \in [1, m]\ and\ \ j \in [1, n] \tag{5}$$

Step 6: Now we need to calculate the difference between each response from the ideal worst,

$$S_i^- = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^-)^2}\ for\ i \in [1, m]\ and\ \ j \in [1, n] \tag{6}$$

Step 7: Now we need to calculate the Closeness coefficient of i^{th} alternative

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad where, 0 \leq CC_i \leq 1, i \in [1, m] \tag{7}$$

The Closeness Coefficient's value illustrates how superior the alternatives are in comparison. A larger CC_i denotes a substantially better alternative, whereas a smaller CC_idenotes a significantly worse alternative.

IV. RESULT AND DISCUSSION

Table 1: Additive Manufacturing Values

DATA SET								
	Mixing number	Number of digital materials	Cost	Elongation at break	Tensile strength	Shore hardness	Frequent order	Visual and aesthetic modeling
Vero Black	6	11	4	25	65	86	6	8
Vero White	5	30	5	25	65	86	9	8
Tango Black	5	19	6	55	2.4	62	7	5
Durus White	4	4	7	50	30	78	2	2
TangoPlu	3	23	8	220	1.5	28	9	6
TangoBlackPlus	3	36	8	220	1.5	28	7	5
Vero Clear	2	20	9	25	65	76	9	9

In the table 1 represents the values in the different properties or characteristics of each material, and the scale or units for each property may vary. For example in the Vero black, the values are Mixing number is 6, There are 11 digital materials available, the cost is rated at 4, elongation at break measures 25, tensile strength stands at 65, Shore hardness reaches 86, there are 6 instances of frequent orders, and the score for visual and aesthetic modeling is 8.

Table 2: Square Root of Matrix

Square root of Matrix							
36.00	121.00	16.00	625.00	4225.00	7396.00	36.00	64.00
25.00	900.00	25.00	625.00	4225.00	7396.00	81.00	64.00
25.00	361.00	36.00	3025.00	5.76	3844.00	49.00	25.00
16.00	16.00	49.00	2500.00	900.00	6084.00	4.00	4.00
9.00	529.00	64.00	48400.00	2.25	784.00	81.00	36.00
9.00	1296.00	64.00	48400.00	2.25	784.00	49.00	25.00
4.00	400.00	81.00	625.00	4225.00	5776.00	81.00	81.00

In this table 2 shows the square root operation has been applied to the numbers in the matrix provided.

Table 3: Normalized Data

Normalized data								
	Mixing number	Number of digital materials	Cost	Elongation at break	Tensile strength	Shore hardness	Frequent order	Visual and aesthetic modeling
Vero Black	0.5388	0.1828	0.2185	0.0774	0.5577	0.4803	0.3074	0.4627
Vero White	0.4490	0.4984	0.2732	0.0774	0.5577	0.4803	0.4611	0.4627
Tango Black	0.4490	0.3157	0.3278	0.1704	0.0206	0.3462	0.3586	0.2892
Durus White	0.3592	0.0665	0.3825	0.1549	0.2574	0.4356	0.1025	0.1157
TangoPlu	0.2694	0.3821	0.4371	0.6815	0.0129	0.1564	0.4611	0.3470
TangoBlackPlus	0.2694	0.5981	0.4371	0.6815	0.0129	0.1564	0.3586	0.2892
Vero Clear	0.1796	0.3323	0.4917	0.0774	0.5577	0.4244	0.4611	0.5205

These table3 shows the values appear to be normalized values based on the original data set, where each value is scaled to fall within a specific range (usually between 0 and 1) to facilitate comparisons and analysis. For example in the Vero White the values are Mixing number is 0.4490, Number of digital materials is 0.4984, Cost is 0.2732, Elongation at break is 0.0774, Tensile strength is 0.5577, Shore hardness is 0.4803, Frequent order is 0.4611 and Visual and aesthetic modeling is 0.4627.

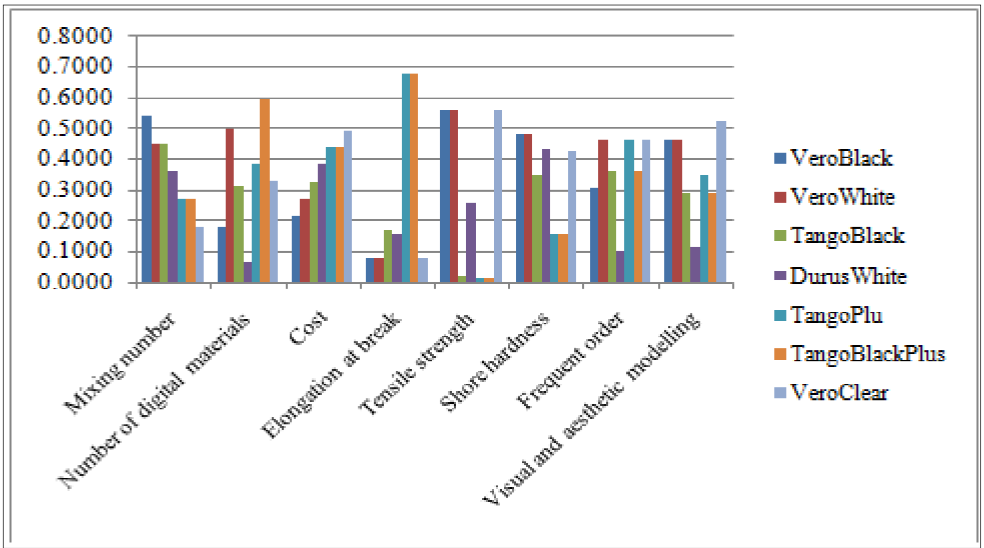


Figure 1: Normalized Data

This figure 1 shows the values appear to be normalized values based on the original data set, where each value is scaled to fall within a specific range (usually between 0 and 1) to facilitate comparisons and analysis. For example in the Vero White the values are Mixing number is 0.4490, Number of digital materials is 0.4984, Cost is 0.2732, Elongation at break is 0.0774, Tensile strength is 0.5577, Shore hardness is 0.4803, Frequent order is 0.4611 and Visual and aesthetic modeling is 0.4627.

Table 4: **Weights**

weights								
	Mixing number	Number of digital materials	Cost	Elongation at break	Tensile strength	Shore hardness	Frequent order	Visual and aesthetic modeling
Vero Black	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Vero White	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Tango Black	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Durus White	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
TangoPlu	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
TangoBlackPlus	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Vero Clear	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16

These weights are evenly distributed (0.16 each) across all properties for each material. Weighting is often used in analysis to assign different levels of importance to different properties or factors when making evaluations or calculations.

Table 5: Weighted Normalized Decision Matrix

weighted normalized decision matrix								
	Mixing number	Number of digital materials	Cost	Elongation at break	Tensile strength	Shore hardness	Frequent order	Visual and aesthetic modeling
Vero Black	0.0862	0.0292	0.0350	0.0124	0.0892	0.0768	0.0492	0.0740
Vero White	0.0718	0.0797	0.0437	0.0124	0.0892	0.0768	0.0738	0.0740
Tango Black	0.0718	0.0505	0.0525	0.0273	0.0033	0.0554	0.0574	0.0463
Durus White	0.0575	0.0106	0.0612	0.0248	0.0412	0.0697	0.0164	0.0185
TangoPlu	0.0431	0.0611	0.0699	0.1090	0.0021	0.0250	0.0738	0.0555
TangoBlackPlus	0.0431	0.0957	0.0699	0.1090	0.0021	0.0250	0.0574	0.0463
Vero Clear	0.0287	0.0532	0.0787	0.0124	0.0892	0.0679	0.0738	0.0833

In this table 5, the values have been multiplied by the corresponding weights for each property, creating a weighted score for each material across the different properties. This approach allows for a more comprehensive evaluation of the materials, taking into account the assigned importance of each property. For example, in the Tango Black the values are Mixing number is 0.0718, Number of digital materials is 0.0505, Cost is 0.0525, Elongation at break is 0.0273, Tensile strength is 0.0033, Shore hardness is 0.0554, Frequent order is 0.0574 and Visual and aesthetic modeling is 0.0463.

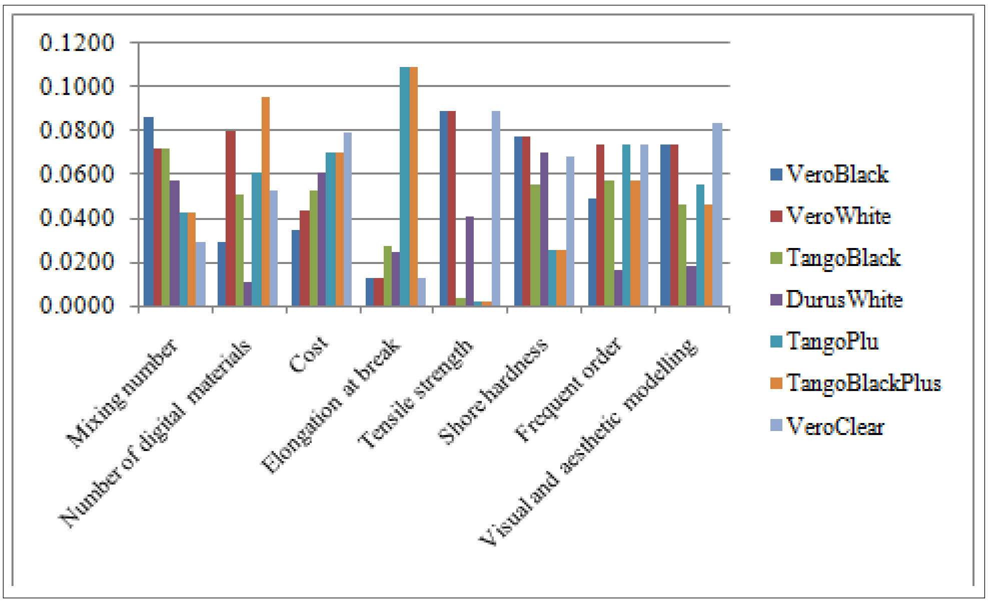


Figure 2: Weighted Normalized Decision Matrix

In this figure 2, the values have been multiplied by the corresponding weights for each property, creating a weighted score for each material across the different properties. This approach allows for a more comprehensive evaluation of the materials, taking into account the assigned importance of each property. For example, in the Tango Black the values are Mixing number is 0.0718, Number of digital materials is 0.0505, Cost is 0.0525, Elongation at break is 0.0273, Tensile strength is 0.0033, Shore hardness is 0.0554, Frequent order is 0.0574 and Visual and aesthetic modeling is 0.0463.

Table 6: Positive Matrix

Positive Matrix							
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833
0.0862	0.0957	0.0787	0.1090	0.0892	0.0768	0.0738	0.0833

In this table 6 appears to be a positive matrix with constant values. This matrix consists of the same values repeated throughout, which suggests that each element of the matrix has been assigned a constant value.

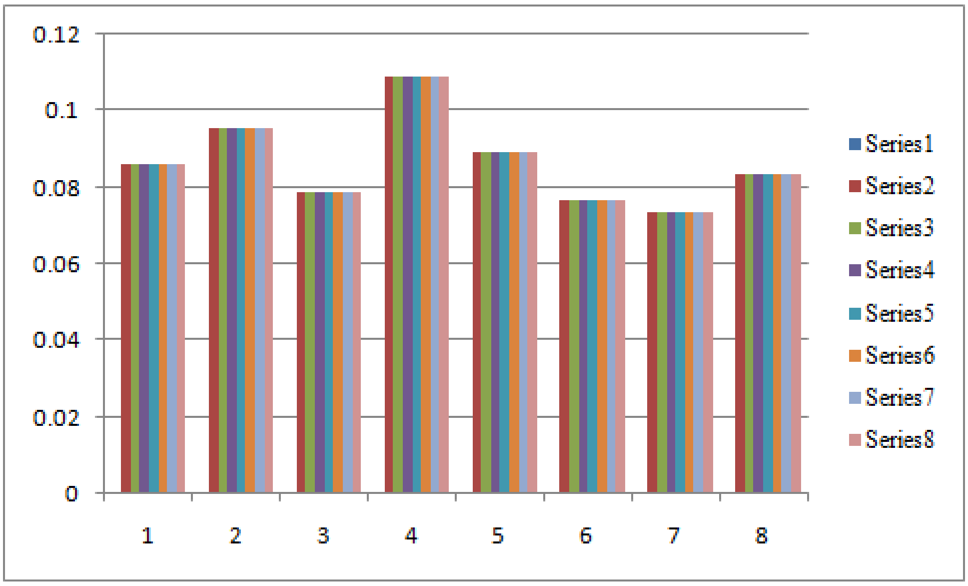


Figure 3: Positive Matrix

In this figure 3 appears to be a positive matrix with constant values. This matrix consists of the same values repeated throughout, which suggests that each element of the matrix has been assigned a constant value.

Table 7: Negative Matrix

Negative matrix							
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185
0.0431	0.0106	0.0350	0.0124	0.0021	0.0250	0.0164	0.0185

In this table 7 appears to be a negative matrix with constant values. This matrix consists of the same values repeated throughout, which suggests that each element of the matrix has been assigned a constant negative value.

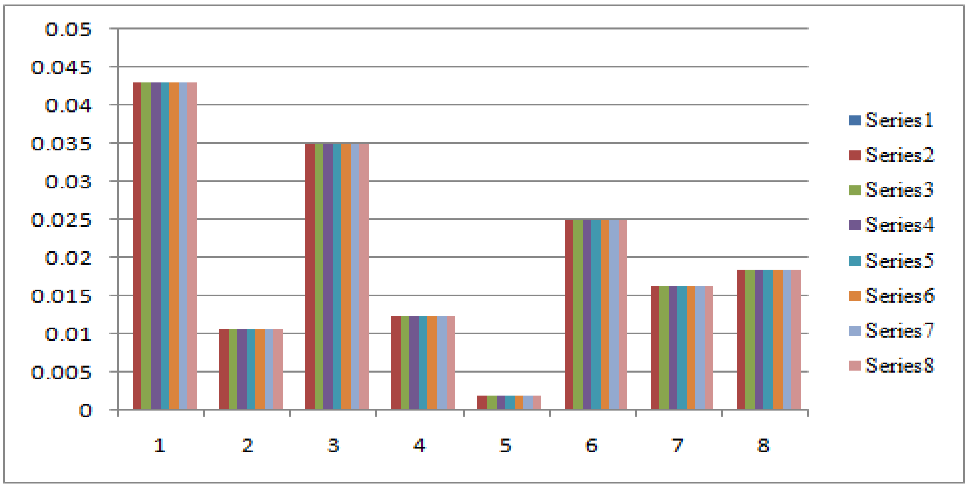


Figure 4: Negative Matrix

In this figure 4 appears to be a negative matrix with constant values. This matrix consists of the same values repeated throughout, which suggests that each element of the matrix has been assigned a constant negative value.

Table 8: SI Plus, Si Negative and Ci

	SI Plus	Si Negative	Ci
Vero Black	0.1279	0.1290	0.5022
Vero White	0.1054	0.1495	0.5864
Tango Black	0.1382	0.0795	0.3651
DurusWhite	0.1591	0.0676	0.2983
TangoPlu	0.1191	0.1333	0.5282
TangoBlackPlus	0.1177	0.1423	0.5473
Vero Clear	0.1206	0.1444	0.5450

This table 8 shows to represent different materials with corresponding values for "SI Plus," "Si Negative," and "Ci" properties. For example in the Vero Black the values are SI Plus is 0.1279, Si Negative is 0.1290 and Ci is 0.5022.

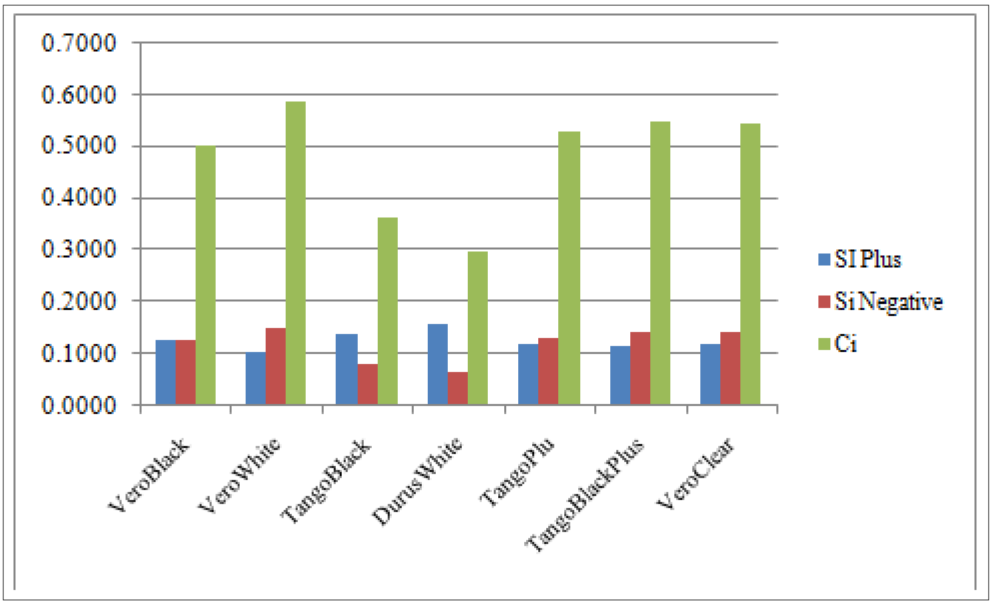


Figure 5: SI Plus, Si Negative and Ci

This figure 5 shows to represent different materials with corresponding values for "SI Plus," "Si Negative," and "Ci" properties. For example in the Vero Black the values are SI Plus is 0.1279, Si Negative is 0.1290 and Ci is 0.5022.

Table 9: Rank

Rank	
Vero Black	**5**
Vero White	**1**
Tango Black	**6**
DurusWhite	**7**
TangoPlu	**4**
TangoBlackPlus	**2**
Vero Clear	**3**

This table 9 shows the ranking of different materials. Each material is assigned a rank based on its position in the list. Vero White got the first rank and the DurusWhite got the last rank..The second rank has TangoBlackPlus, the third rank has Vero Clear,the fourth rank has TangoPlu, the fifth rank has Vero Black and, the sixth rank has Tango Black.

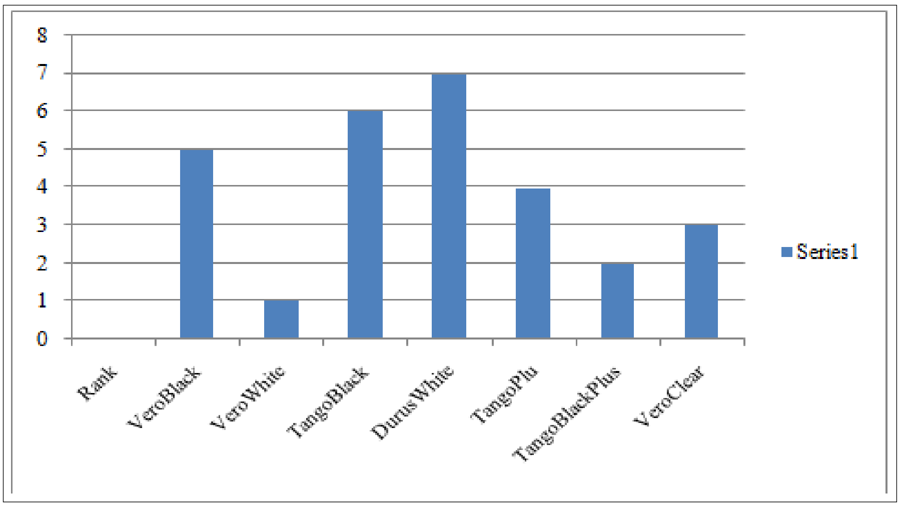


Figure 6: Rank

This figure 6 shows the ranking of different materials. Each material is assigned a rank based on its position in the list. Vero White got the first rank and the DurusWhite got the last rank..The second rank has TangoBlackPlus,the third rank has Vero Clear, the fourth rank has TangoPlu, the fifth rank has Vero Black and, the sixth rank has Tango Black.

V. CONCLUSION

Utilizing additive manufacturing has the capability to swiftly introduce novel designs to the market and contribute to prolonged market viability. The process of selecting the most appropriate Objet260 Connex machine involved a thorough comparison of numerous options among the machines at hand. In this study, the TOPSIS Multi-Criteria Decision-Making (MCDM) methodology is employed. It aids in the choice of an appropriate material from an extensive array of options for the designated Objet260 Connex machine. This research introduces an innovative and optimal approach to both the manufacturing process and decision-making strategies within additive manufacturing, even when faced with intricate design challenges. It offers a superior ranking of construction materials according to the needs of respondents, facilitating tailored services aligned with customer demands. This approach notably minimizes material wastage when transitioning between different materials for varying product types. Furthermore, it empowers customers with a comprehensive understanding of the feasible materials available for their requirements, a perspective that might not have been previously considered. Each material is assigned a rank based on its position in the list. Vero White got the first rank and the DurusWhite got the last rank.The second rank has TangoBlackPlus,the third rank has Vero Clear, the fourth rank has TangoPlu, the fifth rank has Vero Black and, the sixth rank has Tango Black.

REFERENCES

[1] Gardan, Julien. "Additive manufacturing technologies: state of the art and trends." Additive Manufacturing Handbook (2017): 149-168.

[2] Chandra, Mukesh, Faisal Shahab, Vimal KEK, and Sonu Rajak. "Selection for additive manufacturing using hybrid MCDM technique considering sustainable concepts." Rapid Prototyping Journal 28, no. 7 (2022): 1297-1311.

[3] Raigar, Jairam, Vishal S. Sharma, Shekhar Srivastava, Ramesh Chand, and Jaivir Singh. "A decision support system for the selection of an additive manufacturing process using a new hybrid MCDM technique." Sādhanā 45 (2020): 1-14.
[4] Uz Zaman, Uzair Khaleeq, Mickael Rivette, Ali Siadat, and Seyed Meysam Mousavi. "Integrated product-process design: Material and manufacturing process selection for additive manufacturing using multi-criteria decision making." Robotics and Computer-Integrated Manufacturing 51 (2018): 169-180.
[5] Wang, Yuanbin, Robert Blache, and Xun Xu. "Selection of additive manufacturing processes." Rapid prototyping journal 23, no. 2 (2017): 434-447.
[6] Agrawal, Rohit. "Sustainable material selection for additive manufacturing technologies: A critical analysis of rank reversal approach." Journal of Cleaner Production 296 (2021): 126500.
[7] Chaudhuri, Atanu, Hasse Andreas Gerlich, Jayanth Jayaram, Abhijeet Ghadge, Johan Shack, Benjamin Hvidberg Brix, Lau Holst Hoffbeck, and Nikolaj Ulriksen. "Selecting spare parts suitable for additive manufacturing: a design science approach." Production Planning & Control 32, no. 8 (2021): 670-687.
[8] Agrawal, Rohit, and S. Vinodh. "Prioritisation of drivers of sustainable additive manufacturing using best worst method." International Journal of Sustainable Engineering 14, no. 6 (2021): 1587-1603.
[9] Huang, Meifa, Leilei Chen, Yanru Zhong, and Yuchu Qin. "A generic method for multi-criterion decision-making problems in design for additive manufacturing." The International Journal of Advanced Manufacturing Technology 115, no. 7-8 (2021): 2083-2095.
[10] Palanisamy, Manivel, Arivazhagan Pugalendhi, and Rajesh Ranganathan. "Selection of suitable additive manufacturing machine and materials through best–worst method (BWM)." The International Journal of Advanced Manufacturing Technology 107 (2020): 2345-2362.
[11] Qin, Yuchu, Qunfen Qi, Paul J. Scott, and Xiangqian Jiang. "An additive manufacturing process selection approach based on fuzzy Archimedean weighted power Bonferroni aggregation operators." Robotics and Computer-Integrated Manufacturing 64 (2020): 101926.
[12] Anand, M. B., and S. Vinodh. "Application of fuzzy AHP–TOPSIS for ranking additive manufacturing processes for microfabrication." Rapid Prototyping Journal 24, no. 2 (2018): 424-435.
[13] Kadkhoda-Ahmadi, Shervin, Alaa Hassan, and Elnaz Asadollahi-Yazdi. "Process and resource selection methodology in design for additive manufacturing." The International Journal of Advanced Manufacturing Technology 104 (2019): 2013-2029.
[14] Hodonou, C., O. Kerbrat, Marek Balazinski, and Myriam Brochu. "Process selection charts based on economy and environment: subtractive or additive manufacturing to produce structural components of aircraft." International Journal on Interactive Design and Manufacturing (IJIDeM) 14 (2020): 861-873.
[15] Alghamdy, Mohammed, Rafiq Ahmad, and Basel Alsayyed. "Material selection methodology for additive manufacturing applications." Procedia CIRP 84 (2019): 486-490.
[16] Wang, Yuanbin, Ray Y. Zhong, and Xun Xu. "A decision support system for additive manufacturing process selection using a hybrid multiple criteria decision-making method." Rapid Prototyping Journal 24, no. 9 (2018): 1544-1553.
[17] Niaki, Mojtaba Khorram, S. Ali Torabi, and Fabio Nonino. "Why manufacturers adopt additive manufacturing technologies: The role of sustainability." Journal of cleaner production 222 (2019): 381-392.
[18] Wang, YuanBin, Pai Zheng, Tao Peng, HuaYong Yang, and Jun Zou. "Smart additive manufacturing: current artificial intelligence-enabled methods and future perspectives." Science China Technological Sciences 63, no. 9 (2020): 1600-1611.
[19] Liu, Guang, Yi Xiong, and Limin Zhou. "Additive manufacturing of continuous fiber reinforced polymer composites: Design opportunities and novel applications." Composites Communications 27 (2021): 100907.
[20] Wang, Yuanbin, Yuan Lin, Ray Y. Zhong, and Xun Xu. "IoT-enabled cloud-based additive manufacturing platform to support rapid product development." International Journal of Production Research 57, no. 12 (2019): 3975-3991.
[21] Ren, Diqian, Jun-Ki Choi, and Kellie Schneider. "A multicriteria decision-making method for additive manufacturing process selection." Rapid Prototyping Journal 28, no. 11 (2022): 77-91.
[22] Ransikarbum, Kasin, Rapeepan Pitakaso, Namhun Kim, and Jungmok Ma. "Multicriteria decision analysis framework for part orientation analysis in additive manufacturing." Journal of Computational Design and Engineering 8, no. 4 (2021): 1141-1157.
[23] uz Zaman, Uzair Khaleeq, Mickael Rivette, Ali Siadat, and Aamer Ahmed Baqai. "Integrated design-oriented framework for Resource Selection in Additive Manufacturing." Procedia Cirp 70 (2018): 96-101.

[24] Vinodh, S., and Priyanka Shinde. "Parametric optimization of 3D printing process using MCDM method." In Precision Product-Process Design and Optimization: Select Papers from AIMTDR 2016, pp. 141-159. Springer Singapore, 2018.
[25] Taddese, Getasew, Severine Durieux, and Emmanuel Duc. "Sustainability performance indicators for additive manufacturing: a literature review based on product life cycle studies." The International Journal of Advanced Manufacturing Technology 107 (2020): 3109-3134.
[26] Asadollahi-Yazdi, Elnaz, Julien Gardan, and Pascal Lafon. "Multi-objective optimization approach in design for additive manufacturing for fused deposition modeling." Rapid Prototyping Journal 25, no. 5 (2019): 875-887.
[27] Achillas, Ch, D. Aidonis, E. Iakovou, M. Thymianidis, and D. Tzetzis. "A methodological framework for the inclusion of modern additive manufacturing into the production portfolio of a focused factory." Journal of manufacturing Systems 37 (2015): 328-339.
[28] Sartini, Mikhailo, Manuguerra Luca, Favi Claudio, and Mandolini Marco. "A MULTI-CRITERIA DECISION-MAKING APPROACH TO OPTIMIZE THE PART BUILD ORIENTATION IN ADDITIVE MANUFACTURING." Proceedings of the Design Society 3 (2023): 293-302.
[29] Jayapal, Jayakrishnan, Senthilkumaran Kumaraguru, and Sudhir Varadarajan. "Evaluation of Computationally optimized Design Variants for Additive Manufacturing Using a Fuzzy MCDM Approach." (2022).
[30] Khalid, Marwan, and Qingjin Peng. "Sustainability and environmental impact of additive manufacturing: a literature review." Computer-Aided Design and Applications 18, no. 6 (2021): 1210-1232.

EFFECT OF WDEM PROCESS PARAMETERS ON TiNi SHAPE MEMORY ALLOY

Abstract

Ti-Ni alloys are a vital class of shape memory alloys (SMAs). Lately, materials, for example, Ti-Ni based SMAs and different SMAs are normally utilized in therapeutic and a few building uses. Therapeutic application incorporates eye glass frame, careful stent, orthodontic arch wire, dynamic catheter and modern building application is practical gadgets, for example, latches, fixing and coupling, aviation actuators, sensors, radio wires and fuel injector.

Due to its excellent quality at lower to direct temperatures, shape memory effect (SME), excellent wear resistance, considerable consumption resistance, lightweight, high biocompatibility, etc., Ti-Ni combinations are frequently used. When Ti and Ni are combined, the microstructure often goes through a martensitic stage at lower temperature and an austenitic stage at higher temperature.

WEDM uses can likewise be found in therapeutic, optical, dental and R and D regions. Other famous use for WEDM is cutting of extrusion dies.

Integrated shape of Ti-Ni SMAs is hard to machine by conventional machining, in that case WEDM is preferred also the WEDM very precise, accurate and irregular intricate shape can be produced.

Keywords: Ti-Ni, WEDM, SMAs,.

Author

Dr. Adik M. Takale
Associate Professor
Department of Mechanical Engineering
Sharad Institute of Technology
College of Engineering
Maharashtra, India.
adik1617@rediffmail.com

Mr. G. V. Pujari
Assistant Professor
Department of Mechanical Engineering
Sharad Institute of Technology
College of Engineering
Maharashtra, India.
pujari.ganesh@sitcoe.org.in

Mr. P. S. Chougule
Assistant Professor
Department of Mechanical Engineering
Sharad Institute of Technology
College of Engineering
Maharashtra, India.
pschougule@sitcoe.org.in

I. INTRODUCTION

In this chapter, the properties and the processes of machining of SMAs are discussed. A brief review of non- conventional machining of SMAs is presented. The basic principles of macro-WEDM and micro-WEDM processes are elucidated. Also, the research objectives, the scope of research work and the outline of the examination work are presented.

1. **Shape Memory Alloy:** An SMA is a combination that "recollects" its unique shape and not long after miss happening come back to it pre-disfigured shape when heated. SMA is a low-weight, strong state option in contrast that traditional actuator, such as, pressure driven, pneumatic and engine operated framework. SMAs have applications in mechanical autonomy and biomedical ventures.

   The two primary kinds of SMAs are CuAlNi and Ti-Ni alloys. SMAs can likewise be made by blending Zn, Cu, Au and Fe in right extents. The Fe based, Cu-based SMAs, like, Fe-Mn-Si, Cu-Zn-Al and Cu-Al-Ni industrially suitable and cheap compared Ti-Ni. In any case, Ti-Ni based SMAs have been favored for more therapeutic and designing application because of its strength, superior thermo-mechanic, and practicability characteristics.

2. **One-Way Vs. Two-Way Shape Memory:** Ho et al. (2004) [1] observed that SMAs have various shape memory effects (SMEs). Two basic impacts is one- way and two-way shape memory. Result of impacts appears in Figure 1.

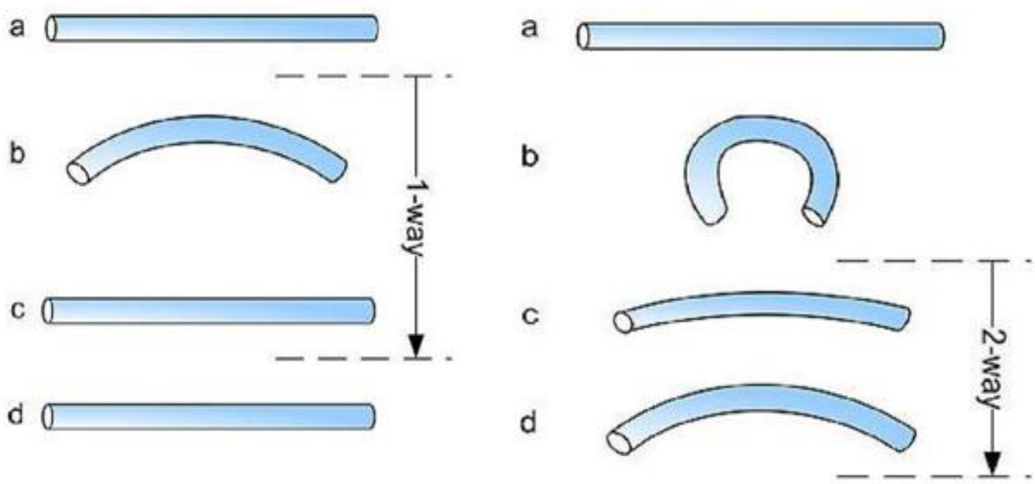


Figure 1: The strategies are fundamentally the same as beginning from martensite
(a), including a reversible twisting for restricted impact serious distortion with irreversible sum for two-way (b), warming example (c) and cooling it once more (d).

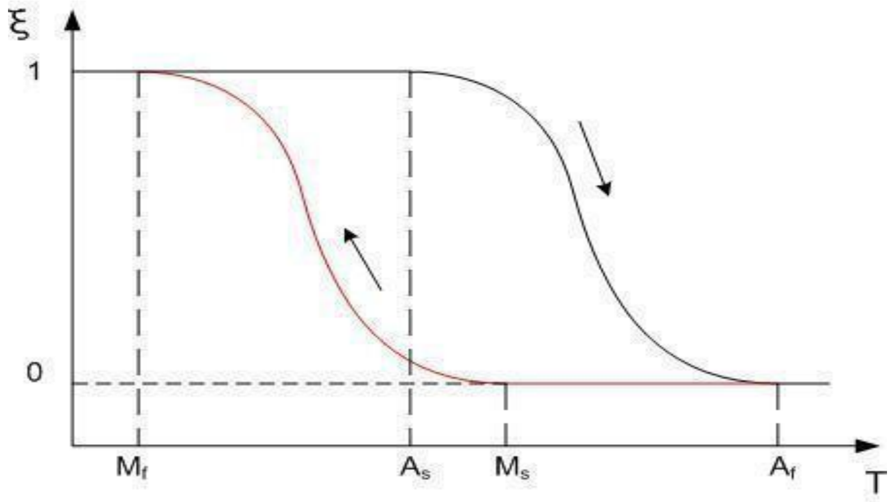


Figure 2: Effect of Shape Memory Alloy.

3. **One-Way SME:** At the point when an SMA is at cool condition (beneath As), metal is twisted or extended and shall take it shapes until warmed over changing temp. After warming, shape alters to it unique. At point when the metal cooled, it shall stay in hot shape, till disfigured once more. On warming, change begins at As and is finished at Af (normally 2 to 20 °C or more blazing, contingent upon the amalgam or stacking condition). As is controlled by compound kind as well as organization and can fluctuate between −150 °C and 200 °

4. **Two-Way SME:** The two-way SME is the impact that the material recollects two distinct shapes: one at low temperatures and one at the high-temperature shape. A material that demonstrates an SME amid both warming and cooling is called two-way shape memory. This can likewise be gotten without the use of an outside power (natural two-way impact). The cause the material carries on so contrastingly in these circumstances lies in preparing. Preparing suggests that a shape memory can "learn" to carry on with a particular goal in mind. Under ordinary conditions, an SMA "recollects" its low-temperature shape, yet after warming to recuperate the high-temperature shape, quickly low-temperature shape. Be that as it may, it very well may be "prepared" to "recall" to abandon a few notices of the distorted low-temperature condition in the high-temperature stages. There are a few different ways of doing this. A formed, prepared question warmed past a specific point will lose the two-way memory impact.

5. **Manufacturing Processes:** Manufacturing procedures can be extensively isolated into two gatherings and they are essential manufacturing procedures and manufacturing assembling forms. The previous one gives fundamental shape and size to the material according to the designer’s necessity. Casting, shaping, powder metallurgy are such procedures to give some examples. Auxiliary manufacturing forms furnish the last shape and size with more tightly control of measurement, surface qualities and so on. Material expulsion forms are essentially secondary manufacturing forms.

6. **Manufacturing Methods of SMA:** Nitinol (Nickel-Titanium Naval Ordnance Laboratory) is exceedingly hard to make because of the astoundingly tight compositional control required and the colossal reactivity of titanium. Each molecule of titanium that

joins with oxygen or carbon is an atom that is victimized from the Ti-Ni grid, in this manner moving the piece and making the changing temperature that a lot colder. There are two essential dissolving strategies utilized today are –

- **Vacuum Arc Remelting (VAR):** This procedure was completed by arresting an electrical arc between a tungsten terminal and the crude material. Liquefying is brought through an electric spark in argon condition so no carbon is presented amid softening.

- **Vacuum Induction Melting (VIM):** VIM process was completed by utilizing substituting attractive fields to warm the crude materials in a cauldron (for the most part graphite). This is likewise arranged in a high vacuum, yet carbon is presented amid the procedure. While the two strategies have favorable circumstances, there are no substantive information appearing material from one process is superior to the next.

  Material expulsion forms indeed can be partitioned into chiefly two gatherings and they are "Conventional Machining Processes" and "Non-Conventional Manufacturing Processes". Instances of conventional machining forms are turning, boring, milling, shaping, broaching, slotting, grinding and so forth. Thus, Ultrasonic Machining (USM), Water-Jet-Machining (WJM), Laser-Machining, WEDM and EDM are a portion of the Non- Conventional Machining Processes.

7. **Conventional Machining of SMAs:** Machining of SMAs is generally a critical, necessary part in creation as segments to use in engineering application. At the point when Ti-Ni SMAs are considered, Ti reactivity towards cutting tool, less heat transfer rate, great quality to hoisted temperature and less elastic modulus results to expanded temperature at apparatus chip interface, component contortions, quick tool wear. Ni based alloys, super compounds like Ti combinations likewise have good quality and is viewed as difficult to machine. Also, because of their austenitic grid nickel super alloys solidify quickly amid machining and will, in general, deliver a consistent chip which is hard to control amid machining. The previously mentioned impacts lead to quickened flank wear, cratering and scoring, contingent upon the tool material and the cutting conditions connected. (Refer to Figure 3).

II. EXPERIMENTAL RESULTS AND ANALYSIS FOR MACRO-WEDM

The present section gives the use of the Taguchi trial plan strategy. To study effect of process factors on the yield parameters, like MRR, SR, KW, and DD, the strategy of concluding studies was selected and the trials were lead using macro-WEDM. The test findings are discussed. Using GRA, procedure variables are multi- objectively adjusted. Also, Salon it is thermal modeling of the macro- WEDM is presented. The study on the surface integrity of the macro-WEDM surfaces is taken up.

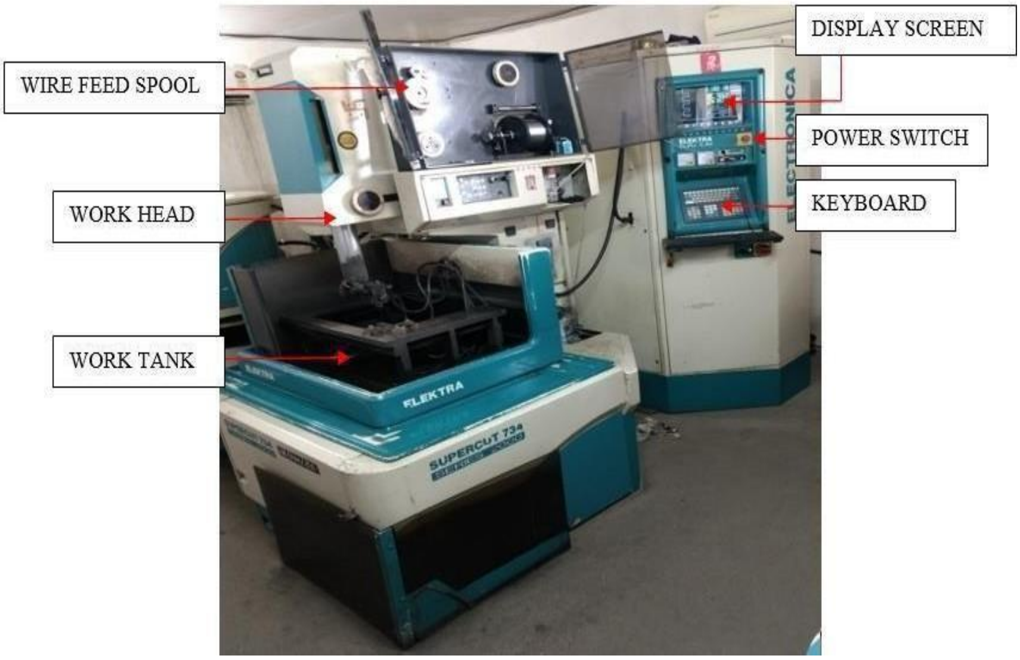


Figure 3: Pictorial View of Macro-WEDM Machine Tool.

For every experiment run of L18 OA of Table 1, the predefined input variable selections were set and specimens of Ti-Ni SMA was machined utilizing zinc coated brass wire electrode. So as to maintain a strategic distance from the blunder crawling into the framework, the preliminaries were randomized. Execution attributes, for example, MRR, SR, KW and DD were evaluated for each of the experimental runs of OA.

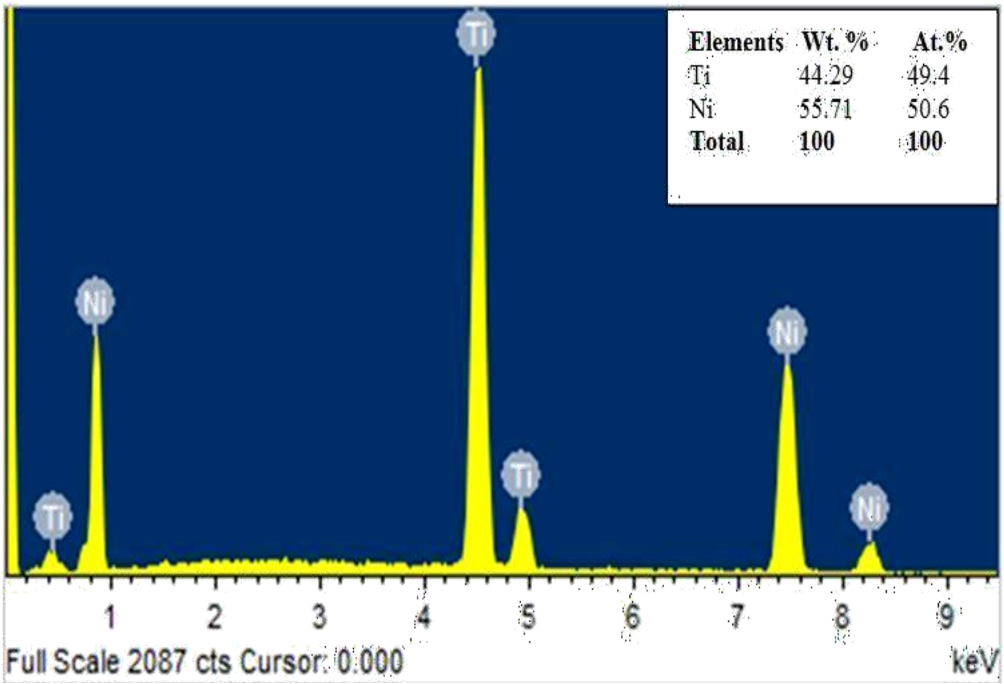


Figure 4: EDS Analysis of As-Cast $Ti_{49.4}Ni_{50.6}$ Alloy

Table 1: Controllable Parameters and their Levels

Variables	Code	Level 1	Level 2	Level 3
Pulse on Time (Machine Unit)	Ton	105	115	--
Pulse off Time (Machine Unit)	Toff	20	40	60
Spark gap set Voltage(V)	SV	30	60	90
Wire Feed (m/min)	WF	3	6	12
Wire Tension (Machine Unit)	WT	3	6	12

Table 2: Experimental Design Using an L18 Orthogonal Array

Experiment Number	Process Levels Variable Settings				
	Ton	Toff	SV	WF	WT
1	105	20	30	3	3
2	105	20	60	6	6
3	105	20	90	12	12
4	105	40	30	3	6
5	105	40	60	6	12
6	105	40	90	12	3
7	105	60	30	6	3
8	105	60	60	12	6
9	105	60	90	3	12
10	115	20	30	12	12
11	115	20	60	3	3
12	115	20	90	6	6
13	115	40	30	6	12
14	115	40	60	12	3
15	115	40	90	3	6
16	115	60	30	12	6
17	115	60	60	3	12
18	115	60	90	6	3

Experimental Results: The trial result of MRR, SR, KW and DD are listed in Table 2. Eighteen investigations were directed utilizing Taguchi exploratory plan procedure and every trial was repeated 3 times for getting S/N ratios. Present investigation, every one of the structures, plots and examination has been completed utilizing Minitab statistical software.

Table 3: S/N Ratio for MRR, SR, KW and DD

Expt. No.	Average MRR	S/N Ratio	Average SR(Ra)	S/N Ratio	Average KW	S/N Ratio	DD (%)	S/N Ratio
1	0.6268	-4.057	1.205	-1.620	0.299	10.487	0.839	1.525
2	1.2929	2.231	1.926	-5.693	0.296	10.574	0.787	2.081
3	1.2282	1.785	1.579	-3.968	0.301	10.429	0.709	2.987
4	0.6338	-3.961	1.785	-5.033	0.293	10.663	0.619	4.166
5	0.5689	-4.899	1.296	-2.252	0.292	10.692	0.774	2.225

6	0.7691	-2.280	1.149	-1.206	0.305	10.314	1.006	-0.052
7	0.1915	-14.357	0.862	1.290	0.297	10.545	0.593	4.539
8	0.1790	-14.943	1.202	-1.598	0.303	10.371	0.464	6.670
9	0.1173	-18.614	1.022	-0.189	0.309	10.201	0.541	5.336
10	3.4970	10.874	2.744	-8.768	0.310	10.173	0.529	5.531
11	1.7054	4.637	2.416	-7.662	0.317	9.979	0.787	2.081
12	2.9815	9.489	2.005	-6.042	0.309	10.201	0.800	1.938
13	2.3930	7.579	2.526	-8.049	0.302	10.400	0.671	3.466
14	4.0065	12.055	2.253	-7.055	0.304	10.343	0.658	3.635
15	1.7155	4.688	1.460	-3.287	0.317	9.979	1.096	-0.796
16	0.6419	-3.851	2.235	-6.986	0.304	10.343	0.477	6.430
17	0.5657	-4.948	1.936	-5.738	0.313	10.089	0.503	5.969
18	0.4621	-6.705	1.947	-5.787	0.324	9.789	0.929	0.640

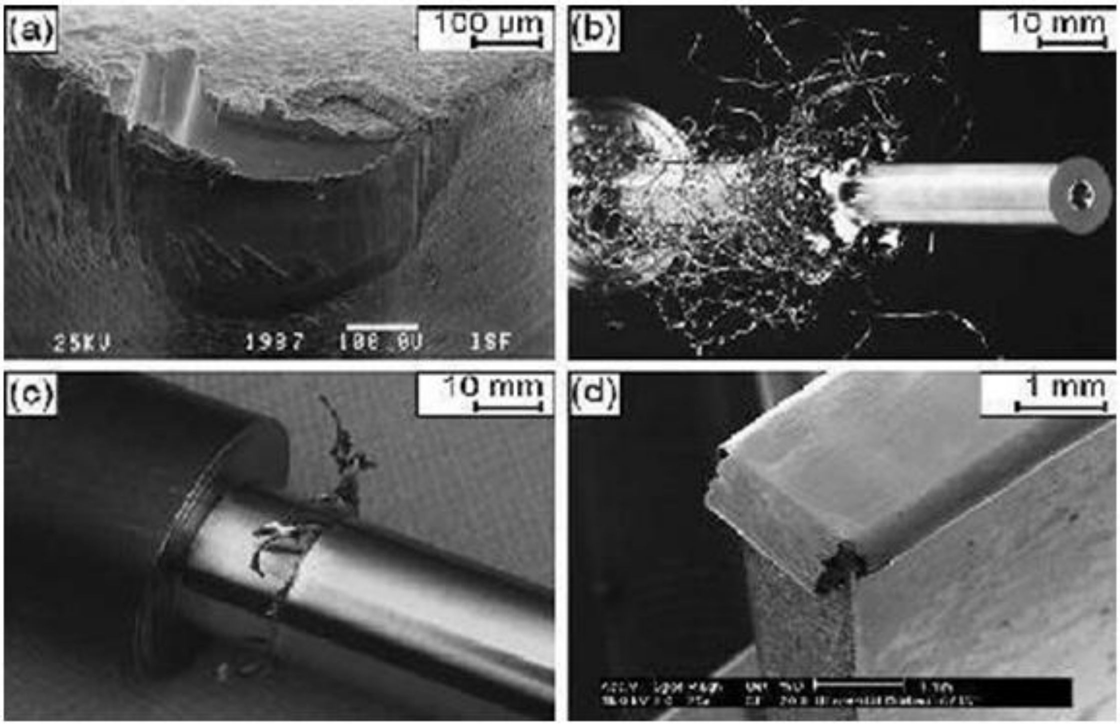


Figure 5: Difficulties occurred during conventional machining of Ti-Ni alloy a) High tool wear b) Adverse chips c) Burr formation after machine in grinding

III. RESULT ANALYSIS AND DISCUSSION

WEDM test was directed utilizing parametric methodology of Taguchi’s strategy. Impacts of single WEDM process variable, on chose ability attributes like MRR, SR, KW and DD have been talked about in this segment. Then again, the normal start hole gets enlarged with expanded SV prompting less power of sparks which causes a decrease in MRR. Simultaneously with increased WF, the liquid material is sprinkled around the surface by flushing pressure. The micro voids are framed on the machined surface because of the release of a huge volume of gases in the channel that spilled out from the liquid pool and thus higher MRR.

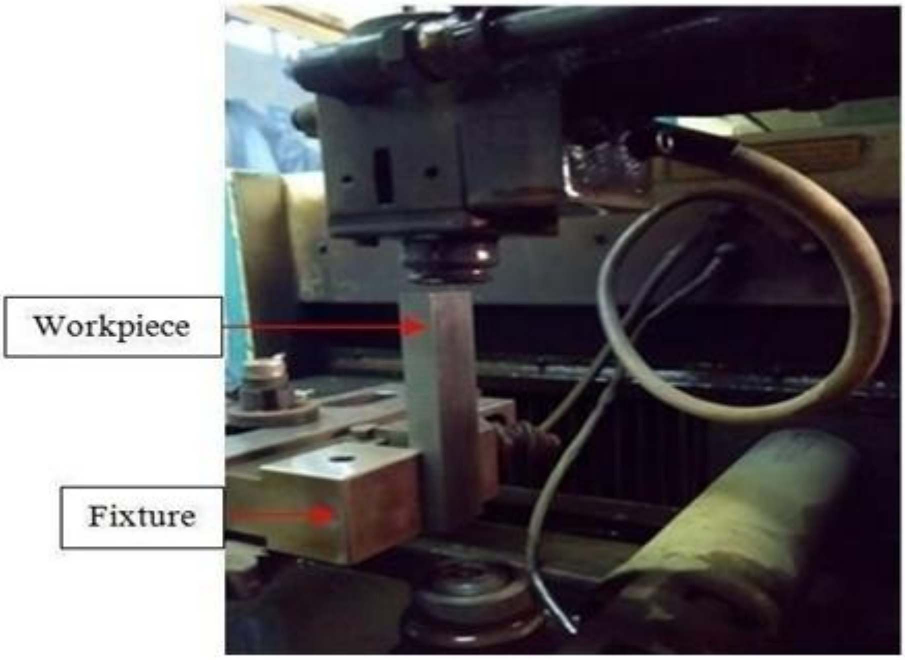


Figure 6: Experimental Setup

The normal esteem and S/N proportion of the reaction attributes for every factor at various dimensions were determined from trial information. The principal impacts of procedure factors for crude information & S/N information were noted. Reaction bends (important impacts) are utilized for inspecting parametric consequences for reaction qualities. ANOVA of raw information, S/N information is completed to recognize important factors also to evaluate its consequences for the reaction qualities. Most positive qualities of process factors as far as mean reaction attributes are set up by breaking down the ANOVA Tables.

IV. CONCLUSION

- The process parameter Ton was the most significant factor for MRR, SR and KW at 95% confidence level, with a percentage contribution of 35.69 %, 59.02% and 47.35% respectively, while the Toff was a significant parameter for MRR and DD with a percentage contribution of 34.70% and 26.92% respectively
- The SV was the most significant factor for DD with a percentage contribution of 30.36%. The WF and WT were insignificant factors for MRR, SR, KW, and DD. The SR improves with an increase in Toff and SV.
- According to Taguchi confirmation analysis, WF and WT had no significant effect on the responses.

REFERENCES

[1] K. H. Ho, S. T. Newman, S. Rahimifard, R. D. Allen (2004), "State of art in wire electrical discharge machining (WEDM)", International Journal of Machine Tools and Manufacture, 44, pp. 1247-1259.
[2] A. P. Markopoulos, I. S. Pressas, D. E. Manolakos (2015), "A review on the machining of nickel-titanium shape memory alloys", Reviews on Advanced Materials Science, 42, pp. 28–35.
[3] K. Weinert, V. Petzoldt (2004), "Machining of NiTi based shape memory alloys", Materials Science A, 378, pp. 180–184.

[4] M. Manjaiah, S. Narendranath, A. Javad (2014), “Optimization of wire electro- discharge machining parameters to achieve better MRR and surface finish”, Procedia Materials Science, 5, pp. 2635–2644.
[5] F. Han, J. Jiang, Y. Dingwen (2007), “Influence of machining parameters on surface roughness in finish cut of WEDM”, International Journal of Advanced Manufacturing Technology, 34, pp. 538–546.
[6] S. L. Chen, S. F. Hsieh, H. C. Lin, M. H. Lin, J. S. Huang (2008), “Electrical discharge machining of a NiAlFe ternary shape memory alloy”, Journal of Alloys and Compounds, 464, pp. 446-451.
[7] S. Saha, M. Pachon, A. Ghoshal, M. J. Schulz (2004), “Finite element modeling and optimization to prevent wire breakage in electro-discharge machining”, Mechanics Research Communications, 31, pp. 451–463.
[8] N. Tosun, C. Cogun, G. Tosun (2004), “A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method”, Journal of Materials Processing Technology, 152, pp. 316-322.
[9] Y. K. Lok, T. C. Lee (1997), “Processing of advanced ceramics using the wire- cut EDM process”, Journal of Materials Processing Technology, 63, pp. 839-843.
[10] G. F. Benedict (1987), “Electrical discharge machining (EDM), non-traditional manufacturing process”, Marcel Dekker, Inc, New York and Basel, pp. 231-232.

IMAGE PROCESSING FOR WIRE ARC ADDITIVE MANUFACTURING CONTROL AND MONITORING

Abstract

Additive Manufacturing (AM), often referred to as 3D printing, has revolutionized traditional manufacturing processes by enabling the creation of complex and customized objects layer by layer. Additive Manufacturing (AM), Wire Arc Additive Manufacturing (WAAM), and the significance of image processing in monitoring and controlling WAAM processes. It succinctly highlights the unique characteristics of WAAM, the broader context of AM techniques, and the role of image processing in enhancing the WAAM process. It provides a clear and informative overview of these concepts. The decision between these methods is made based on the materials used, component size, surface polish, and intended uses. The control and monitoring of Wire Arc Additive Manufacturing (WAAM) processes heavily rely on image processing. Image processing approaches improve real-time monitoring, fault detection, and quality control in WAAM by examining visual data collected during the production process. Unlike conventional AM methods that use powdered material, WAAM utilizes a solid wire as the feedstock material. This method involves the controlled deposition of melted wire through an electric arc, leading to the gradual buildup of a three-dimensional object. Monitoring and control in wire arc additive manufacturing (WAAM) involve the application of various techniques to ensure the quality, accuracy, and consistency of the additive manufacturing process using wire-based deposition

Keywords: Additive Manufacturing (AM), Wire Arc Additive Manufacturing WAAM

Authors

Mr. S M Ghanvat
Mechanical Department
Sharad Institute of Technology College of Engineering
Yadrav, Ichalkaranji, India
smg@sitcoe.org.in

Mr. A A Desai
Automation & Robotics Department
Sharad Institute of Technology College of Engineering
Yadrav, Ichalkaranji, India
ashishdesai@sitcoe.org.in

I. INTRODUCTION

Layer-by-Layer Fabrication is a fundamental characteristic shared by both Wire Arc Additive Manufacturing (WAAM) and other Additive Manufacturing (AM) techniques. This approach involves building components by adding material layer upon layer, which enables the creation of intricate and complex geometries that are often difficult to achieve using conventional manufacturing methods. This method empowers engineers to design and produce parts with intricate internal structures and unique shapes, revolutionizing traditional manufacturing processes. Furthermore, both WAAM and other AM methods offer a high degree of customization. This means that the manufacturing process can be tailored to produce components that match specific requirements. Designers and engineers have the flexibility to create products that are uniquely suited to their intended applications. This customization capability is a significant advantage over conventional manufacturing, where creating complex, personalized items might be impractical or cost-prohibitive. In essence, the shared principles of layer-by-layer fabrication and customization make both WAAM and other AM techniques valuable tools in modern manufacturing, enabling the production of intricate, tailored components that align precisely with the needs of various industries and applications.

In Wire Arc Additive Manufacturing (WAAM), the feedstock material utilized is a solid wire, predominantly composed of metals. This distinctive feature sets WAAM apart from other Additive Manufacturing (AM) techniques. In contrast, various other AM methods leverage a broader spectrum of materials, encompassing polymers, metals, ceramics, and composites. These materials are available in diverse forms, including powders, liquids, and filaments, contributing to the versatility and adaptability of these techniques. The deposition process in WAAM involves the controlled melting of a solid wire using an electric arc, followed by the layer-by-layer deposition of the molten material. This process's unique utilization of solid wire and electric arc technology contributes to the gradual buildup of intricate three-dimensional objects. On the other hand, different AM techniques adopt varying deposition methods. For instance, Stereolithography utilizes selective curing of liquid resins, Selective Laser Sintering employs lasers or electron beams to fuse powdered materials, and Fused Deposition Modeling extrudes heated filaments. Each method addresses specific material properties and application needs, enabling the creation of diverse components with distinct attributes.

Wire Arc Additive Manufacturing (WAAM) is prominently employed for metals and metal alloys, mainly due to its utilization of solid wire feedstock. This specialization sets WAAM apart in its focus on metallic materials, which are well-suited for various industrial applications. Conversely, other Additive Manufacturing (AM) techniques exhibit greater flexibility by encompassing a broader spectrum of material options. These methods extend their reach to polymers, ceramics, and composite materials, catering to diverse industry needs and allowing for the creation of components with varied material characteristics. Surface finish is a distinctive attribute when comparing WAAM to other AM techniques. WAAM's inherent nature can result in rougher surface finishes due to its process characteristics.

Consequently, additional post-processing steps are often necessary to achieve the desired surface quality. Conversely, other AM techniques possess the capability to attain smoother surface finishes, contingent on the specific technology and material employed. This versatility in surface quality serves as a key advantage in applications requiring both functional performance and aesthetic appeal.

The differences in material diversity and surface finish between Wire Arc Additive Manufacturing (WAAM) and other Additive Manufacturing techniques contribute to their distinct strengths and applications. WAAM excels in metal-based production due to its wire feedstock, while other AM methods offer versatility by accommodating a wider range of materials. Surface finish attributes underscore the need for post-processing in WAAM, while other AM techniques can achieve varied surface qualities to meet specific requirements.

II. LITERATURE REVIEW

The concept of "Ease of Use Image Processing for Wire Arc Additive Manufacturing Control and Monitoring" likely pertains to simplifying the utilization of image processing techniques for the purpose of controlling and monitoring the Wire Arc Additive Manufacturing (WAAM) process. Wire Arc Additive Manufacturing (WAAM) is an additive manufacturing technique that employs electric arcs to melt and deposit metal wire to build up objects layer by layer. Process control and monitoring are critical to ensure the quality and consistency of the final product. Image processing, a subset of computer vision, involves the analysis of visual data from cameras and sensors to extract meaningful information.The goal of "Ease of Use Image Processing" is to bridge the gap between complex image analysis techniques and the practical needs of operatorsand engineers in the WAAM environment. By making image processing more user-friendly, manufacturers can harness the benefits of image-based monitoring and control with reduced training requirements and increased process efficiency.

Dissimilar metal deposition in wire and arc-based additive manufacturing involves the process of fusing two distinct metals, stainless steel and a nickel-based alloy, to create complex structures. This method employs an arc-based technique where a wire electrode is melted, generating a molten pool that solidifies to form layers. This process allows the combination of stainless steel and nickel-based alloy to form intricate and functional components with unique material properties and characteristics. This technique is valuable for applications that require specific material properties in different sections of a single component, offeringversatility and performance benefits in various industries.[1]

The "Three-dimensional numerical simulation of arc and metal transport in arc welding based additive manufacturing" involves using computer-based modeling to simulate the complex interactions between the welding arc, molten metal, and the work piece during additive manufacturing processes. This approach employs three-dimensional simulations to understand and optimize the behavior of the welding arc and metal deposition, aiding in the development of more efficient and effective additive manufacturing techniques. These simulations provide insights into the thermal distribution, fluid flow, and solidification processes within the melt pool, contributing to the advancement of arc-based additive manufacturing technologies.[2]

By layering material onto components, Wire Arc Additive Manufacturing (WAAM), a kind of Direct Energy Deposition additive manufacturing, uses the wire welding principles. Due to its low cost and capacity to create huge quantities of parts, this technology has become very popular in the manufacturing industry. Advances in intelligent applications for smart production systems have been observed at WAAM as industry transition to smart manufacturing systems and enhanced computational resources. These applications cover both real-time process parameter control and manufacturing inspection. The cost-effectiveness of WAAM and its integration with intelligent systems work together to meet the changing needs of contemporary industry. [3]

The paper "Process Monitoring and Control in Wire Arc Additive Manufacturing: A Review" (2018) by Zhang et al. provides an in-depth analysis of process monitoring and control techniques in the context of Wire Arc Additive Manufacturing (WAAM). The authors review the state-of-the-art advancements in monitoring and controlling the WAAM process to enhance its efficiency and quality. The paper discusses various methods such as image processing, sensors, and real-time feedback mechanisms that have been employed to monitor and regulate key parameters during the additive manufacturing process. The review highlights the importance of process stability, material deposition accuracy, and defect detection in achieving optimal WAAM outcomes. The authors also emphasize the role of computational modeling and simulation in predicting and improving process behavior. Overall, the paper underscores the significance of robust monitoring and control strategies in advancing WAAM as a reliable and precise additive manufacturing technique.[4]

The concept of a "layer wise monitoring approach using thermal imaging" involves utilizing thermal imaging technology to detect defects and irregularities during the process of metal deposition, even though the discussion is not exclusively centered around wire arc additive manufacturing (WAAM). This method is relevant and adaptable to WAAM processes as well. By employing thermal imaging, which captures temperature variations, the approach aims to identify potential defects and inconsistencies as each layer of material is deposited, thereby ensuring the quality and integrity of the final product. While the techniques may not be explicitly focused on WAAM, their application can be extended to this additive manufacturing method to enhance defect detection and quality control throughout the layer-by-layer deposition process.[5]

III. WIRE AND ARC ADDITIVE MANUFACTURING

Wire Arc Additive Manufacturing (WAAM) is an advanced manufacturing process that belongs to the broader category of additive manufacturing, also known as 3D printing. WAAM is a method that involves building three- dimensional objects by selectively depositing material layer by layer, using an electric arc as the heat source to melt and fuse metal wire, which is then added to the growing workpiece. It focused on sensor technologies employed in WAAM for process monitoring. It discusses optical, thermal, and acoustic sensors as well as their integration into the additive manufacturing setup. The paper highlights the importance of real-time monitoring to ensure quality[6].

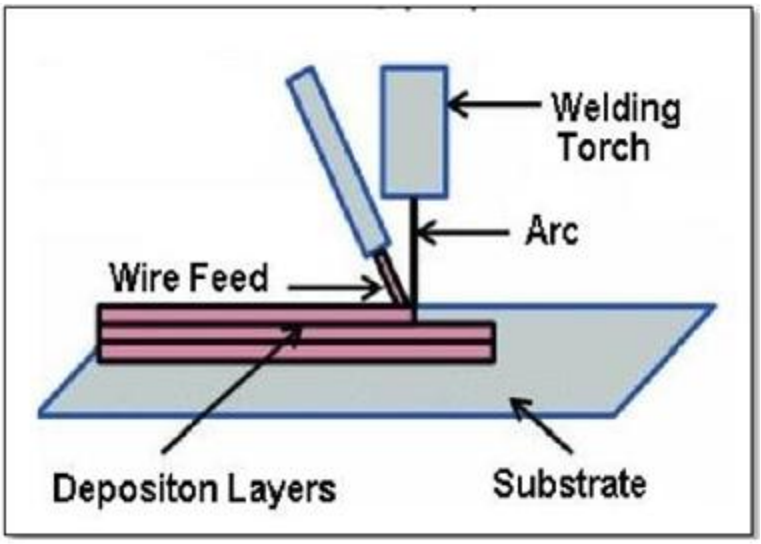


Figure 1: Wire and Arc Additive Manufacturing

- **Layer-by-Layer Building:** Similar to other additive manufacturing techniques, WAAM builds objects layer by layer. A computer-controlled system guides the deposition of material to create the desired shape.

- **Metal Wire Feed:** In WAAM, a continuous metal wire is fed into the welding arc. The wire serves asboth the heat source and the material to be added to the workpiece.

- **Electric Arc:** An electric arc is generated between the wire electrode and the workpiece. The heatgenerated by the arc melts the tip of the wire, creating a molten pool on the workpiece.

- **Material Deposition:** As the wire melts, it is deposited onto the workpiece in a controlled manner. Themolten material solidifies quickly, forming the current layer of the object.

- **Layer-by-Layer Solidification:** The process is repeated layer by layer until the entire object is built.Each layer bonds to the previous one, creating a fully dense and structurally sound component.

By thoroughly defining these specifications, it provide a clear roadmap for the development and implementation of the image processing system in WAAM control and monitoring. This helps in achieving consistent and reliable results throughout the manufacturing process.

- **Hardware and Software Selection:** Choose appropriate hardware (cameras, sensors) and software tools for image acquisition and processing. The selected equipment should be capable of capturing images with the required level of detail and accuracy for analyzing the WAAM process.

- **Calibration and Standardization:** Calibrate the imaging system regularly to ensure accurate measurements and consistent results. Standardize the imaging setup across different manufacturing scenarios to enable meaningful comparisons and reliable analysis.

- **Real-time Processing:** If real-time monitoring and control are required, ensure that the image processing algorithms are efficient enough to process images in real-time without introducing delays in the manufacturing process.

- **Feature Extraction:** Develop algorithms to extract relevant features from the images. For WAAM, this might involve tracking the size and shape of the melt pool, monitoring the deposition path, or identifying defects like cracks and voids.

- **Data Validation:** Implement validation routines to ensure the accuracy of extracted data. This might involve cross-referencing image data with other process parameters or using redundant imaging systems to confirm results.

- **Data Fusion:** Integrate image data with other process data, such as temperature, voltage, and current, to gain a comprehensive understanding of the WAAM process and its performance.

- **Anomaly Detection:** Develop algorithms to detect anomalies and defects in real-time or during post- processing. This could involve identifying irregular melt pool shapes, inconsistent deposition patterns, or the presence of defects that could compromise the structural integrity of the final product.

- **Adaptation and Optimization:** Continuously improve the image processing algorithms based on feedback from the manufacturing process. Adaptive algorithms can help optimize the WAAM process in response to changing conditions.

- Validation and Verification Regularly validate the accuracy and effectiveness of the image processing system against reference standards and known defects. This ensures that the system remains reliable and effective over time.

- Maintain thorough documentation of the image processing specifications, methodologies, algorithms, and results. Clear documentation facilitates knowledge transfer, troubleshooting, and compliance with quality standards.

By carefully considering and implementing these steps, you can maintain the integrity of specifications for image processing in wire arc additive manufacturing control and monitoring, leading to improved process control, defect detection, and overall product quality. while not specific to wire arc, layer wise monitoring approach using thermal imaging to detect defects andirregularities during metal deposition. The techniques discussed could be applicable to WAAM as well. [4]

Thermal imaging cameras are employed to capture temperature data from the surface of the workpiece or the deposition area. Different materials and defects can result in variations in temperature distribution.

- **Real-Time Analysis:** As the material is being deposited layer by layer, the thermal imaging system analyzes the temperature patterns in real time. Deviations from expected temperature distributions can indicate defects or irregularities. Certain defects, such as cracks, voids, or incomplete fusion, can cause temperature anomalies. The thermal imaging system identifies these anomalies as potential defects within the layer being deposited [7].

- **Layer Comparison:** By comparing the thermal data of each layer to a reference or ideal temperature distribution, the system can detect inconsistencies that might compromise the structural integrity or quality of the final product. Immediate Feedback: Any detected defects or irregularities trigger alerts or adjustments in real time. Themanufacturing process can be paused, modified, or corrected to prevent the propagation of defects to subsequentlayers. The thermal imaging data can be stored for each layer, creating a comprehensive record of the manufacturing process and defects detected. This documentation aids in quality assurance, analysis, and processoptimization [15].

Figure 2: WAAM Processed Components

IV. IMAGE PROCESSING TECHNIQUES FOR WIRE ARC ADDITIVE MANUFACTURING(WAAM)

An electric arc is used in the advanced manufacturing method known as "wire arc additive manufacturing" (WAAM) to melt and deposit metal wire in layers, allowing for the construction of complex metal components. For the finished product to be of the highest caliber and integrity, this procedure must be carefully controlled and monitored. It is possible to achieve this control and monitoring through the use of image processing techniques. For WAAM control and monitoring, it is important to properly address the following important image processing techniques:

1. **Thermal Imaging:** Infrared (IR) cameras can record temperature distributions while performing WAAM. These photos may be analyzed using image processing to discover hotspots and track temperature changes. This is essential for identifying problems with

overheating or under heating.

2. **Weld Pool Monitoring:** High-speed cameras may record the behavior of the molten metal pool and analyze it in real time. Analysis of the pool's size, shape, and stability via image processing is possible. Defects in the process can be indicated by variations from the anticipated pool characteristics.

3. **Surface Quality Inspection:** Defect Detection: By examining photographs of the deposited layers, image processing can be utilized to find surface flaws like fractures, porosities, or abnormalities. Algorithms for machine learning can be trained to spot typical flaws.

4. **Geometry Measurement:** Layer Height Measurement: Vision systems may be used to determine the height of each layer that has been deposited. Problems with material deposition can be indicated by variations from the anticipated layer height.

5. **Geometry Reconstruction:** 3D scanning and reconstruction techniques can be used to capture the geometry of the component being manufactured, such as laser scanning or structured light scanning. For a real-time quality assessment, image processing can reconstruct the 3D model and compare it to the desired design.

6. **Monitoring of Smoke and Fumes:** During WAAM, image processing can be used to track the emissions of smoke and fumes. This may provide information on the quality of the welding process and the presence of impurities.

7. **Positioning and Stability:** Alignment Based on Cameras: Cameras can be employed to track the placement and stability of the WAAM system's components. Any tremors or misalignments that can impede the quality of the deposition can be found via image processing.

8. **Color Analysis and Spectroscopy:** Spectroscopic Imaging: The color and spectral properties of the arc and the molten pool can be examined using spectroscopy in conjunction with image processing. Variations in these qualities may be a sign of changes in the material composition.

9. **Data Fusion:** Integration of Sensor Data: To offer a thorough understanding of the WAAM process, image processing should be merged with other sensor data, such as temperature sensors, force sensors, and motion sensors.

10. **Using Machine Learning to Find Anomalies:** To identify patterns linked to defects or process irregularities, train machine learning models. These models have the ability to continuously monitor picture data and, in the event of an anomaly, alert the user or take corrective action.

11. **User Interface:** Create an intuitive user interface that gives engineers and operators access to processed picture data in a format that is easy to understand and use.

It is significant to note that the particular image processing methods and tools employed will rely on the WAAM system, the materials being utilized, and the quality requirements for the finished result. Therefore, for effective control and monitoring in WAAM, it is crucial to have a complete understanding of the procedure and to work with specialists in image processing and computer vision.

V. IMAGE PROCESSING COMPONENTS FOR WIRE ARC ADDITIVE MANUFACTURING (WAAM)

To ensure high-quality manufacturing, it control and monitoring need for a comprehensive solution thatintegrates hardware and software components.

1. Hardware Components

- **High-Resolution Cameras and Sensors**
  - Use high-resolution cameras with frame rates suitable for capturing the rapid movements andchanges in the WAAM process.
  - Integrate temperature sensors, 3D scanners, and spectroscopic sensors for collectingcomplementary data.

- **Infrared (IR) Cameras**
  - Incorporate IR cameras to monitor temperature distributions in real-time.

- **Illumination System**
  - Employ specialized lighting to ensure optimal image quality and reduce shadows and glare.

- **3D Scanning Equipment**
  - Utilize 3D scanners for capturing the geometry of the workpiece and the deposited layers.

- **Computer Hardware**
  - Employ powerful computers or embedded systems with GPUs for real-time image processing.

2. Software Components

- **Image Acquisition and Preprocessing**
  - Develop software for capturing and preprocessing images from cameras and sensors, includingnoise reduction and calibration.

- **Real-time Image Processing**

Implement real-time image processing algorithms to analyze the images and sensor data. Thisincludes:

- Weld pool analysis for size, shape, and stability.
- Surface quality inspection for defect detection.
- Geometry measurement and reconstruction.
- Smoke and fume analysis.
- Color and spectral analysis.
- Data fusion from multiple sensors.

- **Machine Learning and Anomaly Detection:** Train machine learning models for anomaly detection based on historical data and known defect patterns. These models can continuously analyze the data stream and trigger alerts when anomalies are detected.

- **Data Logging and Analytics:** Implement data logging and storage capabilities to maintain a record of process data for quality controland analysis.

- **Feedback Control:** Integrate the image processing system with the WAAM system's control mechanisms to make real-time adjustments based on detected anomalies.

- **Remote Monitoring and Reporting:** Enable remote access and monitoring of the WAAM process, including the ability to generate reports and alerts via email or mobile notifications.

Collaboration between experts in image processing, computer vision, and WAAM is crucial for the successful development and implementation of this solution. Regular maintenance and updates are also essential to keep the system performing at its best and ensuring the production of high-quality WAAM components.

VI. APPROACHES FOR ENHANCING THE WAAM PROCESSES' PERFORMANCE

1. **Process Improvement:** To provide the best possible consistency and quality of the deposition, adjust process variables including the arc voltage, wire feed rate, and travel speed. To study and improve the process for less distortion, residual stress, and porosity, use computer simulations.

2. **Material Options:** To assure the appropriate mechanical and metallurgical qualities, choose high-quality feedstock materials with well-known features and certificates. Verify the compatibility of the components to avoid melting, mixing, and intermetallic formation problems.

3. **Processing Prior to and Afterward:** To relieve residual stresses and enhance material qualities, implement appropriate pre-weld and post-weld heat treatments. To eliminate flaws, reduce surface roughness, and guarantee precise measurements, perform machining or surface finishing.

4. **Layer-by-Layer Investigation:** Examine each layer for flaws and inconsistencies using non-destructive testing (NDT) techniques including ultrasonic testing, X-rays, or computed tomography. Utilize visual inspection or thermal imaging methods to look for irregularities while the material is being deposited.

   Designers may significantly enhance the quality, dependability, and efficiency of the components made using additive manufacturing by combining these techniques and customizing them to the demands of the WAAM process.

VII. RELATION FACTOR WITH EQUATIONS FOR WAAM MANUFACTURING

It seems like you're looking for equations or factors related to Wire Arc Additive Manufacturing (WAAM) manufacturing processes. While I can provide some general factors and concepts related to WAAM, keep in mind that the equations and specific factors can vary based on the particular application, materials used, and process parameters. Here are some relevant factors and equations that might be of interest:

1. **Deposition Rate (D):** The rate at which material is deposited during the WAAM process.
   Equation: $D = v \times w$, where v is the travel speed and w is the deposition width. The "Deposition Rate" in the context of Wire Arc Additive Manufacturing (WAAM) refers to the speed at which material is added to the work piece during the additive manufacturing process. This rate is a critical factor influencing the efficiency and productivity of the manufacturing process. The equation that defines the deposition rate is $D = v \times w$, where "v" represents the travel speed of the welding head, and "w" represents the deposition width of the material being added. This equation reflects the fundamental relationship between the movement speed of the welding head and the amount of material being deposited. By controlling the travel speed and deposition width, manufacturers can adjust the deposition rate to achieve the desired outcome in terms of build speed, material utilization, and overall part quality[14].

2. **Heat Input (Q):** The amount of energy transferred to the workpiece during welding.
   Equation: $Q = V \times I \times t$, where V is the voltage, I is the current, and t is the time."Deposition Rate (D)" and "Heat Input (Q)" are two essential factors in the Wire Arc Additive Manufacturing (WAAM) process that significantly impact the quality and characteristics of the manufactured components.

   Deposition Rate refers to the speed at which material is added to the workpiece during the WAAM process. It plays a vital role in determining the build time, material utilization, and the overall efficiency of the manufacturing process. The equation for Deposition Rate is $D = v \times w$, where "v" represents the travel speed of the welding head, and "w" represents the deposition width of the material being added. This equation illustrates how the combination of travel speed and deposition width affects the amount of material deposited per unit of time.

   Heat Input refers to the amount of energy that is transferred to the workpiece during the welding process.It plays a crucial role in controlling the thermal characteristics of the melt pool and the surrounding material. The equation for Heat Input is $Q = V \times I \times t$, where "V" represents the voltage applied to the welding arc, "I" represents the current flowing through the arc, and "t" represents the time during which the welding process occurs. This equation quantifies the energy input into the system, which affects the temperature distribution, cooling rate, and solidification behavior of the deposited material[13].

Implications

- **Thermal Behavior:** Heat Input directly impacts the thermal behavior of the melt pool. Proper heat input control is crucial for controlling the size and shape of the melt pool, which affects layer bonding, residual stresses, and distortion.

- **Microstructure:** Heat Input influences cooling rates, affecting the microstructure of the deposited material. Rapid cooling can lead to finer grains, impacting mechanical properties such as strength and toughness.

- **Residual Stresses:** Heat Input influences residual stresses formed during the cooling process. Controlling heat input can mitigate the extent of residual stresses, enhancing component stability.

- **Solidification Behavior:** Heat Input influences the solidification rate, affecting the formation of defects such as porosity and cracks. Proper heat input management contributes to minimizing these issues.

- **Efficiency and Throughput:** Proper control of Heat Input ensures efficient energy usage, which is crucial for cost-effective production and reduced thermal distortion.

  Balancing Deposition Rate and Heat Input is vital to achieving consistent part quality and desired material characteristics in WAAM. By understanding and optimizing these factors, manufacturers can enhance the reliability, efficiency, and performance of additively manufactured components.

  Together, Deposition Rate and Heat Input impact the material's microstructure, mechanical properties, and overall quality of the additively manufactured components. Balancing these factors is essential to achieve the desired build speed, structural integrity, and part performance in WAAM processes. Proper control and optimization of these parameters contribute to producing components with consistent and reliable properties[12].

3. **Melt Pool Geometry:** The shape and dimensions of the molten pool during deposition. Equation (for cylindrical melt pool): $V\_melt = \pi \times (d/2)^2 \times h$, where d is the melt pool diameter and h is the depth. "Melt Pool Geometry" refers to the characteristics of the molten pool that forms when material is deposited during an additive manufacturing process, such as Wire Arc Additive Manufacturing (WAAM). The shape and dimensions of the melt pool play a crucial role in determining the final quality and properties of the manufactured component.

   Equation for Melt Pool Geometry (Cylindrical): The equation $V\_melt = \pi \times (d/2)^2 \times h$ quantifies the volume of the melt pool, where:

"V_melt" is the volume of the molten material, "d" is the diameter of the melt pool, and "h" is the depth or height of the melt pool.

4. **Cooling Rate (CR):** The rate at which the molten material solidifies and cools down.
   Equation: $CR = \Delta T / \Delta t$, where ΔT is the temperature change and Δt is the time interval. There are a number of elements that affect the cooling rate in WAAM, including:

   - **Deposition Rate:** As more material is added quickly, a higher deposition rate might result in quicker cooling rates.

   - **Heat Input:** The temperature of the melt pool is influenced by the amount of energy used throughout the process. Slower cooling rates may be the result of more heat input.

   - **Material Conductivity:** The thermal conductivities of various materials vary, which has an impact on howrapidly heat is removed from the melt pool.

   - **Part Geometry:** The dimensions and shape of the part can affect cooling rates by affecting the way heat isdispersed.

   - **Layer Thickness:** Because there is more material and heat involved, thicker layers may cool more slowly.

5. **Thermal Gradient (G):** The change in temperature per unit distance.
   Equation: $G = \Delta T / \Delta x$, where ΔT is the temperature change and Δx is the distance.

6. **Solidification Rate**: The rate at which the molten material solidifies.
   Equation: Solidification Rate = Volume solidified / Time.

   - To control the solidification rate during the WAAM process, manufacturers can adjust several factors, including heat input, deposition rate, and part geometry. Achieving the right balance between these parameters ensures that solidification occurs at a controlled rate, leading to the desired material properties and part quality.

   - **Microstructure:** The solidification rate affects the size and distribution of grains within the material. A slower solidification rate can lead to larger grains, while a faster rate can result in finer microstructures.

   - **Mechanical Properties:** The microstructure influenced by the solidification rate directly impacts thematerial's mechanical properties, such as strength, toughness, and ductility.

   - **Defect Formation:** Proper solidification rates can help prevent defects like porosity and cracking by allowing for controlled material solidification.

   - **Residual Stresses:** The rate of solidification influences how residual stresses develop in the material during cooling. Managing these stresses is important for part stability and performance.

- **Cooling Control:** Managing the solidification rate can help control the cooling rate, which is important for achieving uniform microstructures and properties throughout the part.

7. **Residual Stress (σ):** The internal stresses that remain in a material after cooling.
   Equation: $\sigma = E \times \alpha \times \Delta T$, where E is the elastic modulus, α is the coefficient of thermal expansion, and ΔT is the temperature change.

   In this Equation:
   "σ" represents the residual stress in the material.
   "E" is the elastic modulus of the material, which characterizes its stiffness.
   "α" is the coefficient of thermal expansion, which measures how much the material expands or contracts when its temperature changes.
   "ΔT" is the temperature change experienced by the material during the cooling process.
   Rigorous process planning, optimization, and post-processing are required for controlling and reducing residual stresses in WAAM.

   - **Heat Treatment:** For better part integrity, controlled heat treatments can assist redistribute residual stresses and relieve them.

   - **Implementing progressive cooling techniques:** It can assist prevent the development of abrupt thermal gradients and decrease the accumulation of residual stress.

   - **Process Parameters:** The rate and distribution of residual stress production can be affected by changing parameters including heat input, travel speed, and layer thickness.

   - **Simulation:** Computer simulations can simulate and forecast the development of residual stresses, which benefits process improvement.

   - **Design of the Part:** Design factors, such as part geometry and build orientation, can affect how residual stresses are distributed.

   Making high-quality components with WAAM necessitates balancing the demand for suitable material characteristics and dimensional accuracy while limiting harmful residual stresses.

8. **Weld Penetration Depth (dP):** The depth to which the welding arc penetrates the workpiece.
   Equation: $d_p = K \times I \times t / v$, where K is a constant, I is the current, t is the time, and v is the travel speed.

   In this equation:
   "dP" represents the depth of penetration of the welding arc.
   "K" is a constant that accounts for various factors influencing penetration.
   "I" is the current flowing through the welding arc.

"t" is the time during which the welding process occurs. "v" is the travel speed of the welding head

9. Deposition Efficiency (DE): The ratio of deposited material to the total material fed.
Equation: DE = (Deposited Mass / Fed Mass) × 100%.

In order to control the weld penetration depth in WAAM, process parameters must be adjusted to reach therequired depth while retaining other crucial elements:

Controlling the Weld Penetration Depth in WAAM involves adjusting process parameters to achieve the desireddepth while maintaining other critical factors:

- **Current and Voltage:** Proper welding current and voltage settings have an impact on the energy input intothe process, which in turn has an impact on penetration depth.

- **Travel Speed:** Changing the travel speed affects how much heat is applied and how much material melts,which affects penetration.

- **Heat Input:** The amount of material that melts and, as a result, the penetration depth are both influencedby the welding arc's heat input.

- The depth to which the arc penetrates a material depends on its conductivity, thermal qualities, andmelting characteristics.

- **Part Geometry:** The thickness of the workpiece material and its shape both affect how far the welding arccan go.

10. Layer Height (h_layer): The thickness of each deposited layer.
Equation: h_layer = D × (1 - Overlap), where D is the deposition width and Overlap is the overlapping factor.

In Wire Arc Additive Manufacturing (WAAM), "Layer Height" (h_layer) refers to the vertical thickness of each individual layer that is deposited throughout the additive manufacturing process. The overall build quality, part correctness, and mechanical qualities of the components produced by additive manufacturing are greatly influenced by the layer height[11].

In this equation:
"h_layer" represents the height of each deposited layer.
"D" is the deposition width, which is the horizontal distance covered by the welding arc during material deposition.

"Overlap" is the overlapping factor, which represents the extent to which successive layers overlap each other. These are just a few examples of equations and factors that can be relevant to WAAM manufacturing. The specific equations and factors used in WAAM can vary based on the process setup, materials, and desired outcomes. It's important to consult literature and resources specific to your application to get accurate equations and factorstailored to your needs.

11. **Relevance to WAAM:** A crucial parameter that affects several facets of additive manufacturing is layer height in WAAM:

    - **Build Accuracy:** The final component's vertical resolution is determined by the layer height. Finer features andbetter surface polish result from a lower layer height.

    - **Mechanical Properties:** The layer height can have an impact on the part's strength and resistance to fatigue.

    - **Process Parameters:** Altering the feed rate, heat input, and travel speed can change the layer height.

    For the WAAM process to produce accurate, high-quality, and functionally reliable components, layer height mustbe balanced with other process variables.

VIII. IMAGE PROCESSING TO MEET WAAM SPECIFICATIONS

Image processing for Wire Arc Additive Manufacturing (WAAM) involves using digital image analysis techniques to capture, process, and analyze images related to the manufacturing process. This can include images of the molten pool, deposited layers, and other aspects of the WAAM process[10]. Image processing is crucial in WAAM for several reasons:

1. **Process Monitoring and Control:** Image processing allows real-time monitoring of the additive manufacturing process. By analyzing images, operators can detect anomalies, defects, and deviations from the desired parameters. This enables timely adjustments to prevent or mitigate issues during the build, enhancing the overall quality of the manufactured parts.

2. **Defect Detection:** Image processing techniques can identify defects such as porosity, cracks, lack of fusion, and irregularities in deposited layers. Detecting these issues early on allows for corrective actions to be taken before they impact the final part quality.

3. **Quality Assurance:** Through image analysis, manufacturers can ensure that the deposited layers conform to specifications. This is crucial for meeting quality standards and maintaining consistent part quality across different manufacturing runs.

4. **Layer Registration and Alignment:** Image processing can be used to align and register each successive layer accurately. This is vital for achieving dimensional accuracy and preventing cumulative errors that might occur if layers are misaligned.

5. **In-Process Feedback:** Real-time image analysis provides feedback on the quality of the current layer being deposited. This can enable adaptive control systems to adjust process parameters dynamically, optimizing the build quality.

6. **Process Optimization:** By analyzing images of the molten pool and deposition process, manufacturers can identify opportunities for process optimization. This includes adjusting parameters to achieve desired outcomes more efficiently.

7. **Research and Development:** Image processing allows researchers to gain insights into the behavior of the molten pool, material flow, and thermal characteristics. This information can lead to advancements in WAAM process understanding and optimization.

8. **Documentation and Traceability:** Capturing images throughout the WAAM process provides a visual record of the manufacturing steps. This documentation is valuable for traceability, analysis, and quality audits.

9. **Automation and Industry 4.0:** Integrating image processing into WAAM contributes to the advancement of smart manufacturing. Automated systems can use image analysis to make real-time decisions, reducing the need for manual intervention.

   In summary, image processing is essential to contemporary manufacturing techniques like WAAM. It improves process oversight, defect identification, and quality control, which eventually results in better part quality, less waste, and greater effectiveness. Image processing will become more crucial as the manufacturing sector adopts automation and data-driven decision-making in order to produce high-quality additively madecomponents[8].

IX. APPLICATIONS FOR WAAM

Wire Arc Additive Manufacturing (WAAM) has a wide range of applications across various industries due to its unique capabilities and advantages. Some notable applications of WAAM include:

1. **Aerospace Industry:** WAAM is used to manufacture aerospace components such as engine parts, airframe structures, and landing gear components. Its ability to create large-scale, complex, and customized parts makes it well-suited for the aerospace sector.

2. **Automotive Industry:** WAAM is employed in the automotive sector to fabricate components like engine blocks, transmission parts, and chassis components. The technology's cost-effectiveness and potential for lightweight design contribute to its adoption in this industry.

3. **Oil and Gas Industry:** WAAM is utilized to create parts for oil rigs, pipelines, and other equipment used in the oil and gas sector. The ability to manufacture large and corrosion-resistant components is particularly beneficial in harsh operating environments.

4. **Marine Industry:** WAAM finds application in the marine industry for manufacturing ship components, propellers, and offshore structures. Its ability to create parts with excellent mechanical properties and resistance to corrosion is valuable in marine applications.

5. **Energy Industry:** In the energy sector, WAAM is used to create components for power generation and distribution, including turbine blades, generator parts, and heat exchangers. The technology's flexibility and potential for rapid prototyping are advantageous in this field.

6. **Tooling and Molds:** WAAM is employed to fabricate tooling, molds, and dies used in various manufacturing processes. The technology's ability to create complex shapes and customization is beneficial for producing specialized tooling.

7. **Research and Prototyping:** WAAM is utilized for research purposes and rapid prototyping of new designs. It allows researchers and engineers to quickly produce prototypes for testing and validation before moving to full- scale production.

8. **Repair and Maintenance:** WAAM is used for repairing damaged or worn-out components, particularly in industries where large and expensive parts are involved. It can extend the lifespan of critical equipment and reduce downtime.

9. **Customized and Low-Volume Production:** WAAM is suitable for producing customized and low-volume components that may not be feasible using traditional manufacturing methods. It enables cost-effective production of small batches with specific geometries.

10. **Defense and Military Applications:** WAAM is utilized in the defense sector for producing components such as military vehicles, armored vehicles, and other specialized equipment.

Overall, WAAM offers the capability to create large, intricate, and functional metal components with reduced material waste and lead times. Its versatility, cost-effectiveness, and potential for customization make it a valuable technology in various industries seeking innovative manufacturing solutions.

X. COST WITH WAAM PROCESS

The cost of Wire Arc Additive Manufacturing (WAAM) involves multiple factors, including equipment, materials, labor, energy consumption, post-processing, and more. The specific cost breakdown can vary based on factors such as the complexity of the parts being produced, the size of the components, the chosen materials, and the level of automation in the process[9]. Here's a general overview of cost considerations for WAAM:

1. **Equipment Costs:** WAAM requires specialized equipment, including welding machines, robotic systems, and wire feeders. The cost of this equipment can vary significantly based on the manufacturer, capacity, and features.

2. **Material Costs:** The cost of the metal wire used for deposition is a significant factor. Material selection can impact the overall cost, as different metals have varying prices.

3. **Labor Costs:** Skilled operators and technicians are needed to set up, monitor, and maintain the WAAM process. Labor costs include programming, process control, and quality assurance.

4. **Energy Consumption:** The energy required for welding and powering the equipment contributes to the overall cost. Energy efficiency measures can help mitigate this expense.

5. **Post-Processing:** Depending on the application, post-processing steps such as machining, surface finishing, and heat treatment might be necessary. These steps add to the total cost.

6. **Overhead Costs:** Overhead costs include facility expenses, maintenance, insurance, and administrative costs associated with running the WAAM operation.

7. **Maintenance and Repairs:** Regular maintenance and occasional repairs of equipment can add to operational costs.

8. **Consumables:** Consumables such as welding electrodes, shielding gas, and other auxiliary materials contribute to the ongoing cost of production.

9. **Waste and Material Utilization:** Material waste generated during the deposition process can impact material costs. Efficient use of materials and minimizing waste are essential for cost control.

10. **Automation and Efficiency:** High levels of automation and process optimization can reduce labor and energy costs over time.

11. **Customization and Complexity:** The complexity of the parts and the level of customization required can impact the time and resources needed for programming and production.

It's important to conduct a comprehensive cost analysis specific to your manufacturing scenario to accurately determine the cost of WAAM. The benefits of WAAM, such as reduced material waste, faster production, and the ability to produce complex geometries, should also be considered when evaluating its cost-effectiveness compared to traditional manufacturing methods.

XI. CONCLUSION AND FUTURE SCOPE

In conclusion, image processing has emerged as a transformative tool in the realm of Wire Arc Additive Manufacturing (WAAM), revolutionizing the way manufacturers monitor, control, and optimize the additive manufacturing process. By harnessing digital image analysis techniques, WAAM practitioners can gain insights into the intricacies of the molten pool behavior, layer deposition, and overall process dynamics. This technology brings a multitude of advantages to the forefront:

1. **Enhanced Process Monitoring:** Image processing provides real-time visibility into the additive manufacturing process, allowing operators to identify deviations, defects, and irregularities as they occur. This immediate feedback empowers swift interventions, ensuring that potential issues are nipped in the bud.

2. **Defect Detection and Quality Assurance:** With image analysis, even the minutest defects such as porosity, cracks, and lack of fusion can be pinpointed. This meticulous defect detection enhances the quality of the final product and safeguards against the delivery of subpar components.

3. **Adaptive Control and Optimization:** Leveraging the insights gained from image processing, manufacturers can implement adaptive control systems that dynamically adjust process parameters. This optimization leads to efficient material usage, reduced waste, and enhanced part quality.

4. **Process Understanding and Research:** Image processing enables researchers to delve into the intricacies of the molten pool's behavior, material flow, and thermal interactions. This comprehension paves the way for refining process parameters, exploring new materials, and advancing the entire WAAM technology.

5. **Documentation and Traceability:** Capturing and analyzing images throughout the WAAM process provides a robust visual record that aids in traceability, process validation, and compliance with quality standards.

6. **Automation and Industry 4.0 Integration:** Image processing aligns seamlessly with the principles of Industry 4.0 by automating decision-making processes based on real-time image analysis. This convergence drives forward the march toward smart manufacturing.
   In a technology landscape characterized by rapid advancements, image processing for WAAM stands as a bridge between traditional manufacturing and the future of production. Its ability to harness the power of visual information propels additive manufacturing to new heights of precision, quality, and efficiency. As manufacturers continue to embrace the potential of image processing, the boundaries of what can be achieved with WAAM are being redefined, ultimately reshaping the way we conceptualize and execute modern manufacturing processes.

REFERENCES

[1] Takeyuki Abe ―Dissimilar metal deposition with a stainless steel and nickel-based alloy using wire and arc-based additive manufacturing‖,Precision Engineering, Volume 45,2016,Pages 387-395,ISSN 0141-6359,https://doi.org/10.1016/j.precisioneng.2016.03.016.
[2] Xiangman Zhou, Haiou Zhang, Guilan Wang, XingwangBai,Three-dimensional numerical simulation of arc and metal transport in arc welding based additive manufacturing,International Journal of Heat and MassTransfer,Volume 103,2016,Pages 521-537,ISSN 0017-9310
[3] P. Rangaswamy, M.L. Griffith, M.B. Prime, T.M. Holden, R.B. Rogge, J.M. Edwards, R.J. Sebring,Residual stresses in LENS® components using neutron diffraction and contour method,Materials Science and Engineering: A,Volume 399, Issues 1–2,2005, Pages 72-83,ISSN 0921-5093,https://doi.org/10.1016/j.msea.2005.02.019.
[4] Chunyang Xia, Zengxi Pan, Joseph Polden, Huijun Li, YanlingXu, Shanben Chen, Yuming Zhang,A review on wire arc additive manufacturing: Monitoring, control and a framework of automated system,Journal of Manufacturing Systems,Volume 57,2020,Pages 31-45,
[5] ISSN 0278-6125,https://doi.org/10.1016/j.jmsy.2020.08.008.
[6] Ding D, et al. Wire-feed additive manufacturing of metal components: technologies, developments and future interests. Int J AdvManufTechnol 2015;81(1–4):465–81.
[7] Harris ID, Director A. Development and implementation of metals additive manufacturing. New Orleans: DOT International; 2011.
[8] Wu B, et al. A review of the wire arc additive manufacturing of metals: properties, defects and quality improvement. J Manuf Process 2018;35:127–39.
[9] Bourell DL, Leu MC, Rosen DW. Roadmap for additive manufacturing: identifying the future of freeform processing. Austin, TX: The University of Texas at Austin; 2009. p. 11–5.
[10] Ding D, et al. Towards an automated robotic arc-welding-based additive manufacturing system from CAD to finished part. Comput Des 2016;73:66–75.
[11] Nagesh D, Datta G. Genetic algorithm for optimization of welding variables for height to width ratio and application of ANN for prediction of bead geometry for TIG welding process. Appl Soft Comput

2010;10(3):897–907.
[12] Haleem A, Javaid M. Additive manufacturing applications in industry 4.0: a review. J IndIntegrManag 2019;4(04):1930001.
[13] Dilberoglu UM, et al. The role of additive manufacturing in the era of industry 4.0. ProcediaManuf 2017;11:545– 54.
[14] Rieder H, et al. Online monitoring of additive manufacturing processes using ultrasound. 11th European Conference on Non-Destructive Testing (ECNDT). 2014.
[15] Pan Z, et al. Arc welding processes for additive manufacturing: a review. Transactions on intelligent welding manufacturing. Springer; 2018. p. 3–24.
[16] Chen B, Chen S. A study on applications of multi-sensor information fusion in pulsed-GTAW. Robotic welding, intelligence and automation. Springer; 2011. p. 245–52.

DESIGN OF CYLINDER HEAD GASKET

Abstract

The gas and liquid escaping from the engine due to leakage not only affects the performance of the engine but also pollutes the environment and increases the risk of unexpected accidents. To improve the effectiveness of the gasket sealing, it is important to consider the pre-stressing force of the bolts and the gasket design. Therefore, by applying the appropriate investigative procedures and tests, it becomes important to ensure that the assembly of the cylinder head, bolts, and gasket is both reliable and efficient to achieve the goals of the engine being developed. Before conducting a structural and thermal study of the cylinder head gasket, it is essential to assemble the cylinder head, bolts, and gasket properly, considering the pre-stressing of bolts. The various investigators did not consider the thermal stresses produced on the cylinder head due to temperature distribution in the cylinder head area, and their results reveal that the initial stressing of bolts affects the effectiveness of the cylinder head gasket's sealing.

To evaluate the efficiency of cylinder head gaskets and their stress and strain behavior under different loading conditions, the appropriate design of cylinder head gaskets based on contact theory is required. This chapter provides information about the material selection of cylinder head gaskets with different gasket types and gasket joint calculations to determine loss of preload due to gasket seating, loss of preload due to complete connection, available preload after assembly, maximum permissible tightening torque, torsional stress generated in the smallest cross-sectional area of the bolt, cylinder head fixation required preload for each bolt, and tensile stresses generated in the bolt.

Keywords: Pre-stressing force on bolt, Cylinder head gasket, Gasket joint calculations

Author

Ms. Viddya Sunil Patil
Assistant Professor
Department of Mechanical Engineering
Sharad Institute of Technology
College of Engineering
Yadrav, Ichalkaranji, Maharashtra
vids204@gmail.com

I. INTRODUCTION

A gasket is a mechanical assembly's means of establishing and maintaining a barrier against the passage of liquids and gases between mating surfaces. The cylinder head gasket is used to seal the cylinder head and block of a gasoline or diesel engine. It is an essential component of the engine and has to perform multiple tasks simultaneously when the engine is running. The seal around the combustion chamber, coolants, engine oil, and air must be maintained at the optimum operating pressure and temperature by the cylinder head gasket. The materials used in the gasket's construction and its design must be chemically and thermally resistant to combustion byproducts as well as to the various chemicals, coolants, and oils employed in the engine. The cylinder head gasket becomes an important part of the engine's overall structure when the engine block, cylinder head, and gasket are all assembled, as shown in the figure.1. It holds up the cylinder head and all of its functional parts. It must be capable of withstanding the heat and dynamic forces transferred from the head and block. The cylinder head gasket design will be based on the type of engine used.

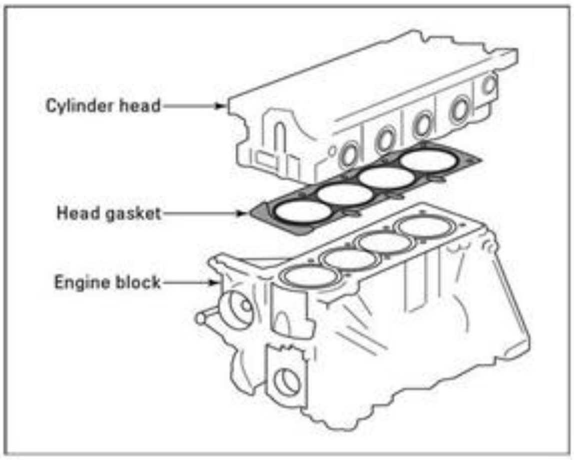


Figure 1: Assembly of Cylinder, Cylinder Head and Gasket

A cylinder head gasket failure could occur if the engine overheats and operates beyond its normal operating range. The high temperatures may cause an excessive amount of stress on the cylinder head. This happens if aluminum cylinder heads are used, because after heating aluminum expands more than cast iron, which could result in a loss of pre-stressing in crucial locations and cause the head gasket to leak.

II. THE ORETICAL BACKGROUND

1. **The Contact Theory:** In contact theory, it is assumed that the cylinder head, bolts, and gasket are not perfectly flat at some scale. The cylinder head gasket initially goes through a plastic deformation process to support the entire contact force. The contact pressure has a direct proportional relationship with the size of the plastically deformed gasket zone, while the hardness of the material has an inverse relationship.

2. **Thermal Stress:** A cylinder head gasket under mechanical stress responds to temperature variations by expanding or contracting. Thermal stresses are those kinds of stresses caused by a change in temperature. It is necessary to do a heat transfer analysis of the

cylinder head before performing the structural analysis. The heat condition equation in the material can be expressed as follows in accordance with the energy conservation principle:

$$\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2} = 0$$

With proper boundary conditions, it is possible to detect the temperature distribution in the material. The strain components of the element, including the thermal strains, are provided below according to generalized Hooke's law.

$\epsilon_X = (\sigma_X - \mu(\sigma_y + \sigma_Z))/E + \alpha\, \Delta T$
$\epsilon_y = (\sigma_y - \mu(\sigma_Z + \sigma_X))/E + \alpha\, \Delta T$
$\epsilon_Z = (\sigma_Z - \mu(\sigma_X + \sigma_y))/E + \alpha\, \Delta T$
$\gamma_{xy} = \tau_{xy}/G$
$\gamma_{yz} = \tau_{yz}/G$
$\gamma_{zx} = \tau_{zx}/G$

Where,
T= temperature,
ε = Normal strain,
σ = Normal stress,
v = Poisson's ratio,
E = Young's modulus of elasticity,
ΔT=Incremental temperature,
α =Coefficient of thermal expansion,
τ=Shear stress, and**γ** is the shear strain.
G=Shear modulus,

III. GASKET DESIGN

In order to fulfill the specific performance requirements of the engine, each application needs a unique cylinder head gasket design.

1. **Selection of Gasket Material:** The materials and designs implemented for the cylinder head gasket are the outcome of evaluating various engineering metals, composites, and chemicals for use in a gasket in order to maintain the requisite sealing capabilities throughout the duration of the engine. The physical characteristics of the material are significant elements for determining the gasket design, and the major selection of a gasket material is based on the temperature and pressure of the fluid to be contained, the degree of corrosivity, and the criticality of the application.

   Important material properties for the selection of a gasket;

   - **Compatibility:** To with stand the sealing of the media being contained.
   - **Heat resistance:** To with stand the environment’s ambient temperature.

- **Compressibility:** Conforms to the irregularities and curves of the mating surfaces of the fanges.
- **Micro-Conformability:** To flow through the surface irregularities of the mating flanges
- **Recovery:** To adhere to the motions produced by thermal and mechanical forces.
- **Creep relaxation:** To sustain sufficient stress for continuous sealing over a lengthy period of time.
- **Compressive strength:** To withstand crushing and/or extrusion brought on by high stresses.
- **Erosion resistance:** To allow fluid impact in situations where the gasket has to act as a measuring device.
- **Tensile strength:** To withstand rupture caused by pressurized media.
- **Autistics:** To ensure gasket removal without sticking.
- **Shear strength:** To manage the shearing motion of the joining flanges caused by the mechanical and thermal effects of the joining flanges.
- **Heat conductivity:** To Permit the heat transfer of the application.
- **Acoustic isolation:** To provide necessary noise isolation for the application.

Non-Metallic Gaskets:

- Non-metallic materials are generally used when the gasket material easily compresses with a light bolt load and has dimensional stability.
- These gaskets are prepared from cork, rubber, plastic, and asbestos material.
- Asbestos gaskets have sharp edges; hence, they provide admirable resistance to crushing loads and cutting action.
- Rubber parts are extremely impermeable and can flow into joint flaws when compressed.
- They are available in the form of compressed fiber sheets, PTFE, graphite and thermo lite, insulating gaskets.
- They are inexpensive but susceptible to fungi and alkalis.
- The Limit temperature for asbestos gasket is 250 and other non-metallic gaskets are70
- Application: low to medium pressure services, extreme chemical services, and temperatures such as heat exchangers, compressors, bonnet valves, and applications involving uneven surfaces.

Semi-Metallic Gasket:

- These composite gaskets are made of metallic and non-metallic materials.
- The gasket's strength and durability come from the metal, while its conformable sealing substance comes from the non-metallic component.
- When compared to full metallic gaskets, semi-metallic gaskets are designed to have soft, malleable sealing materials, which improve the assembly's tightness with lower overall load requirements. Because of this structure, they are the most widely used and are available in a huge range of styles and sizes.
- Typically, they can be fabricated from any metal that is accessible in thin strips or sheets and can be welded. They can therefore be employed over almost any corrosive medium, depending on the metal and filler or facing material that is used.
- They are applicable across the entire temperature range, from cryogenic to around

2000 °F (1093 °C).

- Semi-metallic gaskets such as spiral wound gaskets, metal-jacketed gaskets, and metal-reinforced gaskets are available.
- Application: low and high pressure and temperature applications

Metallic Gasket:

- Lead, copper, or aluminum sheets are the main components of a metallic gasket. When these gaskets are compressed during assembly, they are permanently set, and there is no recovery to consider contact face separation. Additionally, they are vulnerable to corrosion and chemical conditions, and the surface finish of the interacting surfaces affects how well they work.
- The maximum operating temperatures for metallic gaskets are shown in Table No.1.

Table 1: The Maximum Operating Temperatures for Metallic Gaskets

Sr.no	Gasket Material	Maximum Operating Temperature^{0}c
1	lead	90
2	copper/brass	250
3	Aluminum	400

- Metallic gaskets can be found as lens rings, weld rings, ring-type joints, and solid metal gaskets.
- Application: high-pressure and high-temperature applications

The most frequently used gasket materials are as follows:

- **Fiber-Based Composite Materials:** There are three types of fiber composite materials used
  - Carbon Fiber
  - Pyrosic glass ceramic
  - Kevlar fibe

Table 2: the Mechanical Properties of Carbon Fiber, Pyrosic Glass Ceramic, Kevlar Fiber

Sr.no	Property	Carbon Fiber	Pyrosic glass ceramic	Kevlar fiber
1	Modulus of Elasticity (Gpa)	70	43	95
2	Ultimate Tensile Strength (Mpa)	600	350	1300
3	Ultimate Compressive Strength (Mpa)	150	95	280
4	Poisson’s ratio	0.1	0.1	0.34
5	Thermal conductivity (W/mk)	0.90	0.95	30
6	Density (g/cm$^{3)}$	1.78	1.8-2.2	1404

- **Composite Material Properties:**

  - High strength at elevated temperatures
  - Toughness (thermal shock resistance and impact)
  - Improved oxidation and corrosion resistance
  - Conductivity and controlled thermal expansion
  - Greater hardness and erosion resistance

- **Graphite Materials:** Graphite materials are generally used for the outer layer of the gasket.

  - Graphite is excellent at handling high temperatures, and it is anisotropic.
  - It can be crushed and extruded if used in oil over a long period of time.
  - Leaves a covering on the block and head that is challenging to remove.

- **Stainless Steel and Steel of Various Grades and Forms**

  - Steel and stainless steel do not easily corrode.
  - It is not completely stain-resistant.

Table 3: Mechanical Properties of Stainless Steel

Sr.no	Property	Value
1	Modulus of Elasticity (Gpa)	190
2	Ultimate tensile strength (Mpa)	400
3	Ultimate compressive strength (Mpa)	570
4	Poisson's ratio	0.2
5	Thermal conductivity (W/mk)	16.3
6	Density (Mg/m$^{3)}$	7.85

2. Selection of Cylinder Gasket Type:

- **Sandwich Gasket:** The sandwich-type gasket is shown in Figure 2.This gasket is constructed using copper or steel plate on the outer surfaces and asbestos millboard in the center. The grommets, or eyelets, are in corporate in to these gaskets.

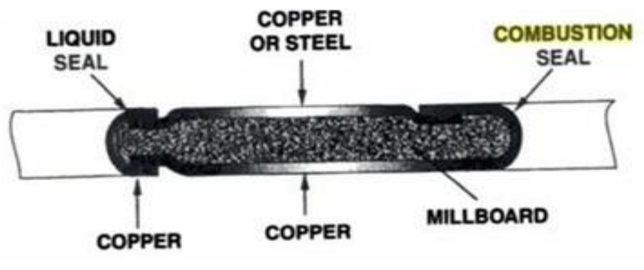


Figure 2: Sandwich gasket

- **Strengthened Sandwich Gasket:**

  The strengthened sandwich gasket is shown in Figure 3. For better sealing, these designs employ a variety of reinforcements at the combustion chamber seal. In many constructions, metal shims and strengthened filler materials are used.

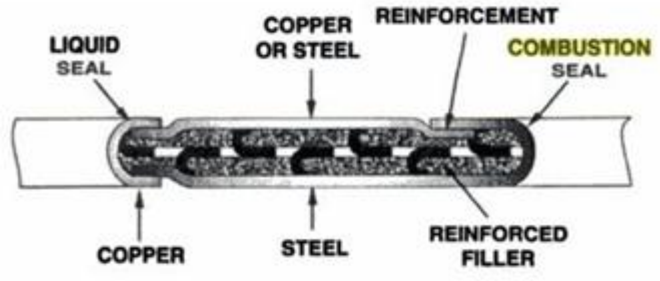


Figure 3: Strengthened Sandwich Gasket

- **Embossed Steel Shim:** An embossed steel shim gasket is shown in Figure 4.A plastic resin covering has been added to the all-metal embossed steel shim gasket for micro-sealing purposes. This gasket naturally has good torque retention. However, as engine displacement increased, the elastic response of the illuminated design was unable to accommodate it. Furthermore, the land gaps, especially those between cylinders, were commonly made smaller to the point where the embossed legs would cover up ports, making efficient sealing difficult
.

Figure 4: Embossed Steel Shim

- **Perforated-Core Head Gasket:** These designs have a perforated steel sheet as the core, and the facing materials are mechanically attached to either side of the core. This works without retorquing the cylinder head bolts, and soft sealing material surfaces are given for water and oil sealing.

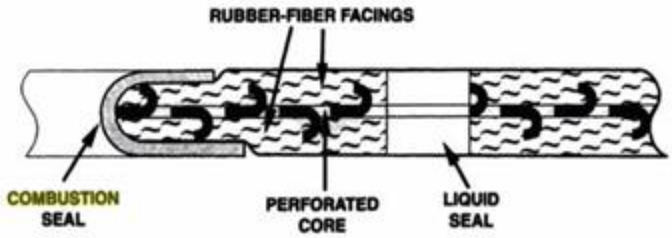


Figure 5 : Perforated-Core Head Gasket

- **Unbroken-Metal-Core Head Gasket:** The unbroken-metal-core head gasket is shown in Figure 6.In this design, instead of a perforated core, an unbroken steel core is used with a rubber-fiber facing, to which an adhesive is applied to bind the facing. Many of the more difficult sealing applications now use this layered gasket. To create greater sealing stress in specific passageways, the gasket body might be embossed. Elastomeric beads are produced at critical passageways using silk screening, which is another method for sealing them.

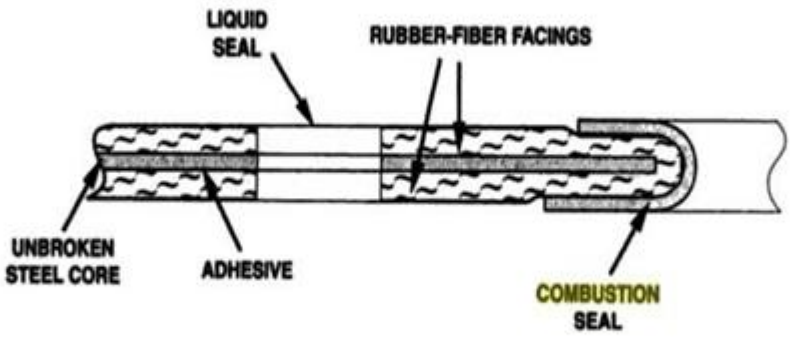


Figure 6: Unbroken-Metal-Core Head Gasket

- **Multilayer Steel Head Gasket:** The multi layer steel head gasket is shown in Figure 7.A rubber coating is applied to many layers of spring-tempered stainless steel that have been embossed. A little change can be seen in these gaskets as the engine runs. High elastic recoveries are obtained when spring-tempered stainless steel is used for embossing layers.

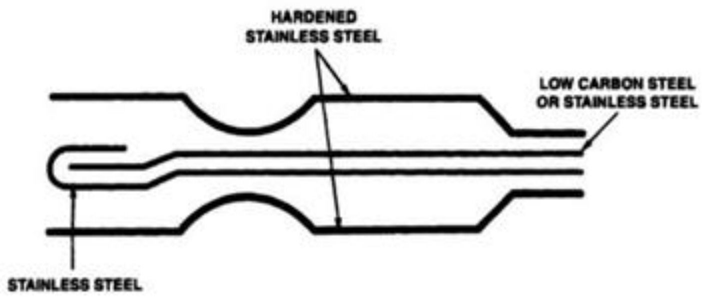


Figure7: Multilayer-Steel Head Gasket

- **Head Gaskets For Combustion Sealing:**

  - **Stainless Steel Armor with a Steel Ring Head Gasket:** The stainless steel armor with a steel ring head gasket is shown in Figure 8. Diesel engines frequently use a low-carbon steel ring, which offers a high unit sealing stress at a very low loading. Typically, using stainless steel armor wrapping, the wire is butt-welded to the gasket body. In certain situations, the wrapping might be tabbed to increase the loading on the wire ring while decreasing the force needed to embed the armor into the body.

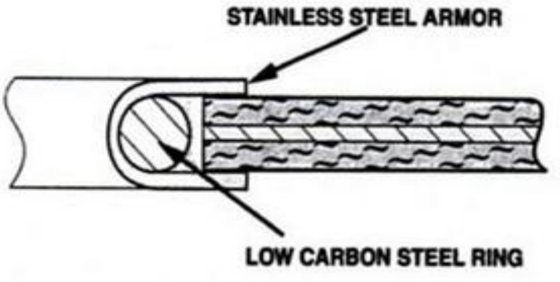


Figure 8 : Stainless Steel Armor with a Steel Ring Head Gasket

- **Armored Embossed Metal:** The armored, embossed metal gasket is shown in Figure 9.This is utilized in many engines to seal up the combustion area. A wide range of load compression qualities can be achieved by varying the height and width of emboss. Since the core of the gasket and emboss are produced from the same piece of metal. When embossing is made from the core of the gasket body, variations in thickness tolerance are minimized. Stainless steel, or low-carbon steel, is used for armor.

Figure 9 : Armored Embossed Metal

3. **Design Strategies for Combustion Sealing:** There are two basic design strategies for combustion sealing. The first combustion sealing strategy known as "massif" refers to the employment of a thick steel gasket blank, or "core" that can be developed either during gasket fabrication or by application of the clamping force during engine building. The second combustion sealing strategy, known as "multi-layer steel," makes use of several layers of formed steel and coatings. 'Functional layers' refers to the developed steel layers of the several-layer steel gasket(SLS). The forming process of these layers is called embossing, and the final component prepared is called embossment. There are two different SLS gaskets available for combustion sealing. Obstacle type and no-obstacle type

   - **Obstacle Type:**

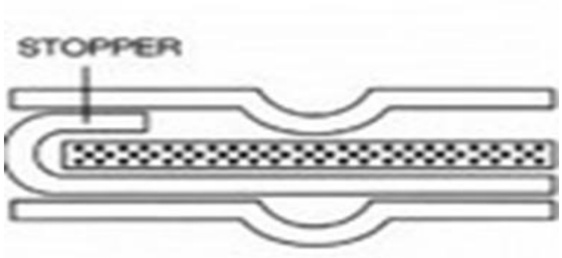


Figure 10: Obstacle-Type Gasket

The obstacle-type gasket is shown in Figure10, Include a sheet with a uniform but variable thickness called the stopper or obstacle layer. It can be placed between two functional layers, directly against the cylinder head or block, or between two functional layers and their distance layer. Obstacle layers are used to prevent functional layers from being completely compressed.

- **No Obstacle-Type:**

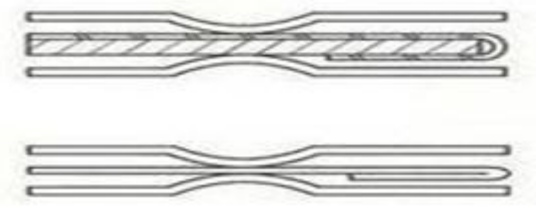


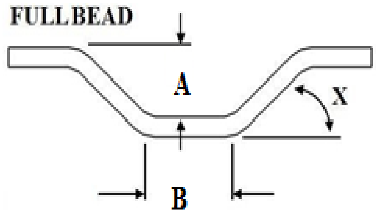
Figure 11: No Obstacle-Type Gasket

A no obstacle-type gasket is shown in Figure 11.It is made up only of an operational layer and an additional layer, or a backup layer. High-temper stainless steel is used to fabricate the functional layers of the SLS gasket, and specially designed embossments are used to give the sealing joint high unit loading and good dynamic recovery. The backup or additional layers are made from carbon steel or stainless steel, which provide a proper compressed thickness and load balancing between the functional layers. The SLS gasket creates a strong, long-lasting micro seal inside the sealing. Current coating materials include nitrite butadiene rubber, fluoropolymer, and molybdenum graphite. Coating materials are always being refined to increase salability.

- **Properties of SLS Gaskets:**

  - High durability
  - Using lower bolt forces to seal
  - High chemical and heat resistance
  - More precise control of the installed compacted thickness
  - Greater bolt retention forces over the course of operation
  - Improve the stability of joints after installation
  - High bolted joint's dynamic responsiveness level
  - Provide the sealing joint with high unit loading and strong dynamic recovery
  - Lower total weight
  - Reduce rigidity

- **Construction of SLS Gaskets:** The SLS cylinder head gasket is made from several steel layers that collectively make up the gasket's body. The gasket's body material is often made of low-strength steel, which serves only to support the gasket. Graphite and composites are two more materials that are commonly used. There are several unique regions inside the layers, all of which are important to the sealing process. The top and bottom sheets, which represent the gasket's active layers, are constructed from beads. The beads transform bolt forces into sealing forces and are responsible for providing excellent sealing. The stopper/obstacle area refers to the bead material that covers the cylinder opening. The section, which acts as the first line of sealing against leakage, has to be the most substantial and stiffest in order to provide sufficient sealing pressure against the combustion gases. Typically, the stopper (also known as the fire ring) is distinct and stiffer than the rest of the gasket. According to research, the stopper area bears between 60 and 80 percent of the stress caused by bolt loading. Therefore, load distribution, head liftoff, bore distortion, and fretting are significantly influenced by the stopper region. The second sealing line, which is made up of beads in the working layers, is situated behind the stopper region. The body's active layers offer sealing for the coolant and oil circuits. Coatings are commonly applied to the gasket's layers; sometimes the top and bottom surfaces are simply coated. The coating affects the shear behavior of the surfaces and serves as an additional barrier against gas and fluid leaks. Beads come in two varieties: full beads and half beads. Both have different geometries and different functions, as shown in Figures 12(A) and 12(B).



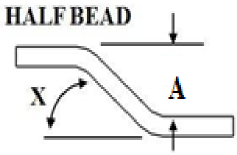
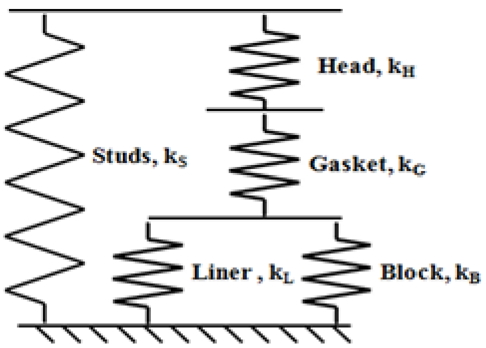


Figure12 (A): Full Bead **Figure12 (B):** Half Bead

The lengths A and B, as well as the angle X, are used to create the beads' particular geometry. During the installation of the head gasket, the full beads are compressed until they reach the stopper's height or until their resistance is equivalent to the tightening force of the bolt. A full bead generates a significant amount of sealing force, and that is needed to completely seal the combustion area. The main purpose is to smooth out the oscillations of the constantly changing sealing gap between the cylinder head and cylinder block at maximum ignition pressures. Half beads are utilized for sealing both coolant and oil in locations far from the cylinder, such as bolt holes, and on outside surfaces. The sealing force of full beads is greater than that of half beads, and they also maintain the necessary sealing force in the combustion chamber area. The steel layer quality, geometry of the bead, sheet thickness, and production process of the bead are the influencing factors for bead stiffness.

The design of a cylinder head gasket is challenging since the gasket must fulfill a variety of functions while having a sufficient usable life. The overall strength of the gasket and its capacity to seal must therefore be balanced. Engine geometry is the main factor influencing gasket design, but other factors also matter, such as combustion temperatures, fluid chemistries, squeezed gasket size, maximum cylinder stresses, deck surface characteristics, bolt tightening force, etc. Geometric beads or embossments are used to create the sealing properties of the gasket. The designer constructs a plane image of the combustion area and every kind of fluid channel to determine the proper design for the sealing beads. Stamping the thin metallic layer between two tool halves produces the beads of each layer and causes residual tensions in the layers. The separate layers are then placed to achieve the requisite compression thickness between the engine block and head as well as the desired spring stiffness characteristics. As shown in Figure 13(A) for engine assembly and in Figure 13(B) for gasket assembly. When the gasket layer beads are combined, they become a single, larger spring from their original state of being small and single. The spring's properties are affected by the material, thickness, hardness, and shape of the layer used for the gasket. There are two types of arrangements for the beads in the subsequent layers: series and parallel, as shown in Figure 14(A) and Figure 14(B).

There are numerous bead configurations in use, making it challenging for the gasket manufacturing sector to match the static and dynamic requirements of engine assembly. The entire gasket must withstand the effects of fatigue throughout its full life and provide appropriate sealing at the highest, lowest, and intermittent loads. The major goal of a gasket designer is to optimize the gasket contact stresses and reduce dynamic head motion because any deterioration of sealing ability would lead to decreased engine performance and even failure.



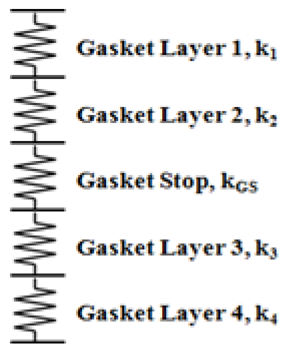


Figure 13(A): Engine Assembly **Figure 13(B):** Gasket Assembly

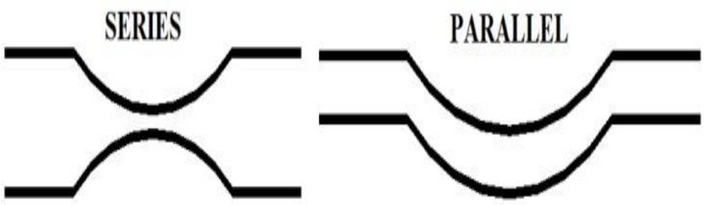


Figure14 (A): Series **Figure 14(B):** Parallel

4. Gasket Joint Calculations:

- Stiffness of Cylinder Head (K_h) is calculated by,

$K_h = E_h \times \frac{\text{Area}_{Eq}}{L_h}$ (N/mm)

Where,
E_h= Young's modulus of elasticity of cylinder head
Area $_{Eq}$ = Equivalent area of cylinder head
L_h = Effective height of head

- Stiffness of Bolt (Kb) is calculated by,

$(Kb)=\frac{E_b}{\frac{L1}{A1}+\frac{L2}{A2}+\frac{L3}{A3}}$ (N/mm)

Where,
L_1, A_1= Length and Area of head to shank of bolt respectively
L_2, A_2 = Length and Area of shank of bolt respectively
L_3,A_3= Length and Area of full thread of bolt respectively

- Stiffness of Gasket (K_g),

$K_g = E_g \text{ x } \frac{\text{Area}_{Eq}}{L_g}$

Where,
E_g = Young's modulus of elasticity of gasket material
Lg = Height of gasket
Area $_{Eq}$ = Equivalent area of gasket

- Combined Stiffness (Kc): When there is bolted assembly of cylinder block, cylinder head and gasket They act as three compression springs, which are in series hence their combined stiffness is calculated by,

$$\frac{1}{K_c} = \frac{1}{K_h} + \frac{1}{K_{bl}} + \frac{1}{K_g}$$

Where,
K_c=Combined stiffness
K_h= Stiffness of cylinder head
K_{bl} = Stiffness of cylinder block
K_g = Stiffness of gasket

- Loss of Preload Due to Gasket Seating only(Fg) is calculated as,

$F_g = \frac{0.1}{\frac{1}{K_b}+\frac{1}{K_h}}$(N)

- Loss of Preload due to Complete Connection

(Fs)=1.3×Fg (N)

- Maximum Combustion Force (Fc),

$Fc = \frac{\pi}{4} x D^2 x P_{Peak}$ (N)
Where,
D= Bore diameter of cylinder head
P_{peak}= Cylinder peak pressure

- Available Preload after Assembly ($F_{Avail.}$),

$$F_{Avail.} = \frac{A_{min} \times S_{yt}}{\sqrt{1+3\times(\frac{\sigma to}{\sigma t})^2}} \text{ (N)}$$

Where,
A_{min}= Area of minimum C/S of bolt=$\frac{\pi}{4} x D_{min}{}^2$
D_{min}= Diameter of minimum C/S of bolt =D-1.226 x P
P= Lead of head of thread
S_{yt} =Yield strength of bolt
Σto= Torsional tension produced in smallest C/S area of bolt
σt =Tensile stress

$$\frac{\sigma to}{\sigma t} = 2 \times \frac{D_p}{D_{min}} \times (\frac{P}{\pi \times D_p} + 1.155 \times \mu)$$

Where,
D_p=Pitch diameter of thread
μ = Friction coefficient

- Maximum Permissible Tightening Torque (T_{per}),

$$T_{per} = F_{Avail} \text{ x } \{\frac{D_p}{2} \times \left(\frac{P}{\pi \times D_p} + 1.155 \times \mu\right) + \frac{D_m}{2} \times \mu\} \text{ (Nmm)}$$

Where,
D_m = Mean diameter of bolt head

- Torsional Tension produced in smallest C/S area of bolt (σto),

$$\sigma to = \frac{FAvail \times \frac{D_p}{2} \times \left(\frac{P}{\pi \times D_p} + 1.155 \times \mu\right)}{\pi \times \left(\frac{D_{min}}{16}\right)^3} \text{ (N/mm}^2\text{)}$$

- Tensile Stress (σt),

$$\sigma t = \sqrt{S_{yt}{}^2 + 3 \times \sigma to^2} \text{ (N/mm}^2\text{)}$$

- Bolt Force at Yield Strength (F_{Syt}),

$$F_{Syt} = \sigma t \text{ x } \frac{\pi}{4} \text{ x } D_{min}{}^2 \text{ (N)}$$

- Cylinder Head Fixation Required Preload for Each Bolt ($F_{Pre.}$),

$$F_{Pre} = K \text{ x } Fc + n \times \frac{Fs}{n} \quad (N)$$

Where,
K=Constant depends on bolt material and size
n = No. of bolts

Table 4: Typical Values for K-

Sr.no	Condition	K value
1	Normal dry	0.2
2	Non-plated black finish	0.3
3	Zinc-plated	0.2
4	Slightly lubricated	0.18
5	Cadmium-plated	0.16

- Residual Preload on each bolt=0.9 x F_{Avail}–Fs (N)

- Factor of Safety (FOS) = $\frac{S_{yt}}{\sigma t}$

Example: Bolts are used to secure the cylinder, cylinder head, and gasket. The maximum pressure is 20 MPa, and the cylinder's ID is 115 mm. Four bolts with an M16*1.5 thread size secure the cylinder head to the cylinder. Preload of 70 KN is first provided by each bolt. Steel is used for the gasket and bolts. The cylinder head's material is GCI grade 25. Calculate the bolt safety factor while accounting for the gasket's impact.

Below is information about the M16*1.5 bolt and the cylinder head,

Table 5: Length, Diameter and area of each C/S of Bolt size M16*1.5

Bolt Specification	Length	Diameter	Area
Head to shank(L1)	10	16	201.06
Shank(L2)	140	14	153.93
Full thread (L3)	50	14.99	176.47
Collar	33		

Table 6: Cylinder Head Bolt details

Bolt Size	M16*1.5	Unit
Pitch	1.5	mm
No of Bolt around cylinder(n)	6	
Modulus of Elasticity	210000	Mpa

bolt(steel)		
Yield strength(S_{yt})	900	Mpa
Friction Coefficient(μ)	0.2	
Lead of head of thread(P)	1.5	mm
Pitch diameter of thread (Dp)	14.99	mm
Mean diameter of bolt head (Dm)	16	mm

Table 7: Cylinder Head Details

Description	**Value**	**Unit**
Bore(D)	115	mm
Cylinder peak pressure (Ppeak)	20	Mpa
Modulus of Elasticity of cylinder head(Eh)	118000	Mpa
Modulus of Elasticity of Gasket (Eg)	190000	Mpa
Height of cylinder head(Hcyl)	115	mm
Cylinder head gasket thickness(Tg)	2	mm

Solution:

- Stiffness of bolt(Kb),

$$Kb=\frac{E_b}{\frac{L1}{A1}+\frac{L2}{A2}+\frac{L3}{A3}}$$

$$=\frac{210}{\frac{10}{201.06}+\frac{140}{153.93}+\frac{50}{176.47}} = 169.35 \text{ KN/mm}$$

- Stiffness Of Cylinder Head (K_h) ,

$$K_h= E_h \text{ x } \frac{A_{Eq}}{L_h}$$

Where,
L_h= Height of cylinder head= 115 mm
A_{Eq}=Equivalent area of cylinder head

It is difficult to predict the area of cylinder head compressed by the bolt hence It is assumed that a hollow circular area of (3D) and (D) as an outer and inner diameters respectively is under the grip of the bolt.

$$A_{Eq}=\frac{\pi}{4}[(3D)^2 - D^2] = 2\pi D^2 = 2\pi 16^2 = 1608.49 \text{ mm}^2$$

- Stiffness Of Cylinder Head (K_h)= E_h x $\frac{A_{Eq}}{L_h}$

$$=118 \text{ x} \frac{1608.49}{115}$$

= 1650.45KN/mm

- Stiffness of Gasket (K_g) ,
  $K_g = E_g \text{ x } \frac{A_{Eq}}{L_g}$

  Where,
  L_g= Height of gasket = 2 mm
  A_{Eq}=Equivalent area of Gasket

  Stiffness of Gasket (K_g) =$190 \times \frac{1608.49}{2}$
  = 152807.06 KN/mm

- Combined stiffness = $\frac{1}{K_c} = \frac{1}{K_h} + \frac{1}{K_C} + \frac{1}{K_g}$

  $$\frac{1}{K_c} = \frac{1}{1650.45} + \frac{1}{1650.45} + \frac{1}{152807.06}$$

  Kc=820.81 KN/mm
  Resultant bolt load,

  $\frac{Kb}{Kb+Kc} = \frac{169.35}{169.35+820.81}$= 0.1710

  Each bolt is initially tightened with a preload (F)=70 KN.

- Cylinder head fixation required preload for each bolt (F_{Pre})=K × Fc + n × $\frac{Fs}{n}$

  Where,
  Fc =Maximum combustion force,
  Fc =$\frac{\pi}{4} \times D^2 \times P_{Peak} = \frac{\pi}{4} \times 115^2 \times 20 = 207711.85$

  Fs = Loss of preload due to complete connection,
  (Fs)=1.3×Fg

  Fg = Loss of preload due to gasket seating only
  $F_g = \frac{0.1}{\frac{1}{K_b}+\frac{1}{K_h}} = \frac{0.1}{\frac{1}{169.35}+\frac{1}{1650.45}}$ =15.35 KN = 15350 N

  Hence,
  (Fs)=1.3×15350 = 19955 N

  Cylinder head fixation required preload for each bolt,
  (F_{Pre})= 0.18 x 207711.85+4 x 19955/4 = 57343.133 N

  The resultant load on the bolt is given by,

$F_{Res.} = F + F_{Pre}(\frac{Kb}{Kb+Kc})$

$F_{Res.}$ =70000+57343.133 x 0.1710 = 79805.67 N

Resultant tensile stress in the bolt$\sigma t = \frac{F_{Res}}{\frac{\pi}{4}\times D^2} = \frac{79805.67}{\frac{\pi}{4}\times 16^2} = 396.92$

Factor of safety = (FOS) = $\frac{S_{yt}}{\sigma t} = \frac{900}{396.92} = 2.2$

IV. CONCLUSION

The design of a cylinder head gasket is a critical aspect of engine design. The design factors to consider include gasket material selection, thickness, shape, and the inclusion of features like fire rings, coolant passages, and oil passages. The material used in the gasket should be able to withstand high temperatures, pressures, and chemical exposure while maintaining its sealing properties. The thickness should be optimized to provide sufficient compression and sealing without interfering with engine performance. The pre-stressing of bolts is an important parameter to consider when designing a cylinder head gasket. Pre-stressing refers to the intentional application of tension to the bolts that secure the cylinder head to the engine block before the gasket is compressed. This tension helps to create a clamping force that ensures a tight and secure seal between the cylinder head and the engine block and also maintains the integrity of the gasket's seal under the high pressures and temperatures experienced in the combustion chamber. It prevents the gasket from being squeezed out or losing its compression, which can lead to leakage of combustion gases or coolant due to gasket failure and subsequent issues such as loss of compression, overheating, and potential engine damage. Therefore, considering the pre-stressing of bolts is an important parameter in the design of a cylinder head gasket. Thus, information about the material selection of cylinder head gaskets with different gasket types and gasket joint calculations to determine loss of preload due to gasket seating, loss of preload due to complete connection, and available preload after assembly is provided in this chapter. Additionally, the theoretical formula for maximum tightening torque, torsional stress generated in the smallest cross-sectional area of the bolt, and the necessary preload on each bolt for cylinder head fixation.

REFERENCES

[1] MalothSaiGopalnayak, Dr. D. Damodarareddy, “Design and thermal analysis of head engine gasket by varying its materials”,Journal of Engineering Sciences , Volume 13, Issue11, 2022

[2] Yang Jun Wang, Zheng, “Cylinder head gasket leakage trouble shooting analysis”, SAE International, Sept 2021

[3] Yaxiang Yin, Kun Wang, “Cylinder head gasket design optimization based on high definition metrology”, Journal of physics conference series , Volume 1983(1), 2021

[4] Long Wang, ZhengxingZuo, “Research on the coordination and matching of cylinder head gasket strength and sealing performance”, Journal of physics conference series , Volume 1885(1), 2021

[5] R.Abik , A.AntoJeberson , K.Ashif Ibrahim , Balamurugan , R.Prabaharan, “Selection and Optimization of Gasket Materials”,International Journal of Innovative Research in Science, Engineering and Technology,Vol. 9, Issue 2, February 2020

[6] Yi Dong, Jianmin Liu, “The optimization research of diesel cylinder gasket parameters based on Hybrid Neutral network and improved grey wolf algorithm”, Journal of Mathematical problems in engineering, volume 2020

[7] Sangle, D., Ozarde, A., and McNay, G., "Cylinder Head Gasket Fretting Simulation for High Horse Power Engine," SAE Int. J. Adv. &Curr. Prac. in Mobility 1(1):133-136, 2019

[8] S. Sanavulla, N. Bhaskar, “Analysis of engine gasket to improve sealing performance”, International Journal of scientific research and review, Volume 8,Issue11,2019

[9] Shaiksai Malik, Kanumuri Rajesh, Dr. D. Vijayaganapathy, "Head gasket finite element model correlation" International Journal of Pure and Applied Mathematics, Volume 120 No. 6 2018, 3965-3974, June 2018
[10] L.Vijayabaskar, "Thermal Analysis of Cylinder Head Gasket Using Ansys", Imperial journal of interdisciplinary research,Vol-2, Issue-12, 2016
[11] D.Vinod Kumar, Prof. Dr.C.UdayaKiran, Y.Vijaya Kumar, " Design and Analysis of Gasket Sealing ofCylinder Head under Engine Operation Conditions"", International Journal of Innovations in Engineering and Technology, Volume 2 Issue 3 – June 2013
[12] Raub, J. H. (1992), "Structural Analysis of Diesel Engine Cylinder Head Gasket Joints," SAE Paper 921725
[13] ZinzuvadiaBhushan,Jayendra B. Kanani, "FEA of Cylinder Head Gasket of Oil Engine",International Journal for Research in Technological Studies, Vol. 2, Issue 3, February 2015 .
[14] Shinji Fukase, Tsuyoshi Takahashi and Jouji Kimura, " Experimental Study of Static and Dynamic Behavior of the Cylinder Head Gasket in a Turbocharged Diesel Engine with Intercooler", SAE technical paper series, September 1999.
[15] Frank Popielas, Colin Chen and Stefan Obermaier, "CAE Approach for Multi- Layer-Steel cylinder head gasket", SAE technical paper series, March 2000.
[16] M.Srikanth, B.M.Balakrishnan, "Cylinder Head Gasket Analysis to Improve its ThermalCharacteristics Using Advanced Fem Tool", International Journal of Machine and Construction Engineering,Volume 2 Issue 1 Mar 2015.
[17] Pavan P. Jorwekar, Yogesh V. Birari, Mayur M. Nadgouda, "Cylinder Head Gasket Contact Pressure Simulation for a Hermetic Compressor", International Compressor Engineering Conference at Purdue, July 17-20, 2006.
[18] Bhushan K Zinzuvadia, Jayendra B Kanani, " Design and analysis cylinder head gasket of oil of engine", International Journal of Advance Engineering and Research Development,Volume 2, Issue 5, May -2015.
[19] S.Karthikeyan, P.Sakthivel, "Design and Structural Analysis of Aluminum Cylinder Head Gasket under Engine Operation", International Journal of Engineering Development and Research,volume 3,Issue 2,2015.
[20] Chang-Chun Lee, Kuo-NingChiang,Wen-King Chen, Rong-Shieh Chen, "Design and analysis of gasket sealing of cylinder head under engine operation conditions", Finite Elements in Analysis and Design, 7 April 2005.
[21] LotfiGrine, Abdel-Hakim Bouzid, "Analytical and Experimental Studies of Liquid and GasLeaks through Micro and Nano-Porous Gaskets", Materials Sciences and Applications, August 2013.
[22] AlexandreSchalch Mendes, "Structural Analysis of the Aluminum Cylinder Head for a High-Speed Diesel Engine", Society of Automotive Engineers, 2007.

PART 2

Futuristic Trends in Mechanical Engineering

Series Id: IIPV3EBS01_G25

Series Editors

Mr Prof. Ajay Kumar Agarwal

Associate Professor

Department of Mechanical Engineering

JB Knowledge Park

Faridabad (Haryana, Delhi NCR, India)

Mr Venkatesh Donekal

(Ph.D) Professor

Department Of Mechanical Engineering

Ramaiah Institute Of Technology

M S R Nagar, Msrit Post

Mathikere, Bangalore-560054, Karnataka State

Sneha

(PhD) Assistant professor

Siddhartha Educational

Academy Group of Institutions

Gollapalli, Tirupati

Dr.G M Swamy

Assistant Professor

Department of Mechanical Engineering

JSSATE, Bangalore

REVOLUTIONIZING MECHANICAL ENGINEERING (M.E.): EXPLORING FUTURISTIC TRENDS & INNOVATIONS

Abstract

Mechanical engineering has been a critical part of human progress and innovation for centuries. From the steam engine to the internal combustion engine, the field has continuously evolved to improve our world. With the advent of new technologies and materials, mechanical engineering is entering a new era of innovation, and we are witnessing some truly incredible advancement. In this blog post, we'll explore some of the most exciting futuristic trends and innovations in mechanical engineering. We'll look at everything from smart materials and nanotechnology to robotics and 3D printing. So buckle up and get ready to be amazed as we take a journey into the future of mechanical engineering.

Keywords: Mechanical engineering is entering a new era of innovation.

Authors

Ajay Kumar Agarwal
Associate Professor in Mechanical Engineering
JB Knowledge Park (JBKP)
Faridabad (Haryana)
ajaymechengineer@gmail

I. INTRODUCTION TO REVOLUTIONARY TRENDS IN MECHANICAL ENGINEERING

Mechanical engineering has long been a cornerstone of innovation and progress, shaping the world as we know it. From the invention of the steam engine to the advancement of robotics, the field has constantly pushed boundaries and revolutionized various industries. However, in recent years, there has been a surge of futuristic trends and innovations that are set to transform mechanical engineering even further.

One such trend is the rise of additive manufacturing, commonly known as 3D printing. This groundbreaking technology allows engineers to create intricate and complex designs with ease, revolutionizing the manufacturing process. With 3D printing, it is now possible to create prototypes, customized components, and even entire structures with unmatched precision and efficiency.

Another trend that is reshaping mechanical engineering is the integration of artificial intelligence (AI) and machine learning. AI-powered systems and algorithms are being utilized to optimize processes, enhance automation, and improve decision-making in various mechanical engineering applications. From predictive maintenance in manufacturing plants to autonomous vehicles, AI is paving the way for a more efficient and intelligent future.

Furthermore, the concept of green engineering is gaining momentum in the field of mechanical engineering. As sustainability becomes a global priority, engineers are focusing on developing eco-friendly solutions that minimize environmental impact. This includes the advancement of renewable energy technologies, energy- efficient systems, and the integration of sustainable materials in design and manufacturing processes.

In this blog post, we will delve deeper into these revolutionary trends and explore the innovations that are driving mechanical engineering into a new era. From the possibilities offered by 3D printing to the potential of AI and the importance of sustainability, we will uncover the exciting advancements that are shaping the future of mechanical engineering.

Prepare to be inspired by the limitless possibilities and incredible potential that lie ahead as we revolutionize the world through engineering excellence.

II. THE RISE OF AUTOMATION AND ROBOTICS IN MECHANICAL ENGINEERING

In recent years, there has been a remarkable rise in the utilization of automation and robotics in the field of mechanical engineering. This technological revolution has brought about significant advancements, transforming traditional manufacturing processes and opening up new possibilities for innovation.

Automation, which involves the use of control systems and machines to perform tasks with minimal human intervention, has revolutionized various aspects of mechanical engineering. From assembly line operations to quality control, automation has greatly improved efficiency, precision, and productivity. With automated systems in place, labor-intensive tasks can now be completed faster and with reduced errors, leading to cost savings and higher output.

Similarly, robotics has played a pivotal role in reshaping the landscape of mechanical engineering. Robots are being employed in a wide range of industries, from automotive manufacturing to healthcare. These intelligent machines are capable of performing intricate tasks that were previously deemed challenging or dangerous for humans. They can handle repetitive tasks with precision, work in hazardous environments, and even collaborate with human workers in a seamless manner.

One of the key advantages of automation and robotics in mechanical engineering is the ability to enhance safety standards. By delegating risky tasks to robotic systems, the potential for accidents and injuries can be significantly reduced. Moreover, robots can be equipped with advanced sensors and algorithms to detect anomalies and prevent potential failures, adding an extra layer of safety to various processes.

The rise of automation and robotics has not only impacted traditional industries but has also paved the way for new opportunities and innovation. The integration of artificial intelligence (AI) and machine learning algorithms with robotic systems has enabled them to adapt, learn, and make decisions based on real-time data. This has resulted in the development of self-optimizing systems, where robots can continuously improve their performance and efficiency.

In conclusion, the rise of automation and robotics in mechanical engineering has brought forth a new era of technological advancements and possibilities. From streamlining manufacturing processes to enhancing safety standards and fostering innovation, these futuristic trends are revolutionizing the field and shaping a future where machines work alongside humans to accomplish remarkable feats.

III. EXPLORING THE POTENTIAL OF ADDITIVE MANUFACTURING (3D PRINTING)

Additive manufacturing, commonly known as 3D printing, has emerged as a groundbreaking technology in the field of mechanical engineering. This innovative process allows for the creation of complex and customized objects with unprecedented precision and efficiency.

Imagine a world where intricate mechanical components can be produced with ease, eliminating the need for traditional manufacturing processes that often involve time-consuming and costly procedures. Additive manufacturing has the potential to revolutionize the way mechanical engineers design and fabricate parts, leading to greater flexibility, reduced lead times, and enhanced product performance.

One of the key advantages of 3D printing is its ability to enable the production of highly intricate geometries that were previously unattainable through conventional manufacturing methods. This opens up a realm of possibilities for engineers to create complex structures and components with intricate details, such as lightweight lattice structures for aerospace applications or intricate internal channels for fluid flow optimization.

Moreover, additive manufacturing offers the advantage of material optimization, allowing engineers to tailor the material composition and properties of a part based on its specific requirements. This level of customization can result in lighter, stronger, and more durable components, ultimately enhancing the overall performance and efficiency of mechanical systems.

Additionally, 3D printing enables rapid prototyping, reducing the time and cost associated with traditional prototyping processes. Engineers can now quickly iterate and test their designs, making necessary modifications and improvements on the fly. This accelerated development cycle not only speeds up the product development process but also fosters innovation and creativity within the field.

The potential applications of additive manufacturing in mechanical engineering are vast and varied. From aerospace and automotive industries to healthcare and consumer goods, 3D printing is revolutionizing the way products are designed, manufactured, and delivered to the market. As this technology continues to evolve, we can expect to see even more advanced materials, larger-scale printers, and novel applications that will further transform the landscape of mechanical engineering. Embracing and exploring the potential of additive manufacturing is crucial for staying at the forefront of this technological revolution and driving innovation in the field of mechanical engineering.

IV. THE IMPACT OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ON MECHANICAL ENGINEERING

Artificial intelligence (AI) and machine learning (ML) have emerged as powerful tools that are revolutionizing various industries, and mechanical engineering is no exception. These cutting-edge technologies are transforming the way mechanical engineers design, analyze, and optimize complex systems.

One of the key areas where AI and ML have made a significant impact is in the design process. Traditional design methods often rely on human intuition and experience, which can be time-consuming and limited in terms of optimization. However, AI and ML algorithms can now generate innovative designs by analyzing vast amounts of data and identifying patterns that humans might miss. This not only speeds up the design process but also leads to more efficient and optimized solutions.

Moreover, AI and ML algorithms can assist in the simulation and analysis of mechanical systems. By training these algorithms on large datasets of real-world scenarios, engineers can predict the behavior of a system under different conditions and make informed decisions. This predictive capability enables engineers to identify potential issues and optimize designs before physical prototyping, saving both time and resources.

Additionally, AI-powered robotics and automation are transforming manufacturing processes in the mechanical engineering field. With the integration of AI and ML algorithms, robots can now perform complex tasks with greater precision and efficiency. This has led to advancements in areas such as assembly line automation, quality control, and material handling, resulting in increased productivity and reduced human error.

Furthermore, AI and ML are enabling predictive maintenance in mechanical systems. By analyzing real- time sensor data, these technologies can detect anomalies and predict equipment failure before it happens. This proactive approach to maintenance not only minimizes downtime but also extends the lifespan of machinery, ultimately reducing costs for businesses.

As AI and ML continue to evolve, the possibilities for their application in mechanical engineering are boundless. From advanced robotics to intelligent design systems, these technologies are reshaping the industry and driving unprecedented levels of innovation. Embracing these futuristic trends will be crucial for mechanical engineers to stay ahead of the curve and unlock new possibilities in their field.

V. HARNESSING RENEWABLE ENERGY SOURCES FOR SUSTAINABLE MECHANICAL ENGINEERING

In the pursuit of a greener and more sustainable future, mechanical engineering has taken center stage in harnessing renewable energy sources. With the growing concern over climate change and the depletion of non- renewable resources, the adoption of sustainable practices in this field has become increasingly crucial.

One of the most significant trends in sustainable mechanical engineering is the integration of renewable energy technologies. Engineers are exploring innovative ways to tap into the power of sources like solar, wind, hydro, and geothermal energy to drive mechanical systems. By utilizing these clean and abundant sources, mechanical engineering can significantly reduce its carbon footprint and contribute to a more sustainable energy landscape.

Solar power, for instance, has gained remarkable momentum in recent years. Engineers are actively developing solar panels and systems that can efficiently convert sunlight into electricity. These advancements have not only made solar power more accessible but have also enabled its integration into various mechanical applications. From solar-powered heating and cooling systems to solar-driven water pumps, these innovations are revolutionizing the way mechanical engineering operates.

Similarly, wind energy has become a key focus in sustainable mechanical engineering. Engineers are designing advanced wind turbines capable of harnessing the power of the wind and converting it into usable energy. These turbines can be integrated into various mechanical systems, such as power generation, water pumping, and even transportation. Embracing wind power as a sustainable energy source not only reduces reliance on fossil fuels but also offers endless possibilities for mechanical engineering advancements.

Hydroelectric and geothermal energy sources are also being harnessed in innovative ways. Engineers are developing systems that can efficiently capture the energy from moving water or the heat trapped beneath the Earth's surface. These renewable energy sources can be utilized to power mechanical systems, such as turbines, pumps, and generators, enabling sustainable operations and minimizing environmental impact.

The adoption of renewable energy sources in mechanical engineering not only addresses the urgent need for sustainability but also opens up new avenues for technological advancements. As engineers continue to push the boundaries of innovation, the integration of renewable energy will continue to revolutionize the field, paving the way for a brighter and more sustainable future.

VI. THE INTEGRATION OF INTERNET OF THINGS (IOT) IN MECHANICAL SYSTEMS

The integration of the Internet of Things (IoT) in mechanical systems has revolutionized the field of mechanical engineering in recent years. IoT refers to the network of interconnected devices that can communicate and exchange data with each other. When applied to mechanical systems, IoT enables the monitoring, control, and optimization of various processes and equipment, leading to enhanced efficiency, productivity, and safety.

In today's rapidly evolving world, mechanical systems are no longer standalone entities but are connected to the internet, allowing them to gather and analyze real-time data. This connectivity enables engineers to remotely monitor and manage mechanical systems, ensuring they operate at peak performance and identifying potential issues before they escalate.

One of the significant advantages of IoT integration in mechanical engineering is predictive maintenance. Traditional maintenance practices are often reactive, leading to unexpected downtime and costly repairs. However, with IoT-enabled sensors and data analytics, mechanical systems can be monitored in real-time, providing insights into the health and performance of various components. This data helps engineers predict when maintenance is required, allowing for proactive preventive measures to be taken, reducing downtime and increasing the lifespan of equipment.

Moreover, IoT integration opens up opportunities for automation and optimization. Mechanical systems can now communicate with each other, enabling seamless coordination and synchronization. For example, in a manufacturing plant, IoT can connect machines, robots, and conveyors, creating a fully automated production line where tasks are performed with precision and efficiency. This level of integration allows for streamlined workflows, reduced waste, and increased productivity.

Safety is another area where IoT integration has made significant strides. With real-time monitoring and data analysis, potential safety hazards can be identified and addressed promptly. For instance, in a building's HVAC system, IoT sensors can detect abnormal temperature or gas leaks, triggering immediate alerts and actions to prevent accidents or damage.

In conclusion, the integration of the Internet of Things (IoT) in mechanical systems has brought about a paradigm shift in the field of mechanical engineering. It has unlocked new possibilities for efficiency, productivity, and safety. As the world progresses towards a more connected future, the role of IoT in revolutionizing mechanical engineering will continue to expand, paving the way for even more futuristic trends and innovations.

VII. NANOTECHNOLOGY: THE FUTURE OF MATERIALS AND COMPONENTS IN MECHANICAL ENGINEERING

Nanotechnology is rapidly emerging as a game-changer in the field of mechanical engineering. This cutting-edge technology involves the manipulation and control of materials and components at the nano-scale level, which is incredibly small - typically on the order of one billionth of a meter.

One of the most exciting aspects of nanotechnology is its potential to revolutionize the materials used in mechanical engineering. By harnessing the unique properties and behaviors of nano-particles, engineers can create materials that are stronger, lighter, and more durable than ever before. These advanced materials have the potential to enhance the performance and efficiency of mechanical systems, leading to significant advancements in various industries.

For instance, carbon nano-tubes, which are cylindrical structures made of carbon atoms, possess exceptional strength and stiffness. Their incorporation into mechanical components can significantly enhance their structural integrity, making them ideal for applications in aerospace, automotive, and even biomedical fields.

Additionally, nanotechnology enables the development of self-healing materials, which have the ability to repair themselves when damaged. This groundbreaking innovation has the potential to extend the lifespan of mechanical components, reduce maintenance costs, and improve overall system reliability.

Furthermore, nanotechnology also offers exciting possibilities in the field of sensors and actuators. Nano- scale devices can be used to create highly sensitive and responsive sensors that can detect minute changes in temperature, pressure, or other environmental factors. These sensors can provide real-time data, enabling engineers to monitor and optimize the performance of mechanical systems with unparalleled precision.

The integration of nanotechnology into mechanical engineering is still in its early stages, with ongoing research and development pushing the boundaries of what is possible. As this field continues to evolve, we can expect to witness groundbreaking advancements that will shape the future of mechanical engineering, creating a world where lighter, stronger, and more efficient machines are the norm. Embracing nanotechnology in our engineering practices will undoubtedly pave the way for a new era of innovation and propel the industry forward into uncharted territories.

VIII. VIRTUAL AND AUGMENTED REALITY IN MECHANICAL DESIGN AND SIMULATIONS

Virtual and augmented realities (VR/AR) have become game-changers in various industries, and mechanical engineering is no exception. These cutting-edge technologies are revolutionizing the way designs are created, prototypes are tested, and simulations are conducted.

With VR, engineers can immerse themselves in a virtual environment, allowing for a more intuitive and immersive design process. They can visualize their concepts and make real-time modifications, enhancing creativity and collaboration. VR also enables engineers to experience their designs in a simulated environment, identifying potential flaws or improvements before physical prototypes are even created.

On the other hand, AR brings virtual elements into the real world, overlaying digital information onto physical objects. This technology has immense potential in mechanical engineering for tasks like assembly instructions, maintenance procedures, and training programs. AR can provide real-time visual guidance, highlighting parts, displaying step-by-step instructions, and offering interactive 3D models, enhancing efficiency and reducing errors.

Moreover, VR/AR simulations are becoming invaluable tools for mechanical engineers. By creating realistic virtual environments, engineers can test and analyze complex interactions, mechanical behavior, and structural integrity. This eliminates the need for costly physical prototypes and accelerates the design process. Simulations in VR/AR enable engineers to identify design flaws, optimize performance, and make informed decisions, ultimately leading to more innovative and reliable products.

As VR and AR technologies continue to advance, the potential for their integration into mechanical engineering workflows is vast. These futuristic trends are reshaping the industry, offering new possibilities for design, prototyping, and simulation. Embracing VR/AR in mechanical engineering enables engineers to push boundaries, streamline processes, and create groundbreaking solutions that were once unimaginable. The future of mechanical engineering is undeniably being transformed by the immersive power of virtual and augmented reality.

IX. ADVANCEMENTS IN AUTONOMOUS VEHICLES AND TRANSPORTATION SYSTEMS

Advancements in autonomous vehicles and transportation systems have undoubtedly revolutionized the field of mechanical engineering. With the rapid development of technology, engineers are now exploring futuristic trends and innovations that are reshaping the way we commute and transport goods.

Autonomous vehicles, once considered a distant dream, are now becoming a reality. These self-driving cars are equipped with a myriad of sensors, cameras, and artificial intelligence algorithms that allow them to navigate the roads without human intervention. From Tesla's Autopilot to Waymo's self-driving taxis, the race to perfect autonomous technology is in full swing.

Beyond personal transportation, autonomous vehicles are also transforming the logistics and delivery industry. Companies like Amazon and UPS are testing drone delivery systems, where unmanned aerial vehicles can efficiently transport packages to customers' doorsteps. This not only improves delivery speed but also reduces the need for traditional delivery methods, such as trucks and vans.

Moreover, the concept of smart cities is gaining traction, where transportation systems are interconnected and intelligent. This includes traffic management systems that optimize traffic flow, reduce congestion, and enhance safety. For instance, traffic lights that communicate with vehicles to create smooth traffic patterns, or dynamic rerouting systems that suggest alternative routes based on real-time data.

In addition to autonomous vehicles, engineers are exploring innovative propulsion systems that are more sustainable and eco-friendly. Electric vehicles (EVs) have gained significant popularity due to their zero- emission nature, and advancements in battery technology have extended their range and charging capabilities. Furthermore, hydrogen fuel cell technology is being explored as an alternative to traditional combustion engines, offering clean energy solutions for transportation.

The future of transportation is poised to be more efficient, safer, and environmentally friendly, thanks to the advancements in autonomous vehicles and transportation systems. As mechanical engineers continue to push the boundaries of innovation, we can expect remarkable breakthroughs that will shape the way we travel and transport goods in the years to come.

X. CONCLUSION: EMBRACING INNOVATION AND PREPARING FOR THE FUTURE IN MECHANICAL ENGINEERING

In conclusion, it is clear that embracing innovation and preparing for the future is essential in the field of mechanical engineering. The rapid advancements in technology and the emergence of futuristic trends have revolutionized the way we approach engineering projects and design solutions.

By staying updated with the latest trends and innovations, mechanical engineers can gain a competitive edge and contribute to the development of groundbreaking solutions. The integration of artificial intelligence, robotics, and automation has opened up new possibilities and enhanced efficiency in various industries.

It is crucial for mechanical engineers to continuously upskill and adapt to the changing landscape of their field. Embracing emerging technologies such as 3D printing, Internet of Things (IoT), and sustainable energy solutions will not only improve efficiency but also reduce environmental impact.

Moreover, collaboration and interdisciplinary approaches will play a significant role in the future of mechanical engineering. Engaging with professionals from diverse backgrounds and leveraging their expertise will lead to the creation of innovative solutions that address complex challenges.

To prepare for the future, mechanical engineers must foster a mindset of continuous learning and adaptability. Engaging in professional development programs, attending conferences and workshops, and participating in industry forums will help them stay abreast of the latest trends and developments.

In summary, the future of mechanical engineering is filled with exciting possibilities.

By embracing innovation, harnessing emerging technologies, and preparing for the challenges ahead, mechanical engineers can revolutionize industries and contribute to shaping a better and more sustainable future. It is an exhilarating time to be part of this dynamic and ever-evolving field.

In conclusion, the future of mechanical engineering holds immense possibilities and promises to revolutionize the way we live and work. From advancements in robotics and automation to breakthroughs in materials and energy systems, this blog post has explored various futuristic trends and innovations that will shape the field. As we move forward, it is crucial for mechanical engineers to stay abreast of these developments and embrace them to push the boundaries of what is possible. By doing so, we can create a world where technology and engineering merge seamlessly to enhance our lives and propel us into a future limited only by our imagination. Let's embark on this exciting journey of innovation together!

REFERENCES

[1] www.google.com
[2] www.wikipedia.org
[3] encyclopedia.com

THE NEED OF INTEGRATION OF ELECTRONICS AND MECHANICAL ENGINEERING IN THE ERA OF DIGITAL TRANSFORMATION

Abstract

Mechanical engineering has been an integral part of our lives for centuries. From the first steam engine to modern-day robotics, mechanical engineering has evolved to meet the needs of the times. In recent years, electronic and communication technologies have revolutionized the field of mechanical engineering, making it possible to create machines that can perform complex tasks with ease. In this post, we will explore the future of mechanical engineering in the electronic and communication era. We will discuss how these advancements are changing the way we design and manufacture machines, and explore the potential impact of these developments on our society. So, whether you are a mechanical engineer looking to stay ahead of the curve or just interested in the future of technology, this post is for you.

Keywords: Communication technologies have revolutionized the field of mechanical engineering.

Authors

Prof. (Dr.) Parvinder Bangar
Director Of Technical Institution & Professor
In Ece Department
Greater Noida Institute of Technology
(Gnit - Ipu)
Greater Noida, Uttar Pradesh, India.
parvinder.bangar@gmail.com

Ajay Kumar Agarwal
Associate Professor
Department of Mechanical Engineering
JB Knowledge Park (JBKP)
Faridabad, Haryana, India.
ajaymechengineer@gmail.com

I. AN INTRODUCTION TO RECENT ADVANCEMENTS IN MECHANICAL ENGINEERING

Mechanical engineering has long been hailed as a field that drives innovation and propels technological advancements. Traditionally focused on designing and building physical structures and machinery, mechanical engineers have played a crucial role in shaping the world we live in today. However, with the rapid emergence of the electronic and communication era, the role of mechanical engineering is undergoing a significant transformation.

In this ever-evolving digital landscape, mechanical engineers are now tasked with integrating electronic and communication systems into their designs. The once purely mechanical systems are now becoming interconnected with sensors, controllers, and data networks, giving rise to a new era of smart and interconnected devices.

This shift towards electronic and communication integration brings about a multitude of opportunities and challenges for mechanical engineers. On one hand, it opens doors to a world of possibilities, allowing engineers to create sophisticated systems that can communicate, analyze data, and adapt to changing conditions in real-time. On the other hand, it requires mechanical engineers to broaden their skillsets and embrace new technologies in order to remain relevant in the ever-changing industry.

As the boundaries between mechanical, electronic, and communication engineering continue to blur, interdisciplinary collaboration becomes the key to success. Mechanical engineers must now work hand in hand with experts from various fields, such as electrical engineering, computer science, and telecommunications, to develop cutting-edge solutions that seamlessly merge physical and digital technologies.

The future of mechanical engineering in the electronic and communication era holds immense potential. From the development of smart homes and autonomous vehicles to the advancement of robotics and renewable energy systems, mechanical engineers will continue to push the boundaries of innovation. By adapting to the evolving landscape and embracing the fusion of mechanical, electronic, and communication technologies, engineers can shape a future where machines not only perform tasks efficiently but also communicate intelligently, revolutionizing industries and improving lives.

II. AN INTRODUCTION TOTHE IMPACT OF ELECTRONICS ON MECHANICAL ENGINEERING

The field of mechanical engineering has long been known for its focus on the design and development of physical systems and machinery. However, in recent years, the rapid advancements in electronics and communication technologies have had a profound impact on this traditional discipline.

The integration of electronics and communication in mechanical engineering has brought about a new era of innovation and efficiency. Today, mechanical engineers are not only concerned with the mechanical aspects of a system but also with its electronic components and their seamless integration. This convergence has given rise to a multitude of exciting opportunities and challenges.

One of the key impacts of electronics and communication on mechanical engineering is the increased automation and control of mechanical systems. With the advent of sensors, actuators, and embedded systems, mechanical engineers can now develop intelligent systems that can adapt, respond, and communicate with their environment. This has led to the development of smart factories, autonomous vehicles, and advanced robotics, revolutionizing various industries.

Moreover, electronics and communication have also enhanced the design and analysis capabilities of mechanical engineers. The use of computer-aided design (CAD) software allows for more precise and efficient modeling and simulation of complex mechanical systems. Additionally, the integration of sensors and data acquisition systems enables engineers to gather real-time data, analyze performance, and optimize designs, leading to more robust and reliable products.

Furthermore, the advancements in electronics and communication have facilitated the development of interconnected systems and the Internet of Things (IoT). Mechanical engineers can now design and implement smart systems that can communicate, share data, and collaborate with other devices and systems. This interconnectedness has opened up new avenues for innovation and has the potential to transform industries such as healthcare, transportation, and energy.

In conclusion, the impact of electronics and communication on mechanical engineering cannot be overstated. The integration of these technologies has revolutionized the field, enabling engineers to create intelligent, connected, and efficient systems. As we venture into the future, it is clear that the collaboration between mechanical engineering and electronics and communication will continue to shape the way we live, work, and interact with technology.

III. INTEGRATION OF ELECTRONICS AND MECHANICAL ENGINEERING

In today's rapidly evolving world, the integration of electronics and communication technologies has become a game-changer in the field of mechanical engineering. Gone are the days when mechanical systems operated in isolation, limited only to their mechanical components. Now, with the advent of advanced electronics and communication technologies, these systems have been revolutionized, opening up a whole new realm of possibilities.

The integration of electronics and communication technologies in mechanical systems has paved the way for enhanced functionality, improved efficiency, and greater control. By incorporating sensors, actuators, and microcontrollers, mechanical engineers can now design systems that can communicate, adapt, and optimize their performance in real-time.

One remarkable development in this integration is the rise of mechatronics, a field that combines mechanical engineering, electronics, and computer science. Mechatronics systems, such as robotic arms or autonomous vehicles, exemplify the seamless integration of mechanical components with electronic sensors, microprocessors, and communication modules. These systems can now perceive their surroundings, make decisions, and interact with their environment, showcasing the transformative power of this integration.

Moreover, the integration of electronics and communication technologies has also led to advancements in areas such as automation, robotics, and smart manufacturing. Mechanical systems can now be equipped with intelligent control systems, enabling them to operate autonomously, adapt to changing conditions, and optimize their performance. This not only increases productivity but also enhances safety and precision in various industries.

In the era of the Internet of Things (IoT), mechanical systems are now capable of connecting to the internet and sharing data with other devices and systems. This connectivity opens up a wide range of possibilities, from remote monitoring and diagnostics to predictive maintenance and real-time optimization. Imagine a world where machines can communicate with each other, analyze data, and make decisions collaboratively, leading to unprecedented levels of efficiency and productivity.

As the integration of electronics and communication technologies continues to advance, the future of mechanical engineering holds immense potential. From intelligent systems that can learn and adapt to futuristic technologies such as 3D printing and nanotechnology, the possibilities are truly endless. Mechanical engineers of the future will need to embrace and master these technologies to stay at the forefront of innovation and drive the evolution of the field.

In conclusion, the integration of electronics and communication technologies in mechanical systems has ushered in a new era of possibilities and opportunities. The fusion of these domains has transformed traditional mechanical systems into intelligent, connected, and adaptive entities, shaping the future of mechanical engineering in the electronic and communication era. Embracing this integration will not only revolutionize various industries but also pave the way for exciting advancements yet to be imagined.

IV. ADVANCEMENTS IN ROBOTICS AND AUTOMATION IN REFERENCE TO THE MECHANICAL ENGINEERING

Advancements in robotics and automation are revolutionizing the field of mechanical engineering, paving the way for a future filled with cutting-edge technologies and increased efficiency. As we enter the electronic and communication era, these advancements are set to play a crucial role in shaping the future of mechanical engineering.

One of the key areas where robotics and automation are making significant strides is in manufacturing processes. Traditional assembly lines are being replaced by highly automated systems that can handle complex tasks with precision and speed. Robots equipped with advanced sensors and artificial intelligence are now capable of performing intricate assembly processes, reducing human error and increasing productivity. This not only improves the quality of the final product but also enhances overall operational efficiency.

Additionally, robotics and automation are transforming the way maintenance and repairs are conducted in various industries. Drones equipped with cameras and sensors can now inspect hard-to-reach areas, such as bridges and power lines, with ease. This eliminates the need for manual inspections that are not only time-consuming but also potentially hazardous. Autonomous robots are also being developed to perform maintenance tasks, such as cleaning and repairing machinery, reducing downtime and increasing the lifespan of equipment.

In the field of transportation, autonomous vehicles are becoming a reality, with major advancements being made in self-driving cars and trucks. These vehicles have the potential to revolutionize the way we commute and transport goods, offering increased safety, reduced congestion, and improved fuel efficiency. Mechanical engineers are at the forefront of developing and refining the technologies that power these autonomous vehicles, pushing the boundaries of what is possible in the transportation industry.

Moreover, the integration of robotics and automation with the Internet of Things (IoT) is opening up new opportunities for mechanical engineers. The ability to connect machines, devices, and systems through the internet allows for real-time data collection and analysis, enabling predictive maintenance and optimizing performance. Mechanical engineers are now involved in designing and implementing smart systems that can communicate and coordinate with each other, leading to more efficient and sustainable operations.

As we look to the future, it is evident that the advancements in robotics and automation will continue to shape the field of mechanical engineering. From revolutionizing manufacturing processes to transforming transportation and maintenance, these technologies are unlocking new possibilities and driving innovation. Mechanical engineers will play a vital role in harnessing these advancements, pushing the boundaries of what is possible and shaping a future that is more connected, efficient, and technologically advanced.

V. THE SIGNIFICANT ROLE OF ARTIFICIAL INTELLIGENCE IN SHAPING THE FUTURE OF MECHANICAL ENGINEERING

In the rapidly evolving landscape of mechanical engineering, the integration of artificial intelligence (AI) has emerged as a transformative force. As we enter the electronic and communication era, AI is playing an increasingly pivotal role in shaping the future of this field.

Traditionally, mechanical engineering has been characterized by the design and development of physical systems and machinery. However, with the advent of AI, the boundaries of what can be achieved have expanded exponentially. AI-driven technologies such as machine learning and deep learning algorithms have the ability to process vast amounts of data, enabling engineers to make more informed decisions and optimize designs.

One area where AI is revolutionizing mechanical engineering is in the realm of automation. Smart factories and robotic systems are becoming more prevalent, and AI-powered robots are being employed to perform intricate tasks with precision and efficiency. These robots can adapt to changing conditions, learn from their experiences, and continuously improve their performance, leading to enhanced productivity and cost-effectiveness.

Another significant aspect of AI in mechanical engineering is predictive maintenance. By analyzing sensor data and utilizing AI algorithms, engineers can accurately predict when machinery or components are likely to fail. This proactive approach enables timely maintenance interventions, minimizing downtime and maximizing operational efficiency. This not only saves costs but also enhances safety by reducing the risk of unexpected failures.

Furthermore, AI is facilitating advancements in design optimization. Through the use of algorithms, engineers can explore an extensive range of design options and identify the most efficient and innovative solutions. This not only accelerates the design process but also allows for the creation of complex geometries and structures that were previously unattainable. As a result, the future of mechanical engineering is poised to witness groundbreaking advancements in areas such as aerospace, automotive, and renewable energy.

However, it is important to note that the integration of AI in mechanical engineering does not mean the replacement of human engineers. Rather, it empowers them with powerful tools and capabilities to push the boundaries of what is possible. Collaborations between humans and AI technologies will be essential in unlocking the full potential of this transformative era.

In conclusion, artificial intelligence is revolutionizing the field of mechanical engineering in the electronic and communication era. From automation and predictive maintenance to design optimization, AI is driving innovation and pushing the boundaries of what can be achieved. As we embrace this future, the role of mechanical engineers will evolve, and their expertise in harnessing the power of AI will be invaluable in shaping a world of limitless possibilities.

VI. THE EMERGENCE OF SMART MATERIALS AND THEIR APPLICATIONS IN MECHANICAL ENGINEERING

The field of mechanical engineering is constantly evolving, and with the emergence of the electronic and communication era, new opportunities and challenges are arising. One of the most exciting developments in recent years is the advent of smart materials and their applications in mechanical engineering.

Smart materials, also known as intelligent or responsive materials, are designed to respond to external stimuli such as temperature, light, pressure, or electrical current. These materials have the ability to change their properties, shape, or behavior in a controlled and predictable manner. This opens up a whole new world of possibilities for mechanical engineers.

One area where smart materials are making a significant impact is in the design and manufacturing of sensors and actuators. Traditional mechanical systems often require separate sensors and actuators to detect and respond to stimuli. With smart materials, however, these functions can be integrated into a single material, simplifying the overall design and reducing the number of components.

For example, shape-memory alloys (SMAs) are a type of smart material that can change shape in response to temperature. This property makes them ideal for applications such as self-repairing structures, adaptive optics, and biomedical devices. By incorporating SMAs into mechanical systems, engineers can create innovative designs that are more efficient, lightweight, and responsive.

Another area where smart materials are revolutionizing mechanical engineering is in the development of energy harvesting technologies. These materials have the ability to convert ambient energy, such as mechanical vibrations or solar radiation, into usable electrical energy. This opens up opportunities for self-powered sensors, wearable devices, and Internet of Things (IoT) applications.

Furthermore, smart materials are also being used in the field of robotics and automation. By integrating shape-changing materials into robotic systems, engineers can create robots that can adapt to different environments and tasks. This flexibility and adaptability are crucial for applications such as search and rescue, industrial automation, and medical robotics.

In conclusion, the emergence of smart materials is revolutionizing the field of mechanical engineering in the electronic and communication era. These materials offer unique properties and capabilities that enable engineers to design more efficient, responsive, and innovative mechanical systems. As technology continues to advance, we can expect to see even more exciting applications of smart materials in the future of mechanical engineering.

VII. THE SIGNIFICANCE OF DATA ANALYTICS AND PREDICTIVE MAINTENANCE IN MECHANICAL SYSTEMS

As technology continues to advance and the world becomes increasingly connected, the role of data analytics and predictive maintenance in mechanical systems is growing in importance. In the electronic and communication era, mechanical engineers are now leveraging the power of data to optimize the performance and reliability of their systems.

Data analytics allows engineers to collect valuable information from various sensors and devices embedded within mechanical systems. This data can provide insights into the performance, efficiency, and health of the system, enabling engineers to identify trends, patterns, and potential issues.

Predictive maintenance takes data analytics a step further by using advanced algorithms and machine learning techniques to predict when maintenance is needed before a breakdown occurs. By analyzing historical data and real-time performance metrics, engineers can proactively schedule maintenance activities, replace components, or make adjustments to prevent costly downtime and improve overall system reliability.

The benefits of data analytics and predictive maintenance in mechanical systems are numerous. By harnessing the power of data, engineers can optimize energy consumption, reduce operational costs, and extend the lifespan of mechanical components. Furthermore, by identifying potential failures before they happen, maintenance can be planned and executed more efficiently, minimizing disruptions to operations.

In the future, as the Internet of Things (IoT) continues to evolve and more devices become interconnected, the amount of data generated by mechanical systems will only increase. This abundance of data presents new opportunities for mechanical engineers to gain deeper insights into system behavior and further enhance performance.

As the electronic and communication era progresses, the importance of data analytics and predictive maintenance in mechanical engineering cannot be overstated. By leveraging the power of data, engineers can unlock new possibilities, optimize system performance, and ensure a sustainable and efficient future for mechanical systems in the digital age.

VIII. THE ROLE OF INTERNET OF THINGS (IOT) IN ENHANCING EFFICIENCY AND FUNCTIONALITY OF MECHANICAL ENGINEERING

In the ever-evolving landscape of mechanical engineering, the integration of the Internet of Things (IoT) has emerged as a game-changer. IoT refers to the network of interconnected devices that communicate and exchange data with each other, creating a seamlessly connected ecosystem. In the context of mechanical engineering, IoT has opened up a realm of possibilities for enhancing efficiency and functionality.

One of the key advantages of IoT in mechanical engineering is the ability to gather real-time data from various components and systems. Sensors embedded in machinery can collect valuable information such as temperature, pressure, vibration, and more. This data can then be analyzed to detect potential issues, predict maintenance needs, and optimize performance. By leveraging IoT capabilities, engineers can proactively address problems before they escalate, minimizing downtime and maximizing productivity.

Moreover, IoT enables remote monitoring and control of mechanical systems. Through connected devices, engineers can access and manage equipment from anywhere in the world, providing unprecedented flexibility and convenience. This not only improves operational efficiency but also enables proactive decision-making and troubleshooting.

Additionally, IoT plays a vital role in enabling predictive maintenance strategies. By continuously monitoring equipment performance and analyzing data patterns, engineers can anticipate when maintenance or repairs are required. This shift from reactive to proactive maintenance not only reduces costs associated with unplanned downtime but also extends the lifespan of mechanical systems.

Furthermore, the integration of IoT in mechanical engineering opens doors for innovative applications such as smart factories and industrial automation. With interconnected systems, processes can be streamlined, and production can be optimized. Real-time data exchange between machines and connected devices enables seamless coordination, improving overall efficiency and reducing errors.

As the electronic and communication era continues to advance, the role of IoT in mechanical engineering will only become more prominent. It presents a new frontier of possibilities, revolutionizing the way engineers design, monitor, and optimize mechanical systems. By embracing IoT technologies, mechanical engineers can stay at the forefront of innovation and shape the future of their field.

IX. CHALLENGES AND OPPORTUNITIES IN THE DIGITAL ERA FOR MECHANICAL ENGINEERS

The electronic and communication era has brought forth both challenges and opportunities for mechanical engineers. As technology continues to advance at an unprecedented pace, mechanical engineers must adapt and evolve to stay relevant in this rapidly changing landscape.

One of the main challenges faced by mechanical engineers in the electronic and communication era is the integration of electronics into mechanical systems. With the rise of smart devices and the Internet of Things (IoT), mechanical engineers must now possess a strong understanding of electronics and how they can be seamlessly incorporated into their designs. This requires a multidisciplinary approach, where mechanical engineers collaborate closely with electrical and computer engineers to create innovative and interconnected systems.

Furthermore, the increasing demand for automation and robotics presents both challenges and opportunities for mechanical engineers. On one hand, the automation of processes can lead to a reduction in the need for manual labor, potentially impacting certain job roles within the industry. On the other hand, this opens up new avenues for mechanical engineers to specialize in the design, development, and maintenance of robotic systems. By embracing automation, mechanical engineers can enhance efficiency, improve productivity, and explore new possibilities in various sectors such as manufacturing, healthcare, and transportation.

The electronic and communication era also brings opportunities for mechanical engineers to contribute to sustainable and green technologies. As the world becomes more conscious of environmental impact, mechanical engineers can play a crucial role in designing energy-efficient systems and exploring renewable energy sources. This includes developing advanced heating, ventilation, and air conditioning (HVAC) systems, optimizing energy consumption in transportation systems, and designing efficient industrial processes.

In conclusion, the electronic and communication era presents both challenges and opportunities for mechanical engineers. Adapting to the integration of electronics, embracing automation, and contributing to sustainable technologies are crucial for the future success of mechanical engineers in this evolving landscape. By staying ahead of the curve and continuously expanding their skill sets, mechanical engineers can thrive in the exciting and dynamic field of engineering in the electronic and communication era.

X. CONCLUSION

In conclusion, the future of mechanical engineering in the electronic and communication era is filled with exciting prospects. As technology continues to advance at an unprecedented pace, the integration of mechanical engineering principles with electronic and communication systems opens up a world of possibilities.

One of the key areas where mechanical engineering will play a vital role is in the development of advanced robotics and automation. With the increasing demand for more efficient and autonomous systems, mechanical engineers will be at the forefront of designing and building machines that can perform complex tasks with precision and reliability.

Moreover, the advent of the Internet of Things (IoT) has created a need for mechanical engineers who can design smart devices and sensors. These devices will be capable of collecting and transmitting data, enabling seamless communication between different systems and improving overall efficiency.

Another exciting prospect lies in the field of renewable energy. As the world shifts towards sustainable and clean energy sources, mechanical engineers will be instrumental in developing innovative technologies for harnessing and utilizing these resources. From designing more efficient wind turbines to improving the performance of solar panels, mechanical engineering will play a crucial role in shaping the future of renewable energy.

Furthermore, the convergence of mechanical engineering with electronic and communication systems will revolutionize industries such as automotive, aerospace, healthcare, and manufacturing. From self-driving cars to advanced medical devices, the integration of these disciplines will lead to groundbreaking innovations that will enhance our lives in numerous ways.

In conclusion, the future of mechanical engineering in the electronic and communication era is filled with immense potential. As technology continues to evolve, mechanical engineers will be at the forefront of developing cutting-edge solutions that will shape our world for years to come. Embracing these exciting prospects and staying abreast of the latest advancements will be key for aspiring mechanical engineers to thrive in this dynamic and rapidly evolving field.

In conclusion, the future of mechanical engineering in the electronic and communication era is incredibly promising. As technology continues to advance at an unprecedented rate, mechanical engineers will play a crucial role in integrating electronic systems into mechanical devices, creating innovative solutions for various industries. The convergence of mechanical engineering with electronics and communication opens up vast opportunities for advancements in automation, robotics, renewable energy, and smart infrastructure. By staying updated with the latest trends and acquiring the necessary skills, mechanical engineers can position themselves at the forefront of this exciting era and contribute to shaping the future of technology. Embrace the possibilities and embark on this remarkable journey as the future of mechanical engineering unfolds before us.

REFERENCES

[1] Enterprise IoT, 2015, Data-driven manufacturing, Available at: http:// enterprise-iot.org/wp content/uploads/2014/11/FoF.png
[2] European Cloud Partnership (2014). 'Establishing a Trusted Cloud Europe: A policy vision document by the Steering Board of the European Cloud Partnership‘
[3] European Commission, 2016, Mechanical Engineering,
Available at: http://ec.europa.eu/growth/sectors/mechanicalengi neering/index_en.htm
[4] McKinsey Digital 2015, ‘Industry 4.0 How to navigate digitization of the manufacturing sector

[5] Porkodi, S & Balushi, Shahla & Balushi, Marwa & Hadi, Khulood&Balushi, Zulfa. (2023). Assessing the Effects of Influential Factors and Demographic Traits on the Digital Employee Experience in Oman's Telecommunications Industry. 6. 4280-4289. 10.47191/ijsshr/v6-i7-53.
[6] Roland Berger, 2014, Industry 4.0 – The new industrial revolution
[7] Sima, Violeta & Gheorghe, Ileana &Subić, Jonel&Nancu, Dumitru. (2020). Influences of the Industry 4.0 Revolution on the Human Capital Development and Consumer Behavior: A Systematic Review. Sustainability. 12. 4035. 10.3390/su12104035.
[8] Spöttl, Georg &Windelband, Lars. (2020). The 4 th industrial revolution -its impact on vocational skills. Journal of Education and Work. 34. 10.1080/13639080.2020.1858230.
[9] Thurner, Michael &Glauner, Patrick. (2020). Digitalization in Mechanical Engineering. 10.1007/978-3-030-41309-5_9.

PART 3

Futuristic Trends in Mechanical Engineering

Series Id: IIPV3EBS01_G26

Series Editors

Venkatesh Begori

Professor

Professor of Mechanical Engineering

Vardhaman College of Engineering Kacharam Village

Shamshabad Mandal Rangareddy

Dist PIN:501218, Telangana, India

Chitransh Atre

Project Officer

Department of Applied Mechanics

IIT Madras, IIT Madras

Chennai, pin- 600036, Tamil Nadu

Govindarajulu

Assistant Professor

VIgnan's Foundation for Science

Technology and Research Vadlamudi

Guntur, Andhrapradesh, India

Komal Mohan Garse

Assistant Professor

Department of Mechanical Engineering

Sinhgad College of Engineering

S. No. 44/1, Vadgaon (Budruk)

Off. Sinhgad Road, Pune 411 041.

FEA ANALYSIS AND VALIDATION OF HELICAL COMPRESSION SPRING USED IN MEDICAL SURGICAL TOOLS USING COMPOSITE MATERIAL

Abstract

The Medical Sector has exhibited a growing interest in utilizing composite materials to replace ferrous metals due to their high strength-to-weight ratio. This study introduces a novel approach to designing helical compression springs by employing Finite Element Analysis (FEA) with the use of composite materials. The investigation includes both experimental and FEA analyses of the springs, and the results are compared against traditional steel springs.

The findings of the study demonstrate that by using composite springs, a significant reduction in weight can be achieved. Consequently, these composite material springs can serve as effective replacements for the heavier steel springs. The study also explores the correlation between design parameters and compressive stress, with a primary focus on reducing product weight while maintaining its strength.

Keywords: FEA Analysis, Helical Compression Spring, Medical Surgical Tools, Composite Material.

Authors

Ranjit Mali
Assistant Professor
Sinhgad College of Engineering
Pune, India.
ranjitmali98@gmail.com

Akshay Godse
Assistant Professor
Sinhgad College of Engineering
Pune, India.

Komal Garse
Assistant Professor
Sinhgad College of Engineering
Pune, India.

Shubham Chandgude
Assistant Professor
Dr. D. Y. Patil Institute of Engineering
Management & Research
Akurdi, Pune, India.

I. INTRODUCTION OF HELICAL COMPRESSION SPRING

According to A.M. Whal, a mechanical spring can be described as an elastic body that deflects or distorts under load, absorbing energy, and returns to its original shape when released after being distorted. Whal classifies springs into four main functions: shock absorption, force application, structural support, and load control [5].

Considering the diverse properties and functions of springs, it is essential to use specific techniques for analyzing each type. In this proposal, our focus will be solely on the helical compression spring . These springs are the most common type and find widespread use in various devices due to their advantageous characteristics, including nearly linear rate (especially after the initial 20% deflection), versatility in materials for construction, and ease of manufacturing. As a result, helical compression springs have been in use for an extended period [5]

1. Objectives of Spring:

- Springs serve various purposes, including providing cushioning to absorb or control energy arising from shocks and vibrations. For instance, car springs or railway buffers are utilized to effectively manage energy, while springs-supports and vibration dampers play a similar role [12].
- Another essential function of springs is motion control. They ensure continuous contact between two elements, such as in the case of cams and their followers. Additionally, springs are crucial in generating the necessary pressure within friction devices like brakes or clutches. Furthermore, they help restore machine parts to their original positions when external forces are withdrawn, as seen in the case of governors or valves.
- Springs are also valuable in force measurement applications, as demonstrated by their use in spring balances and gauges.
- Additionally, springs play a significant role in storing energy, which finds practical applications in clocks or starters [11].

2. Use Of Helical Compression Spring in Surgical Tools:

- Surgical Staple Guns
- Peristaltic Pump
- Catheters
- Endoscopic Devices
- Surgical tools and Orthopedic Tools

3. Commonly Used Spring Materials: When designing springs, a crucial aspect to consider is the selection of the appropriate spring material. There are several common spring materials available, each with its specific characteristics [12].

- **Hard-drawn wire:** This cost-effective spring steel is cold drawn and ideal for low-stress applications and static loads. However, it is unsuitable for sub-zero temperatures and temperatures exceeding 1200°C.

- **Oil-tempered wire:** A versatile spring steel, cold drawn, quenched, and tempered, suitable for general purposes. Nonetheless, it should not be used under conditions of fatigue or sudden loads, at sub-zero temperatures, or temperatures exceeding 1800°C.
- **Chrome Vanadium:** An alloy spring steel suitable for high-stress conditions and temperatures up to 2200°C. It boasts excellent fatigue resistance and can endure long periods of shock and impact loads.
- **Chrome Silicon:** This material is well-suited for highly stressed springs, offering excellent service life and resilience to shock loading at temperatures up to 2500°C.
- **Music wire:** Most commonly used for small springs, it is exceptionally tough with high tensile strength, making it capable of withstanding repeated loading at high stresses. However, it is not suitable for use in sub-zero temperatures or temperatures above 1200°C.
- **Stainless steel:** A widely utilized alloy for spring materials due to its various favorable properties.
- **Phosphor Bronze / Spring Brass:** Known for good corrosion resistance and electrical conductivity, it is commonly employed for contacts in electrical switches. Spring brass, in particular, can be used in sub-zero temperatures.

II. LITERATURE REVIEW

1. **Goedland et al (2016**).Laparoscopic surgery is a minimally invasive procedure performed through a small incision in the abdomen. This approach allows for complete operations to be conducted. Throughout the surgery, cutting and stapling functions are commonly required, for which specialized staplers have been developed. Recently, the demographic of surgeons has evolved, with more women and older individuals joining the field.

   However, current laparoscopic surgical staplers pose challenges for our client, a young female surgeon. The main issues she encounters are the limited accommodation of a wide range of hand sizes, grip strengths, and various usage orientations by the existing devices. To address these problems, we propose an innovative in-line handle design concept.

   Our concept aims to incorporate standard grip dimensions, reduced grip force via battery assistance, and the top placement of the clamping trigger to facilitate more natural wrist angles during use in different orientations. To achieve this, a complete redesign of the current devices is necessary. Therefore, the input and feedback from practicing surgeons are vital aspects of our development process.

2. **Mansour, (2015)** Tactile displays have gained significant attention in the field of human-computer interaction, particularly for applications where the sense of touch is lost, such as in laparoscopic surgeries where surgeons need to feel the tissue hardness. In this research, a novel multi-modal tactile display device capable of showing both the surface shape and stiffness of an object is introduced.

   The design of this device centers around the use of two springs made of Shape Memory Alloys (SMA), one for displaying shape and the other for stiffness. Design parameters are carefully selected, taking into account the spatial resolution of the human finger and the elasticity range of soft tissue. The Finite Element Method (FEM) is employed to simulate the device's behavior and study the impact of design parameters on the resulting stiffness.

3. **Mahshidet et al (2012)** Mechanical torque devices (MTDs) are widely recommended for delivering precise torque to dental implant screws. Among them, spring-style mechanical torque devices (S-S MTDs) have gained popularity. However, there have been recent concerns about the accuracy of these devices, as it directly affects the joint stability and survival rate of fixed implant-supported prosthesis.

   The impact of steam sterilization on the accuracy of MTDs remains poorly understood, as there is limited information available on this subject. Therefore, the objective of this study is to evaluate the effect of steam sterilization on the accuracy of spring-style mechanical torque devices used for dental implants. The study aims to assess whether the accuracy remains within ±10% of the target torque after the sterilization process.

4. **Ling Chen, (2022)** Composite helical springs (CHSs) find widespread applications in the transportation and aerospace sectors, including automobile suspension, railway bogies, and aircraft engine systems. A notable trend in these industries involves replacing traditional metal helical springs with CHSs due to their ability to conserve energy during service and reduce emissions during manufacturing. The numerous advantages of CHSs, such as their lightweight nature, high specific strength, high specific modulus, corrosion resistance, fatigue resistance, and excellent strain energy storage capacity, make them highly promising for further development.

5. **M.-S. Scholz, et al (2011**). This review focuses on the utilization of fiber-reinforced composite materials in biomedical applications. The advancements in polymer composite materials have significantly contributed to technological progress in modern orthopedic medicine and prosthetic devices. Compared to monolithic materials, composites exhibit superior strength-to-weight characteristics and demonstrate excellent biocompatibility. As a result, they are highly advantageous for various hard and soft tissue applications, as well as in prosthesis design.

   A notable breakthrough is the development of specifically designed carbon fiber sports prostheses, enabling lower-limb amputees to actively participate in competitive sports. Furthermore, ongoing developments are expected to introduce sensory feedback systems, porous composite materials for tissue engineering, and functional coatings for metallic implants in the next generation of orthopedic medicine.

6. **S Ramakrishna, (2001)** This paper provides an overview of the diverse biomedical applications of polymer-composite materials, as documented in the literature over the past three decades. To offer comprehensive insights to readers, the paper also includes general information on tissue structure and function, types and purposes of implants/medical devices, and other materials commonly used in the field.

The paper delves into different types of polymer composites currently employed or under investigation for various biomedical applications. Furthermore, it emphasizes the specific advantages of utilizing polymer-composite biomaterials in selected applications

7. **Anil Antony Sequeira, (2016).** In the automobile sector, rapid innovation and tough competition drive the reengineering of old products with new composite materials. Particularly in the suspension area of vehicles, continuous innovations take place. The automobile industry is significantly interested in Fiber Reinforced Material (FRP) components due to their high strength-to-low weight ratio, which makes them a viable alternative to steel components.

8. **Mali et al (2022)** The automotive industry has increasingly shown interest in replacing ferrous metals with composite materials due to their high strength-to-weight ratio. This study introduces a novel approach to designing helical compression springs using workbench software. The composite materials employed in the study are E-glass/Epoxy and Carbon fiber/Epoxy.

   The analysis of the springs is carried out using Finite Element Analysis (FEA), and the results are compared with those of steel springs. The findings demonstrate that the composite springs achieve weight reduction without compromising strength. This indicates that composite material springs can effectively replace heavy steel springs.

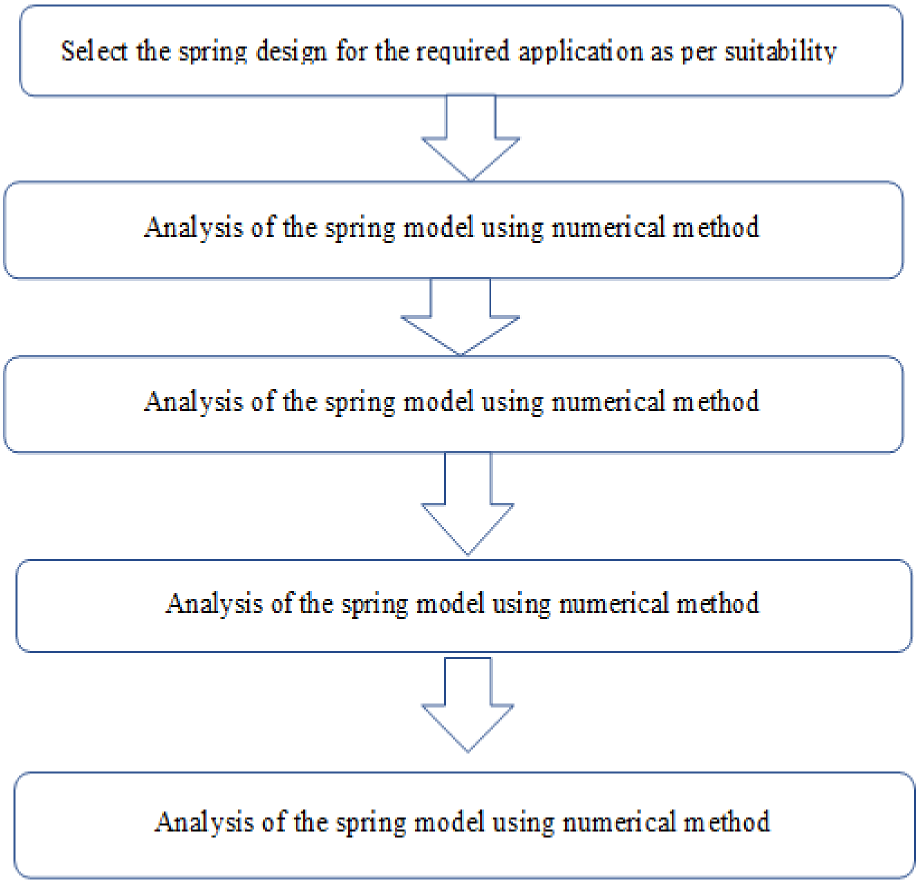
9. **Mehdi Bakhshesh1, (2012).** Highly efficient springs with a substantial capacity for storing potential energy play a crucial role in various industries. Among them, helical springs have found widespread use in car suspension systems. This research focuses on studying a steel helical spring used in light vehicle suspension systems, subjecting it to uniform loading. The study involves a comparison between Finite Element Analysis (FEA) and analytical solutions to understand the spring's behavior.

10. **Chatterjee et al (2020)** In recent times, fiber-reinforced composite materials have garnered significant commercial attention in modern orthopedic medicine due to their exceptional strength and biocompatibility. These materials have also made remarkable technical advancements in the field of cosmetic dentistrAs researchers continue to explore new frontiers, their focus lies in enhancing current prosthetic technologies by incorporating sensory feedback systems. The aim is to create prostheses with value-added capabilities that can provide more natural and responsive functionalities, thus improving the overall user experience. This cutting-edge approach is set to revolutionize the field of prosthetics and offer better solutions to individuals in need of such devices.y and lower limb prostheses.

11. **Gupta et al (2016)** Composite materials offer vast opportunities and applications across various industries, including automotive, aerospace, wind energy, electrical, sports, domestic use, civil construction, and medical chemical sectors. Their potential is particularly noteworthy in structures exposed primarily to compressive loads.

    With their unique combination of properties, composite materials provide excellent structural integrity and strength, making them highly suitable for withstanding compressive forces. As a result, they are widely utilized in a wide range of applications, enabling significant advancements and innovations in different industries. The versatility and strength of composites make them a valuable choice for developing efficient and reliable structures in various fields.

III. METHODOLOGIES



1. **Research Gap:** In medical sector almost in every operation cutting and stapling is needed throughout the surgery, for that multiple specialized staplers have been designed for this purpose. Even peristaltic pumps are also used during surgery, and in both equipment helical compression spring is used, and till now hard drawn wire, Bronze, Nikel, Crome and silver material is used for the spring. Since in this research we are going to to use composite material for spring to reduction of weight of equipment's/tools with enhancing its strength. Input from practicing surgeons is an important aspect of our development process. Further discussion with surgeons and optimization of our design will be performed in order to develop a device best suited to their needs.

2. **Problem Definition:** Current surgical staplers fail to accommodate a large range in hand sizes, grip strengths, and use orientations. these are the main problems our client, a young female surgeon and also high force is required to operate with these devices. In Currant surgical equipment's uses steel spring which is having high weight and low strength compared with composite spring.

IV. OBJECTIVES OF THE PROJECT WORK

- To determine the most suitable design for a compression spring that best fits the given application.
- To conduct a comprehensive analysis of the spring using both experimental methods and Finite Element Analysis (FEA) techniques.
- To identify and assess various factors and influences that the spring may encounter during its operation, which could potentially impact its longevity.
- To pinpoint critical parameters or factors that require further investigation and research.
- To propose recommendations for enhancing the spring's lifespan through improvements in design, material selection, and manufacturing processes

V. CONCLUSION

By utilizing FEA analysis and validation techniques, manufacturers and researchers can confidently adopt composite helical compression springs in medical surgical tools, thereby contributing to advancements in healthcare technology. The continued exploration and application of composite materials in medical devices hold promising potential to revolutionize the medical industry, enhancing patient outcomes and surgical procedures while advancing the field of medical engineering.

REFERENCES

[1] Madelyn Goedland, "Ergonomic Redesign Of A Surgical Stapling Device" BME Design 200/300 December 14, 2016

[2] Nader A. Mansour, "Design, Characterization And Control Of SMA Springs-Based Multi-Modal Tactile Display Device For Biomedical Applications" mechatronics. 2015.08.004

[3] Minoo Mahshid, "The Effect Of Steam Sterilization On The Accuracy Of Spring-Style Mechanical Torque Devices For Dental Implants" 10.2147/CCIDEN.S32052 2012 Jul 31.

[4] M.-S. Scholz "The Use Of Composite Materials In Modern Orthopaedic Medicine And Prosthetic Devices": A review Volume 71, Issue 16, 14 November 2011, Pages 1791-1803

[5] S Ramakrishna, "Biomedical Applications Of Polymer-Composite Materials: A Review" Volume 61, Issue 9, July 2001, Pages 1189-1224

[6] Anil Antony Sequeira, "Comparative Analysis Of Helical Steel Springs With Composite Springs Using Finite Element Method" Journal of Mechanical Engineering and Automation 2016, 6(5A): 63-70

[7] Mehdi Bakhshesh1, "Optimization of Steel Helical Spring by Composite Spring" International Journal Of Multidisciplinary Sciences And Engineering, Vol. 3, No. 6, June 2012.

[8] Saurabh Singh- "Optimization of Design of Helical Coil Suspension System by Combination of Conventional Steel and Composite Material in Regular Vehicle" International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.7 No.11 (2012)

[9] Ahmed Frikha, Patrice Carried, Fabien Trussed "Mechanical modeling of helical structures accounting for translational invariance. Part 1: Static behavior/ Frikha et al. / International Journal of Solids and Structures 50 (2013) 1373–138

[10] Chang-Hsuan Chiu , Chung-Li Hwan , Han-Shuin Tsai , Wei-Ping Lee An experimental investigation into the mechanical behaviors of helical composite springs C.-H. Chiu et al. / Composite Structures 77 (2007) 331–340

[11] Tausif M. Mulla1, Sunil J. Kadam2, Vaibhav S. Kengar3,"Finite Element Analysis Of Helical Coil Compression Spring For Three Wheeler Automotiv Front Suspension", International Journal Of Mechanical and Industrial Engineering (IJMIE) ISSN No. 2231 –6477, Vol-2, Iss-3, 2012

[12] Becker L.E., G.G.Chasssies:- " On the Natural frequencies of helical compression springs" L.E. Becker et al. / International Journal of Mechanical Sciences 44 (2002) 825– 841.

[13] Satyanarayana, K.G., Sukumaran, K., Mukherjee, P.S., Pavithran, C. and Pillai, S.G.K., “International conference on low cost housing for developing countries”, pp. 171-181, (Rookree, 1984).
[14] Satyanarayana, K.G., Pai, B.C., Sukumaran, K, and Pillai, S.G.K., “Lingocellulosic fiber reinforced polymer composites”, (New York, Marcel Decker, Vol.1, pp.339.
[15] Hinrichsen, J, “The Material Down-selection Process for A3XX, CAES”, 19th European Conference on Materials for Aerospace Applications, Munich, pp.6-8, 2000.
[16] Hinrichsen, J. & Pora, J., “Airbus A380: Requirements for the Selection of Materials and Manufacturing Technologies”; Aluminium Chair 2001: Aluminium in the Aerospace Industries, SONACA SA, Gosselies, Belgium, 8th March 2001.
[17] Pora, J. & Hinrichsen, J.: “Material and technology developments for the Airbus A380”; 22nd International SAMPE Europe Conference of theSociety for the Advancement of Material and Process Engineering, La Défense, Paris, France, 27th – 29th March 2001.
[18] Blythe, A.R., “Electrical properties of polymer”, Cambridge University Press Cambridge, London, (1979).
[19] Karthikeyan B., Ramanathan S., Ramakrishnan V., “Thermo physical property measurement of metal matrix composites”, Materials andDesign, pp. 82-86, 2010.
[20] Georgios Koronis., Arlindo Silva and MihailFontul (2013), ‘Green Composite: A review of adequate materials for automotive application ,Composites: Part B., Vol.44, pp.120-127.
[21] F. Robicsek, "THE BIRTH OF THE SURGICAL STAPLER," (in English),Surgery Gynecology & Obstetrics, Article vol. 150, no. 4, pp. 579-583, 1980.
[22] T.S. Manjunatha and D. Abdul Budan, Manufacturing and Experimentation of Composite Helical Springs for Automotive Suspension, International Journal of Modern Engineering Research, 1(2), (2012).
[23] B. Raghu Kumar, V. ViajayPrakassh and N.Ramesh, Static analysis of mono leaf spring with different composite materials, Journal of Mechanical Engineering Research, 5(2), (2013), 32-37.
[24] G. Sidharamanna, S. Shankar, S. Vijayarangan, Mono Composite Leaf Spring for Light Weight Vehicle–Design, End Joint Analysis and Testing, Materials Science, 12(3), (2006).
[25] B. Mehdi and B. Majid, Optimization of Steel Helical Spring by Composite Spring, International Journal of Multidisciplinary Sciences and Engineering ,3(6), (2012).
[26] Yusup, E. M., Mahzan, S., & Kamaruddin, M. A. H., (2019). Natural Fiber Reinforced Polymer for the Application of Sports Equipment using Mold Casting Method, IOP Conf. Series: Materials Science and Engineering, Article ID 012040, 494.
[27] Jeon, J-H. et al., (2009). Novel biomimetic actuator based on SPEEK and PVDF,Sensors & Actuators: B. Chemical, 143, 357–364.
[28] Yeh, C-C., & Wen-Pin, S., (2010). Effects of water content on the actuationperformance of ionic polymer–metal composites, Smart Materials and Structures, 19,Article ID 124007.
[29] Shahinpoor, M. et al., (1998). Ionic polymer–metal composites (IPMCs) asbiomimetic sensors, actuators and artificial muscles – a review, Smart Materials andStructures, 7, R15.
[30] Shan, Y., & Kam K. L., (2009). Frequency-weighted feed forward control fordynamic compensation in ionic polymer–metal composite actuators, Smart Materials and Structures, 18, Article ID 125016.
[31] Li, S-L. et al., (2011). A helical ionic polymer–metal composite actuator for radiuscontrol of biomedical active stents, Smart Materials and Structures, 20, Article ID035008.
[32] Shahinpoor, M., & Kim, K. J., (2005). Ionic polymer–metal composites: IV.Industrial and medical applications, Smart Materials and Structures, 14, 197.
[33] Shahinpoor, M. A. (2007). (NM, US), Electrically-controllable multi-fingeredresilient heart compression devices, Environmental Robots, Inc. (Albuquerque, NM, US):United States.
[34] Tu, Z. et al., (2021). Biomimetic high performance artificial muscle built on sacrificial coordination network and mechanical training process, Nature Communications, 12, 2916.
[35] Burg, K. J. L., Porter, S., & Kellam, J. F., (2000). Biomaterial developments for bone tissue engineering, Biomaterials, 21, 2347–2359. https://doi.org/10.1016/s0142-9612(00)00102-2
[36] Cao, H., & Kuboyama, N., (2010). A biodegradable porous composite scaffold of PGA/ [beta] TCP for bone tissue engineering, Bone, 46, 386–395.
[37] Guarino, V. et al., (2010). Morphology and degradation properties ofPCL/HYAFF11® composite scaffolds with multi-scale degradation rate, CompositesScience and Technology, 70, 1826–1837.
[38] Huang, Y-C., & Huang, Y-Y., (2006). Biomaterials and strategies for nerve regeneration, Artificial Organs, 30, 514–522.
[39] Schmidt, C. E., & Leach, J. B., (2003). Neural tissue engineering: strategies for repair and regeneration, Annual Review of Biomedical Engineering, 5, 293–347.
[40] Pei, B. et al., (2017). Fiber-reinforced scaffolds in soft tissue engineering, Regenerative Biomaterials, 257–

268
[41] Moffat, M., (2004). Braving new worlds: to conquer, to endure, Physical Therapy, 84, 1056–1086.
[42] South, B. J. et al., (2010). Manufacture of energy storage and return prosthetic feet using selective laser sintering, Journal of Biomechanical Engineering, 132, 015001- 015006.
[43] Dyer, B. T. J. et al., (2010). The design of lower-limb sports prostheses: fair inclusion in disability sport, Disability & Society, 25, 593–602.
[44] Nolan, L., (2008). Carbon fibre prostheses and running in amputees: a review, Foot and Ankle Surgery, 14, 125–129.
[45] Versluys, R. et al., (2009). Prosthetic feet: state-of-the-art review and the importance of mimicking human ankle–foot biomechanics, Disability and Rehabilitation: Assistive Technology, 4, 65–75. https://doi.org/10.1080/17483100802715092.

FABRICATION OF ECONOMICAL VERTICAL AXIS WIND MILL

Abstract

The world's energy demand is steadily increasing, as is the demand for fossil fuels. We will not be able to meet future demand for fossil fuels at our current pace of consumption, and the detrimental environmental impact of carbon emissions will continue to hurt the world. We need to move toward more sustainable solutions with alternative energy technology to keep up with the growing demand for energy and reduce our reliance on fossil fuels. Rather than keeping a single central production location, the alternative energy industry has been decentralizing (i.e., multiple production sources are spread out over a vast area). If a node in a network falls down, a decentralized alternative energy market allows each individual in the community to maintain themselves and the network. Wind energy is a non-conventional form of energy that will never run out.. Conventional sources will be phased out in the near future. In a percentage basis, wind has been the fastest-growing power source on the planet. Many times, we notice that street lights are illuminated during the day.These lights are intended to be turned off early in the morning, but due to the negligence of linemen, they are illuminated irregularly. It is a hot topic for debate, especially in larger cities. The person in charge of these lights must turn them on immediately before or during sunset, and they must beturned off shortly before sunrise.

However, because to the tiredness of the linemen, these street lights are sometimes left on during the day. Every day, a significant amount of energy is squandered in this manner; as a result, automatic street light control instruments are required and should be installed

Authors

B.Venkatesh
Professor
Mechanical Engineering
Vardhaman College of Engineering
Hyderabad, India.

C. Anil Kumar Reddy
JRF
Department of Mechanical Engineering
Vardhaman College of Engineering
Hyderabad, India.
c.anilkumar.jrf@vardhaman.org

S.B. Sai Krishna
Student
Department of Mechanical Engineering
Vardhaman College of Engineering
Hyderabad , India.

L.Tej Vardhan Reddy
Student
Department of Mechanical Engineering
Vardhaman College of Engineering
Hyderabad, India.

B. Deepak Raj
Student
Department of Mechanical Engineering
Vardhaman College of Engineering
Hyderabad , India.

everywhere. As a result, this project work is created, which automatically energizes the streetlights when natural light disappears and de energizes them when natural light returns using vertical axis windmill to charge the battery. The goal of this project, which includes a vertical-axis windmill, is to further individual sustainability design. The vertical-axis windmill shown is low-cost, compact, and capable of supporting a load. Propellers, a LDR unit, and a generator will make up the vertical-axis windmill's three elements. Each component has a distinct purpose. Wind energy is converted into mechanical energy by the propellers, mechanical energy is converted to electrical energy by the generator, and then further, the energy is stored in battery and sent to the LDR unit and circuit to lighten up and turn off the streetlights depending upon the light fallen on LDR unit.

Keywords: Energy, Fossil fuels,vertical axis wind mill, battery,LDR Unit.

I. INTRODUCTION

A combination of rapidly growing costs and a decrease in supply and demand the search for sustainable energy alternatives is being fuelled by concerns about global climate change. Some of the proposed alternatives, such as large-scale biofuel use, may not be practical or sustainable in the long run. Other outlandish possibilities, such as geothermal energy, may exist, but only on a tiny and limited scale. Because solar cells are tiny, expensive, and inefficient, they are still in their infancy. As a result, oil, coal, natural gas, and wind appear to be the world's primary energy sources. Energy is one of the main components of economic infrastructure and is the fundamental input to sustain economic growth. The connection between economic progress and energy usage is substantial. The more a country develops, the greater the per capita usage of energy and vice versa. Human civilization depends on several energy sources.[1] Our globe has enough wind to provide most, if not all, of humanity's energy needs. Wind was the world's fastest increasing power source in terms of percentage gain from 1990 to 2002. Europe and the United States have a large number of winds generating stations. In 2004, the global wind capacity was 47,317 MW. Something new is clearly needed if the wind is to contribute considerably to the worldwide production of electricity. This item might be a windmill on the vertical axis.

Vertical axis windmills have the distinct advantage of being able to take wind from any direction and without requiring the complex head mechanics seen in traditional horizontal axis windmills. As a result, new vertical axis designs capable of significant power generation must be developed and tested. The usage of energy increased dramatically over the twentieth century. Atthe beginning of the 20th century, coal was the prevalent energy source and because of its higher energy density, oil was the major rival. Following WWII, there was a shift from coal to oil, which is still the dominant energy source today. Economic and demographic growth have been spurred by the availability of low-cost energy. More than 40percent of global energy use is accounted for by oil. There have been several forecasts regarding when oil might runout or become too expensive to extract. Windmill is now the most cost-effective means to gather horizontal wind power. They are located in a known area of wind on land or at sea. The two or three layers of most horizontal axis mills. On the top of a turbine are the primary rotor shaft and the power generator. And the wind should go. Small mills are marked by a simple wind vane whereas big mills are usually connected to a servomotor via a wind sensor. It comprises mostly of a gearbox that makes the low turning of the blades intoa faster, more suited rotation for driving a generator.

The various horizontal turbines provide several sizes and power ratings. The biggest electricity-generating turbine has blades of high school height length. The wind turbine has an extraordinary height of 20 storeys and the rotors have a diameter of up to 25 feet. An power supply to a water pump, residence, or telecommunications system is available from a wind turbine of this size. A tiny turbine can produce 50 kW of electricity. The power generation is done via a wind farm. A wind farm is formedby several windmills gathered together. The electric power generated by the turbines is transferred from a power grid to clients. The power grid functions much like a regular power station.

II. MATERIALS AND METHODS

Renewable energy exploration is a technique which reduces our reliance on fossil fuels. Wind energy is the only resource in this study among various renewable energy resources. The project concentrates on the utilization of wind for the clean and safe provision of electricity as a renewable resource.. The project is aimed at fabricating and implementing a vertical axis windmillwith LDR unit. The key benefit is that this prototype may be used at any area or building under maximum operating circumstances and work in less wind. We have chosen this power generation project. Power production isproportional directly to the size of assembly that comprises mainly the number of blades, capacity of generator, etc. The compact vertical axis windmill rotates when wind comes contacts with the blades, making the dc generator generating energy. This energy is stored in a battery which is used by the LED’s passing through the LDR unit which detects absence of light and the resistors resists the amount of electricity sentto the LEDs depending upon the intensity of light detected.

1. Materials Required:

- D.C motor
- PVC blades shaft
- LDR circuit
- Battery
- Relay
- White LEDs
- Bearing

2. Fabrication of Blades: We used a 75mm PVC pipe to fabricate the wind blades. We used a cutting machine to cut the pipe into 4 parts. Each blade is of 0.4cms thick and 39cms in length. We could have also used to stainless steel blades, but to avoid formation of rust and heavy weight of overall setup, we used PVC pipes which were easily available in local market and are of light weight too.

3. Fabrication of Shaft: After fabricating the blades, we move on to fabricating of shaft with mild steel rod. The length of the shat we fabricated is maintained to be 41 cms and thickness is more than 2 cms.

4. Fabrication of Stand: We used mild steel rods again here to make a support stand using arc welding in nearest welding shop. The height of the stand which is attached to the bottom of the setup is to be 14cms in height, length is about 30cms and coming to thickness of single rod in stand is 2.45cms. This stand is attached to a 350rpm DC generator. Also, “+” shaped mild steel rods are welded to the main shaft to which the blades are fixed using screws and bolts. One at the top of the shaft and one at the middle of the shaft. 2 attachments are made so as to give a proper and fixed placement of the blades.

5. Assembling of Shaft and Rotating Part: As above mentioned, the shaft of given specifications is fabricated and is joined to the pitch bearing of height 5.5cms with the help of arc welding.

6. **Making of LDR and Relay Unit:** As shown in above chapters and following the circuit diagram, a LDR unit and relay unit are fixed on a cardboard sheet with a 12 volt battery (4 sets of three batteries connected in series) on one end of it. A small model of streetlight is also made using cardboard and bunch of LED lights.

7. **Assembly:** Finally, the blades are fixed to the rods the stand is connect to the shaft and the generator and shaft of blades are connected and welded together and the dc generator wires are connected to the batteries using a small 3 pin connecter.

Figure 1: Assembled Prototype

Figure 2: Wind Mill

III. RESULTS AND DISCUSSIONS

By the experiment, we learnt that a wind turbine's output swings according on wind rates or wind speeds. The output voltage increases when the wind speed increases, vice versa. The produced voltage is used for power charges such as lights and ventilators. The angular rate is measured by means of a non-contact tachometer of a windmill, which can also measure wind turbine rpm and measure output voltage via a voltmeter.

Calculations: The turbine power is linked to the generated kinetic energy. The volume V' flowing in unit time through an area A, with wind speed Vis denoted by AV and mass M is the product of Volume V' and density so:

$$M = \rho * A * V$$

By including the M in kinetic energy the equation that we receive

$$Kinetic\ Energy = 0.5 * \rho * A * V^3$$

Power, on the other hand, is nothing more than the kinetic energy created by the turbine.

Hence:
$Air\ Density(\rho) = 1.225 kg/m^3$

Where,
Air Density(ρ) = 1.225kg/m3

Table 1: Test Cycle outcomes for Prototype

Sr. No	Speed of the Windmill (in RPM)	Output voltage (in Volts)	Angular velocity (Rad/Sec)	Power in watts
1	25	1.72	2.57	0.51
2	50	3.49	5.2	4.59
3	75	5.26	7.81	15.65
4	100	7.0	10.4	37.2
5	120	8.4	12.5	64

Area (A) = Swept Area of turbine blades
Velocity (V) = wind speed in m/s

The formula below depicts major parameters that affect a wind turbine's performance. It's worth noting that the wind speed, V, has a 3 exponent. As a result, even a slight increase in wind speed results in a significant gain in power. As illustrated in the Wind Speeds Boost with Height graph, a taller tower will increase the productivity of any wind turbine by allowing it access to higher wind speeds. The formula for calculating power is as follows:

$$Power = k * Cp * 1/2 * \rho * A * V^3$$

Where;

P = Power output, kilowatts Cp = Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59)

$$\rho = air\ density, kg/m^3$$
$$A = Rotor\ swept\ area, \pi * D^2/4$$

V = Wind speed, KMPH
k = 0.000133 A constant to yield power in kilowatts.

IV. CONCLUSION

The main advantages of using wind as a source are that it is relatively inexpensive and that it is a natural power source that can be used to create energy affordably. This is a non-polluting and clean power source. Maglev wind turbines assist to lower noise factor compared to conventional wind turbines since noise factor is quite low and may be presumed to be zero. It does not need to be lubricated. The blades of this wind turbine may be rotated by wind from any direction.

We opted to build a windmill project for our main project. In the beginning, we felt it was a pretty basic initiative that would show us the natural resources that are not exploited sufficiently in our nation. We chose, however, to do a wind energy experiment after investigation instead, and we thus started the project which involves a little amount of electrical background projects that may enable us to improve the appropriate use of the energy source. It offered us a holistic and mechanical understanding due to the amount of mechanical knowledge needed to build an actual windmill. The compilation of electronics was straightforward as the windmill was created and the one great difficulty, we were not aware of was the choosing of our power generator and the creation of the LDR-circuit.

Many information about practical elements and how to execute various things in the workshop was acquired through the manufacturing process. The weather was not very helpful during the testing. Sometimes even 10 m/sat once blew incredibly strong winds. It was just about 1-2 m/s sometimes. Sometimes rain arrived to the celebration as well and in only a few secondsit got everything wet.

But at the end of the day these things were the most significant and essential things in the future and the lessons that they taught. Sometimes the bravery improved during the simulation period contributed to the manufacturing and testing. They were all good lessons, therefore.

Although our project did not create as much power as we originally planned, with an efficiency assessed at 7,52 percent it could provide a reasonable quan tity of electricity. Overall, the project has taught us engine selection, power generation, ratings for efficiency, mechanical design, problem resolution and other abilities. Even though we were able to make this design of Vertical Axis Wind Mill but there is always a procedure to enhance innovations and new ideas. Wind turbines are a beginning for civilization to minimize damage to the world by not utilizing pollution-generating energy sources. from table 1 it is evident that if RPM increases output power also increases and which will increases Wind mill efficiency and makes it economical.

Hopefully, the project may promote VAWM Frameworks research and tests, and provide insight for various gatherings, so that vertical windmills may be further tested and enhanced productivity and execution. The project will give a competent lighting system approach and facilitate and efficiently save the entire energy process. As the quantity of light output may be changed based on the external state, an invention with a large number of future applications is undoubtedly not only possible in many modern technicians such as headlights, street light, parking lights, industrial lights, and many more. There is no question that the use of the intelligent lighting system will revolutionize the world we see today. The most cost-efficient source of electricity in the foreseeable future is wind power. In fact, it might be argued that this status has already been obtained. There is no genuine knowledge of the exact life-cycle cost for fossil fuels, but likely significantly greater than the present wholesale pricing.

The possible depletion of these sources of energy will require quick priceincreases which, on average, will lead to postponed real prices that are unacceptable to the current norm during the short term of usage. And this even does not take into account the environmental and political cost of using fossil fuels that rise every day quietly and not so quietly.

Thus, it can create more energy constantly with efficient output using wind and sun energy using hybrid power generation techniques. By using these strategies and changing the output capacity of the wind turbine in the top-most buildings, it may also grow. By analyzing the wind blade PVC with other materials, we found that PVCs are less weightless and the generation of energy is higher than the other substances.

REFERENCES

[1] Peter South and Raj S Rangi. "A wind tunnel investigation of a 14 ft diameter vertical axis windmill". In: (1972).
[2] Mohammed Hadi Ali et al. "Experimental comparison study for Savonius wind turbine of two & three blades at low wind speed". In: *International Journal of Modern Engineering Research (IJMER)* 3.5 (2013), pp. 2978–2986.
[3] Javier Castillo Tudela. "Small-Scale vertical axis wind turbine design".B.S. thesis. Universitat Politècnica de Catalunya, 2012.
[4] UK Saha, S Thotla, and D Maity. "Optimum design configuration of Savonius rotor through wind tunnel experiments". In: *Journal of Wind Engineering and Industrial Aerodynamics* 96.8-9 (2008), pp. 1359–1375.
[5] D Sarkar, AR Sengupta, P Bhadra, S Alam, and B Debnath. "Review of the Hybrid H-Savonius Rotor's Design and Performance". In: *Recent Advances in Mechanical Engineering*. Springer, 2021, pp. 33–40.
[6] M Abid, KS Karimov, HA Wajid, F Farooq, H Ahmed, and OH Khan. "Design, development and testing of a combined Savonius and Darrieus vertical axis wind turbine". In: *Iranica Journal of Energy and Environment*6.1 (2015), pp. 1–4.
[7] S Rassoulinejad-Mousavi, M Jamil, and M Layeghi. "Experimental study of a combined three bucket H-rotor with savonius wind turbine". In: *World Applied Sciences Journal* 28.2 (2013), pp. 205–211.
[8] S Brusca, R Lanzafame, and M Messina. "Design of a vertical-axis wind turbine: how the aspect ratio affects the turbine's performance". In: *International Journal of Energy and Environmental Engineering* 5.4 (2014), pp. 333–340.
[9] Kristy L Hansen, Richard M Kelso, and Bassam B Dally. "Performance variations of leading-edge tubercles for distinct airfoil profiles". In: *AIAA journal* 49.1 (2011), pp. 185–194.
[10] Franklyn Kanyako and Isam Janajreh. "Implementation and economical study of HAWT under different wind scenarios". In: *Sustainable Cities and Society* 15 (2015), pp. 153–160.
[11] Nawfal M Ali, Sattar Aljabair, and AK Abdul Hassan. "An Experimental and Numerical Investigation on Darrieus Vertical Axis Wind Turbine Types at Low Wind Speed". In: *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS* 19.06 (2019), pp. 97–110.
[12] Bavin Loganathan, Harun Chowdhury, Israt Mustary, Md Masud Rana, and Firoz Alam. "Design of a micro wind turbine and its economic feasibility study for residential power generation in built-up areas". In:*Energy Procedia* 160 (2019), pp. 812–819.

ALTERNATIVE REFRIGERANTS FOR AIRCRAFT: A REVIEW OF ENVIRONMENTAL IMPACT, SAFETY, AND PERFORMANCE

Abstract

The aviation industry has been under increasing pressure to reduce its environmental footprint and address the adverse effects of traditional refrigerants used in aircraft systems. The present paper aims to explore the feasibility and potential benefits of alternative refrigerants for aircraft applications. We review the environmental impact, safety considerations, and performance characteristics of these substitutes to provide valuable insights for industry stakeholders and researchers. By understanding the advantages and challenges of adopting alternative refrigerants, we can pave the way towards more sustainable and efficient aviation systems.

Keywords: Hydrofluorocarbons, Global Warming Potential, Direct Emissions.

Authors

Mr. Akshay Godse
Assistant Professor
Department of Mechanical Engineering
Sinhgad College of Engineering
Pune, India.
akshaygodse12@gmail.com

Mr. Ranjit Mali
Assistant Professor
Department of Mechanical Engineering
Sinhgad College of Engineering
Pune, India.

Mr. Shivkumar Chhappare
Assistant Professor
Department of Mechanical Engineering
Sinhgad College of Engineering
Pune, India.

Mr. Dattatray Bankar
Assistant Professor
Department of Mechanical Engineering
Sinhgad College of Engineering
Pune, India.

I. INTRODUCTION

Air conditioning and cooling systems are essential components of aircraft to ensure passenger comfort and optimal performance of various onboard systems. Traditionally, hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) have been employed as refrigerants due to their excellent thermal properties. However, their high global warming potential (GWP) and ozone depletion potential (ODP) have raised environmental concerns. In response, researchers and industry professionals have been actively investigating alternative refrigerants with lower environmental impact and improved safety profiles.

II. LITERATURE REVIEW

The aviation industry's pursuit of sustainable and environmentally friendly practices has led to significant research and development in the field of alternative refrigerants for aircraft air conditioning systems. This literature review synthesizes the findings from a selection of key references, each addressing various aspects of the search for more climate-friendly refrigerants.

1. **(Gao&Wang, 2020)** offer a comprehensive overview of hydrofluorocarbon (HFC) alternatives in aircraft air conditioning systems. They highlight the environmental concerns associated with traditional HFCs due to their high global warming potential (GWP) and ozone depletion potential (ODP). The study assesses alternatives such as hydrocarbons (HCs), hydrofluoroolefins (HFOs), ammonia (NH_3), and carbon dioxide (CO_2). The authors emphasize the need to consider safety aspects, system compatibility, and energy efficiency when selecting alternatives.

2. **(Tian et al, 2018)** explore the potential of natural refrigerants as alternatives in air conditioning and refrigeration systems. They discuss the advantages of natural refrigerants such as ammonia, hydrocarbons, and carbon dioxide in terms of their low environmental impact, zero ODP, and low GWP. The authors emphasize the need for careful system design and control due to the flammability and toxicity of some natural refrigerants.

3. **(Schiferl,2019)** technical paper investigates the potential of low-GWP refrigerants for air conditioning and refrigeration applications. The author emphasizes the significance of refrigerants' GWP in mitigating climate change. The study reviews alternative refrigerants and their thermodynamic properties, highlighting HFOs as promising candidates due to their low GWP and performance compatibility.

4. **UN Environment Programme. (2020).** Refrigerant Driving License: A guide to climate-friendly and efficient refrigerants presents a comprehensive guide to climate-friendly and efficient refrigerants. It underscores the importance of selecting refrigerants with low GWP and highlights the role of regulations and standards in promoting environmentally friendly choices. The guide provides insights into the latest developments in alternative refrigerants and their application across various sectors.

5. **European Commission. (2014).** Regulation focuses on the reduction of fluorinated greenhouse gases (F-gases) within the European Union. It sets out measures to limit the use of high-GWP refrigerants and encourages the adoption of low-GWP alternatives. The regulation underscores the urgency of transitioning to more sustainable refrigerants in air conditioning and refrigeration systems.

6. **International Civil Aviation Organization (ICAO). (2016)** Manual provides guidance on various aspects of aviation's environmental impact, including the use of alternative refrigerants. The manual emphasizes the need for sustainable practices in aviation and addresses the considerations for selecting alternative refrigerants that align with both environmental and safety requirements.

7. **(Brown, 2017)** evaluates the potential of hydrofluoroolefins (HFOs) as refrigerants for future aircraft use. The study assesses HFOs' performance in terms of thermodynamic properties, compatibility with materials, and environmental impact. It highlights the promising attributes of HFOs, including their low GWP and good energy efficiency, making them suitable candidates for aircraft air conditioning systems.

8. **(Kim &Samaras, 2018)** analyze alternative aircraft air conditioning technologies to minimize environmental impact. They assess various options, including refrigerant alternatives, and analyze their potential benefits in terms of energy consumption and emissions reduction. The study emphasizes the importance of a holistic approach to system design that considers not only refrigerants but also energy efficiency and operational practices.

9. **International Institute of Refrigeration (IIR). (2017)** discusses the contributions of refrigeration, air conditioning, and heat pump systems to global warming. It highlights the need for alternatives to high-GWP refrigerants and provides insights into the characteristics and applications of various alternative refrigerants. The guide emphasizes the importance of informed decision-making to mitigate environmental impact.

   ASTM International's standard specification addresses the performance of active vibration control systems. While not directly focused on refrigerants, it reflects the broader efforts to enhance aviation technologies for efficiency and sustainability. This standard underscores the multidisciplinary nature of aviation innovations, including those related to air conditioning systems and refrigerants.

III. ENVIRONMENTAL IMPACT OF TRADITIONAL REFRIGERANTS

Traditional refrigerants used in aircraft, such as hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), have significant environmental impacts, primarily due to their high global warming potential (GWP) and ozone depletion potential (ODP). These refrigerants have been widely used in air conditioning and cooling systems in aircraft due to their excellent thermodynamic properties, but their environmental drawbacks have led to a global push for their phasedown and replacement with greener alternatives. Below are the main environmental impacts of traditional refrigerants:

1. **Global Warming Potential (GWP):** The GWP of a refrigerant measures its ability to trap heat in the atmosphere over a specific time period compared to carbon dioxide (CO2). CO2 serves as a baseline with a GWP of 1. Traditional HFCs, such as R-134a (1,1,1,2-tetrafluoroethane), have significantly high GWP values, reaching several thousand times that of CO2. For instance, R-134a has a GWP of 1,430 over a 100-year period. When released into the atmosphere, these high-GWP refrigerants contribute to global warming and climate change.

2. **Ozone Depletion Potential (ODP):** While HFCs do not deplete the ozone layer, some traditional refrigerants, like HCFCs, do have ODP. HCFCs, such as R-22 (chlorodifluoromethane), have both a high GWP and a moderate ODP. The release of HCFCs into the atmosphere can lead to the degradation of the stratospheric ozone layer, which plays a critical role in absorbing harmful ultraviolet (UV) radiation from the sun. Ozone depletion can lead to increased UV exposure on the Earth's surface, posing health risks to both humans and ecosystems.

3. **Direct Emissions:** Refrigerants can leak from aircraft cooling systems during operation, maintenance, or accidents, leading to direct emissions into the atmosphere. These emissions contribute to both global warming and ozone depletion. Given the confined space in aircraft, refrigerant leaks can become a significant concern, affecting both cabin air quality and the environment.

4. **Indirect Emissions:** The environmental impact of refrigerants extends beyond direct emissions. Indirect emissions occur throughout the lifecycle of these refrigerants, including their production, transportation, and disposal. The manufacturing process of these chemicals often involves energy-intensive procedures and the release of greenhouse gases.

5. **Long Atmospheric Lifespan:** Many traditional refrigerants have long atmospheric lifespans, which means that once released into the atmosphere, they can persist for years or even decades before being naturally removed. During their lifetime, these refrigerants continue to contribute to global warming and ozone depletion, exacerbating their environmental impacts.

   Due to these environmental concerns, global initiatives such as the Montreal Protocol and the Kigali Amendment have been implemented to regulate and phase down the production and consumption of high-GWP and ozone-depleting substances, including traditional refrigerants. These agreements aim to encourage the adoption of environmentally friendly alternatives to protect the Earth's climate and ozone layer. By transitioning to alternative refrigerants with lower GWP and no ODP, the aviation industry can significantly reduce its environmental impact and contribute to a more sustainable future.

IV. CRITERIA FOR EVALUATING ALTERNATIVE REFRIGERANTS

Evaluating alternative refrigerants for aircraft requires considering various criteria to ensure their suitability and safety. The following are key criteria used to assess and compare different options:

1. **Global Warming Potential (GWP):** GWP measures the global warming impact of a refrigerant relative to carbon dioxide (CO2) over a specific time horizon (usually 20, 100, or 500 years). Lower GWP values indicate a reduced contribution to climate change, making refrigerants with lower GWP more environmentally friendly.

2. **Ozone Depletion Potential (ODP):** ODP evaluates the potential of a refrigerant to deplete the ozone layer when released into the atmosphere. Ozone-depleting refrigerants, such as HCFCs, can lead to stratospheric ozone depletion, which has adverse effects on human health and ecosystems. Alternative refrigerants should have zero ODP to prevent further damage to the ozone layer.

3. **Thermodynamic Properties:** The thermodynamic properties of a refrigerant, including its critical temperature, pressure, and specific heat, determine its efficiency and performance in cooling systems. Refrigerants should offer suitable pressure-temperature characteristics to operate effectively in aircraft cooling applications.

4. **Toxicity and Flammability:** Safety is paramount when selecting refrigerants for aircraft systems. Alternative refrigerants should have low toxicity and be non-flammable or have a low flammability level to minimize risks to passengers, crew, and aircraft in the event of a leak or system malfunction.

5. **Material Compatibility:** Refrigerants should be compatible with common materials used in aircraft cooling systems, such as seals, gaskets, and lubricants. Compatibility ensures that the refrigerant does not cause degradation or damage to system components over time.

6. **Energy Efficiency:** The energy efficiency of a refrigerant influences the overall efficiency of the cooling system. Refrigerants with high energy efficiency contribute to reduced fuel consumption and lower greenhouse gas emissions during aircraft operation.

7. **Atmospheric Lifetime:** The atmospheric lifetime of a refrigerant refers to the length of time it remains in the atmosphere before undergoing natural degradation or removal. Short-lived refrigerants are preferred to minimize their long-term impact on global warming and ozone depletion.

8. **Cost:** The cost of alternative refrigerants, including production, handling, and maintenance expenses, plays a crucial role in their practicality and adoption in the aviation industry. Cost-effectiveness is essential for ensuring the economic viability of using alternative refrigerants.

9. **Regulatory Compliance:** Compliance with international environmental agreements, such as the Montreal Protocol and the Kigali Amendment, is necessary to ensure that the selected refrigerants align with global efforts to protect the environment and phase down high-GWP and ozone-depleting substances.

10. **Retrofitting and System Compatibility:** The feasibility of retrofitting existing aircraft cooling systems with alternative refrigerants is a significant consideration. Compatibility with existing equipment and potential modifications required to accommodate the new refrigerant should be evaluated.

11. **Global Availability and Supply Chain Considerations:** Availability of alternative refrigerants in different regions and a stable supply chain are important factors in ensuring continuous access to refrigerants for maintenance and servicing of aircraft worldwide.

    By evaluating alternative refrigerants against these criteria, the aviation industry can make informed decisions regarding the most suitable and environmentally responsible options for aircraft cooling systems.

V. COMMONLY STUDIED ALTERNATIVE REFRIGERANTS

In response to the environmental concerns associated with traditional refrigerants, researchers and industry experts have been actively studying and evaluating various alternative refrigerants for aircraft applications. Some of the commonly studied alternatives include:

1. **Hydrocarbons (HCs):** Hydrocarbons, such as propane (R-290) and isobutane (R-600a), are natural refrigerants that have gained attention due to their low environmental impact. They have zero ozone depletion potential (ODP) and extremely low global warming potential (GWP). HCs are also energy-efficient and compatible with many materials used in aircraft cooling systems. However, their flammability requires careful handling, and safety standards need to be strictly adhered to.

2. **Carbon Dioxide (CO2) - R-744:** Carbon dioxide, or CO2, has been explored as an alternative refrigerant due to its negligible GWP and zero ODP, making it an environmentally friendly option. CO2 is non-flammable and non-toxic, but its relatively high operating pressures can be challenging for some cooling system designs. CO2-based systems often require specialized components to handle the higher pressures, but they offer good energy efficiency and are suitable for certain aircraft cooling applications.

3. **Ammonia (NH3) - R-717:** Ammonia is another natural refrigerant that has been considered for aircraft cooling systems. It has zero GWP and zero ODP, making it an attractive environmentally friendly option. However, ammonia is highly toxic, and its use in aircraft requires strict safety measures and considerations. Due to its toxicity and potential hazards, ammonia may be more suitable for ground-based cooling systems rather than cabin air conditioning.

4. **Hydrofluoroolefins (HFOs):** HFOs are a new class of synthetic refrigerants designed to have low GWP values. Examples include R-1234yf and R-1234ze, which are being used as replacements for high-GWP HFCs like R-134a. HFOs have GWP values less than 1, making them very environmentally friendly. They are also non-ozone depleting and have lower toxicity and flammability compared to some other alternatives.

5. **Hydrofluorocarbons (HFCs) with Lower GWP:** As an intermediate solution, some HFC blends with lower GWP have been considered, such as R-32 (difluoromethane) and R-1234ze (trans-1,3,3,3-tetrafluoropropene). While these options are not as environmentally friendly as natural refrigerants, they offer a substantial reduction in GWP compared to traditional HFCs like R-134a.

6. **Hydrofluoroethers (HFEs):** HFEs are another class of synthetic refrigerants with low GWP. Some examples include HFE-7000 and HFE-7100. These refrigerants have zero ODP and low toxicity, making them attractive alternatives for aircraft cooling applications.

   It's important to note that each alternative refrigerant has its advantages and limitations. The choice of refrigerant will depend on factors such as the specific cooling system requirements, safety considerations, retrofitting feasibility, and regulatory compliance. Additionally, ongoing research and development in this field may lead to the emergence of new alternative refrigerants with even better environmental and performance characteristics in the future

VI. FUTURE PROSPECTS

The future of alternative refrigerants for aircraft holds promising opportunities for advancing sustainability and reducing the aviation industry's environmental impact. As research and technology continue to evolve, several key prospects are likely to shape the adoption and implementation of alternative refrigerants:

1. **Advancements in Refrigerant Technology:** Ongoing research and development will likely lead to the discovery and design of new alternative refrigerants with even lower GWP, improved energy efficiency, and enhanced safety profiles. These advancements will further expand the options available for the aviation industry.

2. **Increasing Regulatory Support:** Global efforts to address climate change and ozone depletion will continue to drive regulatory support for environmentally friendly refrigerants. Stricter regulations and international agreements, such as the Montreal Protocol and the Kigali Amendment, will incentivize the transition to low-GWP and zero-ODP refrigerants.

3. **Enhanced Safety Standards:** As more alternative refrigerants are introduced, safety standards and guidelines for handling, storage, and maintenance will be refined and expanded. This will ensure that aircraft systems operate safely while using these new refrigerants.

4. **Growing Awareness and Consciousness:** The aviation industry and the general public are becoming increasingly aware of environmental issues and the need for sustainable practices. As eco-consciousness grows, there will be greater demand for aircraft manufacturers and airlines to prioritize greener refrigerant options.

5. **Industry Collaboration:** Collaboration between researchers, manufacturers, airlines, and regulatory bodies will play a pivotal role in advancing the adoption of alternative

refrigerants. Sharing knowledge, expertise, and best practices will expedite the integration of these refrigerants into aircraft cooling systems.

VII. RECOMMENDATIONS

To successfully transition to alternative refrigerants for aircraft, the following recommendations should be considered:

1. **Comprehensive Lifecycle Analysis:** Conduct a thorough lifecycle analysis of different refrigerant options, considering their environmental impact from production to disposal. This analysis should include assessments of carbon footprint, energy consumption, and waste generation.

2. **Robust Safety Protocols:** Develop and implement stringent safety protocols and training programs for handling and using alternative refrigerants. Safety measures must be in place for maintenance personnel, ground crew, and aircraft engineers to prevent accidents and ensure passenger safety.

3. **Public Awareness and Education:** Raise public awareness about the importance of using environmentally friendly refrigerants in aircraft. Educating passengers about the industry's efforts to reduce emissions and protect the environment can foster support and understanding.

4. **Financial Incentives:** Governments and regulatory bodies can offer financial incentives or subsidies to encourage airlines to adopt alternative refrigerants. These incentives can offset initial implementation costs and promote faster adoption.

5. **Collaborative Research:** Encourage collaborative research efforts between academia, research institutions, and industry stakeholders to share findings, data, and best practices related to alternative refrigerants. This will accelerate progress and foster innovation in this area.

6. **Continuous Monitoring and Improvement:** Implement monitoring and reporting mechanisms to track the performance and environmental impact of alternative refrigerants in real-world applications. This data will help identify areas for improvement and drive continuous advancements in refrigerant technology.

VIII. CONCLUSION

The adoption of alternative refrigerants for aircraft cooling systems represents a critical step towards achieving a more sustainable and environmentally responsible aviation industry. Traditional refrigerants, with their high global warming potential (GWP) and ozone depletion potential (ODP), have raised significant environmental concerns. The exploration of alternative refrigerants has offered a ray of hope, presenting viable solutions to mitigate the industry's environmental impact.

Through this paper, we have discussed the environmental impact of traditional refrigerants, highlighting their role in global warming and ozone depletion. The urgent need to transition away from these environmentally harmful substances has been emphasized, considering the detrimental effects on the climate and the Earth's protective ozone layer.

Commonly studied alternative refrigerants, such as hydrocarbons (HCs), carbon dioxide (CO2), ammonia (NH3), hydrofluoroolefins (HFOs), and low-GWP hydrofluorocarbons (HFCs), have been reviewed in terms of their environmental impact, safety considerations, and performance characteristics. Each refrigerant offers unique advantages and challenges, presenting a range of choices for the aviation industry to consider.

Looking to the future, the prospects for alternative refrigerants in aviation are promising. Ongoing advancements in refrigerant technology, growing regulatory support, increased safety standards, and enhanced awareness of environmental issues are likely to drive the adoption of greener refrigerants in aircraft.

To successfully implement alternative refrigerants, collaboration among researchers, manufacturers, airlines, and regulatory bodies is essential. Continuous monitoring and improvement, along with public awareness and education, will further support the transition to more sustainable refrigeration solutions.

The adoption of alternative refrigerants for aircraft represents a positive step towards a greener aviation industry. By choosing refrigerants with lower environmental impact, the industry can contribute to global efforts in mitigating climate change and protecting the ozone layer. With continued research, collaboration, and dedication to sustainability, the aviation industry can pave the way for a more eco-friendly future in air travel.

REFERENCES

[1] Gao, D., & Wang, Q. (2020). Review of hydrofluorocarbon alternatives for aircraft air conditioning systems. International Journal of Refrigeration, 115, 82-95.
[2] Tian, S., Liu, X., & Wang, X. (2018). A review of natural refrigerants and their applications for air conditioning and refrigeration systems.Applied Thermal Engineering, 140, 161-176.
[3] Schiferl, R., J. (2019). Potential of Low GWP Refrigerants in Air Conditioning and Refrigeration Applications.SAE Technical Paper, 2019-01-1893.
[4] UN Environment Programme. (2020). Refrigerant Driving License: A guide to climate-friendly and efficient refrigerants.
[5] European Commission. (2014). Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases.
[6] International Civil Aviation Organization (ICAO). (2016). Environmental Technical Manual: Fourth Edition.
[7] Brown, J. S. (2017). Evaluation of Hydrofluoroolefin (HFO) Refrigerants for Future Aircraft Use.SAE Technical Paper, 2017-01-2163.
[8] Kim, J. W., & Samaras, C. (2018). Analysis of alternative aircraft air conditioning technologies with reduced environmental impact. Applied Energy, 228, 1398-1411.
[9] International Institute of Refrigeration (IIR). (2017). Guide on Refrigeration, Air Conditioning and Heat Pumps: Contributions to Global Warming.
[10] ASTM International. (2019). Standard Specification for Performance of Active Vibration Control Systems.

MODELLING AND ANALYSIS OF AIRCRAFT WIND SHIELD MADE OF PVB AND PMMA MATERIAL

Abstract

The portion of a car, bus, motorcycle, or tram that faces forward is called the windscreen. The windscreen is a crucial component of an airplane and is dependent upon for the functionality of one of its most significant features. Some of the most important characteristics of the windscreen are visibility through the canopy, structure stiffness, impact resistance, dependability of the internal mechanics, and construction lightness. On light training aircraft, glass is the windshield material of choice. It is suggested that the glass be replaced by a light trainer in the current development. In the current experiment, two more materials for windshieldspolymethyl methacrylate (PMMA) and polyvinyl butyl (PVB) were taken into consideration. Pro/Engineer software was used to create a 3D model of the windscreen. ANSYS, the Fluid-Solid-Interaction (FSI) approach, and computational fluid dynamics (CFD) were used in a dynamic simulation to evaluate fluid pressure, stress distribution, and windshield deformation at varied air speeds. Analysis is conducted on all three materials at various air speeds of 900, 800, 600, and 400 km/hr. In this thesis, the pressure, velocity, stress, and deformation are calculated for various materials and speeds using the FSI analysis.

Keywords: CFD, PMMA, PVB, FSI Technique, wind shield, ANSYS.

Authors

Manish Sharma
Assistant Professor
Mechanical Engineering
Malla Reddy Engineering College
Hyderabad , India
manish.mvs@gmail.com

Dilawar Husain
Assistant Professor
Mechanical Engineering
MM Ahmed Nadvi Technical Campus
Malegaon, Nashik, India

C Anil Kumar Reddy
JRF, Mechanical Engineering
Vardhaman College of Engineering
Hyderabad, India

B Shravya Sri
Student
Mechanical Engineering
Malla Reddy Engineering College
Hyderabad, India

I. INTRODUCTION

The windshield or windscreen of an aircraft, car, bus, motorcycle, or tram is referred to as the front window in Commonwealth countries and North America, respectively. The majority of current windshields are composed of laminated safety glass, a type of treated glass, which is fused between two sheets of glass (often curved) for protection and bonded into the window frame. The majority of motorcycle windscreens are made of high-impact acrylic plastic. Windshields provide a front glass that is aerodynamic and protect the car's occupants from flying debris including dust, insects, and rocks as well as the wind. To block harmful ultraviolet rays, the screen's outside may be coated with a UV coating. This is normally not necessary, though, as the majority of car windshields are made of laminated safety glass. The glass absorbs the majority of UV-B rays, while the PVB bonding layer is responsible for most UV-A and the remainder of UV-B absorption. In comparison to a car, a motorcycle's principal function is to shield the rider from the wind. When the rider gets the ideal aerodynamic configuration with his or her body cooperating with the vehicle, the windshield's principal function in sports and racing bikes is to reduce drag. When seated upright, it does not shield the rider from the wind. Various air speeds are utilized in conjunction with computational fluid dynamics (CFD) and fluid-solid interaction (FSI) methods to compare and evaluate fluid pressure, stress distribution, and deformation in wind shields for all 4 materials. In order to determine pressures during stress study, air speeds of 900, 800, 600, 555, and 400 km/hr were applied to the windshield during fluid analysis.

II. MATERIALS AND METHODS

A dynamic simulation was conducted using ANSYS, the Fluid-Solid-Interaction (FSI) method, and computational fluid dynamics (CFD) to assess fluid pressure, stress distribution, and windshield deformation at various air speeds. All three materials are subjected to analysis at varying air speeds of 900, 800, 600, and 400 km/hr. In the current experiment, backup materials such as polymethyl methacrylate and polyvinyl butyl for windshields were taken into consideration. A 3D model of the windscreen was produced with the use of Pro/Engineer software.

Table 1: ANSYS Parameters

Speed (km/hr)	Velocity (m/s)	materials
900	250	Glass, polymethyl methacrylate & Poly vinyl butyl
800	222.22	
600	166.66	
400	111.11	

"Fluid-structure interaction" (FSI) is a method for combining the laws controlling fluid dynamics and structural mechanics. The interaction of a deformable or moving structure with an internal or external fluid flow—which may be steady or oscillatory is what causes this phenomenon. A solid is put under pressures and strains that could deform it when a fluid flow interacts with a structure. Depending on the pressure, velocity, and material composition of the flow, these deformations can range from fairly big to very little. As long as the temporal fluctuations are also very gradual and modest, the behavior of the fluid won't be considerably impacted by the stresses that result from the deformations of the structure.

However, even minor structural deformations will cause pressure waves in the fluid if the time variations are rapid—greater than a few cycles per second. These pressure waves cause structures to shake, which creates sound. Instead of considering these problems as fluid-structure interactions, consider them as acoustic problems. A bi directionally coupled multi physics analysis is required to find a solution since the fluid's velocity and pressure fields will be altered by the structure's significant deformation. Fluid pressure affects structural deformations as well as the fields of flow and pressure.

III. RESULTS AND DISCUSSIONS

As seen in the fig.1 and 2, finite element analysis (FEA) represents an actual project as a "mesh" made up of a number of little, connected, regularly formed tetrahedrons. After which enormous arrays of simultaneous equations are built up and solved. The results are more precise as the mesh is finer, but more processing power is needed. The input parameters cannot be used directly in CFD. As a result, boundary conditions for air entry and air outflow must be established. right-click, create named section, input name, choose faces, and then click the air inlet right-click, create named section, input name, select faces, and then click the air outlet.

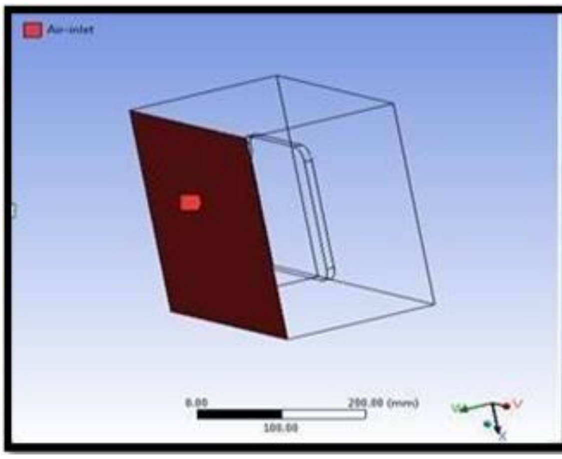


Figure 1: Air Inlet

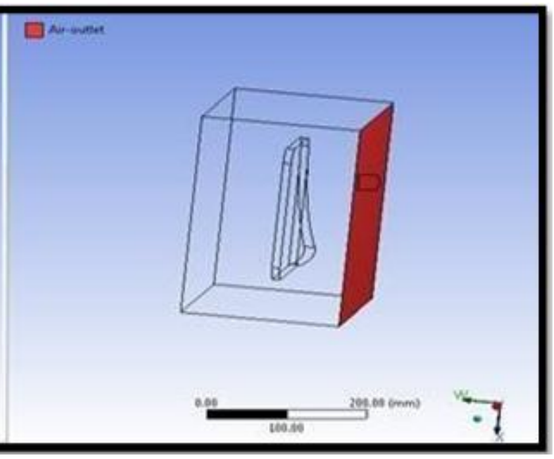


Figure 2: Air Outlet

Project update>model setup>edit model selection>energy equation (on)>ok Choose a fluid substance or specify parameters in Materials> Materials > new >create or update > OK. Choose a liquid. put the necessary inlet values after boundary conditions and inlet. Speed of the inlet air

Table 2: Boundary Conditions

Speed	Velocity
900 km/hr	250 m/s
800 km/hr	222 m/s
600 km/hr	166 m/s
400 km/hr	111 m/s

Temperature=313K and pressure=101325Pa

Hybrid Initialization > Solution Initialization > Done
Calculate; set the number of iterations to 100; calculate; and then click "OK"
Results>edit>select contours>ok>select a location (such as an outlet or a wall)>select pressure>apply

1. **Counter of Pressure:** The corners of the border of the intake are where static pressure is highest, and the boundary of the outflow is where static pressure is lowest, as seen by the contour map above. The maximum static pressure is 7.51e+02Pa, and the minimum static pressure is 3.75e+01Pa, according to the contour map above.

2. **Magnitude for Velocity:** According to the contour map above, the wind shield's maximum velocity magnitude is inside the border and its minimum velocity magnitude is outside. The contour figure above shows that the maximum velocity is 2.51e+02m/s and the minimum velocity is 1.28e+01m/s.

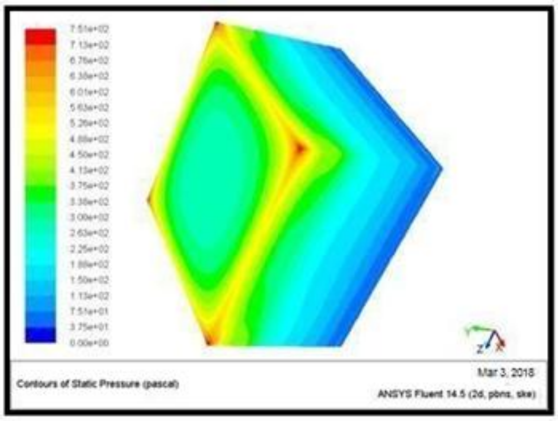


Figure 3: Pressure Counter

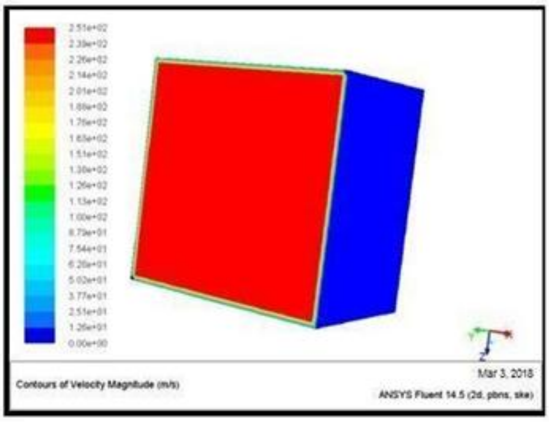


Figure 4: Velocity Magnitude

3. **Deformation:** This method produces the distortion of the wind shield caused by opposing air forces, which is necessary for the wind shield to operate precisely under difficult circumstances. It has been noted that the wind shield has significantly deformed. When the applied loads, namely velocity and pressure, are imported and placed on the wind shield, the maximum deformation value is 2.5173e-5. The wind shield's edge receives the highest stress value of 0.0082824MPa and the lowest stress value of 0.00012595MPa when the stresses of pressure and velocity are applied. The greatest strain value at one edge of the wind shield is 1.2947e-7, and the minimum strain is 2.7565e-9 when the stresses, such as pressure and velocity, are applied.

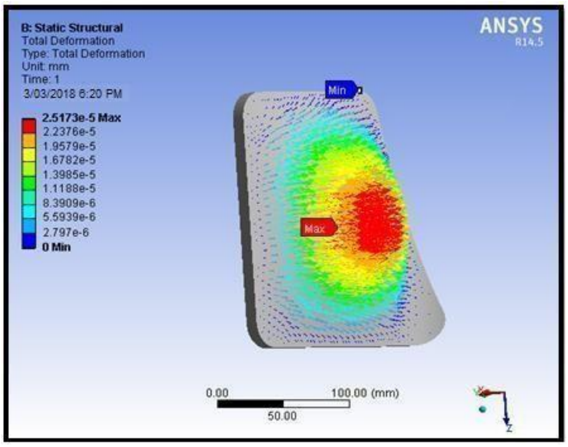


Figure 5: Deformation in Glass Material

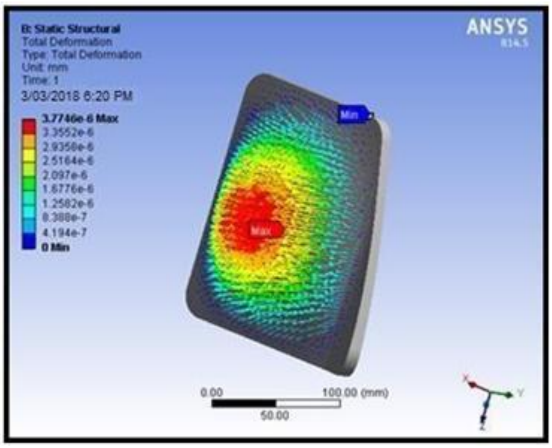


Figure 6: Deformation in Polymethyl Methacrylate (PMMA)

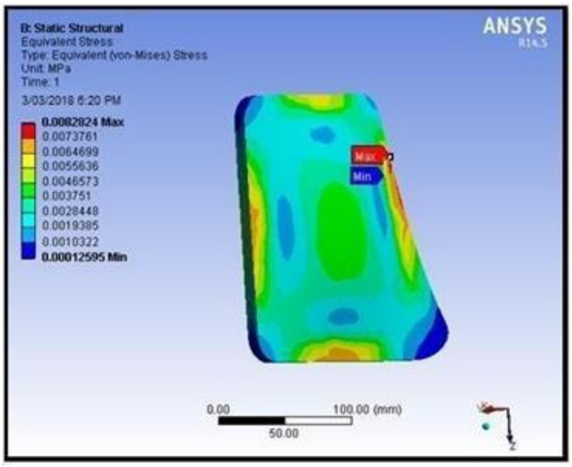


Figure 7: Maximum Stress

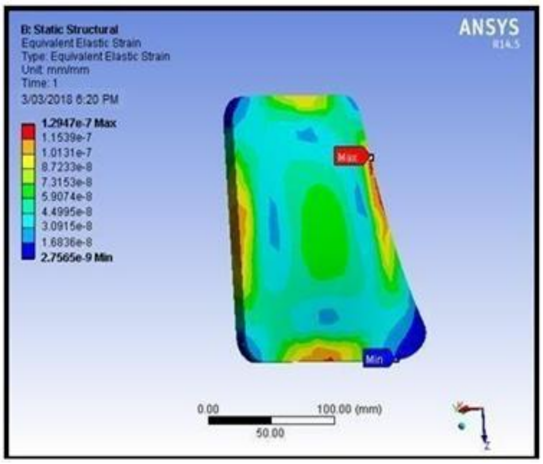


Figure 8: Maximum Strain

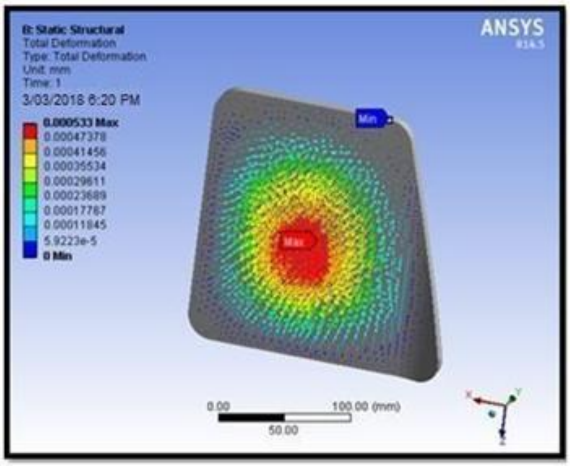


Figure 9: Deformation in Poly Vinyl Butyl material(PVB)

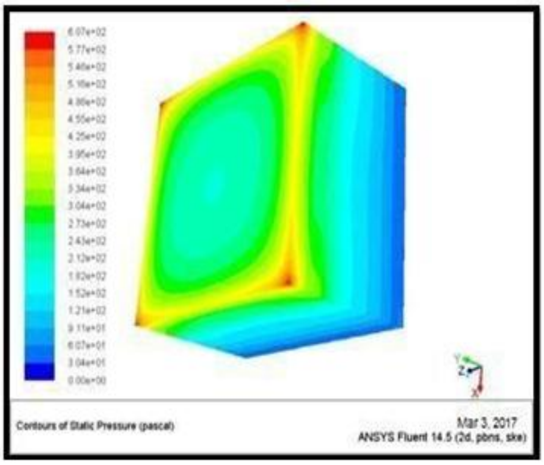


Figure 10: Pressure Contour

Table 3: CFD Result Table

Speed	Pressure	Velocity
900 km/hr	7.51e+02 pa	2.51e+02 m/s
800 km/hr	6.07e+02 pa	2.23e+02 m/s
600 km/hr	3.54e+02 pa	1.67e+02 m/s
400 km/hr	1.66e+02 pa	1.12e+02 m/s

Table 4: Structural Analysis Table with Stress and Strain Values

Speed km/hr	Material	Deformation Values in mm	Stress values	Strain values
900	Glass material	$2.5173e^{-5}$ mm	0.00828 mpa	$1.2947e^{-7}$ mpa
	PMMA	$3.7746e^{-6}$ mm	0.00820 mpa	$2.2197e^{-8}$ mpa
	PVB	0.000533 mm	0.00823 mpa	$3.1699e^{-6}$ mpa
800	Glass material	$2.0156e^{-5}$ mm	0.00665 mpa	$1.041e^{-7}$ mpa
	PMMA	$3.0223e^{-6}$ mm	0.00660 mpa	$1.7859e^{-8}$ mpa
	PVB	0.00042677 mm	0.00662 mpa	$2.5505e^{-6}$ mpa
600	Glass material	$1.1825e^{-5}$ mm	0.00391 mpa	$6.1193e^{-8}$ mpa
	PMMA	$1.7731e^{-6}$ mm	0.00388 mpa	$1.0498e^{-8}$ mpa
	PVB	0.00025038 mm	0.00389 mpa	$1.4993e^{-6}$ mpa
400	Glass material	$5.6415e^{-6}$ mm	0.00186 mpa	$2.9088e^{-8}$ mpa
	PMMA	$8.4594e^{-7}$ mm	0.001843mpa	$4.9874e^{-9}$ mpa
	PVB	0.00011945 mm	0.001849 mpa	$7.1224e^{-7}$ mpa

4. **Pressure Plot:** Figure 11 above depicts a plot between maximum pressure and velocity using the FSI technique. The graphic shows the fluctuation in the maximum static pressure. Speed increases result in a rise in maximum static pressure.

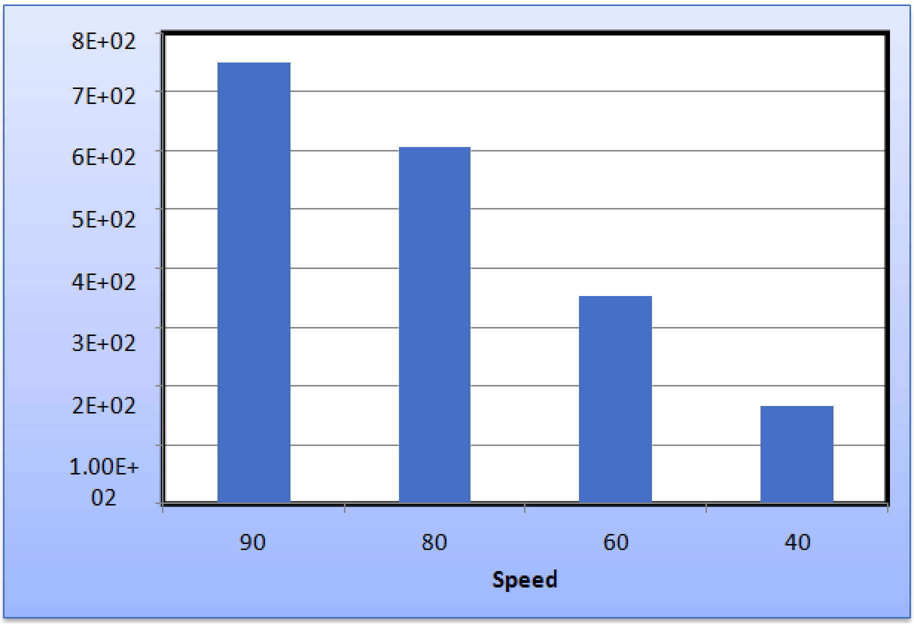


Figure 11: Pressure plots at various speeds (Pressure vs Speed)

5. **Velocity Plots:** The FSI approach is used to exhibit the relationship between maximum velocity and speeds in Figure 12. The graph displays the maximum velocity's variation. As speed increases, maximum velocity also rises.

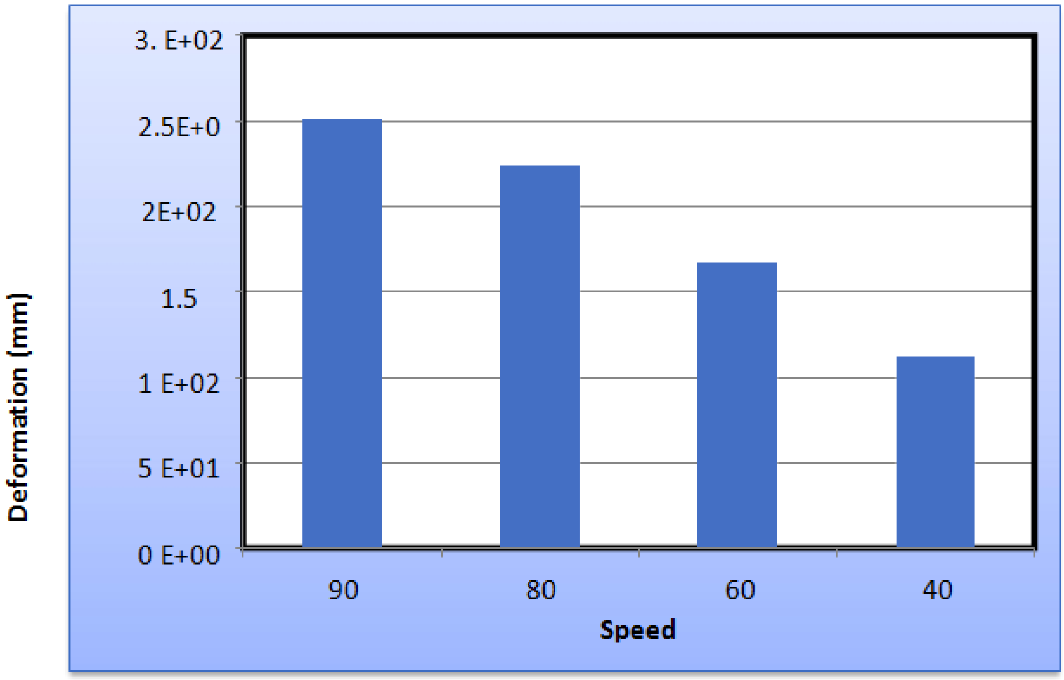


Figure 12: Velocity Plots (Velocity vs Speed)

IV. CONCLUSION

In order to assess fluid pressure, stress distribution, and deformation, a windscreen for a light trainer aircraft is examined in this work utilizing computational fluid dynamics (CFD) and a fluid-solid interaction (FSI) technique at various air speeds using ANSYS. The Pro-E Wildfire 5.0 software was used to create the windscreen's 3D model. Glass, poly methyl methacrylate, and poly vinyl butyl were the three materials that were taken into consideration to assess the deformation and stress at varied speeds of 900, 800, 600, and 400 km/hr. According to the CFD study's findings, pressure and velocity rise as air speed does. The CFD research shows that when speed increases, velocity likewise increases but pressure decreases. The static analysis shows that lowering the speeds lowers the stress values, and the varied pressure values are gathered through the CFD study. Compared to glass and poly vinyl butyl, poly methyl methacrylate material has a lower stress value. In light of this, we may say that poly methyl methacrylate is a better material for wind shields.

REFERENCES

[1] Ahmed mukhtar.,bojan,šekutkovski, sonjapetrović, aleksandarbojanić “windshielddesign for the light trainer aircraft”, accepted and published in International Journal of Recent Trends in Mechanical Engineering (IJRTME),Vol.3(2011) No 1, ISSN 1821-1259 ,pp. 61-64 , 28.03.2011
[2] Uzair Ahmed Dar, Weihong Zhang, YingjieXu “fe analysis of dynamic response of aircraft windshield against bird impact” accepted and published in International Journal of Aerospace Engineering (IJAE),Volume 2013 (2013), Article ID 171768,12 pages

[3] Wang Xinjun, FengZhenzhou, Wang Fusheng, YueZhufeng "Dynamic response analysis of bird strike on aircraft windshield based on damage-modified nonlinear visco elastic constitutive relation" accepted and published in ChineseJournal of Aeronautics (CJA),Volume 1 ,Issue 1 31 July 200
[4] Jun Wang, Yingjie Xu, Weihong Zhang, Finite element simulation of PMMA aircraft windshield against bird strike by using a rate and temperature dependent nonlinear viscoelastic constitutive model, Composite Structures, Volume 108, February 2014, Pages 21-30.
[5] G. Mallikarjuna , B. Anjaneyulu , K. Kiran Kumar Rao , Sandya Rani Borukati, Design and Analysis of Aircraft Windshield by Using FSI Technique, International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 5 Issue I, January 2017.
[6] Arun Patil, Design and Analysis of Alternative Material for Bird Strike on Aircraft Windshield, Technological Engineering XV(2):5-10,2019.
[7] Ahmed Uzair, Jun Wang, Ying Jie Xu, Wei Hong Zhang, High-Speed Bird Impact Analysis of Aircraft Windshield by Using a Nonlinear Viscoelastic Model , Applied Mechanics and Materials (Volume 290), 85-90,2013.
[8] Wang Xinjun, Feng Zhenzhou, Wang Fusheng, Yue Zhufeng, Dynamic Response Analysis of Bird Strike on Aircraft Windshield Based on Damage-modified Nonlinear Viscoelastic Constitutive Relation, Chinese Journal of Aeronautics 20(2007) 511-517.
[9] Arijeet Nath, Raunika Anand, Jeet Desai, M.T.H. Sultan and S. Aravind Raj, Modelling and Finite Element Analysis of an Aircraft Wing using Composite Laminates, *IOP Conf. Ser.: Mater. Sci. Eng.* 1183 (2021) 012006.

BALANCING AUTOMATION AND HUMAN EXPERTISE: A CRITICAL EXAMINATION OF THE NEED FOR HUMAN INTERVENTION IN THE AUTOMATION SECTOR

Abstract

The Automation sector has made remarkable strides in recent years, transforming industries and streamlining processes through the adoption of advanced technologies such as Artificial Intelligence (AI), Robotics, and Internet of Things (IoT). While these advancements promise unprecedented levels of efficiency and productivity, they have also sparked discussions surrounding the essential role of human intervention in automation systems. While automation systems excel in repetitive, rule-based tasks, there remain critical aspects of decision-making, adaptability, creativity, and ethical judgment that demand human expertise. The chapter delves into specific areas within the automation sector, such as manufacturing, healthcare, and transportation, to highlight instances where human intervention is indispensable. It examines scenarios where human judgment is irreplaceable, such as complex problem-solving, handling unexpected situations, ensuring ethical considerations, and maintaining quality control.

Moreover, the emphasizes the ongoing evolution of human roles in automated environments, from machine operators to system supervisors and decision-makers. The concept of "human in the loop" or "human on the loop" is explored, where humans work alongside automated systems to complement and enhance their capabilities. The importance of striking a delicate balance between automation and human intervention, acknowledging that the synergy of both can lead to safer, more

Authors

Govindarajulu Eedara
Assistant Professor
Vignan’s Foundation for Science
Technology and Research
Andhra Pradesh, India
govind305@gmail.com

A Sindhuja
Student
Vignan’s Foundation for Science
Technology and Research
Andhra Pradesh, India
sindhu19.nani@gmail.com

Y Manjunath Reddy
Student
Vignan’s Foundation for Science
Technology and Research
Andhra Pradesh, India
reddymanjunath959@gmail.com

R. S. S Bhargav
Student
Vignan’s Foundation for Science
Technology and Research
Andhra Pradesh, India
bhargavravinutala03@gmail.com

efficient, and more ethical operations across various sectors. As industries continue to embrace automation technologies, understanding the nuanced relationship between humans and machines becomes pivotal for ensuring success, innovation, and long-term sustainability.

This will serve as a precursor to an in-depth exploration of the need for human intervention in the automation sector. It sets the stage for a comprehensive examination of how the workforce is evolving in response to automation, and how industries can harness the unique strengths of both humans and machines to achieve unprecedented levels of efficiency, productivity, and ethical responsibility.

Keywords: Artificial Intelligence (AI), IOT, Automation Technologies, Human-Machine Relationship, Decision-Making.

I. INTRODUCTION

The automation sector has ushered in a new era of technological advancement, promising unparalleled levels of efficiency, precision, and productivity across industries. With the rapid integration of cutting-edge technologies such as Artificial Intelligence (AI), Robotics, and the Internet of Things (IoT), automation has not only transformed the way we work but has also redefined the boundaries of what is achievable. Yet, amid this wave of automation-driven progress, a critical question emerges: what is the role of human intervention in this increasingly automated landscape**.**

Automation systems, known for their unwavering accuracy and tireless operation, excel in executing repetitive, rule-based tasks with remarkable consistency. They promise to eliminate errors, optimize processes, and drive down operational costs. However, in this journey towards full automation, it has become evident that there are dimensions of work that extend beyond the capabilities of machines.

This exploration delves into the pressing need for human intervention in the automation sector. It recognizes that while automation can handle routine operations effectively, there are facets of human judgment, creativity, adaptability, and ethical reasoning that are indispensable. These attributes come to the forefront in scenarios requiring complex problem-solving, addressing unexpected situations, ensuring ethical considerations, and maintaining stringent quality control.

This chapter extends its focus to diverse areas within the automation sector, ranging from the manufacturing floor, where precision meets innovation, to the healthcare realm, where patient care demands compassion and clinical expertise, and to the transportation industry, where safety and decision-making in dynamic environments are paramount.

Moreover, this exploration underlines the dynamic shift in the roles of human workers within automated environments. It acknowledges the transition from traditional machine operators to system supervisors and decision-makers. The concept of "human in the loop" and "human on the loop" is explored, highlighting scenarios where humans work alongside automated systems, complementing and enhancing their capabilities.

In the broader context, this research underscores the imperative of achieving a delicate balance between automation and human intervention. It asserts that the synergy of both elements can lead to safer, more efficient, and ethically responsible operations across a multitude of sectors. As industries continue their rapid adoption of automation technologies, understanding the intricate relationship between humans and machines becomes pivotal for ensuring success, fostering innovation, and securing long-term sustainability.

This introduction lays the foundation for a comprehensive exploration of the necessity for human intervention in the automation sector. It sets the stage for an in-depth analysis of how the workforce is evolving in response to automation and how industries can harness the unique strengths of both humans and machines to attain unprecedented levels of efficiency, productivity, and ethical responsibility in this transformative era.

II. THE IMPACT OF AUTOMATION ON THE WORKFORCE

As automation is providing many changes and increasing its quality but it also brings change in the work force:

1. **Job Displacement and Transformation:** One of the primary concerns surrounding automation is the ability displacement of sure jobs. Some jobs like repetitive tasks, scheduled tasks etc. can be replaced by the automated machines which may cause the laying of and displacing of jobs.

2. **Skill Shift:** As most of the physical work can be done through automated machines, the manual labor work can be neglected and the new works like programmer, system designer, monitoring works etc. came into picture.

3. **Human-Machine Collaboration:** Automation doesn't mean to entire alternative of human employees. Collaborative robots (cobots) and human-robotic organizations demonstrate a shift toward human-system collaboration. Jobs like judgment, creativity, complex problem-fixing, and emotional intelligence stay crucial and cannot be without problems automatic.

4. **Changing Work Environments:** Automation causes place of work dynamics by way of changing how work is organized. Remote work, flexible hours, and telecommuting grow to be extra possible as automation reduces the need for physical presence in certain duties.

5. **Ethical Considerations:** Automated machines cannot do critical thinking they don't know the right path so to consider which may leads to wrong outputs. So, to take ethics into consideration human intervention is needed.

6. **Training and Education:** Although the automated machines can do the work, but they need some preliminary training. To teach them human presence is needed, which we term it as "Machine learning".

7. **Exception Handling:** Automatic systems may additionally encounter unforeseen situations that require human intervention. Human workers are answerable for identifying anomalies, making decisions, and implementing corrective moves when the automated system deviates from the norm.

III. NEED OF HUMAN WORK IN AUTOMATION

1. **System design and programming:** Although Automated Machines work on their own. Humans are required for designing, programming, and configuring the automation system. Humans are only responsible for training the machines to do their work.

2. **Monitoring and Supervision:** *A*utomatic systems often require human operators to display their performance, make certain that duties are executed effectively, and intrude if any problems stand up. Human oversight guarantees that the automation system is jogging easily and that any anomalies are addressed directly.

3. **Maintenance and Repair:** Automated equipment and structures require regular upkeep to make certain of their right functioning. Human technicians are chargeable for analyzing, diagnosing, and repairing any mechanical or technical problems that can arise. in addition, they perform preventive upkeep to prevent unexpected downtime.

4. **Problem-Solving:** Despite the advancements in AI and automation, complex problems often require human problem-solving skills. If any unexpected situation occurs the AI was unable to take the decision where humans can solve it

5. **Continuous Improvement:** Humans plays a major role in improving the existing machine if we need to improve the automation machine human critical thinking is required.The data refinig by the humans can enhance the automation.

6. **Ethical Considerations:** Automated machines cannot do critical thinking they don’t know the right path so to consider which may leads to wrong outputs. So, to take ethics into consideration human intervention is needed.

7. **Training and Education:** Although the automated machines can do the work, but they need some preliminary training. To teach them human presence is needed, which we term it as “Machine learning”.

8. **Exception Handling:** Automatic systems may additionally encounter unforeseen situations that require human intervention. Human workers are answerable for identifying anomalies, making decisions, and implementing corrective moves when the automated system deviates from the norm.

9. **Adaptation to Change:** Automation can cause modifications in job roles and obligations. Human people want to adapt to new duties, discover ways to engage with automatic structures, and collect capabilities relevant to the evolving work surroundings.

10. **Crisis Management:** If the company gets any unexpected crisis the humans have the ability to take charge on decision – making and manage the crisis time. They manage contingencies and rapidly evolving conditions that may not be inside the scope of automated responses.

11. **Human Oversight:** Automatic systems may on occasion fail or come across conditions they are no longer programmed to handle. Human oversight is vital to step in all through critical moments, stopping mistakes and ensuring safety.

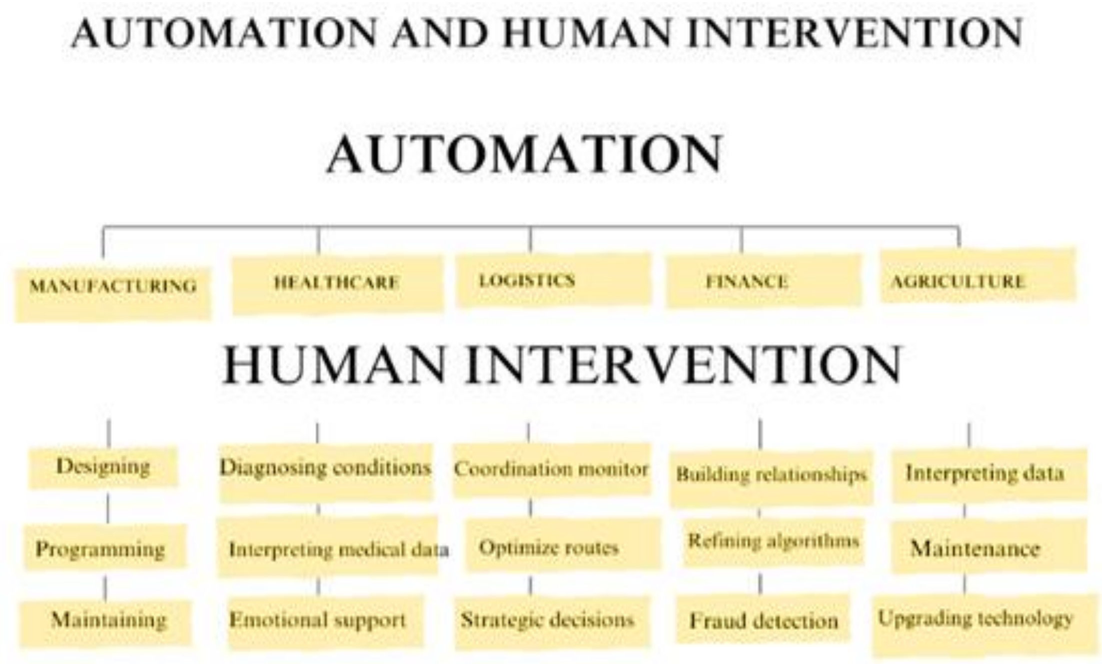


Figure 1: Represents the Automation functioning and the involvement of Human in the task

IV. CASE STUDY

Let's consider some case studies to understand it in more detail. We have considered HRC (Human Robot Collaboration) to show the need of Humans while working with autonomous things.

HRC in Automotive Industry: Automotive is the largest industrial sector in the world. Considering the UK only, 3.7 million employees are working in the automotive sector and the economical contribution of the UK economy is about $26 billion [1]. In the automotive industry, assembly cells are playing an important role where 83% of production units involve. assembly tasks [2]. However, some manual operations are still needing more flexibility and robustness to be performed efficiently; thus, relying on the industrial robot to perform these tasks alone may not be a practical solution as human abilities can't be fully replaced [3]. Therefore, the focus is to combine both abilities of humans and robots to work in collaboration while safety is assured to prevent any accident during the work [4]. From [5], in the assembly stage, the collaborative robot is responsible for the screwing task through the sensing integration with a human operator who will be able to share the work area and task. Also, installing the vision system is allowing the collaborative robot to collect information about the working environment and the human intentions that will be used for further improvements such as path planning and human movement predictions. As a result, the implementation of the HRC system is showing the needed capacity to perform complex tasks.

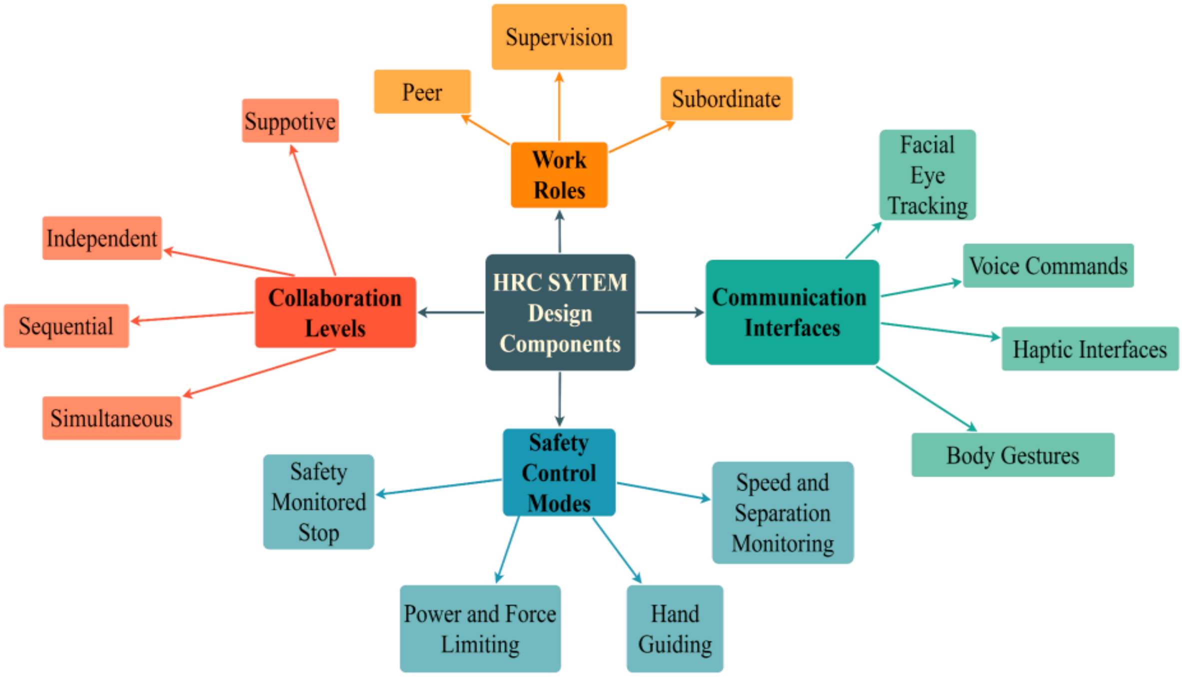


Figure 2: Describing the Human Robot Collaboration [6]

V. CONCLUSION

Automation, undoubtedly, enhances efficiency and streamlines repetitive tasks, but it cannot entirely supplant human intervention. The automation process cannot entirely takeover any industrial process, if any issues and any new technology has to be done it will only be possible by humans. Human intervention is much more important in the automation process. Human intervention is not just important; it is paramount in the realm of automation. Even within a fully automated company, human presence is indispensable. This is because automation processes are inherently devoid of human emotions, and emotions often play a critical role in decision-making and interpersonal interactions.

Furthermore, the depth of human intelligence far surpasses that of any machine. In scenarios where tasks or processes require a level of intelligence beyond what machines can provide, it is irrefutable that humans must step in. In essence, the synergy between automation and human expertise is not merely a choice but a necessity. It is the fusion of automation's precision and human ingenuity, emotions, and intelligence that paves the way for progress and innovation in modern industries. This harmonious collaboration between machines and humans ensures that the potential of both is fully harnessed to address the challenges and opportunities of the future.

REFERENCES

[1] Wang, S.M., Liu, Y.L. and Kang, Y., 2002. An efficient error compensation system for CNC multi-axis machines. International Journal of Machine Tools and Manufacture, 42(11), pp.1235-1245.
[2] Wang, S.M., Liu, Y.L. and Kang, Y., 2002. An efficient error compensation system for CNC multi-axis machines. International Journal of Machine Tools and Manufacture, 42(11), pp.1235-1245.
[3] Mei, B., Wang, H. and Zhu, W., 2021. Pose and shape error control in automated machining of fastener holes for composite/metal wing-box assembly. Journal of Manufacturing Processes, 66, pp.101-114.

[4] Callegari, M., Amodio, D., Ceretti, E. and Giardini, C., 2006. Sheet incremental forming: advantages of robotised cells vs. CNC machines. In Industrial Robotics: Programming, Simulation and Applications. IntechOpen.
[5] Vichare, P., Nassehi, A., Kumar, S. and Newman, S.T., 2009. A Unified Manufacturing Resource Model for representing CNC machining systems. Robotics and Computer-Integrated Manufacturing, 25(6), pp.999-1007.
[6] Lyu, D., Liu, Q., Liu, H. and Zhao, W., 2020. Dynamic error of CNC machine tools: a state-of-the-art review. The International Journal of Advanced Manufacturing Technology, 106, pp.1869-1891.
[7] Zhu, S., Ding, G., Qin, S., Lei, J., Zhuang, L. and Yan, K., 2012. Integrated geometric error modeling, identification and compensation of CNC machine tools. International journal of machine tools and manufacture, 52(1), pp.24-29.
[8] Czwartosz, R. and Jedrzejewski, J., 2022. Application of machine learning in the precise and cost-effective self-compensation of the thermal errors of CNC machine tools–a review. Journal of Machine Engineering, 22(3).

PART 4

Futuristic Trends in Mechanical Engineering

Series Id: IIPV3EBS01_G27

Series Editors

Dr.S.Balamurugan
Ph.D Professor And Head
Mechanical Engineering
Mahendra College of Engineering
Attur Main Road, Minnampalli
Salem- 636106, Tamilnadu

Dr.Sivasankara Raju R
Associate Professor
Department of Mechanical Engineering
Aditya Institute of Technology and Management
K.Kotturu Tekkali-532201 Andhra Pradesh,India.

Prof. Soumya Ranjan Giri
Principal
Zenith Institute of Science And Technology
NH-16, Pitapalli, Khordha
Odisha, India.

Kanahaiya Lal Ambashtha
Assistant Professor
Faculty of Information Technology
Gopal Narayan Singh University
Sasaram, Bihar, India

MODELING, ANALYSIS AND FABRICATION OF HOTEL SERVICING ROBOT

Abstract

The research intends to provide a framework for long-term growth in the hospitality sector, which is now experiencing a severe scarcity of workers. The study establishes causal links between the features of a serving robot, customer satisfaction, risk aversion, perceived value, and the likelihood of a return visit. Furthermore, it is crucial that contentment has a positive impact. Several significant theoretical and practical implications that can contribute to the sustainability of restaurants are offered in light of these findings. Rapid developments in AI, smart sensors, big data analytics, and robotics have led to their widespread use in the service industry, where they are used to perform a variety of activities. The main goal of putting robots to work has been to increase output, but the COVID-19 pandemic has made a more urgent goal: providing contactless services to keep people from being alone. Data from actual hotel guests is used in this investigation of how well robots can serve customers. The objective of this project is to build a robot waitress capable of taking and fulfilling guest orders in a hotel.

Keywords: Serving Robots, Workforce Scarcity, Risk Aversion, Perceived Value, Sustainability, AI and Robotics, Contactless Services, Emerging Technologies, CATIA, ANSYS

Authors

Dr V Hari Kiran
Associate Professor
Avanthi Institute of Engineering and Technology, Makavarapalem, Anakapalle District, Andhra Pradesh, India
harikiran3285@gmail.com

Dr Sivasankara Raju Rallabandi
Associate Professor
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali, Andhra Pradesh, India

A N S Surya Prakash
Assistant Professor
Avanthi Institute of Engineering and Technology, Makavarapalem, Anakapalle District, Andhra Pradesh, India

N V Ashok Kumar
Assistant Professor
Avanthi Institute of Engineering and Technology, Makavarapalem, Anakapalle District, Andhra Pradesh, India

S Rishikesh
Assistant Professor
Avanthi Institute of Engineering and Technology, Makavarapalem, Anakapalle District, Andhra Pradesh, India

Corresponding Author
harikiran3285@gmail.com
sivaraju80@gmail.com

I. INTRODUCTION

Humans have always been the ones to supply services in the past. Smart robots are progressively taking the place of employees in the provision of contactless services as a result of the introduction of advanced digital technologies, particularly artificial intelligence (AI) and Internet of Things (IoT), as well as the present pandemic crisis. For instance, intelligent robots have been used at a few hotels, shops, airports, and meal delivery services[1, 2]. Service robots can make it easier for first responders to do their jobs in hospitals without exposing them to viruses. They can also do things for people so they don't have to be alone and do delicate remedies that not medical professionals have the skills or energy to do[3].

In a variety of capacities, including memory, computing power, physical strength, and the ability to perform unpleasant or dangerous tasks, service robots have progressively surpassed human care providers. Although their employment has skyrocketed during the current pandemic, modern service robots are most efficient and widely deployed at the first two levels of intelligence since they are still incapable of performing at the two highest order intelligence. To choose the optimal approach for building and integrating service robots in customer support procedures, businesses must be aware of the advantages and disadvantages of currently available service robots[4, 5].

To investigate customer service performance Robot employed real-world discoveries of expected to contribute to the service robot and offer beneficial new information to service organisations in their strategies to successfully deploy service robots for a great customer experience. For their algorithm, Prejitha et al. [6] used sensors like LDR, LED, and sensors resistance and voltage divider setup. They created a straightforward, inexpensive line-following robot without the use of a microcontroller. Robots for taking orders and delivering meals to tables were being developed by Eksiri et al. [7]. Their robot was modelled after the ABU Robocon competition. One robot is used for ordering, and the other one serves the food. They have utilised two different robots. In order to greet people, they added sounds to their line-following technique. People stopped the robot for selfies because of its lifelike shape, and they included an emergency pause option for this purpose.

The concept of an E restaurant, where food is served by robots, was put forth by Kaushal et al[8]. They put forth a suggestion for how using robots could cut down on the cost of hiring waiters. They clarified that this robot can fulfil one or more orders in a single cycle. Additionally, they have leveraged the concept of a line follower to create a distributed Sensing and Control Framework for Mobile Robot on a local server and website (XAMPP). This actually completes a task on this system and is related to mechanical and aerospace engineering. Transporting a package from a pickup site to a drop-off location is the project's main task. A wheeled mobile robot (WMR) that acts as a lifting device and has a gripper structure in front of it completes the bundle transportation. Pushing a button on the station's floor completes the package accessibility at the pickup station. At the drop-off location, a second push catch has been set up to verify that the bundle was delivered successfully.

Figure 1: Portable Robot Servicing in Hotel

Evidence from Bicci and Kumar Robots using vacuum grippers can pick up packages of goods or objects with ease[8]. As may be seen in Figure 1, vacuum cups (also known as suction cups) are used as the mechanism for grabbing. If the things are smooth, flat, clean, and stored in cartoons, this form of grippers will offer good handling. It just has one surface that can be used to hold stuff. It might not be appropriate for handling the nearby objects that are porous.

II. MODELING

1. **3D Modeling:** Catia V5 has a number of tools for creating a complete digital depiction of the object being designed [9, 10]. The general geometry tools can also build industrial and standard pipe geometry and entire wiring descriptions. Collaborative development tools are also accessible. Several concept design tools can be used to generate initial ideas for Industrial Design, which can later be implemented during the product's engineering phase[11, 12]. Industrial design sketches, point cloud data for reverse engineering, and full-featured freeform surface tools are just a few examples. Figures 2–5 depict the Hotel Servicing Robot's 3D model with all the drawing elements presented, and Figure 6 shows the robot system assembled.

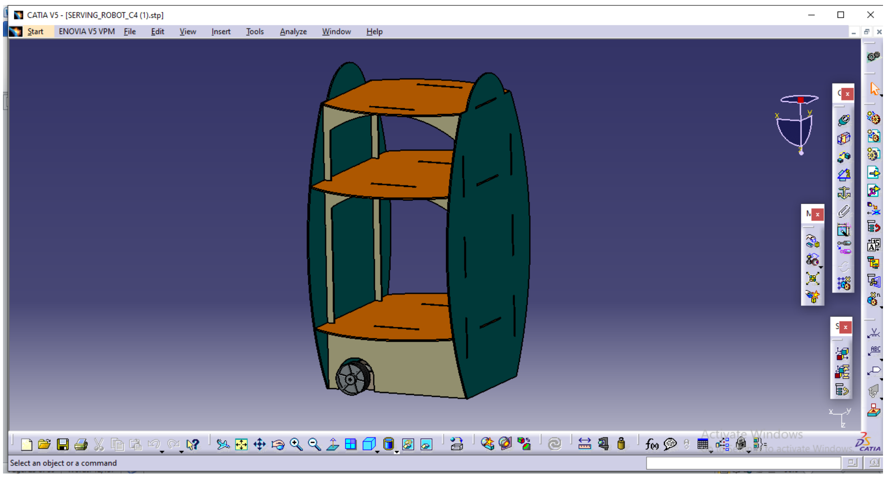


Figure 2: Indicative 3D Design

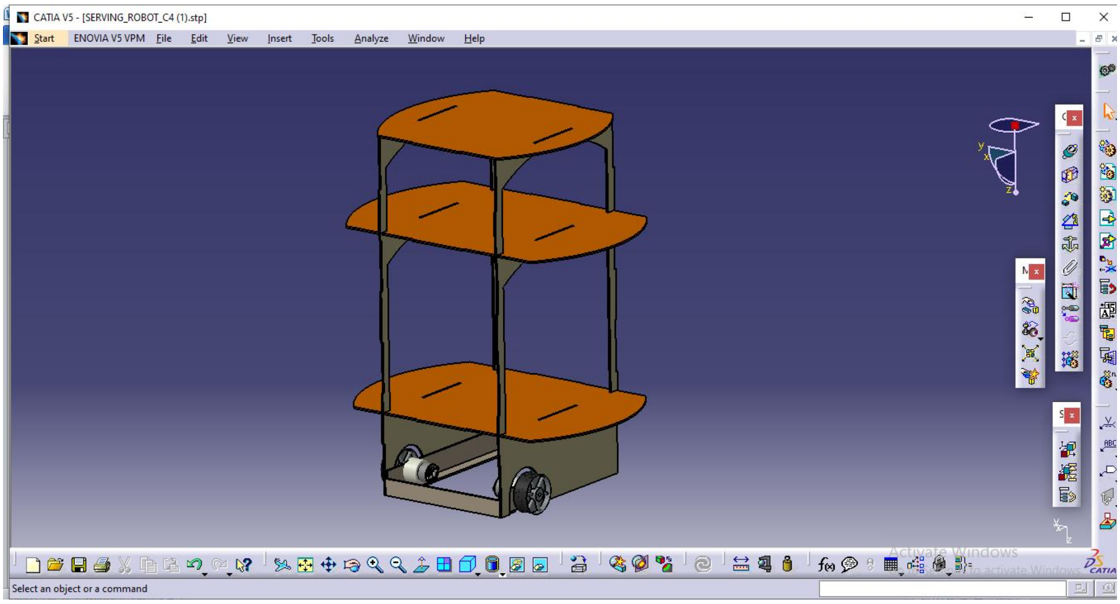


Figure 3: Frame Structure

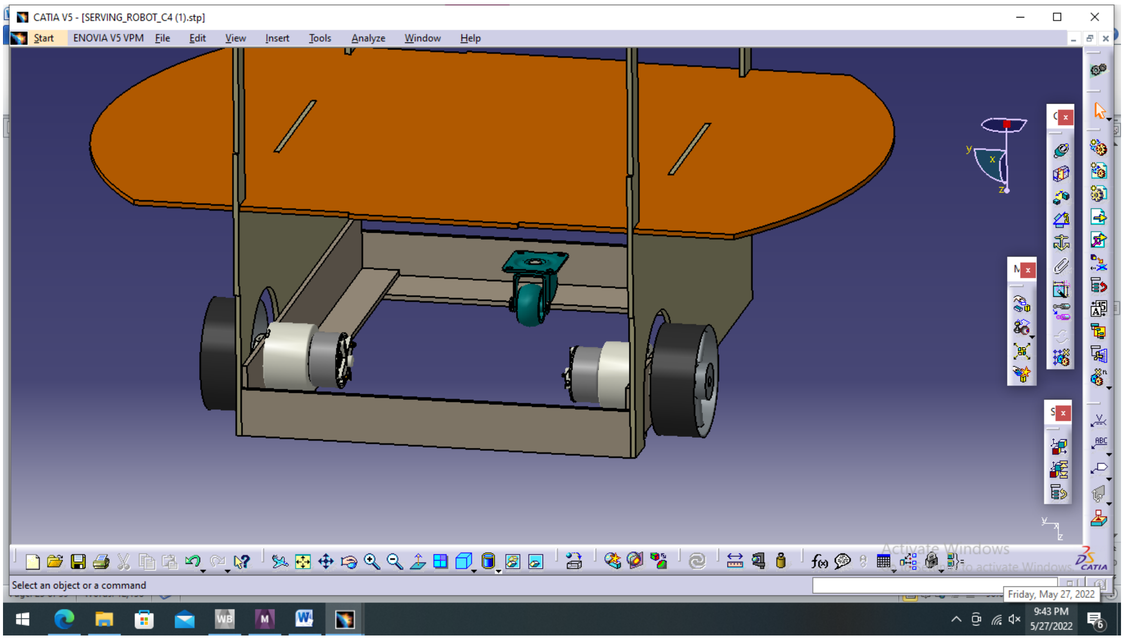


Figure 4: Wheels Assembly

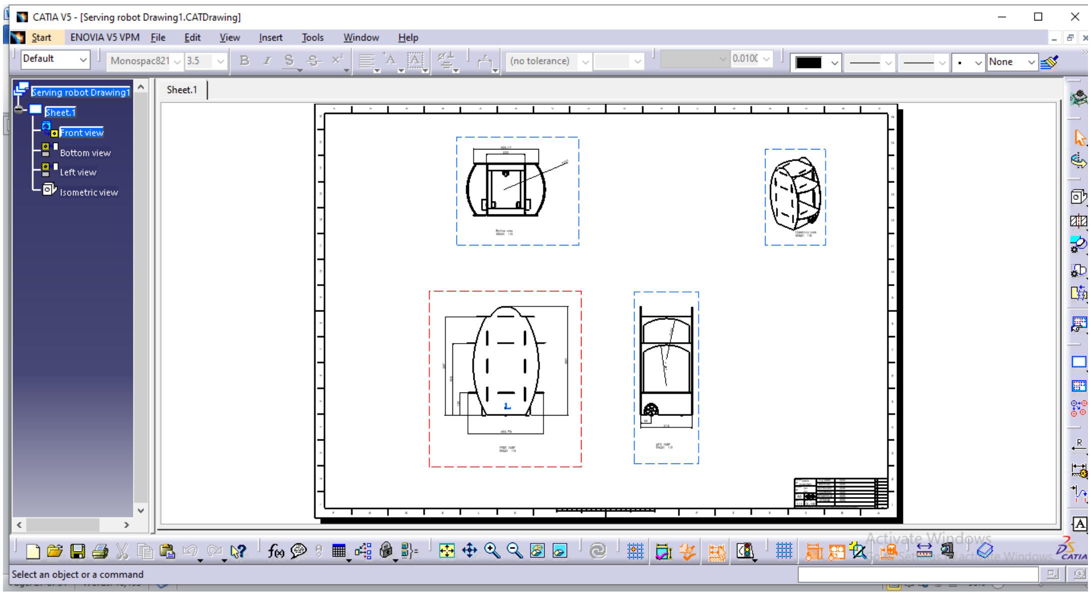


Figure 5: Assembly Drawing

2. **Analysis:** ANSYS has evolved into a powerful design analysis tool, recognised around the world for its many useful capabilities. The updated software is both straightforward and potent in its capabilities. The program's flexibility, usefulness, and speed are all enhanced with each subsequent release. Ansys assists engineers in this way to meet the expectations and challenges of the contemporary product development environment [9, 13, 14]. The robot structure is depicted in the photographs below.

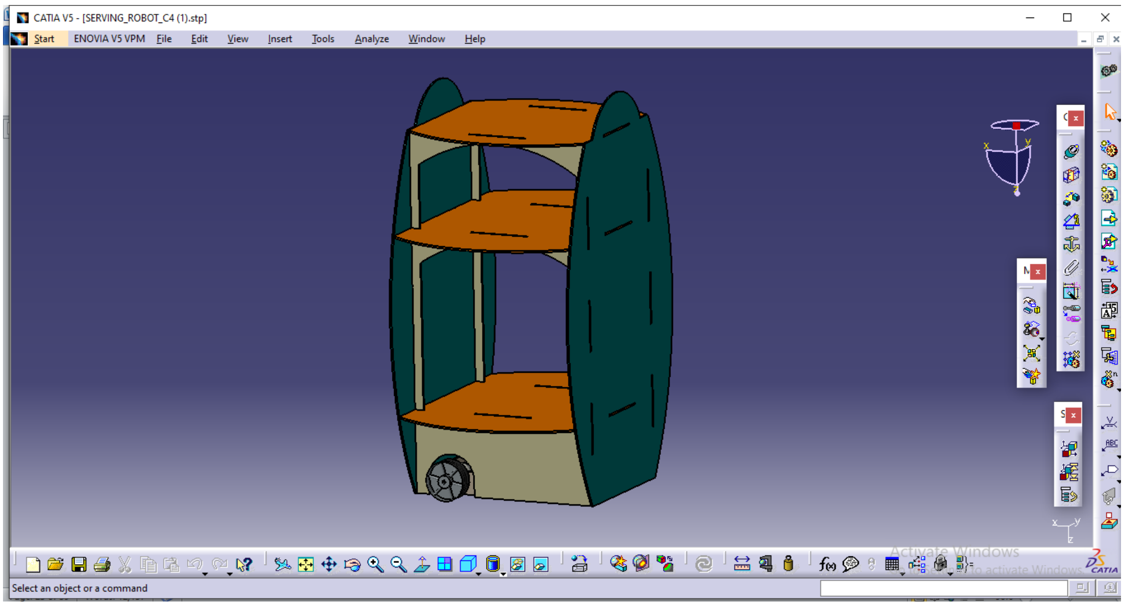


Figure 6: Assembly

The various parts considered for assembly are:

- DC Geared motors 100 RPM 2
- Caster wheel ½ inch

- 70mm dia wheels
- Aluminum channels
- Acrylic sheets
- Arduino UNO – controller
- Motor Driver L2 98D
- SR08 line following sensor
- 12V & 5V regulator 2 amps.
- 4 Channel remote
- DC jacks

The entire robot is designed in such a way that it is compatible so that it can move freely in the restaurant. The electronic parts include sensors, speakers, buzzer, battery and motors. Considering the situations and demand of contact less delivery the design has been made[15]. Unlike regular humanoid restaurant robot this design is unique and serves better for the purpose. It has more space for the food and also can accommodate well and is handy. Industrial aluminum is chosen for the Base frame because it has the strength to carry the load and the finish of it will be an added advantage.

3. **Working:** Food is delivered to the table by the robot from the kitchen. The robot navigates by using a technique called line following with the aid of infrared sensors. The robot will halt if any obstructions are in its path thanks to its ultrasonic sensors. The robot has a keypad built inside it so it will know whose table to serve. Each table will have a QR code that can be scanned to be taken to the app store, where orders for meals will be placed via an app. When food is requested, the order is immediately sent with the table number to the kitchen screen. The robot is initially positioned (on the line) close to the kitchen. The chef can load the prepared food into the delivery robot when it is ready and choose the appropriate table number on the keypad. The robot will start moving along the line towards the table. The ultrasonic sensors will detect any obstructions in the path and halt the robot if necessary. A piezo-buzzer will also inform the user to move or move the obstruction when it detects the impediment. For easy operation, the robot already has the instructions for the table coded in. The underlying ideology's flowchart is depicted in Figure 7.

Figure 7: Flow chart of basic ideology of working

- **DC Geared motors 100 RPM:** Several applications for robotics, involving all-terrain vehicles, can utilize this 12 Volt DC Motor - 100 RPM. These motors include a 3 mm threaded drill hole in the center of their shafts for easy attachment to wheels in addition[4]. These direct current (DC) motors are basic in design and have shaft-mounted gear for optimal performance. These DC-geared motors are known as "center shaft" models because the shaft runs through the gearbox's center. A straight expansion over the straightforward DC motors in Figure 9, Figure 8 shows the exterior design of a DC geared motor.

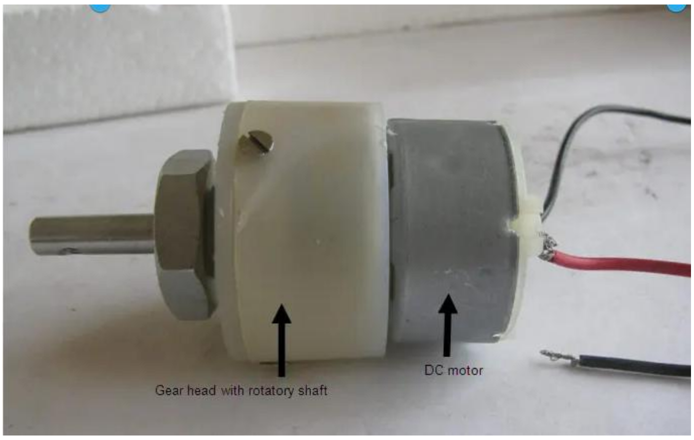


Figure 8: External Structure DC Motor

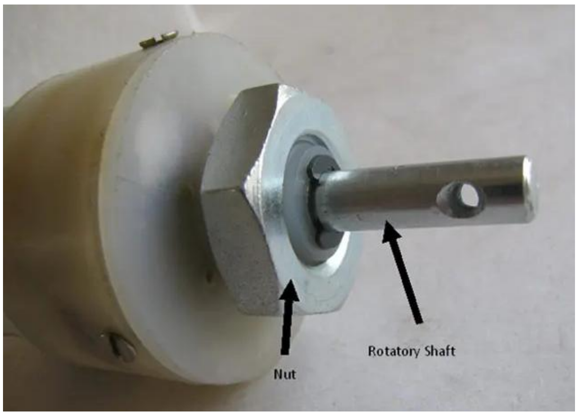


Figure 9: Lateral View DC Motor

- **The DC Geared Motor's Operation:** The DC motor operates over a respectable voltage range. The motor's RPM (rotations per minute) increases with input voltage. For instance, if the motor's operating voltage range is between 6 and 12, its RPM will be lowest at 6 V and highest at 12 V.

RPM = K1 * V, where K1 is the induced voltage constant and V is the applied voltage, can be written as a voltage equation.

In all DC motors, the relationship between RPM and torque is anti-clockwise. Therefore, a lower RPM might be expected from a higher torque gear, and vice versa. Geared DC motors use the concept of pulse width modulation. The smaller duplex component is turned more thoroughly by the larger gear. The smaller duplex portion transfers the torque from the bigger portion of the previous gear, but not the speed. The duplex portion of the third gear contains more teeth than the other parts, which allows it to transmit more torque to the gear that is attached to the shaft.

- **Caster wheel ½ inch**

Figure 10: Caster Wheel

Carts, racks, dollies, and other equipment are simple to move thanks to casters (see Figure 10). Another way to describe it is as a wheel-like, circular cylinder with a variable width that rotates on an axle. There are numerous mechanical uses for the wheel. A wheel is present on a caster. However, it is not just a wheel. It is an assembly that consists of a wheel and a bracket for it. This bracket, which is sometimes referred to as a "fork" or "yoke," is what distinguishes it from a typical wheel.

- **Aluminum Extrusions:** Extrusion is a manufacturing process that produces things with a consistent cross-sectional profile by forcing substances via a die with the correct cross-section[16, 17]. Advantages over traditional manufacturing methods include the ability to create intricate cross-sections and the flexibility to work with brittle materials via solely compressive and shear forces. Figure 11 shows that it also makes great surface finishes and gives designers a lot of freedom When it comes to shapes.

Figure 11: Slotted Extrusion

- **Arduino Uno – micro controller:** Microcontrollers like the Arduino UNO, which employs the ATmega328, are popular for use in electronics projects at the basic level. There are 14 digital I/O pins and 6 analogue I/O pins on the board, as well as an ICSP header, power jack, USB connector, reset button, and other components. A USB cable or the board's onboard DC power source can be used to power the charging process. The design of the board utilised by the novice in their work undergoes routine innovation and problem fixes[2, 18]. The Arduino UNO board, shown in Figure 12, has a list of hardware components for motor control, bluetooth, the internet, and other functions, and it can communicate with those devices. The Arduino UNO is a particular sort of Arduino device that is mostly utilised by novices in electronics projects and circuit design. The board is acceptable for usage and chosen over other Arduino devices because of a number of advantages. The user's requirements determine which Arduino products are best, although the Arduino UNO is a standard board when compared to other Arduino products[19].

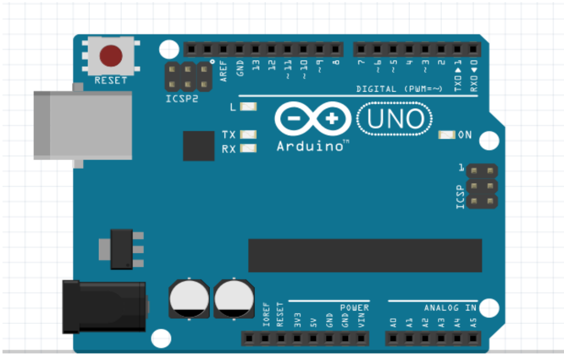


Figure 12: Arduino UNO

- **Voltage regulator:** A voltage regulator is designed to automatically regulate voltage levels. In essence, it regulates the supply voltage by lowering the source voltage to an acceptable level. This ensures the voltage won't dip under load. Electronic voltage regulators rely on the zener diode, an operational diode with a reverse breakdown voltage, as a stable voltage reference source[20, 21]. Voltage regulators are typically employed wherever there is a need to keep the dc output voltage stable. It also reduces the voltage ripple in ac current that the filter can't eliminate. A good voltage regulator may also have safety circuits that protect against short circuits, too much power, heat, and too much voltage.

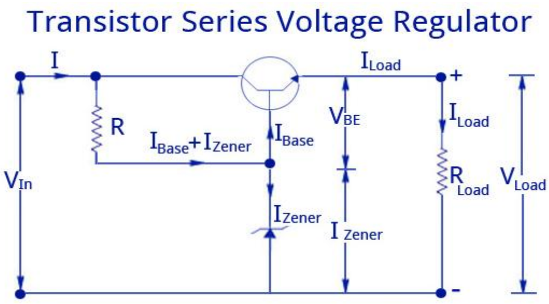


Figure 13: Voltage Regulator Circuit

As shown in Figure 13, the filtered rectifier output is passed to the input terminals, where it is used to provide a regulated output voltage Vload across the load resistor Rload. The zener diode provides the reference voltage, and the transistor works as a variable resistor. The resistance of the transistor changes depending on how the base current, Ibase, is being used.

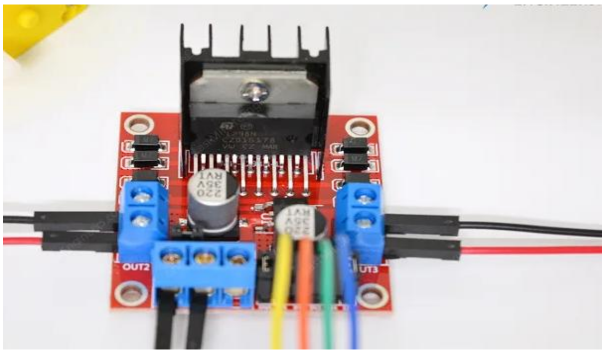


Figure 14: Motor Driver

- **Motor Driver L298D:** Connecting an L298N Motor Driver to an Arduino is one of the simplest and least expensive ways to drive DC motors[22]. The IR sensor is a three-wired device. In our circuit, the red wire is connected to the load, which is the Arduino, while the brown and black wires are utilised to connect the sensor to the power source. The L298N motor controller employs the H-bridge arrangement depicted in Figure 14 for reversing the spin of a DC motor. The ability to supply power directly to the motors is yet another benefit of using an H-bridge. This is crucial when working with an Arduino board, as its 5V output is insufficient for powering two DC motors.

- **Final Assembly:** The final assembly of Figures 15, Figure 16, Figure 17 and Figure 18-19 explained the sequence of operations such as robot bottom portion, electronics, acrylic structure assembled with bottom structure complete assembly shows and demonstrated.

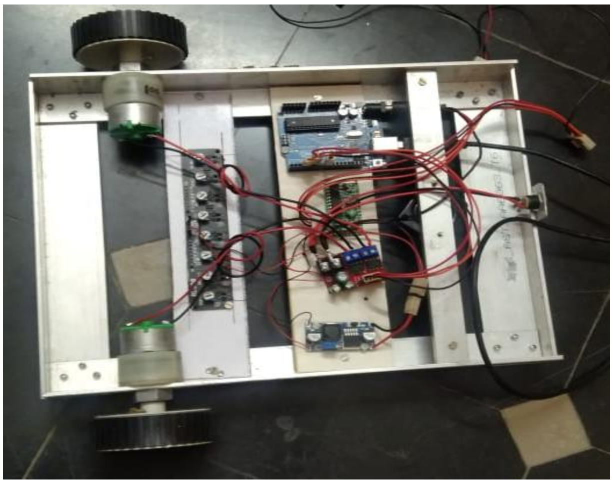


Figure 15: Robot Bottom Portion

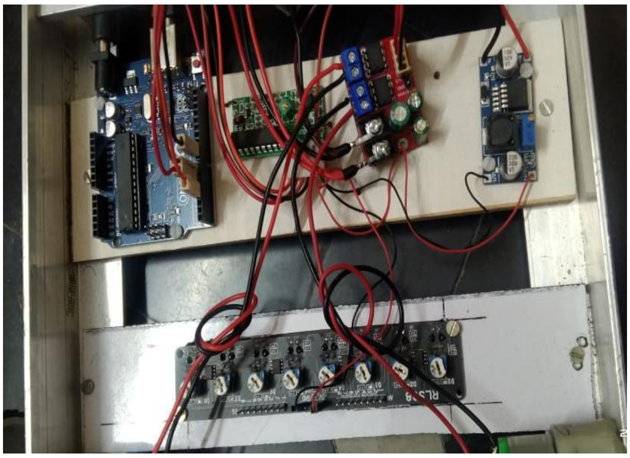


Figure 16: Electronics

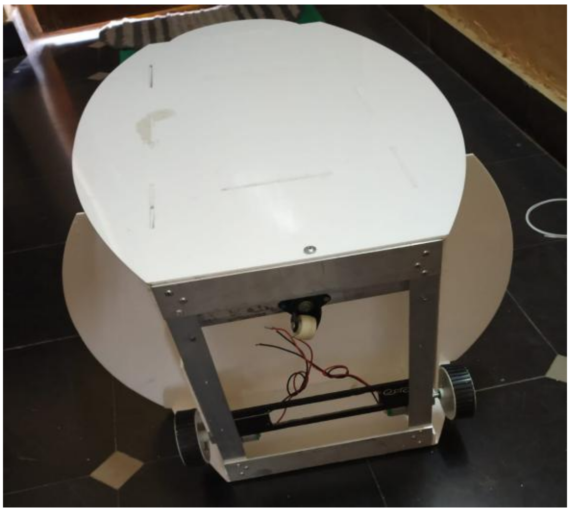


Figure 17: Acrylic Structure Assembled with Bottom Structure

Figure 18: Complete Assembly

Figure 19: Complete Assembly

III. CONCLUSION

AI and other digital technology advancements, falling hardware costs, the advent of 5G networks and the present pandemic problem will all contribute to the rapid adoption of service robots. The major goals of using robots in the past were to increase productivity and accuracy, decrease service time, and replace tedious, risky, dirty, and unsafe tasks. The robot's top structure is made of sheets of acrylic, and its bottom structure is made of aluminium. The structure is strong enough to support the plates and necessary meal items on the three specified spots. The built-in structure can be easily assembled and disassembled for cleaning as needed.

REFERENCES

[1] N, H.K., Deepak, G., Nagaraja, J.: An IoT based Obstacle Detection and Alerting System in Vehicles using Ultrasonic Sensor. Int. J. Eng. Res. Technol. 5, 5–7 (2017).

[2] Jyothis, P., Feba Mary, A., Ken Kurian, G., B J, F., Teena, R.: Automatic Medicine Dispenser using IoT. Int. J. Eng. Res. Technol. 9, 342–349 (2020). https://doi.org/10.17577/ijertv9is080152.

[3] Budijono, A.P., Suwito, D., Zuhrie, M.S., Kurniawan, W.D., Rachmad, S.H., Habib, B.N.: Paramedic Assistant Robot: Feature Review from Generation 1.0 to 3.0. In: ICRACOS 2021 - 2021 3rd International Conference on Research and Academic Community Services: Sustainable Innovation in Research and Community Services for Better Quality of Life towards Society 5. pp. 61–65. Institute of Electrical and Electronics Engineers Inc. (2021). https://doi.org/10.1109/ICRACOS53680.2021.9702094.

[4] Lalegani, M., Hatami, S., Zolfagharian, A., Bodaghi, M.: A pneumatic conveyor robot for color detection and sorting. Cogn. Robot. 2, 60–72 (2022). https://doi.org/10.1016/j.cogr.2022.03.001.

[5] Kargov, A., Asfour, T., Pylatiuk, C., Oberle, R., Klosek, H., Schulz, S., Regenstein, K., Bretthauer, G., Dillman, R.: Development of an anthropomorphic hand for a mobile assistive robot. In: Proceedings of the 2005 IEEE 9th International Conference on Rehabilitation Robotics. pp. 182–186 (2005). https://doi.org/10.1109/ICORR.2005.1501080.

[6] Zeithaml, V.A., Berry, L.L., Parasuraman, A.: Communication and Control Processes in the Delivery of Service Quality. J. Mark. 52, 35–48 (1988). https://doi.org/10.1177/002224298805200203.

[7] Eksiri, A., Kimura, T.: Restaurant service robots development in Thailand and their real environment evaluation. J. Robot. Mechatronics. 27, 91–102 (2015). https://doi.org/10.20965/jrm.2015.p0091.

[8] Kaushal, K., Yadav, K., Vaibhav, V., Sharma, C., Gupta, L., Tripathy, T., Goel, R.: The E-Restaurant. In: 2016 9th International Conference on Contemporary Computing, IC3 2016. pp. 1–5. Institute of Electrical and Electronics Engineers Inc. (2017). https://doi.org/10.1109/IC3.2016.7880205.

[9] Siva Sankara Raju, R., Venkata Siva, B., G., S.R.: Quantitative Analysis of Tribological Performance on Al–CSA Composite Using Orthogonal Array. In: Voruganti, H.K., Kiran Kumar, K., Vamsi Krishna, P., and Xiaoliang, J. (eds.) Advances in Applied Mechanical Engineering (Lecture Notes in Mechanical Engineering (LNME)). pp. 381–388. Springer Nature Singapore Pte Ltd (2020). https://doi.org/https://doi.org/10.1007/978-981-15-1201-8_43.

[10] Nagarajan, S., Reddy, N.V.: STEP-based automatic system for recognising design and manufacturing features. Int. J. Prod. Res. 48, 117–144 (2010). https://doi.org/10.1080/00207540701855419.

[11] Vuddagiri, H.K., Rallabandi, S.R., Vadapalli, S., Pandi, T.: Assessment of mechanical and tribological performance of hybrid Al/MoS2/Al2O3 composite by GFRA. Metall. Mater. Eng. 28, 79–102 (2022). https://doi.org/10.30544/764.

[12] Raju, R.. S.S., B., V.S.: Fabrication and tribological studies of Al-CSA composite using RSM. Int. J. Mater. Eng. Innov. 12, 83–102 (2021). https://doi.org/10.1504/IJMATEI.2021.115596.

[13] Sharma, R.C., Palli, S., Koona, R.: Stress and vibrational analysis of an Indian Railway RCF bogie. Int. J. Veh. Struct. Syst. 9, 296–302 (2017). https://doi.org/10.4273/ijvss.9.5.06.

[14] R, S.S.R., Y, K.K., G, P.K.: Design and Analysis of Rocket Motor Casing by Using Fem Technique. Int. J. Eng. Adv. Technol. 2, 70–74 (2013).

[15] Rallabandi, S.R., Yanda, S., Rao, C.J., Ramakrishna, B., Apparao, D.: Development of a color-code sorting machine operating with a pneumatic and programmable logic control. Mater. Today Proc. (2023). https://doi.org/10.1016/J.MATPR.2023.05.150.

[16] Rao, C.J., Siva Sankara Raju, R., Sreeramulu, D., Sagar, Y.: Fabrication and Evaluation of Optimized Parametric Condition During EDM Machining of Al-CSA Composite Using Taguchi Orthogonal Array. In: Lionel, G., Karthikeyan, R., and Muralidharan, V. (eds.) Advances in Design and Thermal Systems:Select Proceedings of ETDMMT 2020. pp. 411–420. Springer Singapore (2021). https://doi.org/10.1007/978-981-33-6428-8_33.

[17] Raju, S.S., Kumar, K.P.S., Kumar, G.M., Kumar, I.K., Singh, D.: SIMULATION OF ROLLING OPERATION ON AL- CSA COMPOSITES BY USING DEFORM 3D. J. Emerg. Technol. Innov. Res. 6, 459–464 (2019).

[18] Siddiqui, R., Thakur, R.: Flex Sensors Based Robotic ARM for Disabled Persons: A Review. Int. J. Emerg. Technol. Eng. Res. 5, 1–8 (2017).

[19] Rana, M.M.R., Zaman, M.F., Ray, S.K., Faysal, J. Al: Prototype Design and Development of Flex Sensor Controlled Bionic Arm for the Handicapped Person. Int. J. Comput. Appl. 183, 1–4 (2021). https://doi.org/10.5120/ijca2021921410.

[20] Ahmad Al_Issa, H.: Sensors Application Using PIC16F877A Microcontroller. Am. J. Remote Sens. 4, 13 (2016). https://doi.org/10.11648/j.ajrs.20160403.11.

[21] Raju, S.S., Rao, G.S., Siva, B.V.: Experimental studies of mechanical properties and tribological behaviour of aluminium composite reinforced with coconut shell ash particulates. Int. J. Mater. Eng. Innov. 9, 140–157 (2018). https://doi.org/10.1504/IJMATEI.2018.093812.

[22] Hoomod, D.H.K., Al-Chalabi, S.M.M.: Achieving Real-Time Tracking Mobile Wireless Sensors Using SE-KFA. J. Phys. Conf. Ser. 1003, 012039 (2018). https://doi.org/10.1088/1742-6596/1003/1/012039.

MANAGING SOLID WASTE IN A WAY THE FACT IS ENVIRONMENTALLY SUSTAINABLE: A CASE STUDY OF PLASTICIZER-CONCRETE-BRICK-INTERLOCKING

Abstract

The goal of this initiative is to reduce plastic trash and recycle it into valuable items like bricks and in construction. Plastic waste is piling up and harming the environment, especially in high mountain communities where there is no infrastructure for garbage collection. A sizeable amount of plastic is brought into popular hiking locations, where it is thrown away or burned, damaging the environment and the air. These used plastics will therefore be put to good use. High-density polyethylene (HDPE) and polyethylene (PE) bags are cleaned and mixed with sand and gravel at variable ratios to create high-strength bricks with the ability to insulate sound and heat. This reduces pollution and overall expenses. This avoids the amount of sand/clay that would otherwise be extracted from valuable river beds/mines. Since there is a lot of plastic trash, the cost factor is lower. Colour ants can also be added to the mix to get the colour you want. In this study, an effort is made to examine the properties of a brick formed from plastic waste as well as to contrast geo polymer and plastic bricks with more conventional bricks such fly ash, clay, and CLC bricks. Also, by adopting the interlocking idea, cement in the construction area may be replaced to minimise use.

Keywords: Plastic waste, Recycling, Construction of Bricks, Cost savings, Customization, Geopolymer, Insulation, Interlocking design, Cost-efficiency, Environmental impact, and Sustainability

Authors

Sivasankara Raju Rallabandi
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Apparao Damarasingu
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Ramakrishna Bondala
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Venkata Ramana Menda
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Sreeramulu Dowluru
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Srihari Palli
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali
Andhra Pradesh, India.

Corresponding Author: Sivasankara Raju Rallabandi, Email: sivaraju80@gmail.com

I. INTRODUCTION

To preserve critical natural resources, decrease excessive carbon emissions, and protect the public, sustainable industrial processes and garbage disposal are applied. The major objectives are to address environmental concerns while also offering economic opportunity. The solid-state recycling method has demonstrated to be an excellent and strong means of achieving a green state by transforming recyclable waste into useable parts. The proposed method might be classified as a green natural method of production or an eco friendly method. It has a number of benefits, including being simple, cost-effective, and energy-efficient, as well as the capacity to be recycled cleanly without affecting the environment[1]. The use of polymeric products and combinations is rapidly rising relatively low cost and ease of fabrication. As a consequence, a great number of people have been affected. As a result, a large volume of waste plastic has collected, posing a significant disposal difficulty. Organizations are faced with the growing difficulty of finding alternative solutions for dumping a significant number of trash packaging due to the sustainability of plastic for a broad variety of applications. Because of its low biodegradability and abundance, the disposal of plastic garbage in the environment is considered a major issue[2], [3].

Furthermore, during the fabrication of metal items, many types and sizes of metal chips are created. Because of their size and weight, the created chips were recycled using traditional methods like as remitting and casting, which resulted in the loss of sections of chips owing to oxidation. Because it required a lot of energy and produced a lot of pollution, the conventional recycling process became an expensive approach. Furthermore, energy saving and environmental protection are difficult tasks all over the world. As a result, by creating and enhancing lightweight materials, the sustainable manufacturing method is a promising technique for decreasing waste and expense, as well as minimising the use of primary natural resources. Due to its capacity to generate solid pieces directly from solid chips, solid-state metal conversion is one of the most essential technologies for reducing the amount of energy required for melting. Sustainable development is defined as development that meets current needs without endangering populations' ability to meet their own[4]–[6].

The National environmental, Forest & Global Warming announced the suggested Uniform Structure for Product Stewardship (Under Plastic Waste Management Rules 2016) on June 26, 2020, with a July 31 deadline for stakeholder input. India Spend wrote to the Environmental Protection Agency, asking however many suggestions was already received and once the rules would be finalised. On September 10, India's environmental court, the Green Growth Tribunal, requested the environment ministry to finalise and implement the EPR guidelines "as much as practical within three months" in a long-running dispute over plastic waste management. India was the first country to deploy EPR to manage electronic waste in 2012. It was announced in 2016 that the Plastic Waste Management Rules 2016 (PWMR) would be implemented[5], [7]. Various forms of plastics available in the sea shore vide in Figure 1.

Figure 1: Categories of plastic waste forms

One of the key reasons of India's plastic disaster, according to a supplement to the September 2020 global report, Talking Smack: The Corporate Handbook of Faux Remedies to the Plastic Issue, is that the nation's plastic enhanced productivity a variety of techniques to divert, postpone, dilute, and derail proactive plastic control laws that is adverse to them. The article's India chapter was researched and written by Shah, who was previously mentioned in Figure 2. Natural resource usage has increased while resource availability has decreased as a result of urbanisation, rapid industrialisation, and changing lifestyles. Humans, on either hand, have always produced rubbish and dealt of it in some way, causing environmental damage[8].

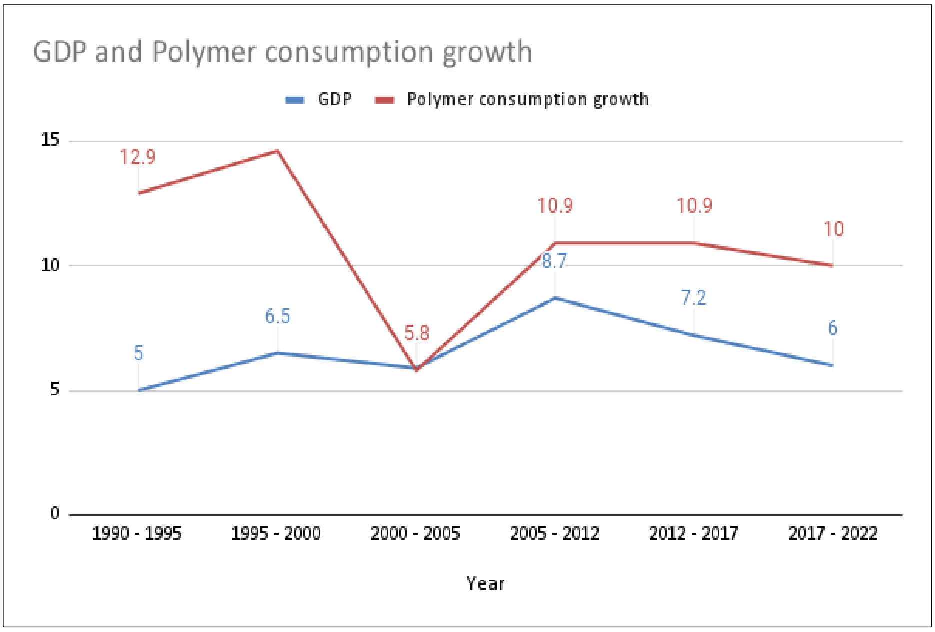


Figure 2: Economical growth of polymers in the nation

As a consequence, research has revealed new types of technology, such as eco-friendly engineering, to aid in the conservation of energy and other resources. The concept of sustainability is based on three principles: societal, environmental, and economic factors[9], [10]. They lead to environmental policies, which eventually leading reducing waste, reuse, and recycling as a way to help close the materials use loop all through the industry by providing waste derived commodities as manufacturing inputs as shown in Figure 3.

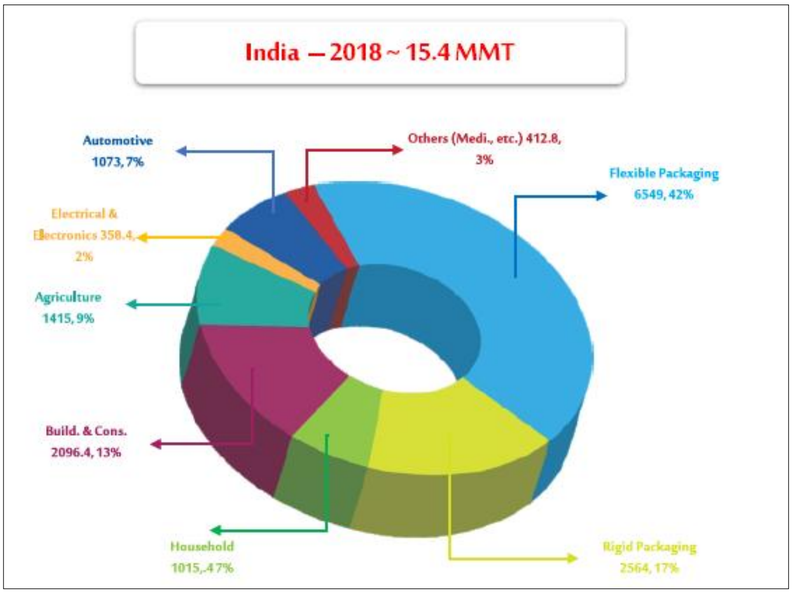


Figure 3: Various commodities of manufacturing used polymers

Under this model, plastic companies are not required to recycle their own plastic waste. The model suggests that in order to satisfy waste management legal requirements, manufacturers should instead buy plastic credits from "fully accredited processors" to prove that an equivalent amount of "packaging garbage" has been recovered and recycled. The proposal stipulates that manufacturers "must receive documentation of recycling or recovery" from suitably trained processors. Plastic makers and processors/exporters can trade plastic credits for money at a price and other terms that they agree on. Therefore, approved processors increase their profits per tonne of reprocessed packaging waste [11].

The main goal of this project is to emphasise the key objective of green manufacturing processes, as well as their impact on greatly reducing production wastes using environmentally friendly ways, and to encourage the use of innovative green science. As a result, this chapter includes a brief review of durability, ecological manufacturing methods, solid waste disposal, and 2 case studies, including innovative studies for recovering plastic trash and nonferrous trash using sustainable manufacturing techniques to reduce waste itself and effect on the environment. The key strategies for saving energy and materials, minimising garbage, and eliminating pollution, and the process of transforming waste into useful products and its consequences, will also be explained.

1. **Restrictions on Overproduction and the Use of Alternative Materials:** An effective EPR strategy, according to Sambyal, should emphasise methods to minimise plastic waste

through changes in packaging design and the development of substitute product packaging. The slogan should be "Refuse > Reduce > Reuse > Recycle > Recover > Dispose". Shah [3]says that the guidelines' main objective should be to decrease wasteful production. "Rather than decrease, targets remain focused on collection and dispose in incineration plants and cement plants," he stated. "Instead, the objective should be to eliminate single-use plastic manufacturing".

Figure 4: An effective EPR strategy used by Ministry of Environment[3]

- **Plastic Waste Burning:** Garbage is found in places that are damaging to the environment due to a lack of adequate waste management. "According to my observations, the majority of the waste was found near school boundaries and comparably less surrounding residential areas," Arya added. I also wanted to point out that the majority of the plastic waste material contained items that are typically considered taboo in society, such as pregnancy test kits, various contraception and tobacco packs. Perhaps individuals are uncomfortable disposing of things at home, and as a result, they end up littering the streets outside!" Due to a lack of trash management in the city, all debris is left on the highways, posing a serious environmental threat. Plastic is left in the soil to decay or is burned as a result of a lack of segregation and recycling, which has negative environmental consequences[3], [4], [8].

2. Case studies on Waste Management

- **Waste plastic cement made of polyethylene:** To increase the mechanical qualities and usability of products, plastic cement can be made from solid polyethylene waste materials. To test the viability of making plastic cement, high-density polyethylene (HDPE) waste is mixed with Portland cement. The impact of replacing sand with different ratios of fine plastic debris is also explored. Due to anthropogenic factors, high-density polyethylene containers or crates have been gathered from municipal and garbage sites. Then, using a specific cutting and grinding equipment, they are shattered into little fragments to obtain tiny particles. The small particles are filtrated to remove them from the granular materials after grinding polyethylene wastes, and then combined with Portland cement as shown in Figure 5.

To examine the impact of substituting sand with identical twin HDPE waste, Concretes and fine plastic waste are combined with water to make a concrete mix that does not require sand. Plastic cement is created from a variety of identical twin polyethylene waste in varied proportions. With level lower water content of 25%, polyethylene was used in the amounts of 15 to 80% with variation of 5% of the blending components. Portland cement and leftover polyethylene are mixed with water to make a single substance that can be poured into the small mould. After samples have dried in the mould, they are immersed in water for two to four days to congeal and cure, which improves cohesiveness.

(a) (b)

Figure 5: Process of making polymer concrete (a) geo polymer mixing (b) plastic cement made of polyethylene

The samples are then taken out of the water and analysed. The next step is to immerse these samples in water for 7 and 28 days to see how stable they are and how water affects their properties. Polyethylene is a semi-crystalline polymer with excellent chemical, corrosion, fatigue, and wear resistant properties. It has a low moisture absorption rate and a strong resistance to organic solvents. It's also a lightweight, quasi, stain-resistant material with high tensile strength and impact resistance. The shape of wet plastic cement is formed by mixing and casting components instead of using motion or a pressing. The items are in good shape and have a low density, which is defined by the percentage of fine polyethylene used.

The plastic cement produced in this investigation has a density with between 1.972 and 1.375 gm/cm^3. It is 1.375 gm/cm^3 when the proportion of polyethylene is 60%. After soaking for 7 and 28 days, the relative humidity of the plastic cemented produced in this study was assessed. The results show that the moisture content of the plastic cement will be lesser after 28 days than after 7 days of immersion. The moisture content after 7 days of immersion ranges from 23.4 to 6.3 percent, and after 28 days, it varies from 11.6 to 3.60 percent. When the amount of fine polyethylene in concrete would be between 25 to 30 percent with a 28-day immerged duration, the results are excellent[6], [12].

As the plastic waste ratio grows, the compressive of recycled plastic cement falls with each curing age. The decrease in interfacial interaction between the recycled plastic barrier and the composite resin can be attributable to this development[13]. The plastic particles appear to have a poor connection with the cement mix. It was discovered that waste polyethylene materials made by human activities, such as food packages or crates, may be used to make plastic cement. The quantity of discarded polyethylene used in the concrete mix determines the density of the created plastic cement. It expanded as the proportion of waste in the environment increased to 30%, then gradually decreased. The density of the product is 1.972 gm/cm^3, which is lower than that of sand and Portland cement mortar. The density of plastic cement generated from high-density polyethylene waste materials is 15% lower than that of traditional concrete. Furthermore, the relative humidity of polymer cement varies between 10.5 and 23.4 percent for items over pressurized for seven days[12], [14].

- **Recycling of non-ferrous metal waste:**Several recycling processes, classified as conventional and non-conventional, have been employed to convert chips into useable parts in recent years. There is little increase in mechanical characteristics when using traditional recycling methods and substantial amounts of slag are produced during the reheating and solidification processes. Furthermore, 20 percent of the components will be lost during the reheating process, which is unavoidable. Thin chips, on the other hand, can result in losses of up to 50%; as a result, energy usage and labour costs will rise, as will expenditures for environmental protection. Non-conventional recycling, on the other hand, uses an extrusion and sintered process, which saves 95 percent of the energy, used in traditional recycling and can minimise solid waste disposal and CO2 emissions[1], [15].

  Direct conversion is a non-traditional recycling approach that is relatively straightforward, cost-effective, and environmentally benign, and can be considered a long-term manufacturing process. One of the most important strategies for minimising waste, cost, and energy required for recycling non-ferrous metal waste is the solid-state metal direct conversion that is key to sustainable production process. Its capacity to produce solid pieces directly from solid state while reheating, reducing waste and costs, making it a potential approach for replacing remitting and casting procedures. During industrial activities such as turning, milling, and sawing, chips of various shapes and sizes were created[16], [17].

  In order to really be formed as a functioning item, these chips must be extracted and remitted in workshops and factories. The normal recycling process is expensive since it necessitates a big number of workers, consumes a lot, and generates a lot of waste, all of which are important issues across the world. A solid-state recycling approach for nonferrous materials such as aluminium, copper, zinc, and related alloy chips was recently developed to address the drawbacks of the current technology. As a consequence, scientists have created new forms of design, such as sustainable responsible and green engineering, that aim to minimise negative impacts while increasing economic, societal, and environmental advantages[18].

  As a sustainable making technology, this work used a solid-state recycling method to get aluminium oxide chips and copper chips to be used right away. Without melting them from their solid state, it is utilised to generate solid components. Al-Zn alloy, zinc, and copper chips that are produced in cutting or production facilities have been recycled directly (see Figures 6a and 6b). Chips 12 mm thick were produced by a cold pressing process using 10, 20, and 30 tonnes of pressure. There was a lot of distortion, which led to good bonding of materials. Following the cutting process, pieces of copper and an Al-Zn alloy in a variety of shapes and sizes are gathered from the factory and sieved with a mesh size ranging from 0.300 to 3.00 mm, as shown in Figure 5. They were combined so that 30% of the chips had a width of less than 1 mm, and 70% of the chips have a width of 1-3 mm. The dimensions of a chip were 11.85 mm in length and 0.39 mm to 0.33 mm in width. These chips didn't need to be heated or reheated in order to be compressed and extruded[19]–[21]. Increased cold-pressing pressure resulted in increased cold-pressed sample density and hardeners, according to experiments. Furthermore, crushing from opposite wings is preferred to pressing from one side since it results in uniform dispersion and high homogeneity. The pieces generated have nearly the same hardness and density throughout. When pushing from one side, the typical components become brittle and incoherent. As seen in Figure 6(c), crushing from two sides resulted in strong and coherent parts with strength and hardness faithful to the actual components. Furthermore, the findings show that smaller, easier chips are greater rates resources for cold compression than larger, more complicated chips; otherwise, warming chips prior to or even during the pressing process is necessary.

(a)

(b)

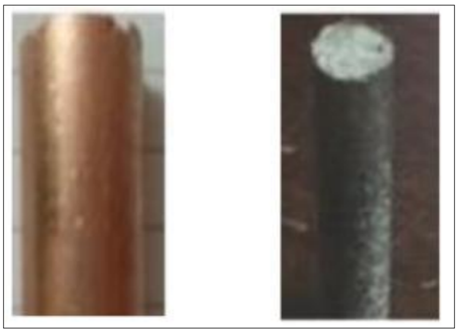


Figure 6: Obtained Chips/powder from scrape of (a) Copper (b) Al-Zn alloy (c) Prepared samples with forming and powder metallurgical route

- **Making of Plastic Brick with Interlocking:** Plastic is a substance that is both beneficial and dangerous on a daily basis. Plastic is proven to be highly useful when it is needed, yet it is simply tossed away after usage, posing a variety of risks. Plastic is a non-biodegradable polymer that has remained a dangerous material for decades. Plastic garbage is becoming increasingly prevalent in solid wastes (MSW). Every ten years, the pace of expansion is anticipated to double. This is owing to fast population increase, urbanisation, development activities, and lifestyle changes, all of which contribute to pervasive littering just on environment[22].

They cannot break down in the environment, and research suggests that some plastics could remain intact for up to 4,500 years. According to estimates, the amount of municipal solid waste produced in India each year is over 40 million tonnes, and it is increasing at a rate of 1.5 to 2% annually. These used plastics will therefore be put to good use. Today, it is challenging for any significant sector to operate efficiently without the usage of plastic, from industry to agriculture. Therefore, even though we cannot outlaw the use of plastic, we think that recycling plastic waste in the building and manufacturing industries is the most sensible usage.

The author is aware of three distinct types of interlocking blocks used in India, and notes that this approach is far from conventional.

- Stabilised earth blocks, also known as SEBs, and fly ash blocks, also known as Hydroform Interlocking Blocks
- Fly ash bricks that are connected to one another
- Cement concrete bricks that interlock

The report details the author's sole practical experience with Hydra form linking blocks in practise. However, the same applies to any interlocking blocks and is not limited to any one type. The native sandy loam soil is used to create stabilised earth blocks (SEB), which are then stabilised with cement, lime, or gypsum. They are hydraulically pressed into a mould, crushed, and allowed to cure for seven days before being used as masonry blocks.

- **Plastic Sand Bricks Casting Procedure:** Plastic soil bricks with high compressive strength are manufactured with varied control mix and evaluated using a compression test rig [CTM] in order to locate them. The proportions of the mix were in the ratio as shown in Table 1. These are the proportions for plastic and river sand, respectively. The making procedure is shown in Figure 7.

- **Batching:** The collected garbage bags are washed with water, dried to eliminate any remaining moisture, and then weighed. A 600 micron sieve was used to sift the sand. Sand and carrier bags were mixed in different amounts, with the plastic being used in the burning process.

Table 1: Batching of Plastic Sand Brick

Mix ratio	1:3	1:4	1:5
For 1 brick (Kg)	1:3	0.8:3.2	0.67:3.35
For 4 brick (Kg)	4:12	4:12	2.68:1.3

Figure 7: Process of making interlocking plastic brick with a least expensive method

- **Burning :** After batching, the plastic items were carried to be burned, where they were tossed into the drum one by one and left to melt. The placement of stones, drum, and needed fuel is the initial step in the burning process. The drum is held in place by the stones, and the timber is deposited in the gap here between stones and lit. The drum is put so over arrangement and heated to eliminate any remaining moisture.

- **Mixing :** One by one, the plastic items are poured into the drum until it has all of the plastic needed to make bricks among one mix proportion. Before the plastic solidifies, carefully scrape it with a trowel. The combination has a very quick setting time, therefore the bags are transformed to a molten condition before adding the river sand. The sand is blended at the appropriate moment. As a result, the mixing procedure should not take too long.

- **Moulding :** After that, the slurry is put into the brickwork mould and crushed using a tamping rod or steel rod. Trowel is used to polish the surface. The sides of the mould are greased before filling it with the slurry to make brick removal easier. After 24 hours, the mould was removed and final form shape as shown in Figure 8.

Figure 8: Interlocking brick made with waste plastic

Table 2: Mechanical Properties of Bricks, Comparison Purpose

Types of bricks	**Load (KN)**	**Compressive strength (KN/mm^2)**
Clay brick	32	3.047
Fly ash brick	62	5.90
Clc block	181	17.23
Geo polymer brick	28	2.66
Plastic brick	54	5.14

The load was applied to several bricks for comparative purposes while the cube specimens were in a compression testing machine, and the results are recorded in Table 2. Without stress, the pressure was applied to the specimen and escalated at a rate of about 140 kg/cm2 min until the specimen's ability to withstand the mounting pressure failed and no more force could be applied. It is important to record the sample's maximum applied force, the way the brickwork appears, and any unforeseen failure symptoms.

Table 3: Water Absorption Values for Bricks

Types of bricks	Dry weight	Wet weight	percentage
Clay brick	0.570	0.700	22.8%
Fly ash brick	0.880	0.970	10.22%
Clc block	1.030	1.070	3.88%
Geo polymer brick	0.960	1.09	13.54%
Plastic brick	0.970	1.010	4.12%

Table 3 shows the results of a water absorption test, in which bricks are first dry-weighed and then submerged in cool water for a set amount of time. After 24 hours, these are taken out of the water and dried with a cloth. After that, the brick is weighed while still damp. Bricks vary in weight because they absorb different amounts of water. The percentage of water absorption is then calculated. Less water is absorbed by bricks of greater quality. A brick of good quality won't absorb more water than 20% of its own weight.

II. CONCLUSION

By converting recyclable rubbish into usable parts, the solid-state recycling industry has shown to be an effective and appropriate means to achieve a green state. The approach developed may be regarded as both a clean recycling technology and a traditional green-forming or ecologically friendly lightweight alloy production process. Moulding and sintered the items do not necessitate the use of powders. Plastic sand brick and Geo polymer brick provide a number of advantages, including economic efficiency, resource efficiency, and reduced greenhouse gas emissions, among others. The amount of alkalis in the water was greatly reduced by using plastic sand bricks. Further study would increase the quality and longevity of these bricks due to their multiple advantages. In comparison to traditional bricks, these plastic and geo-polymer bricks offer a high compressive strength. The use of cement in building can be reduced by incorporating the interlocking principle into the fabrication of these bricks. As a result, the entire cost will be lower.

REFERENCES

[1] A. K. Jassim, "Sustainable Solid Waste Recycling," *Skills Development for Sustainable Manufacturing*, pp. 1–16, 2017. doi: 10.5772/intechopen.70046.

[2] S. Erik, "Single-use Plastics: A Roadmap for Sustainability," *United Nations Environ. Program.*, vol. 1, no. 1, pp. 57–104, 2018.

[3] B. Tripathi, "India Wants Manufacturers To Manage Plastic Waste," *Indiaspend*, 2020. https://www.indiaspend.com/india-wants-manufacturers-to-manage-plastic-waste-heres-how-proposed-rules-fall-short/ (accessed Jun. 10, 2022).

[4] S. M. Gawande, V. Gholap, M. Dimble, M. Gondkar, and V. Jamdar, "Waste Plastic Bottles Offering Innovative Material with Sustainable Application in Safe Guard Tree," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 6, no. 5, pp. 6844–6852, 2017, doi: 10.15680/IJIRSET.2017.0605227.

[5] R. R. N. S. Bhattacharya, K. Chandrasekhar, M. V Deepthi, P. Roy, and A. Khan, "Fact Sheet on Plastic Waste in India," *World Environmental Day*, p. 4pages, 2018. [Online]. Available: http://www.teriin.org/sites/default/files/files/factsheet.pdf

[6] D. JivanPati and S. PragyanDash, "Strategy for promoting utilization of non-biodegradable wastes in affordable housing in India," *Mater. Today Proc.*, vol. 60, no. 1, pp. 26–32, 2022, doi: 10.1016/j.matpr.2021.11.026.

[7] P. Kumbhare, "Recycling as a solution to better plastic waste management at Kolkata, India – Earth5R," *Sustanable Developement Goals*, 2021. https://earth5r.org/recycling-as-a-solution-to-the-plastic-waste-management-at-kolkata-india/ (accessed Jun. 10, 2022).

[8] A. O. Sojobi, S. E. Nwobodo, and O. J. Aladegboye, "Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete," *Cogent Eng.*, vol. 3, no. 1, 2016, doi: 10.1080/23311916.2015.1133480.

[9] K. Ramanaiah, S. P. Sanaka, A. V. R. Prasad, and K. H. Reddy, "Thermo-physical and fire properties of sustainable bio composites: Experimental and computational analysis," *J. Nat. Fibers*, vol. 20, no. 1, p. 2162653, 2023, doi: 10.1080/15440478.2022.2162653.

[10] R. Siva Sankara Raju, B. Venkata Siva, and S. R. G., "Quantitative Analysis of Tribological Performance on Al–CSA Composite Using Orthogonal Array," in *Advances in Applied Mechanical Engineering (Lecture Notes in Mechanical Engineering (LNME))*, Lecture No., H. K. Voruganti, K. Kiran Kumar, P. Vamsi Krishna, and J. Xiaoliang, Eds. Springer Nature Singapore Pte Ltd, 2020, pp. 381–388. doi: https://doi.org/10.1007/978-981-15-1201-8_43.

[11] D. J. Pati, R. Homma, and Kazuhisaikt, "Plastic Bottles Masonry As Alternate Solution To Housing Problems In Urban Area Of India," *Int. J. Archit. Plan. Build. Eng.*, vol. 2, no. 2, pp. 12–15, 2015.

[12] T. Ahmad Dar and F. Azam, "Development of Fly Ash Based Geo-polymer Concrete," *Int. J. Sci. Res.*, vol. 6, no. 6, pp. 1539–1560, 2017, [Online]. Available: https://www.ijsr.net/archive/v6i6/ART20174551.pdf

[13] D. Pati, R. Homma, and K. Iki, "Proposing the Use of Plastic Bottle Waste for Low-Cost Housing under Government Guidelines in India," *Am. J. Eng. Sci. Technol. Res.*, vol. 4, no. 1, pp. 1–10, 2016, [Online]. Available: https://www.researchgate.net/publication/301947862_Proposing_the_Use_of_Plastic_Bottle_Waste_for_Low-_Cost_Housing_under_Government_Guidelines_in_India

[14] S. R. Rallabandi, G. Srinivasa Rao, S. S. R. R, S. R. G, S. R. Rallabandi, and G. Srinivasa Rao, "Assessment of Tribological Performance of Al-Coconut Shell Ash Particulate—MMCs using Grey-Fuzzy Approach," *J. Inst. Eng. Ser. C*, vol. 100, no. 1, pp. 13–22, Feb. 2019, doi: 10.1007/s40032-017-0388-4.

[15] G. V, B. K. N, and T. AE, "Direct recycling of 1050 aluminum alloy scrap material mixed with 6060 aluminum alloy chips by hot extrusion," *Int. J. Mater. Form.*, vol. 3, pp. 853–856, 2010.

[16] B. Panda, A. K. Mahato, C. Varun, and S. S. R. R, "Wear Behavior of Aluminum Based Composite Reinforced With Coconut Shell Ash," *Imp. J. Interdiscip. Res.*, vol. 2, no. 5, pp. 890–895, 2016.

[17] R. S. S. Raju and G. S. Rao, "Assessment of Tribological performance of Coconut Shell Ash Particle Reinforced Al-Si-Fe Composites using Grey-Fuzzy Approach," *Tribol. Ind.*, vol. 39, no. 3, pp. 364–377, Oct. 2017, doi: 10.24874/ti.2017.39.03.12.

[18] T. Wall, "Responsible consumption and production," in *Encyclopedia of the UN Sustainable Development*

Goals, 1st ed., W. L. Filho, A. M. Azul, L. Brandli, P. G. Özuyar, and W. Tony, Eds. Switzerland AG 2020: Springer Nature Switzerland AG 2020, 2021, pp. 32–33. doi: 10.18356/9789213618851c016.

[19] S. Rallabandi, G. Srinivasa Rao, L. Srinivas, S. Dowluru, S. Palli, and A. Duppala, "Sustainable Waste Management for Solid Waste Dominance in Metals, Concrete Brick Mix of Plasticizer with Interlocking - A Case Study," in *Application of Engineering, Technology, Management for Sustainable Manufacturing Sector*, 1st ed., M. Brojo Kishore, K. C. Rath, and H. G. Sharma, Eds. World Leadership Academy, 2022, pp. 155–177. Accessed: Jan. 19, 2023. [Online]. Available: https://www.worldleadershipacademy.live/book-series1/index.php/ojs2/article/view/10/10

[20] R. S. Sankara Raju, M. K. Panigrahi, R. I. Ganguly, and G. Srinivasa Rao, "Tribological behaviour of Al-1100-coconut shell ash (CSA) composite at elevated temperature," *Tribol. Int.*, vol. 129, pp. 55–66, 2019, doi: 10.1016/j.triboint.2018.08.011.

[21] Y. Alemdağ and M. Beder, "Microstructural, mechanical and tribological properties of Al-7Si-(0-5)Zn alloys," *Materials and Design*, vol. 63. pp. 159–167, 2014. doi: 10.1016/j.matdes.2014.06.006.

[22] R. MA and K. HA, "Sustainable manufacturing and design concepts, practices and needs," *Sustainability*, vol. 4, no. 1, pp. 154–174, 2012.

THERMAL ANALYSIS OF MONOCRYSTALLINE PHOTOVOLTAIC CELL USING ANSYS WORKBENCH

Abstract

The purpose of this thesis is to develop monocrystalline silicon photovoltaic cells through the useof current technology and a screen printing method, and then to incorporate them into a photovoltaic device that makes use of these photovoltaic cells, design/methodology/ approach this study will look at the characteristics of modern voltage that will determine fundamental electric properties. The characteristics of monocrystalline silicon photovoltaic cells have been investigatedin the context of conventional examination situations. Photovoltaic, the module was built with the best short-circuit current photovoltaic cells available, which were then connected together in a sequence configuration to form the final product. Concluding remarks: This examination provides an illustration of a conventional technical technique that makes use of a display printed method of manufacturing. Manufacturing of monocrystalline silicon photovoltaic cells is a process. The electricity generated by the sun can be used to power a device that generates electric energy. The sun module was created by connecting cells together in a circular pattern. After that, Schottky and Zener diodes are used to protect the circuit from damage. Usefulness: The module was used to construct a model solar power system, complete with traffic signals and a pedestrian overpass. Thisbridge demonstrates the practical application of a readily available, renewable source of energy, in this case, the sun, in a real-world setting.

Keywords: Monocrystalline, Photovoltic, Schottky, Zener

Author

Venktesh Kumar
Assistant Professor
Faculty of Information Technology
Gopal Narayan Singh University
Jamuhar, Sasaram, India.
venkteshkumar2@gmail.com

I. INTRODUCTION

1. **General Introduction:** The electricity requirement of the world is increasing at alarming rate and the power demand is running much ahead of the supply. Fossil fuels like oil, coal and natural gas provide about 80% of the word energy, but generation of electrical power by fossil fuel is causing adverse environmental, social and economic problems [1]. It is also widely recognized that the fuels (i.e., coal, petroleum and natural gas) are depleting at fast rate [2] therefore, attention has been moved towards other energy resources like: Nuclear energy source which is plentiful and clean alternative to fossil fuels but has increased concern about the safety, cost, and nuclear waste disposal Other traditional supplies may not be appropriate or permitted for catering to the world's ever-increasing need for electrical energy. To overcome problems associated with conventional and nuclear energy resources it mandatory for countries throughout the world to develop different renewable energy source; because nature replenishes, renewable energy source faster than it consume; these sources are inexhaustible, self-generating , produce clean green energy, help in controlling climate changes and global warning [3]. The development of renewable technologies are becoming increasingly cost competitive in number of countries. Renewable based power generation capacity is estimated to have increased by 128 GW in 2014, of which 37% is wind power, almost one third solar power. Earth receive solar energy from the sun at the rate of 1000 KW h/m2 the total energy received by earth in one hour is more than the energy consumed in the whole world for one year. The availability of global average insolation is about 140000 Tera watt (TW) as compared to their consumption of 17 TW.

2. **Solar Cell Technologies:**

   - **Monocrystalline Silicon Solar Cells:** The oldest solar cell technology and still the most popular and efficient are solar cells made from thin wafers of silicon. These are called monocrystalline solar cells. Monocrystalline silicon solar PV cells were made up from single continuous crystal lattice of silicon having virtually no defects or impurities Silicon is mainly occurs as SiO_2 in the form of quartz, sand and silicates it is normally produced from a naturally occurring ore, quartzite gravel (a form of sand stone). In natural occurring quartzite there are several impurities including Al, B, P, Cu, C, Ca, Mg, Fe, Ti, Mn, Mg, etc. The acceptable level of impurities is generally parts per million (ppm) for solar cell applications means 5×10^{16} atoms/cm3 in Si. Various steps are involved in converting an impure quartzite to high purity crystal wafer. The first step is the production of 99 percent pure metallurgical grade silicon (MGS) from its ore, SiO_2 by reduction reaction with carbon in an arc furnace. The energy cost of this step is 50 kWh/kg of silicon. Also in this process CO_2 is produced as a byproduct, which is a greenhouse gas. Electronic grade pure polycrystalline silicon is then obtained by refining it further though various complex operations at an energy cost of 200 kWh/kg of silicon. These two steps are highly energy intensive. Worldwide, about 1 million tons of MGS is produced and less than 5 percent of it is used in making electronic grade silicon [5]. The typical monocrystalline photovoltaic cell is a dark black in colour, and the corners of cells are usually missing as a result of the production process and the physical nature of monocrystalline silicon [6]. Typically, the cells are a few inches across, and a number of cells are laid out in a grid to create a panel. Relative to the other types of cells, they have a higher efficiency (up to 24.2%). These cells are preferred for low available area of panel mounting. The production costs for this type of panel have highest of all the solar panel types since large amount of energy is required for growing large crystals of pure silicon. Although production methods have improved and prices for raw silicon as well as panel development cost of monocrystalline solar cells have fallen. Their efficiency decreases as the temperature increases above 25˚C, so they need to be installed in such a way as to permit the air to circulate over and under the panels to improve their efficiency [7].

- **Polycrystalline Silicon Solar Cells:** Polycrystalline silicon essentially consists of small grains of monocrystalline silicon. Solar cell wafers can be made from polycrystalline silicon directly in various ways, one approach is the controlled casting of molten polycrystalline silicon into cube shape ingots (Si block) with grain size from mm to cm range which are then cut, using fine wire saws, into thin square wafers and fabricated into complete cells in the same way as monocrystalline silicon. Polycrystalline silicon solar cells are easier and cheaper to manufacture than monocrystalline cells, but their efficiency is lesser because light generated electron hole pairs may recombine at the boundaries between the grains with in polycrystalline silicon. However, if the material is processed in such a way that grains are relatively large in size and oriented in top-bottom direction to allow light to penetrate deeply in to each grain the efficiency may be increased. For commercially available polycrystalline solar cell module efficiency has reached 19.3%. Figure 1. Monocrystalline and polycrystalline solar cells.

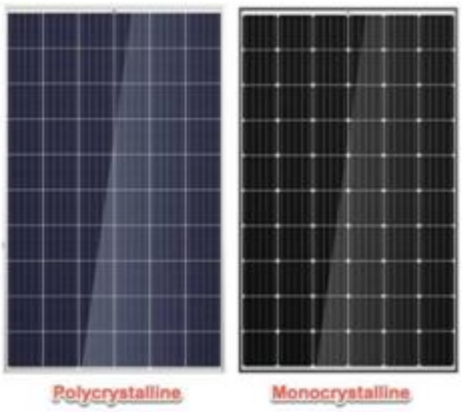


Figure 1: Monocrystalline and Polycrystalline Solar Cell

3. **Structure of Dye-Sensitized Solar cell (DSSC):** A great deal of theoretical and practical effort has been done to explain the effective operation of these solar cells since the development of the nanostructured DSSC. Due to the basic operational differences between the DSSCs and their conventional semi conducting pn-junction solar cells, they are in need of specific theoretical considerations of the photovoltaic effect in DSSCs. The DSSC separates both tasks; photons are absorbed by the dye molecules and charge transport is carried out in the TiO2 electrode and electrolyte. This is in contrast to semiconductor pn-junction solar cells, in which light absorption and charge transport occur in the same material. The charge separation in DSSCs is based on a hole transport

mechanism from the oxidised dye to the electrolyte and an electron transfer process from the dye molecule to TiO_2. The electronic structure of the adsorbed dye molecule and the energy level matching between the excited state of the dye and the conduction band of the TiO_2 are both important factors in the electron transfer mechanism**.**

II. LITRATURE REVIEW

The first generations of photovoltaic cells were researched during 1950's to 1960's for improved performance and reduction in cost. In 1954, the modern use of photovoltaic technology began. The p-n junction diodes under room light created a voltage, as was found by Bell Labs researchers in the United States. They created a silicon p-n junction solar cell with 6% efficiency that year, which is a significant development in photovoltaic technology but was also quite costly.

In 1958, first solar powered satellite was developed in which solar cells were used to power a small radio transmitter. In 1963, Sharp Corporation (Japan) produced the first commercial Si modules. In 1970, Zhores Alferov, Russian physicist and his co-workers, created highly effective first Gallium Arsenide (GaAs) hetero structure solar cells. Year 1973 was also important for photovoltaics because worldwide oil crisis encouraged many countries to seek for renewable energy sources. In 1976 David Carlson and Christopher Wronski, of RCA Laboratories developed first amorphous silicon photovoltaic cells which was less expensive than crystalline silicon devices. The photovoltaic technology developed very fast in the 1980s. University of Delaware developed first thin-film solar cell made of copper sulphide (Cu_2S) and cadmium sulphide (CdS) which exceeded 10% efficiency.

In 1981, Paul Mac Cready developed first solar-powered aircraft and the Solar Challenger. The aircraft flied from France to England across the English Channel, it comprised of over 16,000 solar cells mounted on its wings, which produced a power of 3kW. In 1985, researchers of the University of New South Wales (Australia) broke the efficiency barrier for silicon solar cells under standard sunlight (one sun condition). In 1986, ARCO Solar, developed first commercial thin film photovoltaic module. British Petroleum got a patent for the production of thin-film solar cell and Reflective solar concentrators in 1989. In 1991, efficient Photo electrochemical cells (PEC) later known as Dye sensitized solar cells were developed. In year 1992, A 15.9% efficient thin-film photovoltaic cell made of cadmium telluride was developed, which broke 15% barrier for the first time for this technology. Number of technologies from photovoltaic device using selenium wafers in 1883 to thin-film solar modules in 2000 has been developed to utilize solar energy. In 2000, two new thin-film solar modules, broke previous performance records and achieved 10.8 % conversion efficiency, the highest in the world for thin-film modules of their kind.

The efficiency of commercially available crystalline silicon solar cell modules is about 20% in standard test conditions [8]. Now Australian engineers have taken us closer than ever before to the theoretical limits of sunlight-to-electricity conversion, by building photovoltaic cells that can harvest 34.5% of the Sun's energy without concentrators, setting a new world record, these new photovoltaic cells aren't only more efficient, they also cover far less surface area [9]. The long-term goal is to produce 34% of the total world electricity production by 2050 and to achieve this goal improvement in performance (efficiency) and reduction of direct manufacturing costs is required. Nanotechnology is emerging as a kind of new technology [10].

III. METHOD AND METHODOLOGY

1. **Structure of Dye Sensitized Photovoltaic Cell (DSSC):** A substantial amount of theoretical and experimental diligence has been done to explain the effective operation of these solar cells since the development of the nanostructure DSSC. Due to the basic fundamental distinctions between the DSSCs and standard semiconductor pn-junction solar cells, special theoretical considerations of the photovoltaic effect in DSSCs have to be taken into account. The DSSC isolates either functionality; photons are absorbed by the dye molecules, whilst charge transport is carried out in the TiO2 electrode and electrolyte, in contrast to semiconductor pn-junction solar cells, whereby light absorption and charge transport occur in the same material. In DSSCs, the separation of charge is based on a hole-mediated transport mechanism from the oxygenated dye to the electrolyte and an electron transfer process through the dye molecule to TiO2. The electronic structure of the adsorbed dye molecular structure and the energy level match between the excited state of the dye and the conduction band of TiO2 are both significant variables in the electron transfer mechanism. While charge separation occurred at semiconductor pn-junctions as a consequence of an electric field in the space-charge layer near the junction, this is not the case at the electrode-electrolyte interface for nanoparticles. The nanostructured electrode's individual particle size, which is generally a few tens of nanometers, is too minuscule for a space charge layer to establish itself inside the particles. In semiconductor pn-junction cells, created opposing charges circulate through the same material, nevertheless in DSSCs, electrons move across a network of nanoporous TiO2 while holes move throughout the electrolyte. In the case of a semiconductor pn-junction solar cell, where recombination can only take effect at the semiconductor electrolyte interface, this implies that the requirement for a clean and defect-free semiconductor material is reduced. Sunlight may partially reflect onto the outermost layer of glass of a solar cell, photons of light could be absorbed by dye sensitizers, photons of light can be dispersed inside the solar cell, and photons of light may be partially transmitted when it engages with the solar cell. The main technique of light absorption depends on the light harvester that occupies the photoanode and factors such the photoanode's optical density, extinction coefficient, and the quantity of time that the light utilizes inside the photoanode. A large number of the aforementioned factors have been affected by the incident radiation's wavelength. Enhancing the utilisation of light by light harvesting equipment throughout the broadest wavelength range is necessary, as is minimizing charge recombination, which results in the loss of photogenerated charges [12].

2. **Transparent Substrate for Electrodes (TCO):** Since they combine the physical characteristics of electrical conductivity for current collection with visible light transmittance for light harvesting, transparent conductive oxides (TCOs) are crucial for solar cell applications. Clear glass substrates are often utilized due to their availability, affordability, and great optical transparency in the visible and near infrared spectrums. On one side of the substrate, a thin layer of transparent conductive oxide (TCO), a conductive coating, is applied. Low electric resistance/cm2 is made possible by the conductive film. At room temperature, a typical value for this resistance is 10–20 I/cm2. TCO is a key

material not just for solar cells but also for many other applications, particularly in the optoelectronic industry, such as flat panel displays, LEDs, and waveguide devices. This is because of its unique properties of high transparency and low sheet resistance. TCO is a semiconductor with a broad bandgap and a large concentration of free electrons [13].

- **Tin doped Indium Oxide (ITO):** Due to its high transmittance (in the range of 80% and 90%) as well as excellent conductivity all throughout the decades that followed, ITO has been one of the most widely implemented TCO materials in both industries and labs. Nevertheless, the material's conductivity significantly decreases when heated over 300 °C. This is caused by a reduction in oxygen vacancies at high temperatures, which additionally induces a reduction in the quantity of electric carriers. Additionally, high price tags on materials are a result of the expensive Indium material's scarcity. In addition, the researchers are searching for a better replacement due to the material's toxicity and simplicity in interacting with hydrogen plasma

- **Fluorine Doped Tin Oxide (FTO):** Another TCO that has been utilized extensively, particularly in solar cells, is FTO. This is because of its excellent stability at high temperatures and its affordable price compared to ITO. Due to the change in resistivity caused by the degree of doping, FTO is more frequently utilized. It is ideal for DSSC preparation, which necessitates sintering up to 450°C, as it is thermally stable up to 650°C. The optimized FTO had a thin film with a resistivity of 6.71 103 cmi, an optical bandgap of 3.80 eV, and an average visual transmittance of 83%i

- **Aluminum Doped Zinc Oxide (AZO):** Aluminium oxide compounds (AZO), which are extremely insoluble, thermally stable, and electrically non-conductive. But certain electrically conductive perovskite-structured oxides are finding use as the cathode of solid oxide fuel cells and oxygen production devices.

3. **Nanostructured Photo Electrode (Anode):** Initially, the photo electrodes for photo electrochemical solar cells (PSC) were manufactured from clumsy semiconducting substances like Si, GaAs, or CdS. The photo electrochemical cell's low stability is caused by photo corrosion, which occurs when these types of photo electrodes are exposed to light. Due to their resistance to photocorrosion, sensitized wide-bandgap semiconductors like TO2 or ZnO resulted in a high level of chemical stability of the cell. The issue with large single or polycrystalline wide bandgap is the low light to current conversion efficiency, which is mostly caused by the insufficient adsorption of sensitizer due to the electrode's constrained surface area. Increasing the surface area (the roughness factor) of the sensitized photo electrode is one way to improve light-harvesting efficiency (LHE) and subsequently the light-to-current conversion efficiency [14].

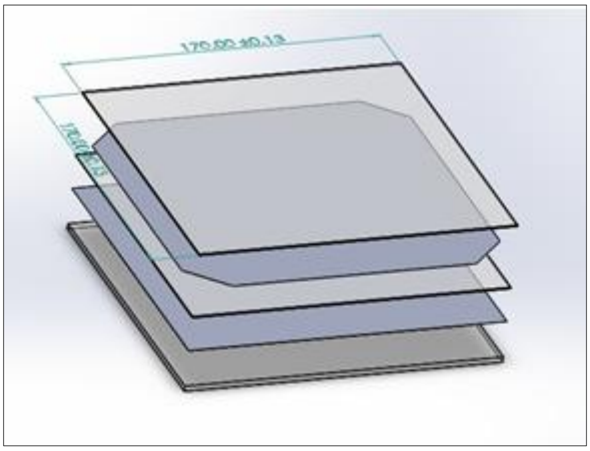
4. **Dye Sensitizer:** The purpose of the dye molecules is to absorb solar energy and introduce electrons into the semiconductor. Therefore, an effective sensitizer must strongly bind to the semiconductor oxide's surface, exhibit intense absorption in the visible spectrum, and have the correct energy level alignment between the dye's excited state and the semiconductor's conduction band edge [15]. The photosensitization material's molecular structure has a significant impact on the performance of DSSCs.

5. **Operating Principle of the Dye-Sensitized Solar Cell:** Anode and cathode constructed of tin oxide coated with fluorine glass (FTO), semiconductor layer of titanium dioxide (TiO_2), dye sensitizer (natural or synthetic), and electrolyte (iodide, tri-iodide) are the key components of a dye-sensitized solar cell. The fundamental concept behind DSSC is that dye sensitizers, whether artificial or organic, absorb photons at a length of wavelength that is equal to the quantity of energy difference between the dye's highest occupied molecular orbital (HOMO) and minimum unfilled molecular orbital (LUMO). Through this process, the dye is excited to its excited state, at which point the electrons travel to the photo-anode and get hooked up with the semiconductor TiO_2's conduction band. The photo-anode's captured electrons go through the outer circuit through a load before returning through the cathode [16].

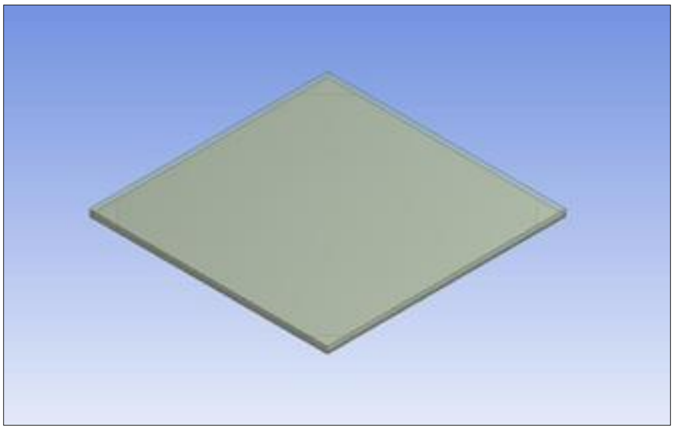
IV. RESULT AND DISCUSSION

1. Monocrystalline Photovoltaic cell (3D Model)

Given: Drawing of Monocrystalline Photovoltaic cell

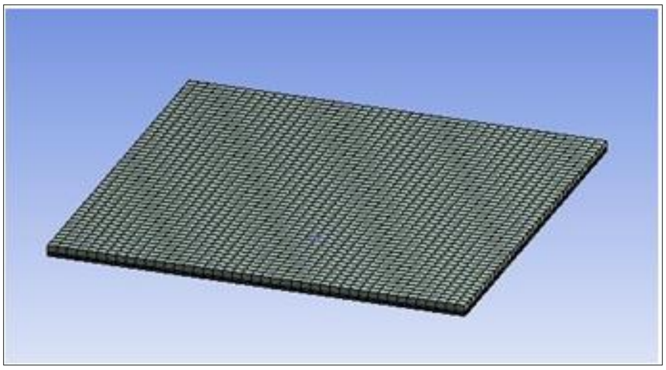


Step 1- Geometry



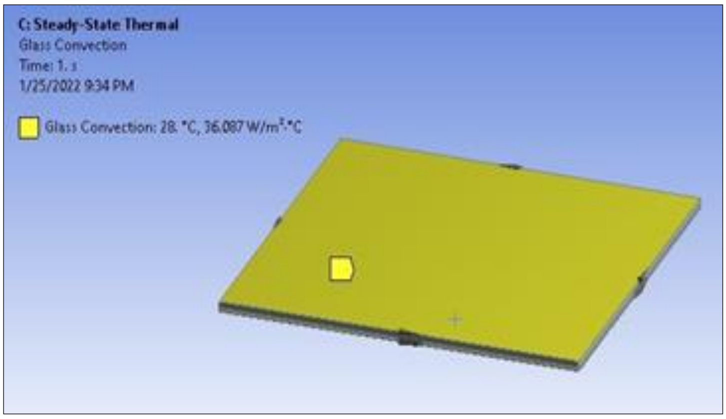
Step 2- Meshing

- **Element Size: 4mm**

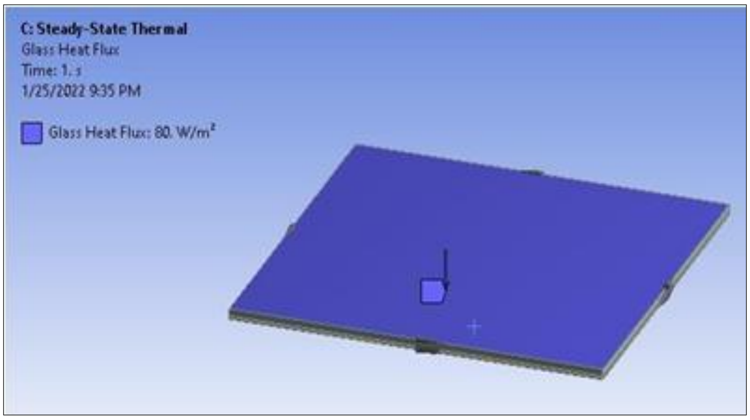


Step 3 – Setup

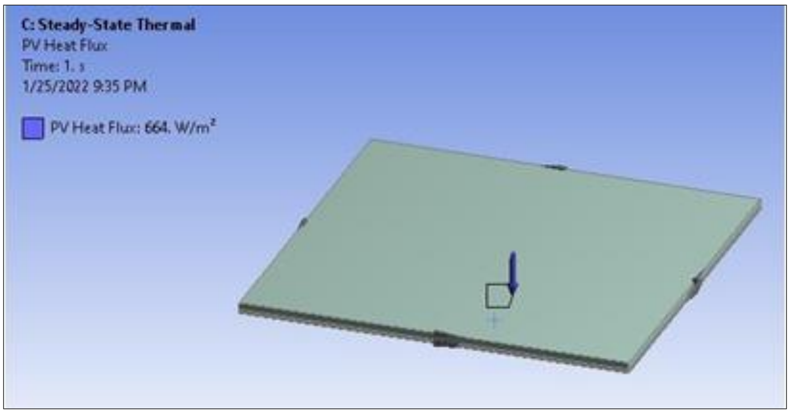
- **Boundary condition**
  - **Glass Convection 28 C, 36.087W/m^2 C**



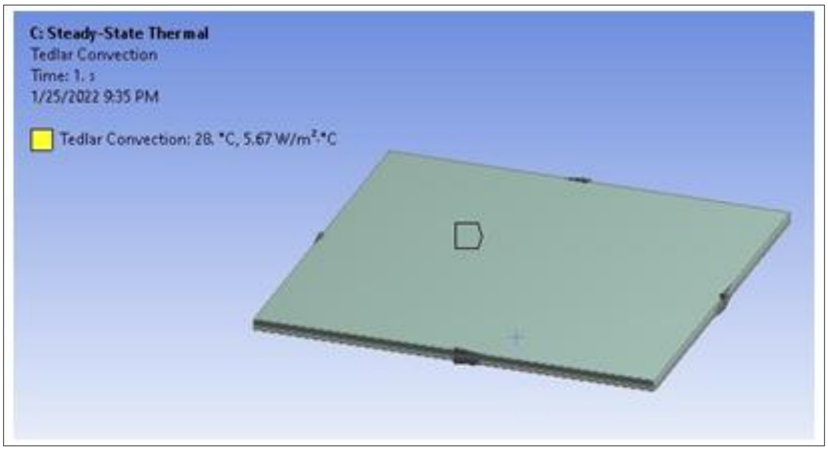
  - **Glass Heat Flux: 80 W/m^2**



  - **PV Heat Flux: 664 W/m^2**

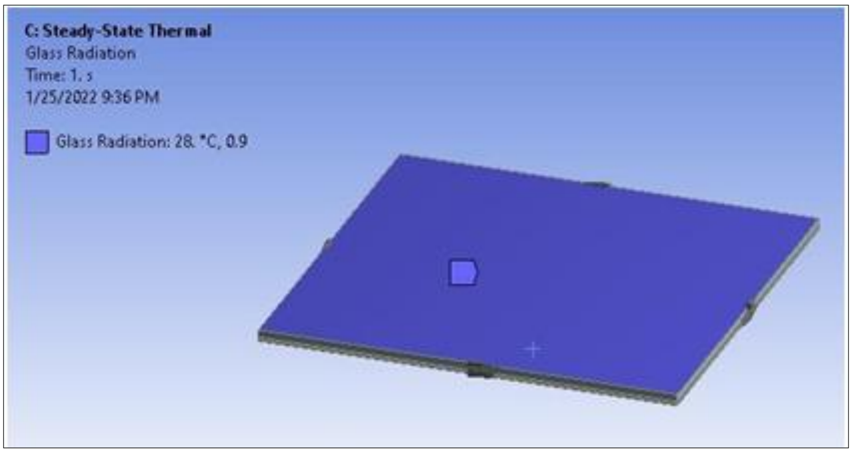


- **Tedlar Convection: 28 C, 5.67 W/m^2 C**



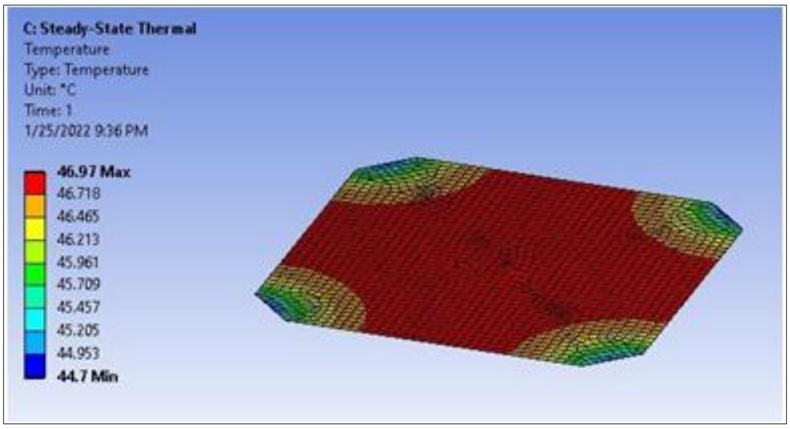
2. Material Properties

- **Thermal Conductivity of EVA:** 0.311 W/mK
- **Thermal Conductivity of Glass:** 0.7 W/mK
- **Thermal Conductivity of Monocryastaline Si:** 148 W/mK



- **Glass Radiation:** 28 C, 0.9 Step 4- Solution and result

- **Temperature Distribution:**
- **Max Temp:** 46.97 CMin Temp: 44.7 C



V. CONCLUSION

As all the values of Temp are below the value which is given for material so our design is safe

1. **Conclusion and Future Scope:** Systematic investigations were carried out to fabricate and evaluate different types of photovoltaiccells, since the nanocrystalline cell is feasible under laboratory conditions various nanocrystalline solar PV cells were developed and tested for their performance under ambient conditions. The working of nanocrystalline DSSC is based on the conduction by electron injection from the dye tothe semiconductor and redox reaction to reduce the dye. The main technological challenges are thevolatility of the iodide electrolyte, the inflexibility of glass substrates and the cell degradation, with the consequent reduction in useful life compared to silicon cells. The parameters of DSSC can be varied by changing its anode material, cathode material, type of dye, type of electrolyte, and the procedure adopted to fabricate the cell. In this thesis different types of cells were developed and tested under standard conditions, for each type of cell at least ten samples were prepared and testedon the basis of various characterization carried out under the present study, following conclusionscan be drawn:

2. **Future Scope:** Monocrystalline and polycrystalline photovoltaic cells have achieved presentable conversion efficiencies and are available in market. The nanocrystalline photovoltaic cells such as DSSC, and perovskite photovoltaic cells are emerging technology. Further future work need to be done for theefficiency enhancement of DSSC using different cathode materials and electrolytes. The costly ruthenium dye may be replaced by natural sensitizers. More work is required on the stability study of these nanocrystalline photovoltaic cells. DSSCs are estimated to significantly provide renewable energy by the year 2020. Although progress is there in perovskite photovoltaic cells but work is required to be done to reduce the effect of moisture on perovskite photovoltaic cell parameters. Other nano composites such as TiO2V2O5 may also be used for DSSC anode fabrication. Hence, future research may be focused on producing more stable, flexible, environmental resistant, lower cost and higher efficient DSSCs. The flexible substrates may be used in place of FTO. Their flexibility and variety of colors and shapes

can be employed and can be used as decoration in colored windows that not only allow light through, but can use this light to generate electricity. Although less efficient than the silicon based photovoltaic cell, DSSC is more cost efficient due to the low cost of the materials and processing, than the silicon photovoltaic cells. I do hope that the work presented in this thesis will encourage further research in the direction of realization of moreefficient and cost effective photovoltaic cells in future.

REFERENCES

[1] B.G. Boyle, B. Everett, G. Alexander, Introducing renewable energy, 2012.
[2] M. Hosenuzzaman, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, A.B.M.A. Malek, A. Nahar, Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation, Renew. Sustain. Energy Rev. 41 (2015) 284–297. doi:10.1016/j.rser.2014.08.046.
[3] M. Thirugnanasambandam, S. Iniyan, R. Goic, A review of solar thermal technologies, Renew. Sustain. Energy Rev. 14 (2010) 312–322. doi:10.1016 /j.rser.2009.07.014.
[4] K.. M. Rajiv Kohli, Developments in Surface Contamination and Cleaning, First, Elsevier, 2011.
[5] M. Gaetzel, A.J. Mcevoy, Principles and Applications of Dye Sensitized Nanocrystalline Photovoltaic cells (DSC), Asian J. Energy Environ. 5 (2004) 197– 210.
[6] M. Hoeven, Energy and Climate Change, World Energy Outlook Spec. Rep. (2015) 1–200. www.worldenergyoutlook.org.
[7] C.S. Solanki, Solar Photovoltaics: Fundamental Technologies and Applications, Second Edi, PHI, 2013.
[8] W. Siemens, Van Nostrands Engineering Magazine, (1885).
[9] M.A. Green, Silicon photovoltaic cells: evolution, high-efficiency design and efficiency enhancements, Semicond. Sci. Technol. 8 (1993) 1–12. doi:10.1088/0268- 1242/8/1/001.
[10] B.I. Kamiya, Engineering of Energy Conversion , Summer Semester 2012 Physics of photovoltaic cells The principles of operation and fundamental physics How to understand photovoltaic cells and other photovoltaics Semiconductor physics & electronics : Topics to be dealt : carrier gen, (2012) 1–11.
[11] M.A. Green, The path to 25% silicon photovoltaic cell efficiency: History of silicon cell evolution, Prog. Photovoltaics Res. Appl. 17 (2009) 183–189. doi:10.1002/pip.892.
[12] B. O'Regan, M. Grätzel, A low-cost, high-efficiency photovoltaic cell based on dyesensitized colloidal TiO2 films, Nature. 353 (1991) 737–740. doi:10.1038/353737a0.
[13] D.J. Friedman, S.R. Kurtz, K.A. Bertness, A.E. Kibbler, C. Kramer, J.M. Olson, D.L. King, B.R. Hansen, J.K. Snyder, Accelerated publication 30.2% efficient GaInP/GaAs monolithic two-terminal tandem concentrator cell, Prog. Photovoltaics Res. Appl. 3 (1995) 47–50. doi:10.1002/pip.4670030105.
[14] M. Gratzel, Photo electro chemical cells, Nat. (London, U. K.). 414 (2001) 338– 344. doi:10.1038/35104607.
[15] M.A. Green, K. Emery, Y. Hishikawa, W. Warta, Photovoltaic cell efficiency tables (version 37), Prog. Photovoltaics Res. Appl. 19 (2011) 84–92. doi:10.1002/pip.1088.
[16] M. Keevers, Engineers just created the most efficient photovoltaic cells ever, (2016) 1– 3. http://www.sciencealert.com (accessed July 7, 2016).

IIP Series is online, open access, peer-reviewed, interdisciplinary Journal. IIP Series provides a comprehensive solution for conferences and edited books that covers research topics across various scientific, technical, and medical disciplines. It aims at disseminating high-level research results and developments to researchers and research groups. It mainly focuses on presenting practical solutions for the current problems in Applied Sciences and Applied Social Sciences. It features original research work, reviews, case reports, tutorial papers, and accounts of practical developments.

Futuristic Trends in Mechanical Engineering

Volume 3 Book 4, 2024, IIP Series

ISBN : 978-93-6252-036-4