Design and Development of Compliant Microgripper By 3D Printing Technology

SUBMITTED BY

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Thesis submitted for the partial fulfillment ofthe requirements for the degree of

BACHELOR OF TECHNOLOGY

ELECTRICAL & ELECTRONICS ENGINEERING DEPARTMENT
INSTITUTE OF ENGINEERING & MANAGEMENT
MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY,
WEST BENGAL
2024

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April 2024

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CERTIFICATE

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ACKNOWLEDGEMENT

A brief acknowledgment, in just one page, only to those persons and organizations who have assisted the candidate in his /'her thesis work or provided relevant data / information / laboratory or research facilities and tools etc. should be given on this page.

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ABSTRACT

In recent years, the field of robotics has witnessed remarkable advancements, particularly in the development of specialized end-effectors known as microgrippers, which play a pivotal role in micromanipulation and micro-assembly tasks. This abstract provides an extensive overview of various types of microgrippers reported in the literature, focusing on their diverse actuation principles and performance characteristics.

One prevalent actuation principle employed in microgrippers is electrostatic actuation, where the application of an electric field induces gripping motion. Similarly, electrothermal microgrippers utilize thermal expansion to achieve precise control over gripping actions. However, challenges such as slow response times and thermal stability issues may arise with these devices, limiting their applicability in certain scenarios.

In contrast, microgrippers utilizing piezoelectric actuation have garnered significant attention due to their exceptional performance characteristics. Piezoelectric materials exhibit mechanical deformation in response to an applied electric field, enabling precise and rapid motion control with sub-nanometer positioning resolution. This remarkable capability makes piezoelectric microgrippers ideal for demanding micromanipulation tasks where precision and speed are paramount.

While the advancements in microgripper technology have been substantial, certain limitations persist. Jointed designs face challenges in maintaining grip stability and preventing part dropping due to issues with air pressure control. Similarly, magnetic grippers, explored in "Magnetic Gripper Using Magnetic Switchable Device," may require specific materials in grasped objects, thereby limiting their applicability to certain types of materials.

Furthermore, the structural components of robotic arms significantly influence their overall performance. The weight-strength ratio, in particular, plays a crucial role in determining factors such as payload capacity and energy efficiency. While traditional materials like aluminum and steel are commonly used for arm construction due to their strength and durability, recent research has explored alternative materials such as ABS plastic.

ABS plastic, known for its lightweight properties and suitability for 3D printing, presents an attractive option for improving both the weight-strength ratio and overall efficiency of robotic arms. By utilizing ABS plastic in arm construction, researchers aim to enhance arm performance while reducing manufacturing costs and complexity. This innovative approach offers the potential to revolutionize the design and construction of robotic arms, paving the way for more efficient and versatile robotic systems in various fields, including manufacturing, healthcare, and scientific research.
In conclusion, advancements in both end-effector design and arm construction are crucial for unlocking the full potential of robotic systems. Further research and development in this area are essential to address existing challenges and propel robotics technology into new frontiers

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INTRODUCTION
1.1 BACKGROUND

The background of Compliant microgrippers lies in the quest for developing robotic grippers capable of delicately manipulating objects with precision and adaptability, particularly at the microscale. Traditional rigid grippers often struggle with handling fragile or irregularly shaped objects without causing damage or deformation. Compliant, the ability to deform or yield under applied forces, offers a solution to this challenge.

The concept of Compliant grippers draws inspiration from biological systems, such as human fingers, which exhibit Compliant to effectively grasp and manipulate objects of varying shapes and sizes. Mimicking this Compliant in robotic grippers allows for gentle and adaptive manipulation, enabling tasks such as picking up delicate electronic components, handling biological samples, or performing intricate assembly operations.

Research in Compliant microgrippers has focused on developing structures and materials that exhibit controlled deformation under applied forces while maintaining sufficient stiffness for stable grasping. Various design approaches, including soft robotics, flexible materials, and Compliant mechanisms, have been explored to achieve the desired Compliant characteristics.

Compliant microgrippers offer several advantages over rigid counterparts, including improved adaptability to object shapes, reduced risk of damage or breakage, and enhanced dexterity in handling delicate items. These attributes make them well-suited for applications in fields such as biomedical engineering, microelectronics assembly, and lab automation, where precise and gentle manipulation of small objects is essential.

The background research on Compliant microgrippers highlights the importance of balancing Compliant with stability and control. Achieving the optimal design requires considerations of material properties, mechanical structures, actuation mechanisms, and control strategies. By leveraging advancements in materials science, fabrication techniques, and robotics control, researchers continue to push the boundaries of Compliant microgripper technology, paving the way for innovative solutions in various industries

1.2 PROBLEM STATEMENT

Despite significant advancements in robotic gripper technology, the development of Compliant microgrippers still faces several challenges. While Compliant offers the potential for gentle and adaptive manipulation of small objects, achieving the desired balance between Compliant and stability remains a key obstacle. Current Compliant microgrippers often struggle to provide precise control over grasping forces and object manipulation, particularly at the microscale. This limitation hinders their effectiveness in tasks requiring delicate handling, such as biomedical research, microelectronics assembly, and lab automation.

Furthermore, the design and fabrication of Compliant microgrippers present additional challenges. The selection of suitable materials with the required mechanical properties, including flexibility, durability, and biocompatibility, is crucial but often complex. Additionally, the integration of Compliant mechanisms and actuation systems while maintaining overall gripper performance poses technical hurdles.

Issues such as structural deformation, hysteresis, and non-linear behavior need to be addressed to ensure reliable and consistent operation of Compliant microgrippers. Moreover, the control and sensing aspects of Compliant microgrippers present significant challenges. Achieving precise control over grasping forces, finger Compliant, and object manipulation in dynamic environments requires advanced sensing and control algorithms. The development of robust control strategies capable of adapting to varying object properties and environmental conditions is essential for maximizing the effectiveness of Compliant microgrippers in real-world applications.

In summary, the problem statement revolves around addressing the challenges associated with achieving optimal Compliant, stability, and control in microscale robotic grippers. By overcoming these challenges, researchers aim to unlock the full potential of Compliant microgrippers and enable their widespread adoption in various industries requiring precise and delicate manipulation of small objects

1.3 AIMS AND OBJECTIVES

Robots have existed for almost 100 years, and the improvement of mechanical movements has never stopped since then. Motion, precision, and control are continually improving and refined to optimize robotic handling. 3D printing is ideal for that robotic design. The objective of a robotic microgripper using Compliant structures is to enable the gripping and manipulation of small objects with precision and delicacy, without causing damage to the objects being handled. Compliant structures are flexible and deformable materials that allow for gentle grasping and manipulation of objects without exerting excessive force.

The use of Compliant structures in microgrippers allows for improved dexterity and sensitivity, making them suitable for a range of applications, including micromanipulation, biomedical research, and industrial automation. The Compliant nature of these grippers also enables them to adapt to irregularly shaped objects, improving their versatility.

Overall, the objective of a robotic microgripper using Compliant structures is to enable precise and delicate manipulation of small objects in a variety of applications, without damaging the objects being handled.

- Integration and Innovation structure to save time and money on the assembly line.
- Structure and design in one line so the structure become lighter.
- Gripper Customization.
- Design and develop an innovative robotic gripper.
- Enable precise and delicate manipulation of small objects.
- Incorporate compliant structures to enhance adaptability.
- Minimize damage to manipulated objects.
- Investigate advanced materials and actuators for improved gripping force and sensitivity.
- Explore applications in biomedical research, industrial automation, and micromanipulation.

CHAPTER 2
LITERATURE REVIEW

The field of robotics, particularly in the realm of micromanipulation and micro-assembly tasks, relies heavily on the development of specialized end-effectors[1] known as microgrippers. These devices are essential for precise handling and manipulation of objects at a microscopic scale, and their design and actuation mechanisms play a crucial role in determining their effectiveness. In the literature, various types of microgrippers have been reported, each employing different actuation principles to achieve the desired functionality[2].

One common actuation principle utilized in microgrippers is electrostatic actuation, where the application of an electric field induces motion in the gripping mechanism[3][4]. Electrostatic microgrippers offer advantages such as simplicity and low power consumption, making them suitable for certain applications. Similarly, electrothermal microgrippers utilize the thermal expansion of materials to achieve gripping motion. While these devices can provide precise control, they may also face challenges such as slow response times and thermal stability issues[6].

Among the different types of microgrippers, those employing piezoelectric actuation have garnered significant attention due to their exceptional performance characteristics. Piezoelectric materials exhibit a unique property where mechanical deformation occurs in response to an applied electric field, enabling precise and rapid motion control. Microgrippers utilizing piezoelectric actuators[7] offer sub-nanometer positioning resolution and high-speed operation, making them ideal for demanding micromanipulation tasks.

However, despite the advancements in microgripper technology, certain limitations persist. In "Some Aspects of Multi-Fingered Grippers," authors discuss the challenges associated with jointed designs, particularly in maintaining grip stability and preventing part dropping due to issues with air pressure control. Similarly, magnetic grippers, as explored in "Magnetic Gripper Using Magnetic Switchable Device," offer simplicity but may require the presence of specific materials in grasped objects, posing limitations in certain applications.

In addition to end-effector design, the structural components of robotic arms also play a crucial role in determining their performance. The weight-strength ratio of a robotic arm is particularly relevant, as it influences factors such as payload capacity, maneuverability, and energy efficiency. Traditional materials such as aluminum and steel are commonly used for arm construction due to their strength and durability. However, recent research has explored alternative materials such as ABS plastic, known for its lightweight properties and suitability for 3D printing[10].

By utilizing ABS plastic in arm construction, researchers aim to improve both the weight-strength ratio and overall efficiency of robotic arms. This innovative approach offers the potential to enhance arm performance while reducing manufacturing costs and complexity. Ultimately, advancements in both end-effector design and arm construction are crucial for expanding the capabilities of robotic systems in various fields, including manufacturing, healthcare, and scientific research.

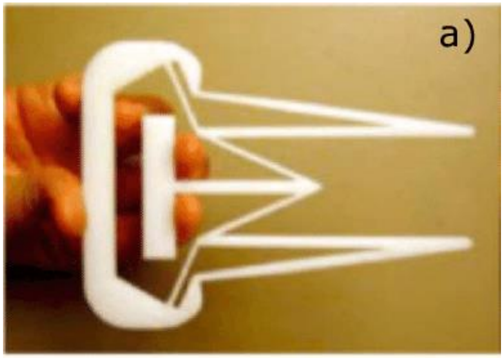
Chapter 3
STRUCTURE AND METHODOLOGY

- **Compliant Structure:** Compliant mechanisms transfer motion, force, or energy through the deformation of their flexible components. It gains some or all of its motion from the relative flexibility of its members rather than from rigid-body joints alone. There are mainly three types of Compliant mechanisms based on their distribution pattern namely:
    1. Lumped Compliant Mechanism.
    2. Distributed Compliant Mechanism.
    3. Hybrid Compliant Mechanism.

Design Method:
- **Kinematics approach:** Kinematics analysis can be used to design a Compliant mechanism by creating a pseudo-rigid body model of the mechanism.
- **Structural optimization approach:** In this method, computational methods are used for topology optimization of the structure. Expected loading and desired motion and force transmission are input and the system is optimized for weight, accuracy, and minimum stresses.

Advantages:
- Low Cost
- Better Efficiency

Disadvantage:
- No purely Compliant mechanism can achieve continuous motion such as found in a normal joint. Also,
- The forces applied by the mechanism are limited to the loads the structural elements can withstand without failure.
- Due to the shape of flexure joints, they tend to be locations of stress concentration.



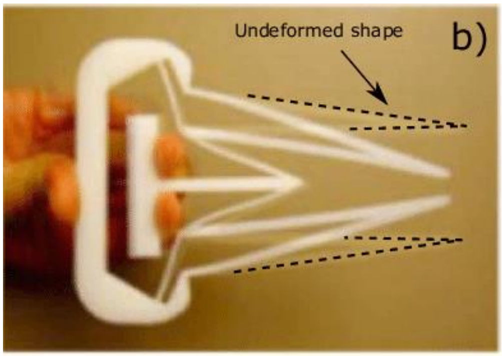


Fig. 1 Normal Position

Fig. 2 After Applying Force

PROPOSED DESIGN

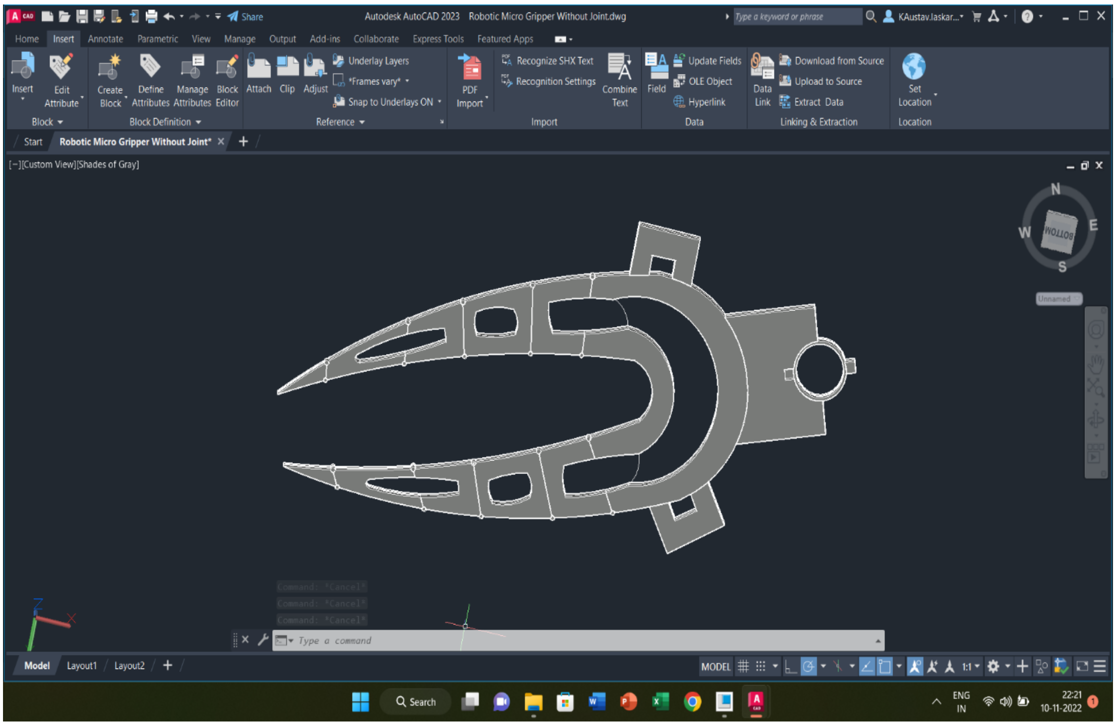


Fig. 3 First CAD Design

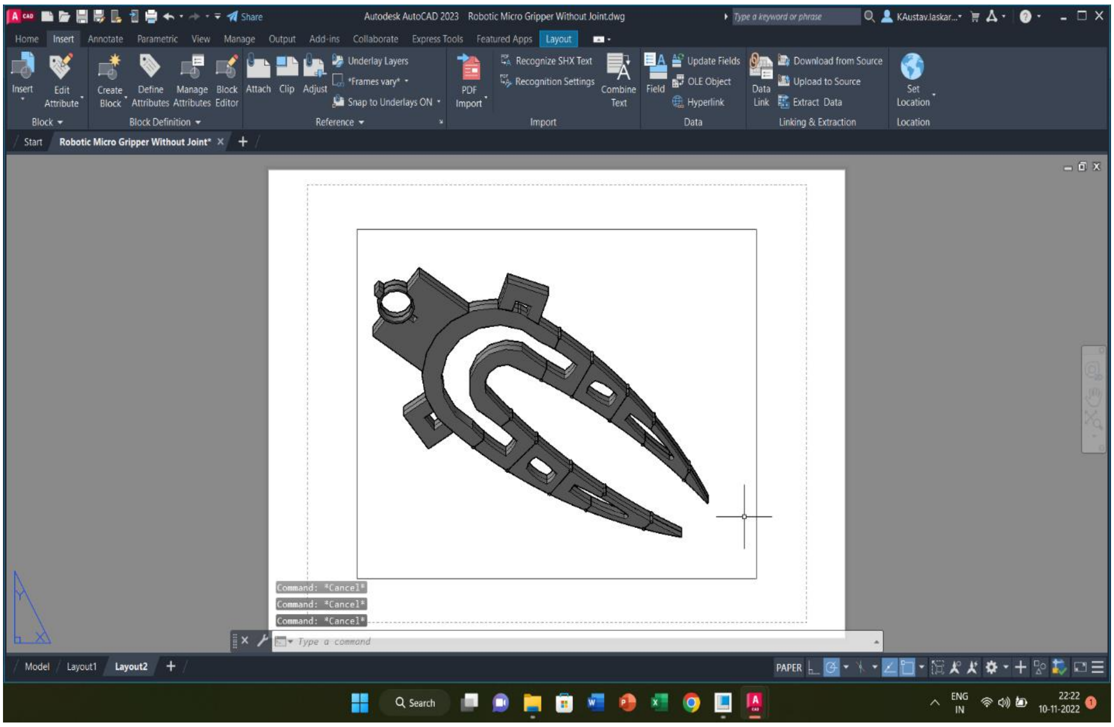


Fig. 4 CAD design Side View

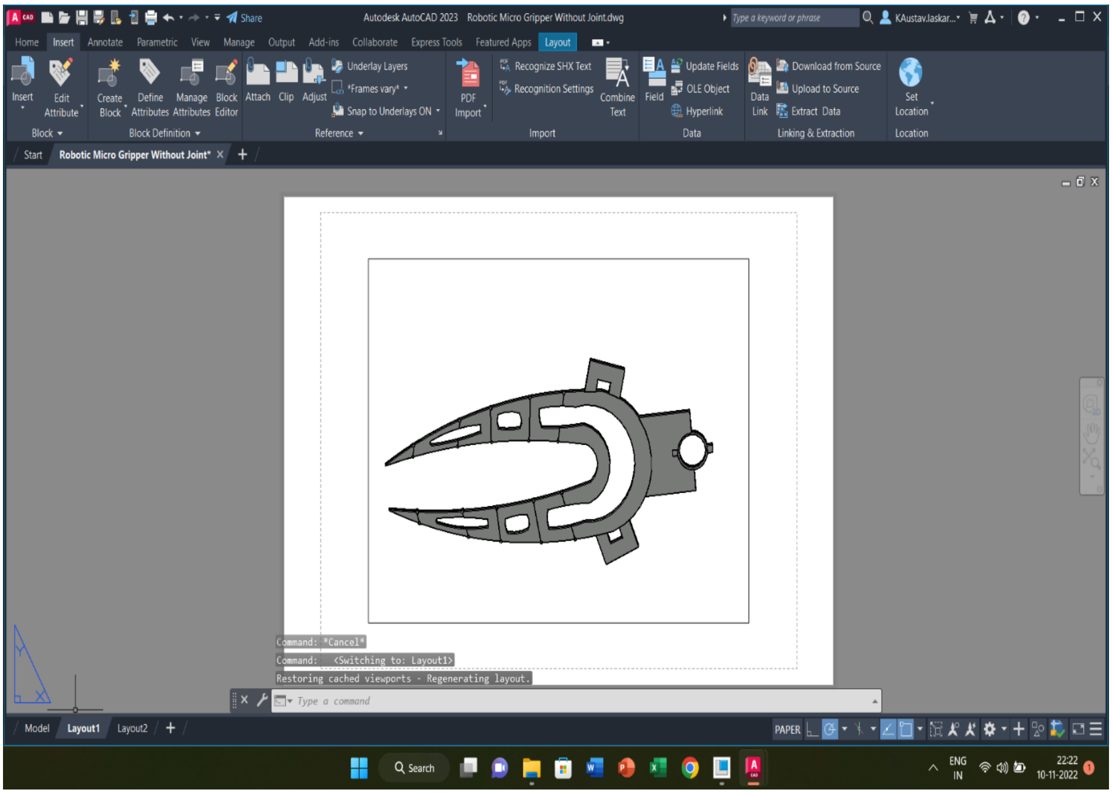


Fig. 5 CAD Design Top View

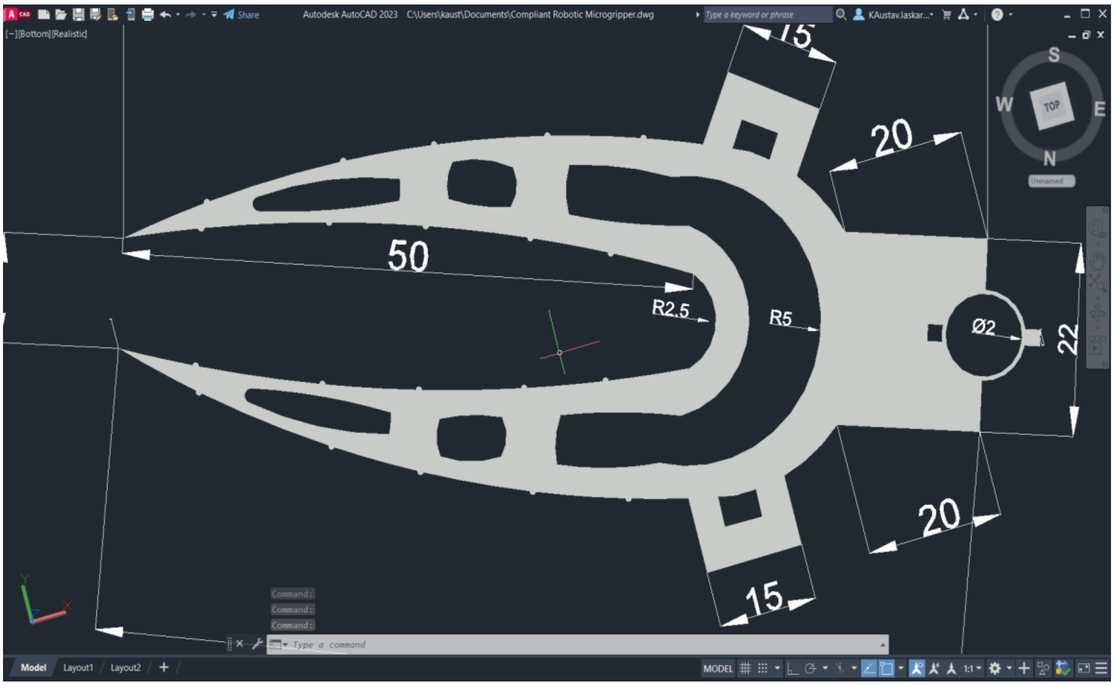


Fig. 6 CAD Dimension View

GRIPPER MATERIAL SELECTION

Low elastic moduli materials and smart structures that are inspired by nature empower soft robots to perform tasks by mechanically adapting their bodies to dynamic environments by undergoing extremely large deformations without any sign of material or structural failures due to their inherent softness. In this project, we have selected three materials primarily ABS, PLA, and Nylon.

- **Polylactic acid (PLA):** PLA is a user-friendly thermoplastic with higher strength and stiffness than both ABS and nylon. With a low melting temperature and minimal warping, PLA is one of the easiest materials to 3D print successfully. Unfortunately, its low melting point also causes it to lose virtually all stiffness and strength at temperatures above 50 degrees Celsius. In addition, PLA is brittle, leading to parts with poor durability and impact resistance. Although PLA is the strongest of these three plastics, its poor chemical and heat resistance force it into almost exclusively hobbyist applications.

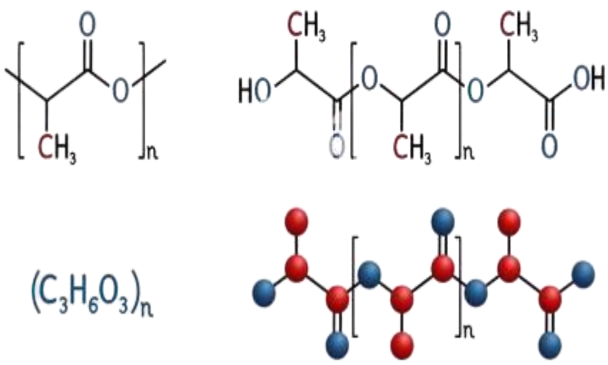


Fig. 7 Structure of PLA

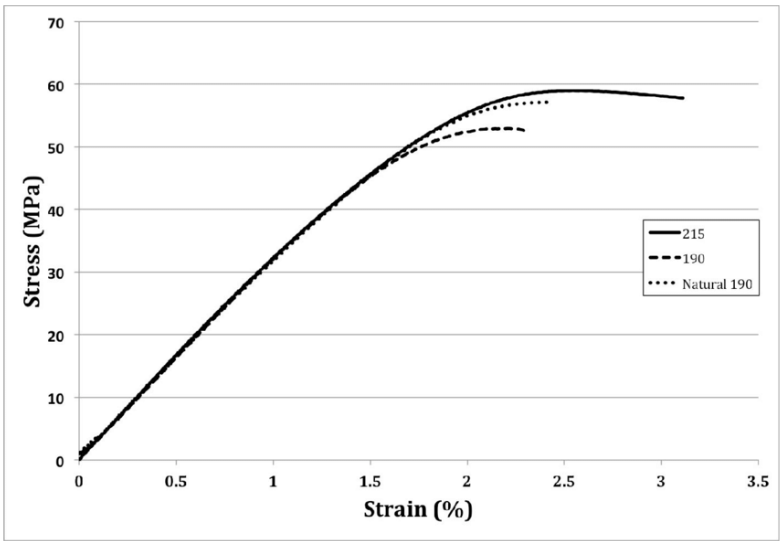


Fig. 8 Stress-strain Curve of PLA Material

❖ **Acrylonitrile Butadiene Styrene (ABS):** ABS, while weaker and less rigid than PLA, is a tougher, lighter filament more suitable for some applications beyond pure hobbyist. ABS is a bit more durable, is about 25% lighter, and has four times the higher impact resistance. ABS does require more effort to print than PLA because it's more heat resistant and prone to warping. This calls for a heated bed and an extruder that is 40-50 degrees Celsius hotter. ABS, while by no means a heat-resistant plastic, has superior heat deflection temperature compared to PLA and nylon.

The improved durability over PLA lends ABS to some more practical applications, such as prototyping and low-stress end-use parts.

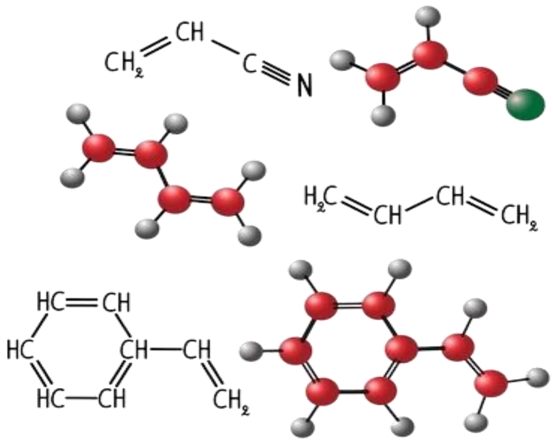


Fig. 9 Structure of ABS

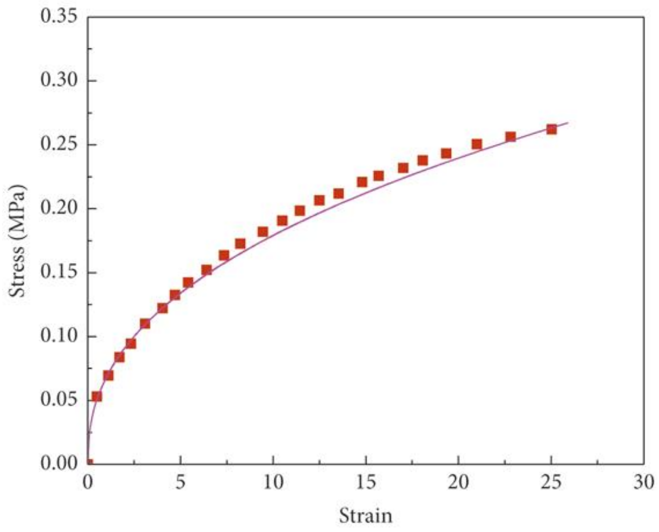


Fig. 10 Stress-strain Curve of ABS Material

❖ **Nylon (With Onyx):** Filled nylon is a mixture of nylon with small particles of a stronger material such as fiberglass or carbon fiber. These mixtures preserve the favorable properties of nylon while adding considerable strength and stiffness. Markforged Onyx filament is an example of one of these mixtures, combining nylon with chopped carbon fiber to improve the material's key properties. Onyx is 1.4 times stronger and stiffer than ABS and can be reinforced with any continuous fiber. The development of 3D-

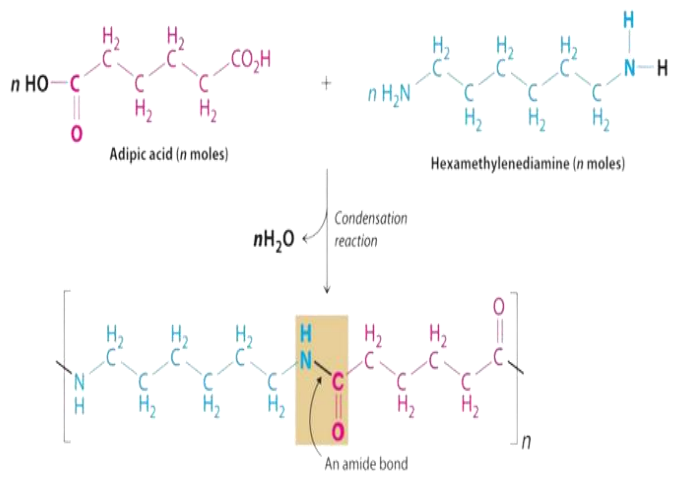


Fig. 11 Structure of NYLON

printed continuous fibers has enabled a new category of stronger 3D parts.

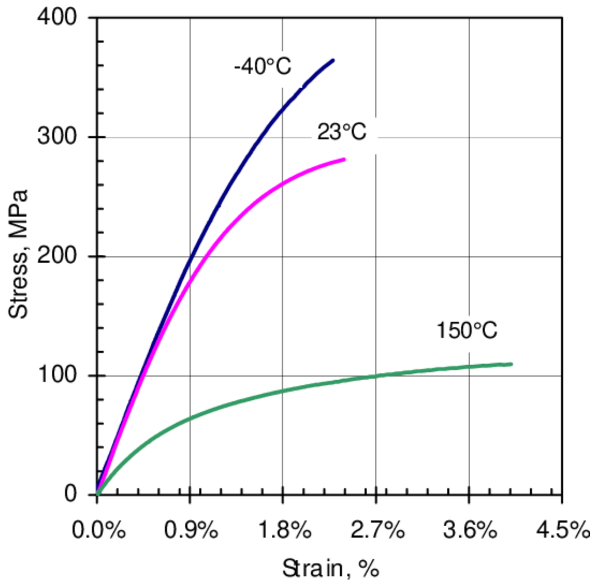


Fig. 12 Stress-Strain Curve of Nylon at Various Sample

❖ **Thermoplastic polyurethane (TPU):** Thermoplastic polyurethane (TPU) is a melt-processable thermoplastic elastomer with high durability and flexibility. It provides several physical and chemical property combinations for demanding applications. It has properties between the characteristics of plastic and rubber. In terms of practical use, TPU offers desirable material properties like flexibility, good tensile strength, and resistance to tears and abrasions.

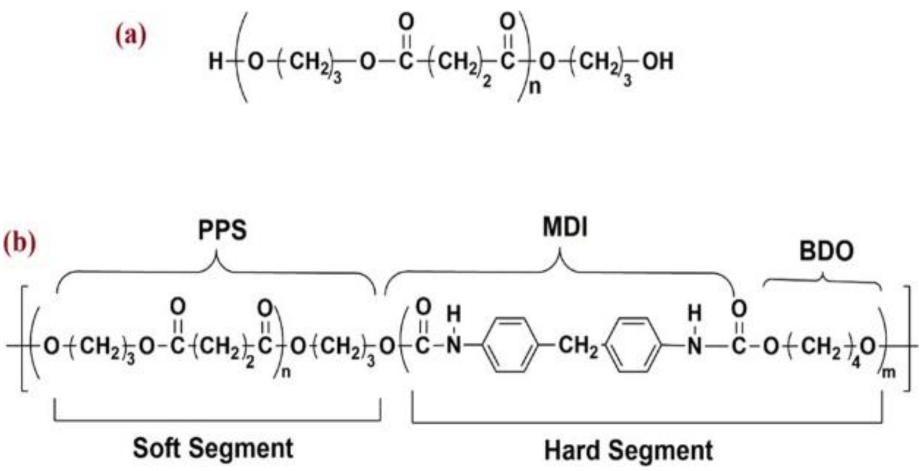


Fig. 13 Structure of TPU

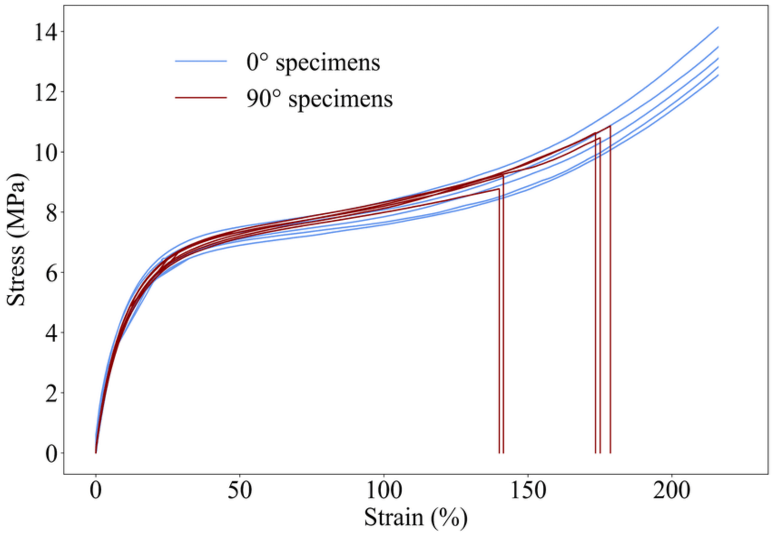


Fig. 14 Stress-strain Curve of TPU Material

COMPARATIVE STUDY

PROPERTIES	Acrylonitrile Butadiene Styrene	Nylon	Polylactic acid	Thermoplastic polyurethane
Strength	●●○○○	●○○○○	●●●○○	●●●●○
Stiffness	●●○○○	●○○○○	●●●○○	●●○○○
Durability	●●○○○	●●●●○	●○○○○	●●●○○
Chemical Resistance	●○○○○	●●●●○	●○○○○	●●○○○
Printability	●●●○○	●●○○○	●●●●○	●●○○○
Heat Resistance	●●○○○	●○○○○	○○○○○	●●○○○

Properties	Acrylonitrile Butadiene Styrene	Nylon	Polylactic acid	Thermoplastic polyurethane
Elongation	10-50%	60-110%	6%	10.0-86.0%
Flexibility	1.6-2.4GPa	3.10GPa	4GPa	0.520-4.50GPa
Hardness Shore	100	80	75	98
Stiffness	1.6-2.4GPa	1.27GPa	50-70MPa	22.0-472MPa
Strength (Tensile)	29.8-43MPa	55-86MPa	50-70MPa	53.7MPa
Young Modulus	1.79-3.2GPa	2.7GPa	3.5GPa	0.621-5.50GPa

❖ From the above discussion, we have primarily selected ABS material for its less rigid, but also tough, and lighter properties which make it a better plastic for prototyping application.

PROTOTYPING

- **Prototype I**: The first iteration of the robotic microgripper consisted of two parallel arms connected by a flexure mechanism. The flexure mechanism was designed to allow the arms to move to each other, enabling the gripper to open and close. The prototype was 3D printed using ABS material. The gripping force was measured using a force sensor. Due to its small size and high material density, the gripper doesn’t work properly. So, we change the design of the gripper and reduce the thickness of the gripper and adjust the mechanism.

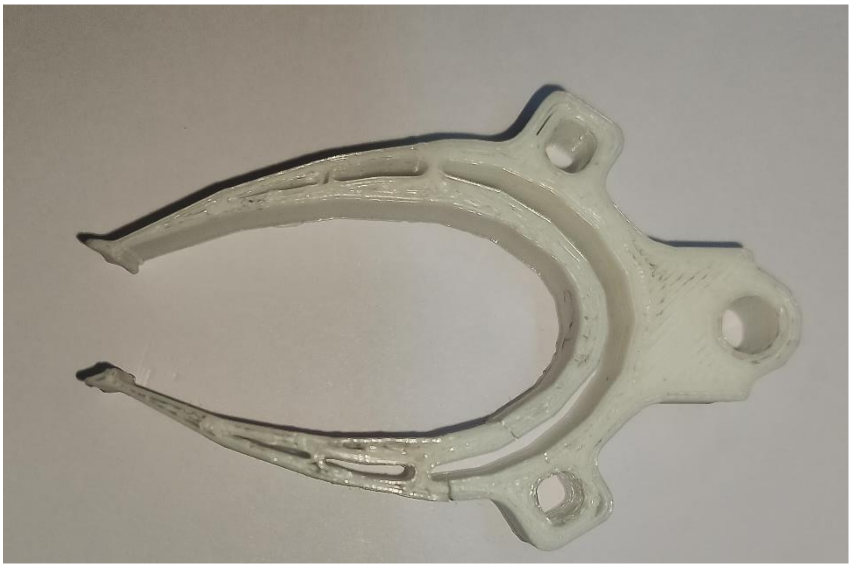


Fig. 15 1St Prototype

Fig. 16 2nd Prototype of 1st Iteration

❖ **Prototype II:** In the second iteration, the flexure mechanism was modified to provide more flexibility, allowing the arms to move more freely. The gripper was also equipped with two fingers with serrated tips to improve the gripping force. The prototype was 3D printed using ABS material. We are planning to work the gripper using a servo motor, and the gripping force was measured using a force sensor. The results showed a significant improvement in gripping force compared to the first prototype.

Fig. 17 1st Prototype of Iteration II

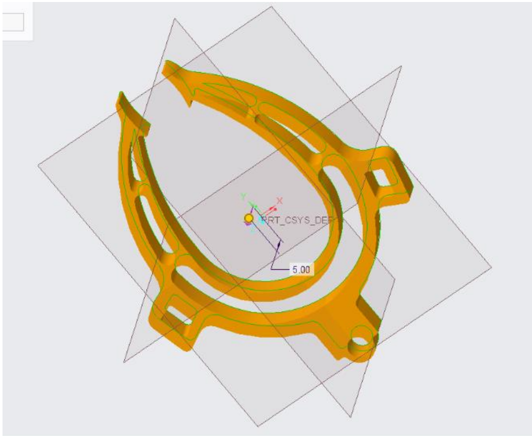


Fig. 18 CAD view f Prototype II

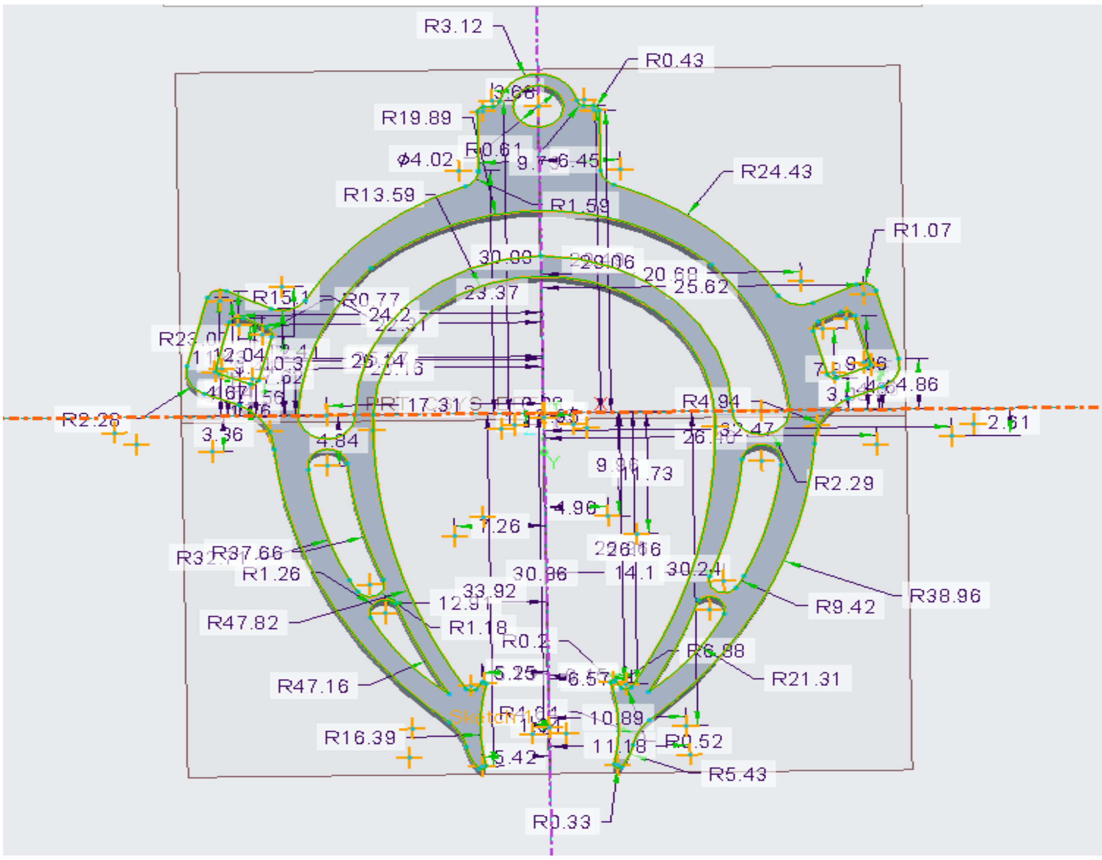


Fig. 19 Dimension View of 2nd Prototype

- **Prototype III :** In the third iteration, the flexure mechanism was modified to provide more flexibility, allowing the arms to move more freely. The shape of this gripper is changed. The prototype was 3D printed using TPU material. The results showed a significant improvement in gripping force compared to the first prototype.

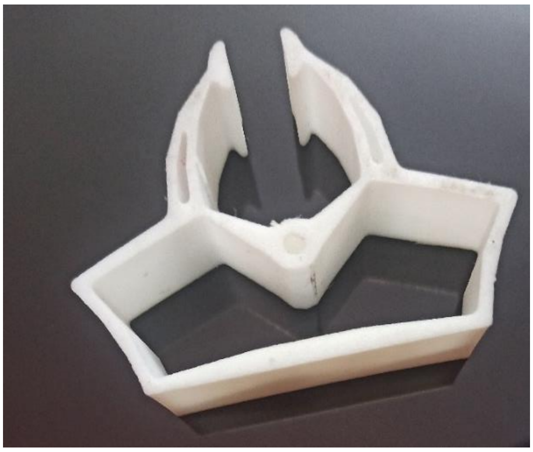


Fig. 20 1st Prototype of 3rd Iteration

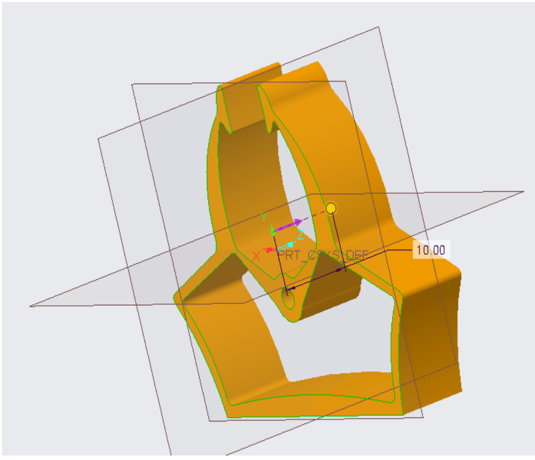


Fig. 21 CAD view of 3rd Prototype

ARM MATERIAL SELECTION

There are two part in arm material section. One is electrical component part and another is 3D printing part.

ELECTRICAL COMPONENT

In the electrical part we have used the following things-

1. Arduino UNO
2. Servo Motor
3. Servo Driver
4. Potentiometer
5. Power Supply
6. Toggle Switch

❖ **Arduino UNO:** The Arduino UNO is a standard board of Arduino. Here UNO means 'one' in Italian. It was named as UNO to label the first release of Arduino Software. It was also the first USB board released by Arduino. It is considered as the powerful board used in various projects. Arduino.cc developed the Arduino UNO board. Arduino UNO is based on an ATmega328P microcontroller. It is easy to use compared to other boards, such as the Arduino Mega board, etc. The board consists of digital and Analog Input/Output pins (I/O), shields, and other circuits.The Arduino UNO includes 6 Analog pin inputs, 14 digital pins, a USB connector, a power jack, and an ICSP (In-Circuit Serial Programming) header. It is programmed based on IDE, which stands for Integrated Development Environment. It can run on both online and offline platforms.

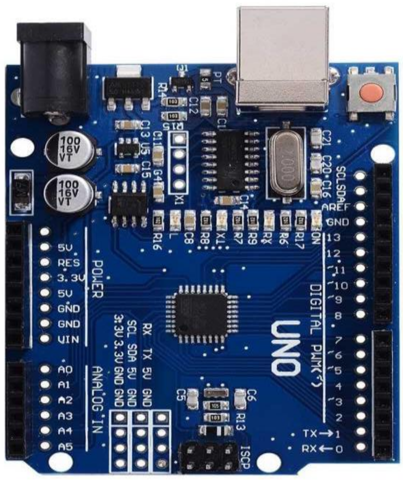


Fig. 22 Arduino UNO

❖ **Servo Motor:** A servo motor is a sophisticated type of electric motor engineered to deliver precise control over angular or linear position, velocity, and acceleration, finding widespread application in industries such as robotics, CNC machining, industrial automation, and aerospace. At its core, a servo motor integrates a feedback mechanism, often in the form of encoders or potentiometers, establishing a closed-loop control system. This system constantly compares the actual position of the motor with the desired position, enabling real-time adjustments to ensure accuracy and stability in operation. Noteworthy for their capability to adjust speed and torque dynamically, servo motors offer

Fig. 23 Servo Motor

unparalleled precision and versatility. Despite their advanced functionality, servo motors typically maintain a compact and lightweight design, making them well-suited for applications where space and weight constraints are paramount. Overall, servo motors stand as indispensable components, facilitating precise motion control in a wide array of industrial and technological endeavors.

- **Servo Driver:** The PCA9685 is a versatile 16-channel PWM (Pulse Width Modulation) controller designed to facilitate precise control over LED brightness or servo motor movements in various applications. Developed by NXP Semiconductors, this integrated circuit offers a simple and efficient solution for managing multiple PWM outputs simultaneously. With its high-resolution 12-bit PWM capability, the PCA9685 allows for smooth and flicker-free dimming of LEDs or accurate positioning of servo motors. Additionally, its I2C interface enables seamless communication with microcontrollers and other devices, simplifying integration into existing electronic systems. The PCA9685 also features a programmable pre scaler to adjust the PWM frequency, providing flexibility to optimize performance based on specific application requirements. Overall, the PCA9685 stands as a reliable and cost-effective solution for achieving precise control over PWM-enabled devices in a wide range of electronic projects and products.

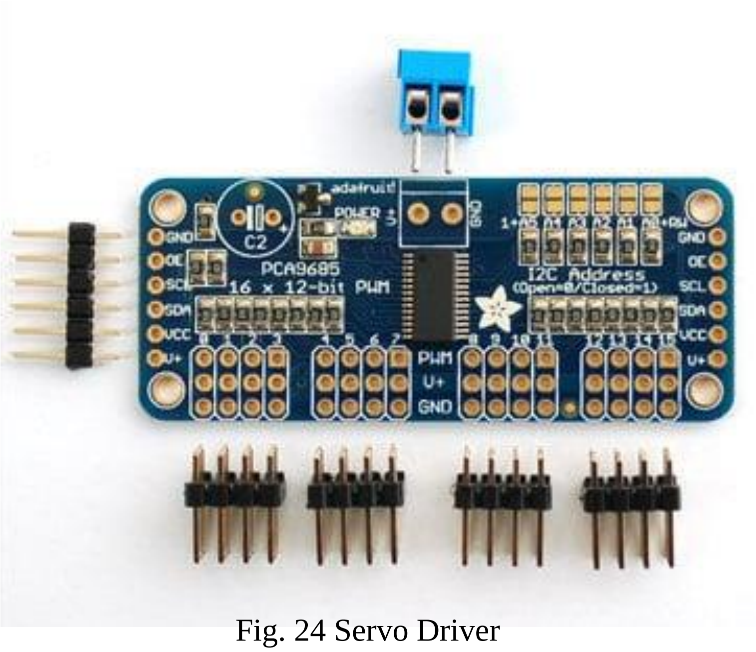


Fig. 24 Servo Driver

- **Potentiometer:** A 10k potentiometer, short for a 10 kilohm potentiometer, is a specific type of variable resistor with a resistance value of 10,000 ohms. It operates in the same manner as a standard potentiometer, featuring three terminals: the two fixed outer terminals and a movable wiper. By rotating the knob or shaft connected to the potentiometer, the position of the wiper along the resistive track changes, resulting in a variable resistance between the wiper and each terminal. In the case of a 10k potentiometer, the resistance between the wiper and one of the outer terminals

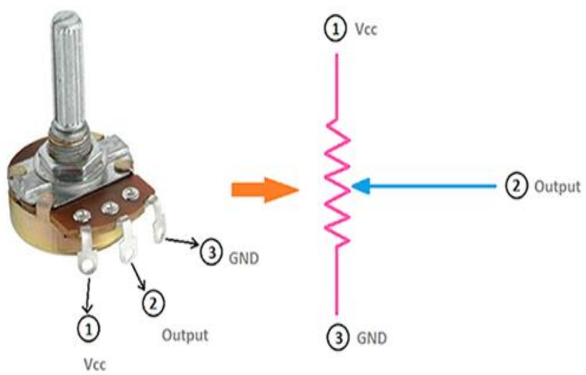


Fig. 25 Potentiometer

ranges from 0 ohms to 10,000 ohms as the wiper is adjusted across the track. This variation in resistance allows the potentiometer to regulate voltage levels or adjust signal levels in electronic circuits. The 10k potentiometer is commonly used in audio equipment, instrumentation, control systems, and various other applications where precise adjustment of resistance or voltage is required.

- **Power Supply:** A 5V 1A (ampere) adapter is a power supply device designed to deliver a stable output of 5 volts and a maximum current of 1 ampere. This adapter is commonly used to power small electronic devices such as smartphones, tablets, Raspberry Pi, Arduino boards, and other low-power gadgets. With its standardized USB output, it provides a convenient and reliable charging solution for a wide range of portable devices, ensuring efficient and safe operation. The compact and lightweight design makes it ideal for travel or everyday use, while its regulated output voltage protects connected devices from overvoltage or fluctuations in power supply.

Fig. 26 Power Supply

- **Toggle Switch :** A toggle switch is a manual electrical switch with a lever that can be toggled between two positions, typically "on" and "off." In the "on" position, the switch allows current to flow through, completing the circuit, while in the "off" position, it interrupts the flow of current. Commonly used in electronic circuits and electrical systems, toggle switches are appreciated for their simplicity, durability, and ease of operation. They come in various configurations and sizes, making them suitable for a wide range of applications, from household appliances to industrial machinery, where reliable control of electrical currents is essential.

Fig. 27 Toggle Switch

- **Jumper Wire:** Jumper wires are flexible insulated wires with connectors on each end, serving to establish temporary electrical connections between components like breadboards, sensors, and microcontrollers in electronic projects. Available in various lengths and connector types, they facilitate easy circuit prototyping and experimentation without the need for soldering. Ideal for hobbyists, students, and professionals, jumper wires simplify wiring tasks, enabling rapid testing and modification of circuit designs for efficient project development.

Fig. 28 Jumper Wire

3D PRINTING PART

In 3D printing Part there are six parts-

1. Base
2. Shoulder
3. Elbow
4. Wrist
5. Hand
6. Controller

❖ **Base:** The base of a robotic arm serves as the foundational support structure upon which the entire arm assembly is mounted. This critical component provides stability and anchorage for the arm's movement and operation. Typically, it houses motors, gears, or other mechanisms necessary for rotating the arm horizontally or vertically, enabling precise positioning of the end effector. Constructed from durable materials like aluminum or steel, the base ensures rigidity and resilience to withstand the forces exerted during operation. Its design influences the arm's range of motion, payload capacity, and overall functionality, making it a fundamental element in robotic arm systems for various applications.

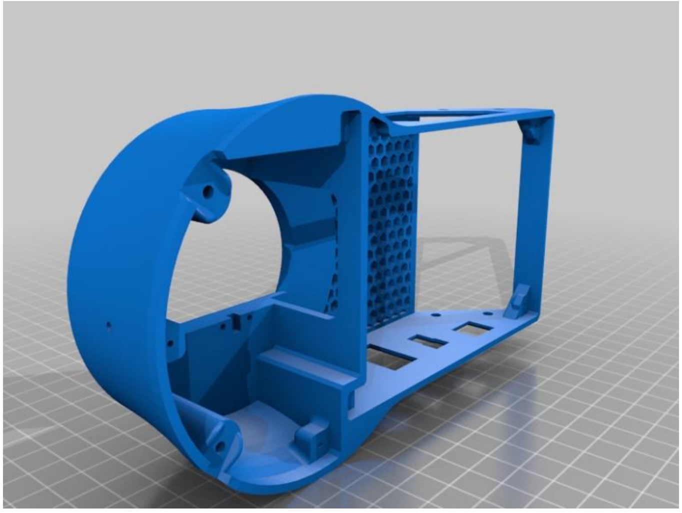


Fig. 29 CAD view of BASE

❖ **Shoulder:** The shoulder of a robotic arm serves as the pivotal joint connecting the arm to the base, allowing for pivotal movement along one axis, typically in the vertical plane. It functions as the primary point of articulation, enabling the arm to raise, lower, and tilt sideways. Equipped with powerful motors and precision gears or actuators, the shoulder provides the necessary torque and control for lifting and

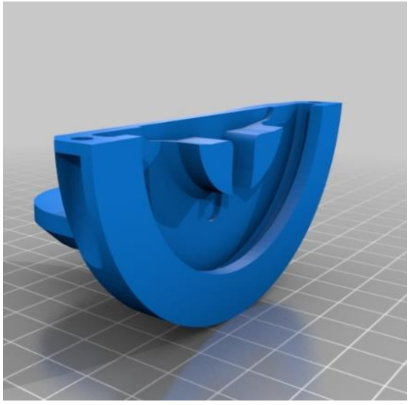


Fig. 30 CAD view of Shoulder I

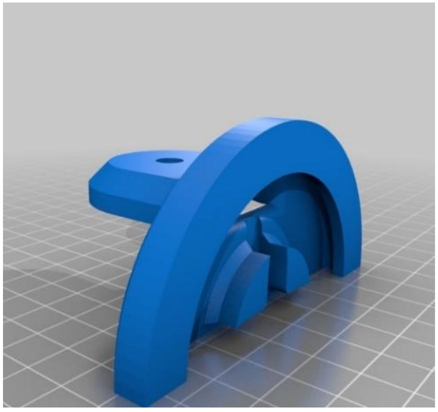


Fig. 31 CAD view of Shoulder II

positioning the arm's payload with accuracy. Its design influences the arm's reach, dexterity, and workspace, crucial for performing tasks across a variety of industries, from manufacturing and assembly to healthcare and research.

❖ **Elbow:** The elbow of a robotic arm serves as a pivotal joint allowing for bending and rotation, typically along one axis, facilitating precise positioning of the arm's end effector. Positioned between the shoulder and wrist, it enables the arm to extend, retract, and bend at various angles, enhancing its flexibility and reach. Equipped with powerful motors and mechanisms, the elbow provides the necessary torque and control for manipulating objects with accuracy and efficiency. Its design influences the arm's range of motion, workspace accessibility, and ability to perform complex tasks in diverse environments, making it a vital component in robotic arm systems across industries.

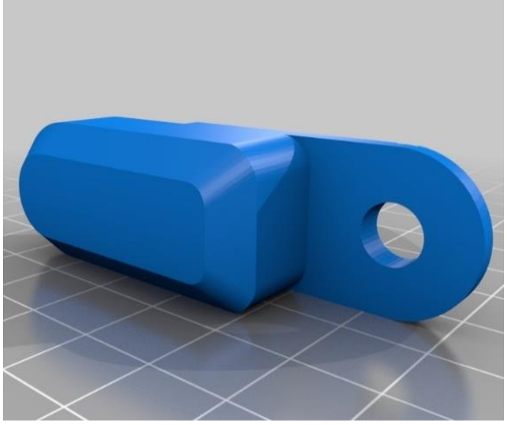


Fig. 32 CAD view of Elbow I

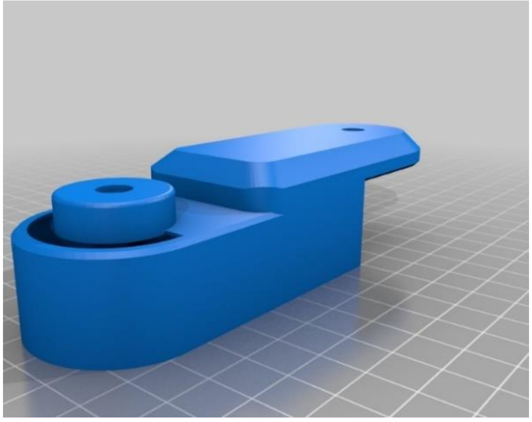


Fig. 33 CAD view of Elbow I

❖ **Wrist:** The wrist of a robotic arm serves as a versatile joint enabling multi-directional movement and orientation of the end effector, enhancing the arm's dexterity and precision. Positioned at the end of the arm, it allows for rotation around multiple axes, facilitating intricate manipulation and positioning of objects in three-dimensional space. Equipped with motors, gears, or actuators, the wrist

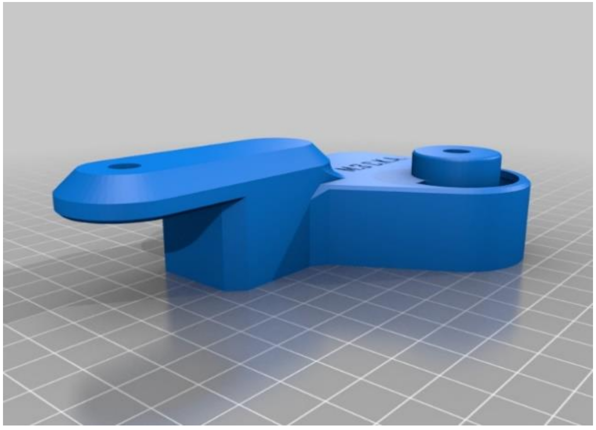


Fig. 34 CAD view of Wrist I

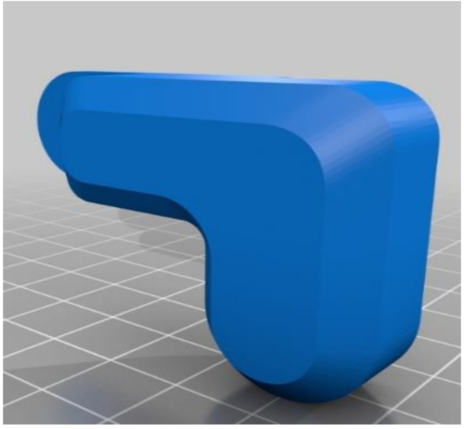


Fig. 35 CAD view of Wrist I

provides the necessary torque and control for precise movements, such as gripping, rotating, and tilting. Its design influences the arm's ability to adapt to various tasks and environments, making it a crucial component in robotic arm systems used in manufacturing, assembly, and research.

- **Hand:** The hand of a robotic arm, often referred to as an end effector, represents the functional interface between the arm and the task it performs. It's designed to mimic the dexterity and versatility of a human hand, with fingers, grippers, or specialized tools tailored to specific applications. Equipped with sensors, actuators, and sometimes cameras, it can grasp, manipulate, and interact with objects with precision and control. The design of the robotic hand varies widely based on the intended task, ranging from simple grippers for picking up objects to more complex designs capable of delicate assembly or intricate tasks in fields such as surgery or space exploration

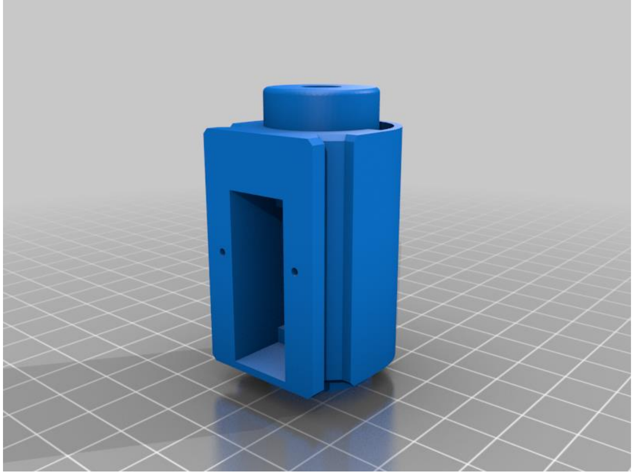


Fig. 36 CAD view of HAND

- **Controller:** A robot controller made using a potentiometer for a robotic arm provides a straightforward and intuitive means of commanding the arm's movements. The potentiometer's variable resistance is harnessed to regulate the arm's actions. By turning the potentiometer's knob or shaft, the operator can precisely adjust the arm's position, velocity, or other parameters in real-time. This analog control method offers immediate and direct manipulation, enabling operators to finely tune the arm's movements with ease. Integrated with feedback mechanisms like encoders or sensors, the controller ensures accuracy and consistency in positioning, enhancing the arm's overall performance. With its simplicity and responsiveness, the potentiometer-based controller is suitable for a range of applications, from precise assembly tasks in manufacturing to delicate operations in medical procedures. Its intuitive nature makes it accessible to users of varying skill levels, facilitating efficient and effective control of the robotic arm in diverse environments

Fig. 37 CONTROLLER

STUDY OF COMPONENT MATERIAL AND THEIR COST

SL NO	PRODUCT	QUANTITY	RATE	AMOUNT
Electrical & Electronics Component				
1	High Torque Servo 20kg LewanSoul LD-20MG	**1pcs**	1400	**1400**
2	Normal Servo MG996R 55g	**4pcs**	330	**1320**
3	Micro Servo	**1pcs**	150	**150**
4	Servo Driver PCA9685 16 Channel 12-Bit PWM	**1pcs**	330	**330**
5	Arduino UNO	**1pcs**	750	**750**
6	Potentiometer WH148 Type B10K 3 Pin	**4pcs**	100	**100**
7	Push Button	**1pcs**	20	**20**
8	Power Switch 6A	**1pcs**	30	**30**
9	T Connector	**1pcs**	20	**20**
10	Led	**5pcs**	2	**10**
11	Clear Acrylic	**1pcs**	25	**25**
12	Power Supply	**1pcs**	150	**150**
13	Shrink Pipe	**20pcs**	30	**30**
14	Araldite	**1Pac**	50	**50**
15	Wire (Red, Yellow, Black)	**52cm**	60	**60**
16	SCREW & GEAR			
	2.5*1.6*4.5 Screw	**10pcs**	450	**450**
	M4*6mm + Washer	**4pcs**		
	M3*8mm + Washer	**4pcs**		
	M2*8mm + Washer(6pcs)	**1pcs**		
	M3*30mm	**4pcs**		
	M2*4mm	**12pcs**		
	M2*6mm	**7pcs**		
	40 Teeth gear	**2pcs**		
	34 Teeth Gear	**1pcs**		
17	Wire Stripper	**1pcs**	60	**60**
18	Screw Driver Set	**1pac**	250	**250**
19	Glue	**1Pcs**	30	**30**
20	Circular Servo Horns	**3pcs**	10	**30**
21	Pin Connector	**2 Row**	5	**10**
3D Printing Component				
22	Arm Printing 720gm(approx.)	**1pcs Full**	Rs.5/gram - PLA	**3600**
23	Gripper Printing	**1Pcs**	1500	**1500**
TOTAL COST				**10375**

ARM DESIGNING AND ELECTRICAL CIRCUIT

A 4-degree-freedom robotic arm, as its name suggests, boasts four independent axes of movement, enabling a range of complex manipulations. Compared to simpler 3-DOF arms, these dexterous machines unlock new possibilities in various fields. The robotic arm is constructed with lightweight yet durable materials to ensure efficient movement and reduce inertia. The 4-DOF configuration providing flexibility in reaching targets from various orientations. The joint mechanisms utilize high-torque actuators and advanced gear systems to enhance payload capacity while maintaining accuracy.

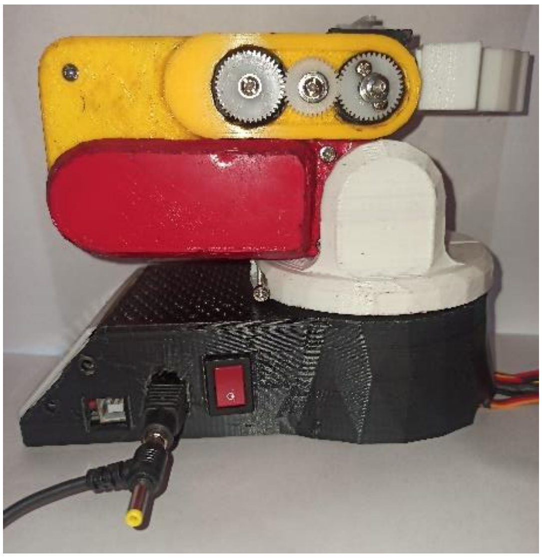


Fig. 38 Side View of Arm

Fig. 39 TOP View of Arm

Fig. 40 Expanded View of Arm

Fig. 41 Arm With Controller

This circuit is used to control the 4-DOF robotic arm controlled by an Arduino Uno. It uses a PCA9685 16-channel I2C PWM driver to control five servos. The PCA9685 is a popular choice for controlling multiple servos with an Arduino because it frees up the Arduino's PWM pins for other tasks. The circuit is being powered by a

12V power supply that is connected to the Arduino's Vin pin. The servos are also powered by the 12V power supply, but they are regulated to 5V using a voltage regulator. The voltage regulator is necessary because servos typically operate at 5V.

The five servos are connected to the PCA9685 driver on the I2C bus. The I2C

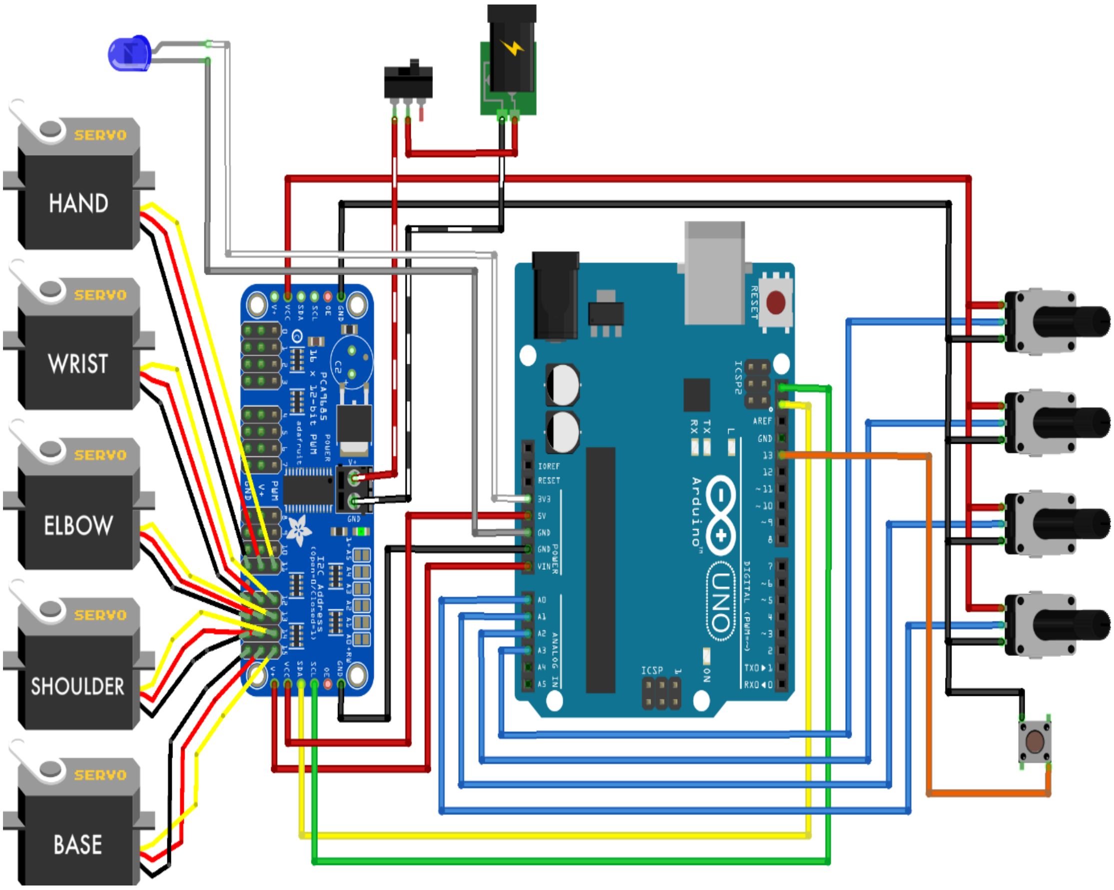


Fig. 42 Electrical Connection Diagram of Arm

bus is a two-wire serial bus that is used to communicate between devices. The Arduino Uno communicates with the PCA9685 driver over the I2C bus to send PWM signals to the servos.

The buttons on the breadboard are connected to the Arduino's digital pins. The buttons can be used to control the movement of the servos. For example, a button could be used to move the servo that controls the shoulder joint of the robotic arm.

The circuit also includes an LCD display. The LCD display can be used to show information about the robotic arm, such as the current position of the servos.

Chapter 4
RESULT AND ANALYSIS

BY USING ABS & PLA MATERIAL:

Applied Pressure(Mpa)	Stress		Displacement(MM)
	Min(Mpa)	Max(Mpa)	
0.1	1.80E+01	2.00E+00	1.06
0.2	3.48E+01	3.86E+00	2.36
0.3	46.36	5.79	2.83
0.4	61.81	7.72	4
0.5	80	10	4.7
0.6	92.72	11.59	5.67
0.7	108.17	13.52	7.45
0.8	123.63	15.45	8
0.9	139.47	17.38	8.51
1	160	20	9.46

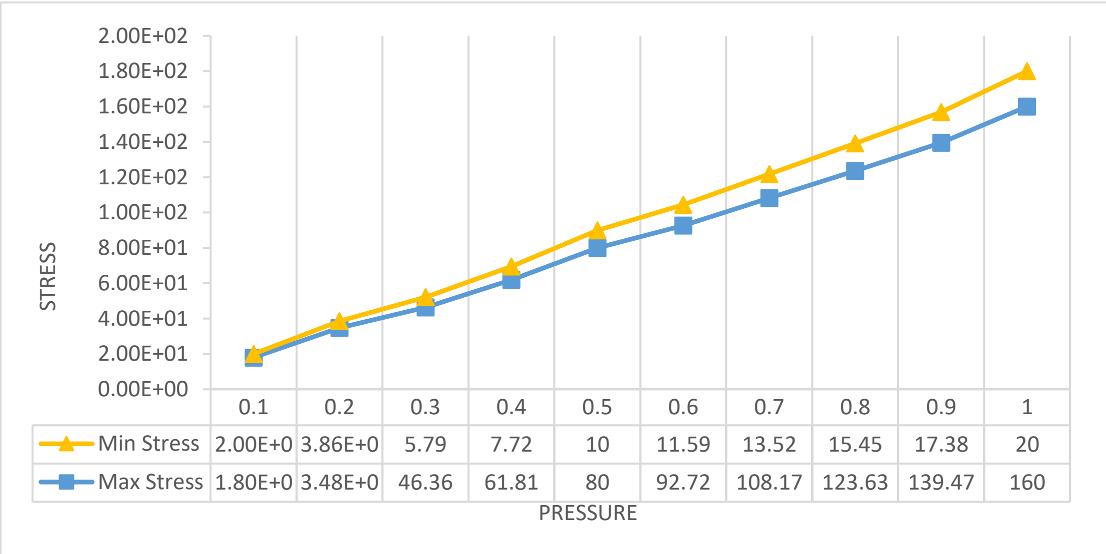


Fig. 43 Stress -Pressure Curve at Various Pressure

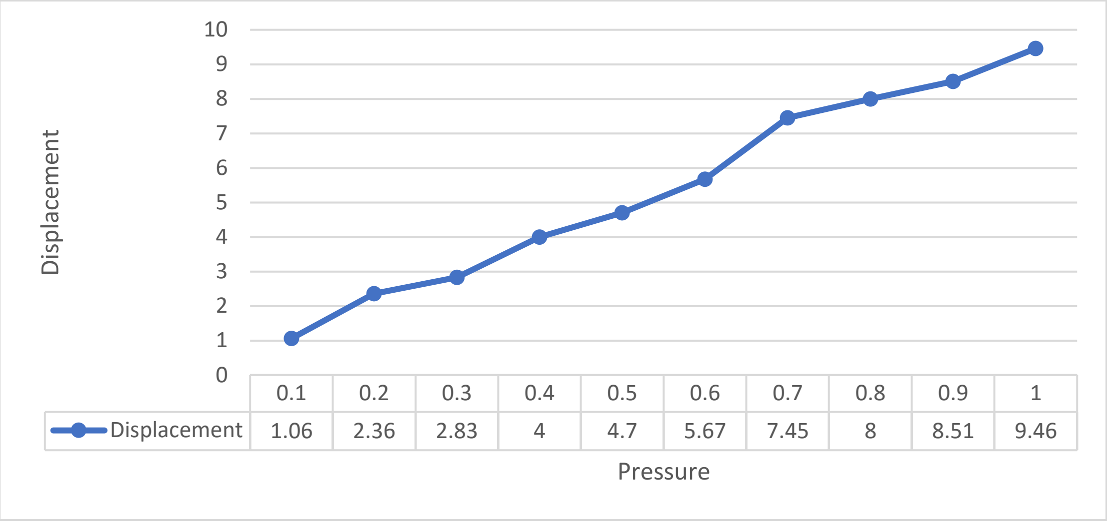


Fig. 44 Displacement -Pressure Curve at Various Pressure

BY USING TPU MATERIAL:

Applied Pressure(Mpa)	Stress		Displacement(MM)
	Min(Mpa)	Max(Mpa)	
0.1	1.25631	11.3058	45
0.2	2.51262	22.6116	90
0.3	3.76893	33.9175	125.886
0.4	5.02525	45.2233	180
0.5	6.28156	56.5291	209.776
0.6	7.53787	67.8349	251.731
0.7	8.79418	79.1407	293.687
0.8	10.0505	90.4466	335.642
0.9	11.3068	101.752	377.597
1	12.5613	113.058	450

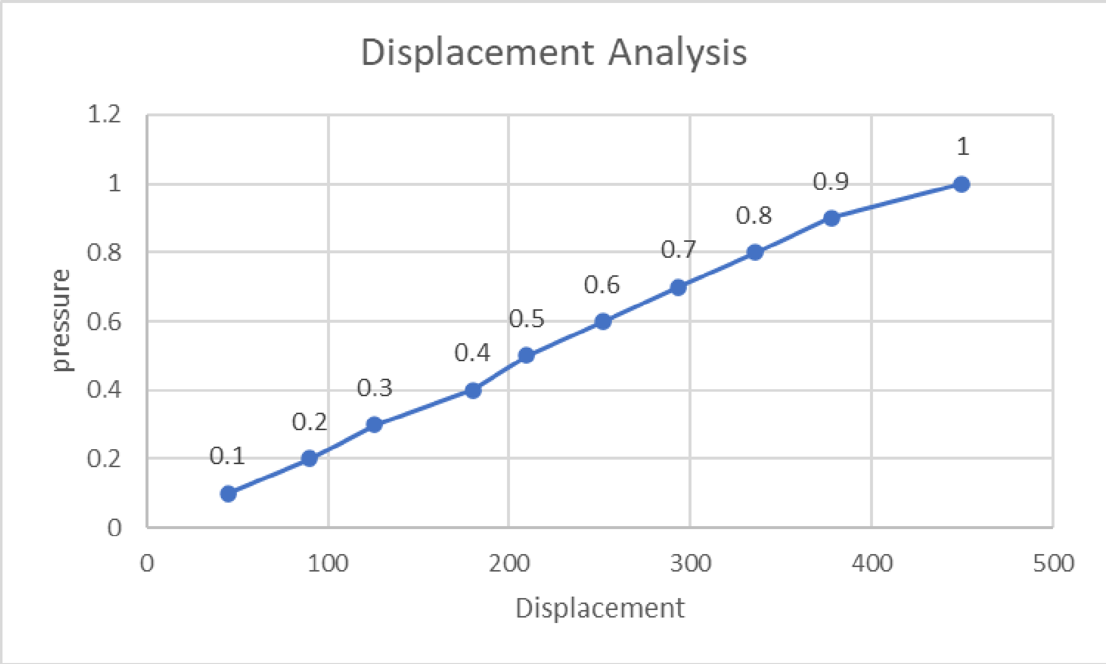


Fig. 45 Displacement -Pressure Curve at Various

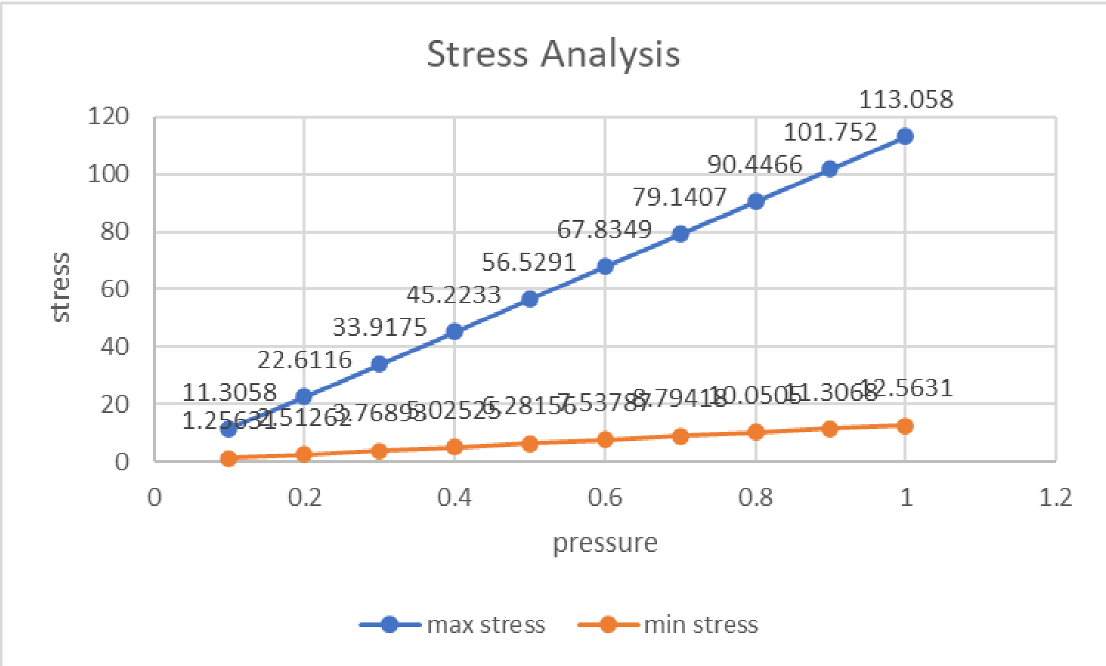


Fig. 46 Stress -Pressure Curve at Various Pressure

Chapter 5
CONCLUSION

The completion of Phase I of this project marks a significant milestone in the advancement of robotic gripper technology. Through meticulous research and development, it has become evident that 3D printed robotic grippers hold immense promise for widespread adoption in the near future, primarily due to their cost-effectiveness and versatile applications. Additionally, the Compliant gripper design has emerged as a valuable innovation, showcasing its capability for high-accuracy grasping of small objects with adaptive control of contact points along the active surface of the finger.

In conclusion, the development of a robotic microgripper utilizing Compliant structures has underscored the potential benefits of this approach for precise and delicate manipulation of small objects. The Compliant nature of the gripper imbues it with flexibility and adaptability, allowing for the secure handling of objects without causing damage or deformation. The successful design and fabrication of the project using Compliant structures highlight the importance of considering multiple factors when selecting a gripper for a specific application. These factors include the size, shape, and material properties of the objects to be manipulated, as well as the gripper's linear displacement, gripping force, and adaptability.

Moreover, the implications of this project extend beyond its immediate scope, with potential applications spanning various fields such as biomedical research, industrial automation, and micromanipulation. By providing a foundation for further research and development in this area, the project opens doors to enhanced precision and delicacy in the manipulation of small objects across diverse applications.

In summary, the completion of Phase I represents a significant step forward in the evolution of robotic gripper technology. The insights gained from this project underscore the potential of 3D printed robotic grippers and Compliant gripper designs to revolutionize the field, offering cost-effective solutions with versatile applications and unprecedented precision. As the project lays the groundwork for future advancements, it holds promise for driving innovation and addressing complex challenges in various industries

Chapter 6
FUTURE WORK

Improvement of Design: Future work can also focus on modification of design to get more flexibility. It is also dependent on how many time the gripper can be used.

Improving gripping force and sensitivity: one of the areas of future work is to improve the gripping force and sensitivity of robotic grippers. This will enable the manipulation of objects with greater precision and delicacy. Improvements in gripping force and sensitivity can be achieved through the use of more advanced materials and actuators, as well as through the integration of new sensing and control technologies.

Integration with other robotic systems: Future work can also focus on integrating robotic grippers with other robotic systems, such as mobile robots, drones, or autonomous vehicles. This will allow for a greater range of applications and will enable the creation of more complex and advanced robotic systems. For example, grippers can be integrated with mobile robots for tasks such as package delivery or warehouse automation.

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