“PARAMETRIC OPTIMIZATION OF NICKEL-TITANIUM-BASED SHAPE MEMORY ALLOY ON ELECTRIC DISCHARGE MACHINE”

This Major-Project report is submitted to

Yeshwantrao Chavan College of Engineering
(An Autonomous Institution Affiliated to Rashtrasant Tukdoji Maharaj Nagpur University)

In partial fulfillment of the requirement

for the award of the degree

Of

Bachelor of Engineering in Mechanical Engineering

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NAGPUR – 441 110

2022-2023

CERTIFICATE OF APPROVAL

Certified that the project report entitled "**Parametric Optimization of Nickel-Titanium-Based Shape Memory Alloy On Electro Discharge Machine**" has been successfully completed by Prajwal Chamat, Tushar Motghare, Shreyash Borghare, Aaradhya Wange under the guidance of Prof. M.S Tufail in recognition to the partial fulfillment for the award of the degree of Master of Technology in Mechanical Engineering, **Yeshwantrao Chavan College of Engineering (An Autonomous Institution Affiliated to Rashtrasant Tukdoji Maharaj Nagpur University).**

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Date of Examination

DECLARATION

We declare that

1. The work contained in this project has been done by me under the guidance of my supervisors.
2. The work has not been submitted to any other Institute for any degree or diploma.
3. I have followed the guidelines provided by the Institute in preparing the project report. I have confirmed the norms and guidelines given in the Ethical Code of Conduct of the Institute.
4. Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the report and giving their details in the references Further, I have taken permission from the copyright owners of the sources, whenever necessary.

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ACKNOWLEDGEMENT

We would like to thank our guide Mr. M. S. Tufail for guidance in the major-project We are extremely grateful and indebted to them for their expert, sincere, valuable guidance and encouragement which was of immense help to us.

We would like to express our sincere gratitude to Dr. Jayant Giri, Head, Department of Mechanical Engineering for her constant encouragement towards the successful completion of our work

We wish to express our sincere thanks to Dr. UP Waghe, the Principal of our college for providing us with all the necessary facilities and the infrastructure without which we would not have been able to complete our project successfully

we would like to thank all the faculty members and non-teaching staff members who helped us despite their busy schedules.

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List of Abbreviation

SMA – Shape Memory Alloy

Ni – Nickel

Ti- Titanium

EDM:- Electro Discharge Machine.

EWR- Electrode Wear Rat.

SR- Surface Roughness.

T-on – Pulse on time.

T-off:- Pulse-off time.

V - Voltage.

I :-Current.

Ip:- Peak Current.

MRR :- Material Removal Rate.

Abstract

Spark erosion machining, also known as electro-discharge machining, is commonly used to machine hard materials, which is hard to do by using the traditional machining process. EDM is prominently used for machining advanced materials like ceramic, composite, metal matrix composite, etc. which is most popular in various fields of application like automobiles, aerospace, defense, etc. EDM machines advanced materials effectively, therefore electro-discharge machining is the most popular among traditional machining processes. Shape memory alloys exhibit survival composition out of which nickel-titanium alloy became relatively popular for its biomedical application due to high corrosion and wear resistance, pseudo elasticity, and biocompatibility. Nickel-titanium-based shape memory alloy also found its application in various fields like automotive aerospace, actuators, sensors, and especially biomedical. Nickel-titanium-based shape memory alloy has been found to be hard also, therefore, it is very difficult to machine by using a traditional machining process hence non-traditional machining process is utilized to machine nickel-titanium-based shape memory alloys. Being the most versatile of all nonconventional machining, the electric discharge machining (EDM) process becomes viable for the machining of these hard-to-machine materials. The present study aimed to investigate the influence of input parameters such as pulse on time, current and flushing pressure on output responses of MRR and SR on nickel-titanium-based shape memory alloy. Taguchi L27 orthogonal array design has been utilized to conduct an experiment and also for optimization.

Keywords—EDM, Shape Memory Alloy, Machining Parameters, Nitinol.

COURSE OUTCOMES & POS`S MAPPING (DETAILD):

HIGH: -3 MEDIUM: -2 LOW 1:

CO	Statement	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO1	PSO2
CO 1	1)Plan (L5) and accomplish (L6) an innovative engineering Major-project, within given constraints, using knowledge and skills developed during the course. [PO1, PO11, PSO1]	**3**										**3**		**3**	
CO 2	2) investigate (L6) a complex problem by formulating (L6) a research question, appraising current literature and developments, and applying (L3) research principles/ methods to produce (L6) scientific content in the form of technical report, thesis, publications, posters and patents. [PO1, PO4, PO6, PO10]	**3**			**3**		**3**				**3**				
CO 3	3)Apply (L3) technological tools/methods/ software effectively to design (L6)/ formulate and conduct(L6) experiments and then Correlate (L4) the theoretical and experimental/simulations results and draw (L3) the proper inferences to come out with concrete solutions. [PO1, PO2,	**3**	**3**	**3**		**3**	**3**							**3**	**3**

	PO3, PO5, PO6, PSO1, PSO2]														
CO 4	4)Develop (L6) conceptual and engineering design/ formulation of any process/mechanical components/ system and also to fabricate/ simulate/operate them applying (L3) different technical skills, engineering tools /management principles/ processes/ application software effectively within technical, budgetary, risk, ethical, societal and time constraints. [PO1, PO2, PO3, PO5, PO6, PO7, PO8, pO11, PSO1, PSO2]	**3**	**3**	**3**		**3**	**3**	**3**	**3**			**3**		**3**	**3**
CO 5	5)Apply (L3) problemsolving methodologies to generate (L6), evaluate (L5) and justify (L4) innovative solutions [PO1, PO2, PSO1]	**3**	**3**											**3**	
CO 6	6)Reflect (L5) on professional engineering practice, management principles and its impact on the project, including safety, ethical, legal, social, cultural and sustainability considerations, along with knowledge of contemporary issues.	**3**		**3**	**3**	**3**		**3**	**3**			**3**		**3**	**3**

	[PO1, PO3, PO4, PO5, PO7, PO8, PO11, PSO1, PSO2]														
CO 7	7)Demonstrate (L3) professionalism, integrity, ethical conduct and professional accountability in all aspects Of project work, including teamwork and multidisciplinary approach. [PO1, PO8, PO9]	**3**							**3**	**3**					
CO 8	8)Demonstrate (L3) effective professional written and oral communication to a variety Of audiences through proposals, reports, documentation and presentations. [PO1, PO8, PO10]	**3**							**3**		**3**				
CO 9	9) Justify (15) the need for lifelong learning activities to cope up with technological changes. [PO1, PO12]	**3**											**3**		
Average Target															

Chapter 1

Introduction

Introduction

1.1 Overview

A shape memory alloy (SMA) is a new generation alloy that “remembers” its original shape after heating. It was first discovered by O¨ lander and the term “shape memory” was discovered by Vernon. These shape memory alloys were not used for any practical purpose till shape memory effect was observed in nickel-titanium alloy. Shape memory alloys exhibit in several compositions, out of which nickel-titanium (NiTi) alloys became relatively popular for its biomedical applications due to high corrosion and wear resistance, pseudo-elasticity and biocompatibility. Nitinol also found its applications in various fields like automotive, aerospace, and actuators, also known as pseudo-elasticity, which is the ability of material to return to their initial shape when the applied stress is removed. It is used in eyeglass frames, hip replacements, orthopaedic braces, etc. Most of the applications of SMA require complex geometries, high accuracy and surface finish. However, these qualities are achieved at the cost of high machining cost, low material removal rate or less tool life. Weinert and Petzoldt concluded that the machining of NiTi-based alloys is complex using conventional techniques like turning, drilling and deep hole drilling. Poor chip breaking, tool wear rate and formation burr have been observed while machining shape memory alloys using conventional machining techniques. High viscosity, toughness, severe strain hardening, poor surface finish are some of the difficulties observed by the researchers for SMAs using conventional machining technique. Thus, machining of shape memory alloys is best suited for non-conventional machining techniques.

In EDM there is no friction between the electrode as well as the work surface. Thus, it undeniably resolves the issues with vibration, noise, and mechanical stress. It also removes material by anodic dissolution. High material removal rates and application regardless of material hardness are benefits of EDM. EDM has input process variables that influence the output response. The process controls variables for getting the appropriate output values for the aluminum-based MMC were quite uncertain . In order to achieve the appropriate output response, and support evaluating the efficacy of EDM, therefore it is crucial to tune the EDM process variables of Al-based MMC.

1.1.1 Die-sink EDM

In a die sink EDM machine, the workpiece and the tool are electrically connected to a de electric power supply. The workpiece is connected to the positive terminal of the electric source (anode). The tool is the cathode. A gap known as the spark gap is maintained between the workpiece and the tool, and a dielectric slurry is forced through this gap at a pressure. When a suitable voltage is applied, the dielectric breaks down, and the electrons are emitted from the cathode and the gap is ionized. A small ionized fluid column is formed owing to the formation of an avalanche of electrons in the spark gap where the process of ionization collision takes place. When more electrons collect within the gap the resistance drops causing an electric spark to leap between the workpiece surface and therefore the tool. Each electric discharge or spark causes a focused stream of electrons to move with a very high velocity and acceleration from the cathode towards the anode and ultimately creates compression shock waves on both the electrode surface, particularly at high spots on the workpiece surface, which are closest to the tool. The generation of compression shock waves develops an area's rise in temperature. The whole sequence of operation occurs within a couple of microseconds. However, the temperature of the spot hit by the electrons is of the order of 10,000°C. This temperature is sufficient to melt a part of the metals. The forces of electric and magnetic fields caused by the spark produce a tensile force and tear off particles of molten and softened metal from this spot in the workpiece. A part of the metal may vaporize and refill the gap. The metal is thus removed in this way from the workpiece. The electric and magnetic fields on the heated metal cause a compressive force to act on the cathodic tool so that metal removal from the tool is at a slower rate than that from the workpiece. Hence, the workpiece is connected to the positive terminal and gear to the negative terminal.

Electrohydraulic servo control is usually used in die-sink EDM. The servo gets its input from the difference between a specific reference voltage and therefore the actual voltage across the gap. The signal is amplified and therefore the tool. because it wears a touch, is advanced by hydraulic control. A short circuit across the gap causes the servo to reverse the motion of the tool until the right gap is established.

1.1.2 Spark generator

The spark-generating circuit may be one of the following types:

(1) relaxation, (2) pulse-generator.

The spark generator supplies current to a condenser, the discharge from which the spark. The workpiece alternatively becomes a positive electrode (anode) or negative electrode (cathode) respectively. On each reversal of polarity, the tool is eroded more than the workpiece. Hence, the tool wear is bigger with this sort of arrangement.

The introduction of pulse generators has overcome the drawbacks of relaxation generators. Pulse generators are available, fitted with a transistorized pulse generator circuit in which reverse pulses are eliminated. These generators consist of electronic switching units which let the current pass periodically. Modem pulse generators possess the means of accurate control over discharge duration, pause time, and the current These factors determine the overcut and hence the accuracy and surface finish. The tool wear is also greatly reduced. While for finding work high frequency and low-amperage settings are used, in roughing work low frequency discharges with high amperage are applied.

1.1.3 Dielectric

A dielectric is an electrical insulator that can be polarized by an applied electric field. When a dielectric material is placed in an electric field, electric charges do not flow through the material as they do in an electrical conductor, because they have no loosely bound, or free, electrons that may drift through the material, but instead, they shift, only slightly, from their average equilibrium positions, causing dielectric polarization. Because of dielectric polarization, positive charges are displaced in the direction of the field and negative charges shift in the direction opposite to the field (for example, if the field is moving parallel to the positive x-axis, the negative charges will shift in the negative x direction). This creates an internal electric field that reduces the overall field within the dielectric itself.

- It should have a higher degree of metal removal and less electrode wear.
- It should be odorless and the smoke should be non-toxic. Also, it should not create skin irritation.
- Flashpoint should be higher.

- Evaporation rate should be less.
- Disruptive voltage should be more.
- Particle suspension should be more for the proper removal of waste carbon particles.
- It should be easily filterable.
- It should not have an adverse effect on machine components.
- It should have a longer life for a better price-to-performance ratio. . It should be easily available and economical.

Functions of a dielectric

1. Insulation: - Proper insulation is required between the electrode and workpiece to avoid disruptive discharges.
2. Ionization: - Quick formation of an electric field to provide a very constricted spark path. The more the spark path is constricted higher the energy density resulting in efficient discharge.
3. Cooling; - Proper cooling of electrode and workpiece and condensation of metal gases into liquid, which is developed during spark erosion.

4 Removal of waste particles: - Proper flushing out of the cavity.

Types of dielectric fluid:

- transformer oil,
- paraffin oil,
- kerosene,
- Deionized water, etc.

1.1.4 Electrode

The basic characteristics of electrode materials are:

- High electrical conductivity: - Electrons are cold emitted more easily and there is less bulk electrical heating
- High thermal conductivity: - For the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear
- Higher density: - For the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.

- High melting point: -High melting point leads to less tool wear due to less tool material melting for the same heat load.
- Easy manufacturability.

1.2 Problem Statement

Shape memory alloys exhibit survival composition out of which nickel-titanium alloy became relatively popular for its biomedical application due to high corrosion and wear resistance, pseudo elasticity, and biocompatibility. Nickel-titanium-based shape memory alloy also found its application in various fields like automotive aerospace, actuators, sensors, and especially biomedical. Nickel-titanium-based shape memory alloy has been found to be hard also, therefore, it is very difficult to machine by using a traditional machining process hence non-traditional machining process is utilized to machine nickel-titanium-based shape memory alloys. Being the most versatile of all nonconventional machining, the electric discharge machining (EDM) process becomes viable for the machining of these hard-to-machine materials EDM has input process variables that influence the output response. The process controls variables for getting the appropriate output values for the nickel-titanium-based shape memory alloy were quite uncertain. In order to achieve the appropriate output response, and support evaluating the efficacy of EDM, therefore it is crucial to tune the EDM process variables of nickel-titanium-based shape memory alloy. In spite of the nickel-titanium-based shape memory alloy attractive properties, it observed very less work has been done as far as the optimization of EDM parameters is concerned.

1.3 Objective.

- To find the feasibility of machining nickel-titanium-based shape memory alloy using Copper Electrodes.
- To design customized tool.
- To Optimize various machining parameters.
- To investigate the process parameter optimization using the design of experiment.

Chapter 2

Review of Literature

Review of Literature

2.1 Literature Review

Nickel-titanium shape memory alloy (NiTi) has a unique capacity to restore its initial shape after deformation, which is highly applicable to orthopedic implantations, especially for the minimization of invasive surgeries. The high nickel content of this alloy can lead to unfavorable effects on the human body upon dissolution; thus, a reliable barrier of coatings on the NiTi surface is required to alleviate the nickel migration and increase its biocompatibility. In this paper, analyses of a titanium oxide layer development on NiTi surface using electrical discharge coating (EDC) process is presented. The recast layer thickness, crater sizes, and surface roughness were characterized based on five parameters; polarity, discharge duration, pulse interval, peak current, and gap voltage. The results show that the discharge duration is the most significant parameter to influence all responses, followed by peak current. The surface characteristics of the EDC substrate is depending on the crater formations and is highly correlated with the discharge energy intensity. As a result, appropriate parametric conditions of the electrical discharge coating process can enhance the NiTi surface for future medical applications, without compromising the shape memory effect.[1]

Smart materials play an important role in global manufacturing market. Smart materials are new generation materials surpassing the conventional structural and functional materials. Smart materials are now days being used in all spheres of human life and technology. NiTi alloy is an important type of smart material which having some unique characteristics. NiTi is having large number of applications in the field of security, marine and aerospace industries. Because of its hardness, NiTi is very hard to cut by traditional machining techniques, hence material can be removed using an electric discharge machining method. Surface roughness is one of a critical parameter affecting the machining of any alloy. Therefore, the aim of this research is to study the optimization of Surface roughness during machining of NiTi shape memory alloy by EDM through Taguchi's technique. The Taguchi's method was employed to optimize the machining parameters.[2]

Memory metals or memory alloys or smart metals are those alloys which get deformed when cold and returns to their preformed shape when subjected to heating. Their exquisite properties make these alloys an ideal material for several engineering applications. The recent developments in these materials have attracted the interest of the scientific community. In this context, an attempt has been made to provide an overview of the shape memory alloys (SMAs) along with their deformation mechanism. The study further explores the classifications and advantages of different shape memory alloys. Various machining processes adopted for machining shape memory alloys as well as the making of these alloys have been also articulated in this review. Besides all these, a light has been also thrown on the significant characteristics of these materials in addition to their applications in automobile, aerospace, robotic, and biomedical fields.[3]

In this decade, shape memory alloys (SMAs) are significantly accepted in industrial trade and biomedical applications due to their unique characteristics of shape memory effect (SME), pseudoelasticity, extraordinary corrosion and wear resistance, biodegradability, biocompatibility, antigenicity, decomposition, etc. Many difficulties were faced by using traditional machining. Also, traditional machining gives undesirable results like high tool wear, less dimensional accuracy, and a time-consuming process. As a solution, the non-traditional machining processes are used to machine the SMAs. The water jet machining (WJM), laser machining, and electrochemical machining (ECM) processes have some limitations with machining complex shapes. However, electrical discharge machining (EDM), wire electrical discharge machining (WEDM) will provide better machining of complex components with high dimensional accuracy. The present study exhibits the compression of the non-traditional machining of SMAs. The recent trends followed in non-traditional machining is evaluated. A discussion of different machining parameters, output responses, and unpleasant results is covered in this study.[4]

The performance of powder-mixed EDM of nitinol SMA with the considerations of design variables of current, pulse-on-time (Ton), nano graphene powder concentration (PC), and pulse-off-time (Toff) on surface roughness, dimensional deviation (DD), and material removal rate (MRR) investigated. Taguchi's L9 (3^ 4) design was employed to perform the experiments and Minitab 17 software was used for statistical analysis of design variables using ANOVA, residual plots, and main effect plots. ANOVA results depicted that PC, Ton, and Toff were identified to be the highest contributing parameters with 75.18%, 29.37%, and 45.72% to affect MRR, SR, and DD, respectively. Obtained results has depicted a preferred combined positive trend of increase in MRR with a simultaneous drop in SR and DD after the addition of nano-graphene PC. HST algorithm was used to optimize single and multiple responses. Validation trials were also conducted to reveal the ability and suitability of the HTS technique. Field emission scanning electron.[5]

Nitinol SMA is characterized as smart material mainly due to capability of shape memory effect and superelasticity. Unique properties of nitinol SMAs find its applications in fields of aerospace, heating and ventilation, safety and security, automation and control, chemical processing, electronics (MEMS devices) industries, automotive, appliance, and robotics. Due to the functional properties of nitinol SMAs, their biomedical application has proven to be more successful by increasing the possibility as well as the performance of minimally invasive surgeries. The combination of nickel-titanium SMA is highly biocompatible which makes them useful as orthopedic implants, surgical instruments, cardiovascular devices, and orthodontic devices. In current study, a detailed review of various applications and possible key areas for shape memory alloys have been discussed.[6]

This review study provides based on the recently published EDM process articles where the objective is to attempt newer work material and advanced electrode that could significantly meet industrial manufacturing domain around the globe. In addition, the concluding observations turn out with defined underlines and technological research gaps making this review article useful to related academic and scientific research community with proper identification of EDM process factors, advance work materials, material electrode tools and sustainable dielectric for achieving favorable outcomes as a frontier machining technology.[7]

The review of traditional and nontraditional machining processes implemented for nickel-based superalloys over the past decade. The challenges faced during the implementation of conventional machining processes and the application areas in which nickel-based superalloys used have also been discussed. Most commonly used nickelbased alloys for a variety of applications and studies are presented. The consolidated information about the implementation of these machining processes for nickel-based superalloys is listed, and the paper concludes with some key findings and gaps about the machining of nickel-based superalloys.[8]

Overview of the EDM process, modeling of process parameters, and influence of process parameters such as input electrical variables, pulse shape, and discharge energy on performance measures such as material removal rate, surface roughness and electrode wear rate dicussed. This study also discusses about controlling the electrical process parameters, and empirical relationships between process parameters and optimization of process parameters in EDM process. From the review results, it has been observed that the efficacy of the machining process can be improved by electrical process parameters, and only less attention has been given for enhancing such parameters.[9]

Electro discharge machining (EDM) is a common fabrication process for miniaturized components in medical technology and micro engineering today. As EDM induces material changes in the near surface zone, the surface integrity becomes ever more important, the smaller the components are. In order to characterize the influence of EDM on the near surface zone, basic metallurgical investigations on pseudo-elastic NiTi shape memory alloys (SMAs) were carried out. Material removal in EDM depends on the electric discharge processes between the tool and the workpiece electrode in a dielectric fluid. Material is removed by melting and vaporization in single sparks. This results in craters with varying size and depth depending on the discharge energy. The microstructure of this melting zone is characterized by hollows, cracks and precipitation. Cracks open at the surface in consequence of randomly and locally overlapping thermal shocks. The cracks grow vertically into the material, starting at the surface. In the melting zone, significant precipitations were detected and subsequently identified by EDX as titanium carbides. The material removal rate, which is an important process factor in manufacturing, approximately increases in linear proportion with the discharge energy, and achieves commercially interesting values by using an electrode made of copper and tungsten. The results of the microstructure analysis require the removal of the near surface zone to ensure the properties of the components. This is possible via a smooth EDM-process, followed by electrolytic polishing.[11]

An innovative modeling approach to account for massive random discharges has been developed based on the stochastic EDM process and probability theory. Die sinking EDM of NiTi alloys was simulated to investigate the thermal damage mechanism with the progression of massive random discharges. The temperature history profiles of both top surface and subsurface showed pulsing characteristics with the progression of massive random discharges, which resulted from high-frequency random discharging phenomenon. A large temperature gradient was also found on the area below the top surface, while it gradually decreased in the deep subsurface. The predicted "coral reef" surface topography and uniform temperature distribution across the surface showed that the proposed model accounting for random discharge phenomenon proved to be an effective approach to investigate the effect of EDM processes.[12]

The effect of input parameters such as workpiece electrical conductivity, gap current, gap voltage, pulse-on-time and pulse-off-time on the responses namely material removal rate (MRR) and tool wear rate (TWR) investigated. Experiments were designed and performed as per the Taguchi's L18 (61 34) array. Taguchi's approach and utility concept were employed for optimizing conflicting responses. Obtained results showed that the over-all utility was significantly affected by gap current, gap voltage, pulse-on-time and pulse-off-time.Thus the obtained optimal values of MRR and TWR are 9.157 mm3/min and 0.128 mm3/min respectively.[12]

Nitinol shape memory alloys (SMA) are widely used in biomedical and aerospace applications because of its outstanding properties such as superelasticity, shape memory, and biocompatibility. Conventional mechanical cutting of Nitinol is very challenging due to rapid tool wear and large burr formation. Laser cutting and electrical discharge machining (EDM) are often used to manufacture Nitinol SMA parts. However, the intensive heat flux in laser cutting and EDM induces thermal damage such as white layer (recast layer) and heat affected zone (HAZ). White layer is formed due to the rapid re-solidification of the molten material in both laser cutting and EDM. However, the properties of white layer from the two very different processes could be very different. Very little work has been done to differentiate their potential properties. This work provides a comparative study on the properties of white layer generated by laser cutting vs. EDM. Surface topography was analyzed by scanning electron microscope (SEM). The grain size and orientation were studied by electron backscatter diffraction (EBSD). Nanoindentation was used to investigate the hardness of the white layer. The elemental contamination was analyzed usingenergy dispersive X-ray spectroscopy (EDS). It was found that the nature of the white layer by laser cutting and EDM is significantly different. The white layer from laser cutting is more uniformly distributed on the surface than the EDMed one. Moreover, nanohardness of the white layer in the laser cut samples is lower than the bulk material, while the EDMed white layer has higher hardness than the bulk. This could be attributed to the different quenching rate and alloying hardening in EDM, which is confirmed by the EDS analysis. In laser cutting, no elemental contamination was detected.[13]

High strength, excellent corrosion resistance, and low density are the main properties that make titanium attractive for a variety of applications such as the production of airframes, engine components, steam turbine blades, superconductors, missiles, etc. Machining of titanium alloy by conventional machines causes the problems such as chipping and premature tool failure, deflections of the work-piece, increases the temperature at the tool-work piece interface, etc. Hence under such circumstances, nonconventional Die sink Electrical Discharge Machining (EDM) process can be alternative to overcome such problems.The primary aim of this paper is to investigate the effects of process parameters (factors) on material removal rate (MRR) in the EDM process. The process parameters considered for this investigation are current (C), voltage (V), pulse on time (Ton), and pulse off time (Toff) for EDM machining of titanium (grade2) alloy with copper as an electrode material. The experiments were designed with the Taguchi method,orthogonal array L9. The maximum MRR obtained was 0.073 mm3/min with the voltage of 40 V, current of 8A, pulse on at 60 ms, and pulse off at 9 ms respectively. While the secondary aim of this research is to investigate the effect of process parameters on fatigue strength of titanium (grade-2) alloy. During fatigue test it was observed, fatigue strength decreases with an increase in current and pulse on time.[14]

Electrical Discharge Machining (EDM) process is an advanced machining process used in wide range of manufacturing applications especially for hard materials. Functioning and quality of EDMed machined parts/components plays important role when put to the service. For this not only selection of optimum machining process but also selection of effective optimization technique need to be given special attention. With this intention the target of the current research is to survey the different optimization techniques (Response surface, Taguchi, Grey regression analysis, Artificial nueral network etc.), research gap indicates scope for implementation of Jaya algorithm which is a modern optimization technique.With use of Jaya algorithm technique research work was carried out to evaluate white layer thickness (WLT) and micro hardness (MH) as output parameters during EDM machining of NiTi60 alloy. These output parameters were evaluated with variations in input process parameters considering voltage (V), current (C), pulse on (Pon) and pulse off (Poff) time. The experiments were conducted using L9 Taguchi orthogonal array and mathematical predictions models were generated using regression analysis. Jaya algorithms were developed with the intention to minimize the WLT and minimize the MH as the objective functions. It is concluded that Jaya optimization technique can be effectively implemented to optimize the process parameters in EDM process which shows considerable reductions in WLT from 5.914to 4.947 mm and MH from 208.71 to 200.3 respectively.[15]

Nitinol shape memory alloy (SMA) is very challenging to machine by conventional mechanical cutting. Wire electric discharge machining (wire-EDM) is an alternative process to machine Nitinol SMAs. The machined surface integrity is critical to product performance such as fatigue, corrosion, and wear, yet few studies have conducted a thorough investigation of the machined surface integrity, in particular white layer (WL). This work focuses on a comprehensive investigation on the crystallography, compositions, and properties of the white layer using transmission electron microscopy (TEM), X-ray diffraction (XRD), electron backscatter diffraction (EBSD), and nanoindentation. The WL by wire-EDM exhibits a porous and non-uniform bi-layered structure. The white layer of Nitinol by EDM is a crystalline structure instead of the traditionally believed amorphous solid. The upper portion of the WL consists of primarily the solid solution phase (Cu+Ni+Zn)-FCC, while Ti2O3 and Nitinol austenite phases dominate the lower portion of the WL. The white layer shows less crystal plastic deformation than the bulk material, and refined grains with random orientation can be found in the WL. The nanohardness of the WL is much higher than that of the bulk material due to oxide hardening.[16]

To withstand in global manufacturing market it is necessary to acquire new technology for producing new products. To achieve this advanced material plays an important role. NiTi alloy is one such class of advanced material which has unique properties such as biocompatibility, high strength, high corrosion resistance, shape memory effect etc. Due to such property these alloys have wide application in the field of defence, aerospace, and medicine. As these applications required high accuracy, precision and high strength of NiTi these are difficult to machine by conventional machining processes. Hence to machine this advanced material non-conventional machining processes i.e. electric discharge machining is employed. However EDM has a wide range of process parameter and the aim of EDM users and manufacturers is to achieve optimal performance of EDM. In view of this objective the present study focuses on optimization of electric discharge machining process parameter for maximization of material removal rate while machining of NiTi alloy. In the present study gap current, pulse on time, pulse off time, workpiece electrical conductivity, and tool conductivity were considered as process variables. Experiments were carried out as per Taguchi's L36 orthogonal array. Based on the analysis it was found that work electrical conductivity, gap current and pulse on time are the significant parameters that affect the material removal rate. The optimized material removal rate obtained was 7.0806 mm3/min based on optimal setting of input parameter.[17]

The performance of powder-mixed EDM of nitinol SMA with the considerations of design variables of current, pulse-on-time (Ton), nano-graphene powder concentration (PC), and pulse-off-time (Toff) on surface roughness,dimensional deviation (DD), and material removal rate (MRR). Taguchi's L9 (3^4) design was employed to perform the experiments and Minitab 17 software was used for statistical analysis of design variables using ANOVA, residual plots, and main effect plots. ANOVA results depicted that PC, Ton, and Toff were identified to be the highest contributing parameters with 75.18%, 29.37%, and 45.72% to affect MRR, SR, and DD, respectively. Obtained results has depicted a preferred combined positive trend of increase in MRR with a simultaneous drop in SR and DD after the addition of nano-graphene PC. HST algorithm was used to optimize single and multiple responses. Validation trials were also conducted to reveal the ability and suitability of the HTS technique. Field emission scanning electron.[18]

Electrical discharge machining (EDM) has emerged as one of the most preferred options for high precision machining of very hard materials. Complex contours and intricate slots are produced in a variety of parts by this approach. Considerable research has been dedicated to several aspects of EDM. This work concentrated on analysis of the effect of EDM processes parameters on performance measures such as material removal rate (MRR), tool wear rate (TWR) and surface roughness. In the present study experiments were designed using response surface methodology. Moreover the analysis of variance was performed for MRR,TWR and surface roughness, along with the empirical models which shows the R2 value as 86.79%,72.80% and 83.47% respectively.[19]

Decrease the martensite transformation temperature of Ti50Ni50 shape memory alloy (SMA) for its use in biomedical applications by Cr addition. In addition, surface modification of Ti50Ni50 and Ti50Ni49.5Cr0.5 SMAs using electrical discharge machining (EDM) is proposed. Nitrogen gas is used as a dielectric medium, and a pure titanium pipe is used as the tool electrode. The machining characteristics and surface properties of Ti50Ni50 and Ti50Ni49.5Cr0.5 SMAs after EDM in nitrogen gas were investigated. Many electrical discharge craters and recast materials are observed on the EDMed surface of these SMAs. Material removal rate, electrode wear rate, and surface roughness increase with increasing pulse current and duration, and they share an inverse relationship with the thermal conductivity of these SMAs. After EDM, the SMAs continue to exhibit good shape recovery, and even the recast layers have high surface hardness. The recast layers, comprising TiN and CrN, with high hardness and good adhesion are expected to improve the SMAs' wear and corrosion resistance.[20]

The current study focused on study the behavior of response parameters along with the variation in machining input parameters The considered process input factors are namely as; pulse on time (Ton), pulse off time (Toff), peak current (Ip), and gap voltage(GV) and their effects were studied on dimensional deviation (DD) and tool wear rate (TWR). The central composite design matrix has been employed for planning the main runs. The 2-D and 3-D graphs represents the behavior of the response parameters along with variations in the machining inputs. The novelty of the work is machining of Cu-based Shape Memory Alloy (SMA) in EDM operations and optimization of parameters using Machine Learning techniques. Furthermore, machine learning based, single and multi-objective optimization of investigated responses were conducted using the desirability approach, Genetic Algorithm (GA) and Teacher Learning based Optimization (TLBO) techniques. The parametric combination attained for optimization of multiple responses (TWR and DD) is: Ton ¼ 90.10 μs, Toff ¼ 149.69 μs, Ip ¼ 24.59 A & GV ¼ 60 V; Ton ¼ 255 μs, Toff ¼ 15 μs, Ip ¼ 50 A & GV ¼ 15 V; Ton ¼ 255 μs, Toff ¼ 15 μs, Ip ¼ 50 A & GV ¼ 15 V, using desirability approach, GA method and TLBO method, respectively.[21]

Shape memory alloys (SMAs) have received significant attention especially in biomedical and aerospace industries owing to their unique properties. However, they are difficult-to-machine materials. Electrical discharge machining (EDM) can be used to machine difficult to cut materials with good accuracy. However, several challenges and issues related with the process at micro-level continue to exist. One of the aforementioned issues is that the micro-EDM (μEDM) process is extremely slow when compared to other non-conventional processes, such as laser machining, although it offers several other benefits. The study considers the analysis and optimization of μEDM by using a multi-objective genetic algorithm (MOGA-II). Drilling of micro-holes is performed by using a tabletop electrical discharge machine. Nickel-Titanium (Ni-Ti) based SMA (a difficult to cut advance material) is used as a specimen. The objective involves determining optimal machining parameters to obtain better material removal rate with good surface finish. The results of the study indicate that MOGA-II is an efficient tool to optimize input parameters. Optimum results are obtained with tungsten electrode at low to moderate capacitance values and low discharge voltage. Conversely, brass electrode yields high MRR at the expense of tool wear and micro-holes quality.[22]

Shape memory alloy (SMA) is a novel functional material and has found increasing applications in many areas. Recently, research efforts have been extended to using SMA for control of civil structures. This paper presents a review of applications of the SMA materials for passive, active and semi-active controls of civil structures. First, an overview of the characteristics of SMA is presented. The shape memory effect (SME) and pseudoelasticity, two major properties of SMA associated with the thermal-induced or stress-induced reversible hysteretic phase transformation between austenite and martensite, are reviewed. These unique properties enable SMA to be used as actuators, passive energy dissipators and dampers for civil structure control. This paper then reviews current research using SMA-based devices for passive, semi-active or active control of civil structures. The operation mechanism, design and experimental results of these SMA-based devices are also presented in the paper.[23]

Various effects of composition and 3D-printing process parameters on changes in transformation characteristics, as well as possible methods for their prevention and post-process heat treatments. It is reported that only by precise process and temperature control it is possible to create 4D products with the ability to realize the multi-stage shape memory effect. Finally, the paper discusses the various application of 3D-printed Nitinol and its advantages as compared to conventional processing routes.[24]

The general concept of SMA, history, shape memory effect (SME), various types of SMA, recent developments in the fabrication technique of SMA, and its application have been discussed in detail. The latest application of SMA in the field of automotive, aerospace, marine, robotics, structures, and biomedical has been reviewed while discussing its challenges and advantages.[25]

Nitinol shape memory alloys have wide applications in medical devices and actuators. However, the unique mechanical properties including superelasticity, high ductility, and severe strain-hardening make Nitinol exceedingly difficult to cut. This work determines dynamic mechanical behaviors of Nitinol in cutting. It is found that the very high strength and specific heat are responsible for large flank wear and fast tribo-chemical crater wear, respectively. The austenitic white layer in cutting is caused by deformation, while the twinned martensitic white layer is caused by quenching in EDM. Alloying from tools is negligible in cutting but unavoidable even in finish EDM trim cut.[26]

Chapter 3

Work Done

Work Done

3.1 Selection of workpiece material

Nickel – Titanium Based Shape Memory Alloy (Nitinol)

Nickel titanium-based shape memory alloy, also known as Nitinol, is a metal alloy of nickel and titanium, where the two elements are present in roughly equal atomic percentages. Nitinol alloys exhibit two closely related and unique properties: the shape memory effect and superelasticity (also called pseudoelasticity). Shape memory is the ability of Nitinol to undergo deformation at one temperature, stay in its deformed shape when the external force is removed, then recover its original shape. Superelasticity is the ability of the metal to undergo large deformations and immediately return to its undeformed shape upon removal of the external load. Nitinol can deform 10–30 times as much as ordinary metals and return to its original shape. Whether Nitinol behaves with the shape memory effect or superelasticity depends on whether it is above the transformation temperature of the specific alloy. Below the transformation temperature it exhibits the shape memory effect, and above that temperature it behaves superelastically.

Table 3.1.1: Composition of Nitinol SMA.

Nickel titanium-based shape memory alloy (NiTinol)	
Elements	% Weight
Titanium (Ti)	Remainder
Nickel (Ni)	55.65%
Cobalt (Co)	0.001%
Copper (Cu)	0.001%
Chromium (Cr)	0.22%
Iron (Fe)	0.01%
Nitrogen (N)	0.001%
Hydrogen (H)	0.00011%
Carbon (C)	0.04%
Oxygen (O)	0.04%
Niobium (Nb)	0.001%

3.2 Selection and customization of electrode

Copper

Figure 3.2.1: Copper electrode

Copper and copper alloys provide better resistance than brass alloys they are difficult to machine than graphite or brass Copper has very high heat conduct which is the desired property for electrode material but it is more expensive in graphite. It also has high strength and can be used to machine materials that are required to have a high finish.

Density - : 8.96 gm/cc

Weight - : 65.6 g

Figure 3.2.2: Weight of copper electrode

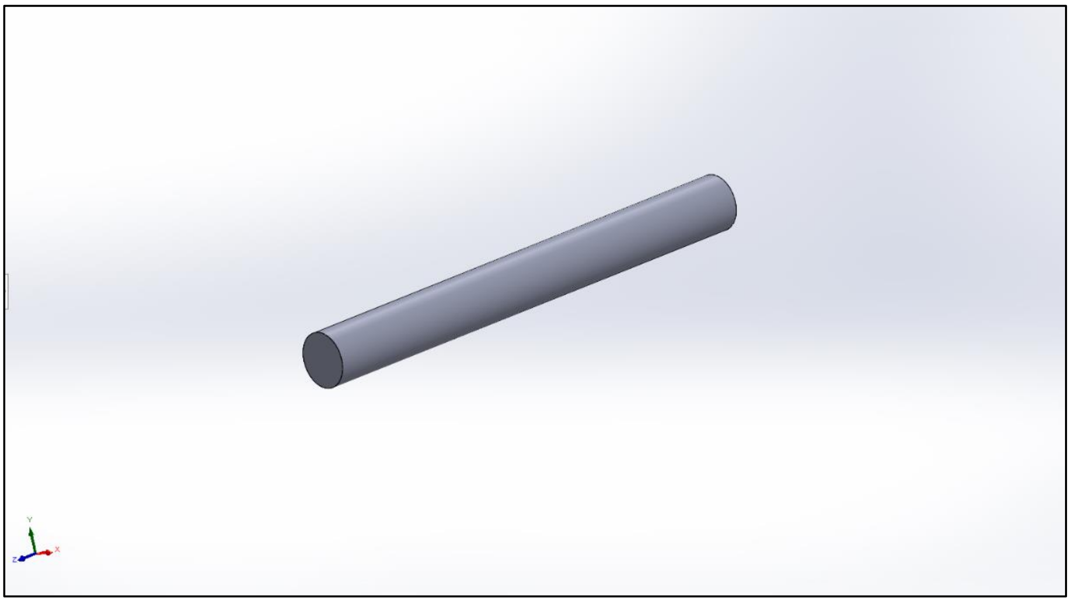
Figure 3.2.3 CAD Model of Customized Copper Electrode

3.3 Electro-discharge machine

Figure 3.3.1: Die-Sink EDM Machine.

The machine can perform a series of electrical pulses generated by the pulse generator unit. ich is applied between the workpiece and the tool electrode. In the event of spark discharge, there is a flow of current across the tool electrode workpiece gap. The energy contained in a tiny park discharge removes a fraction of the workpiece material, leaving behind a small crater on the piece's surfac

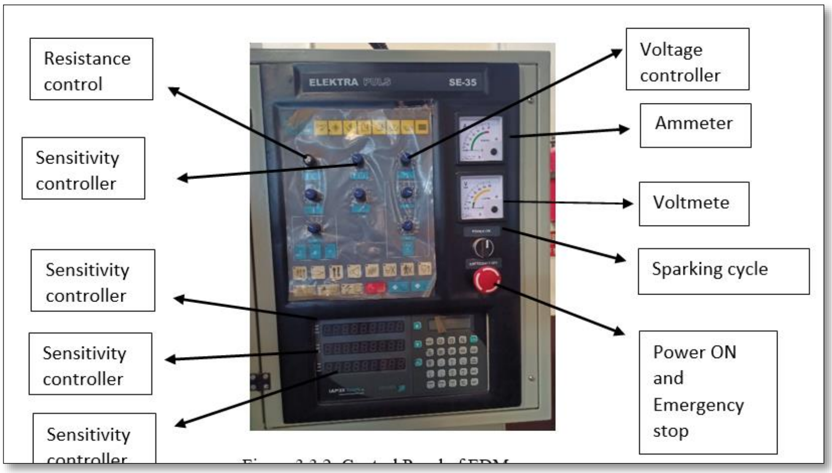

Figure 3.3.2: Control Panel of EDM.

3.4 Working principal of EDM

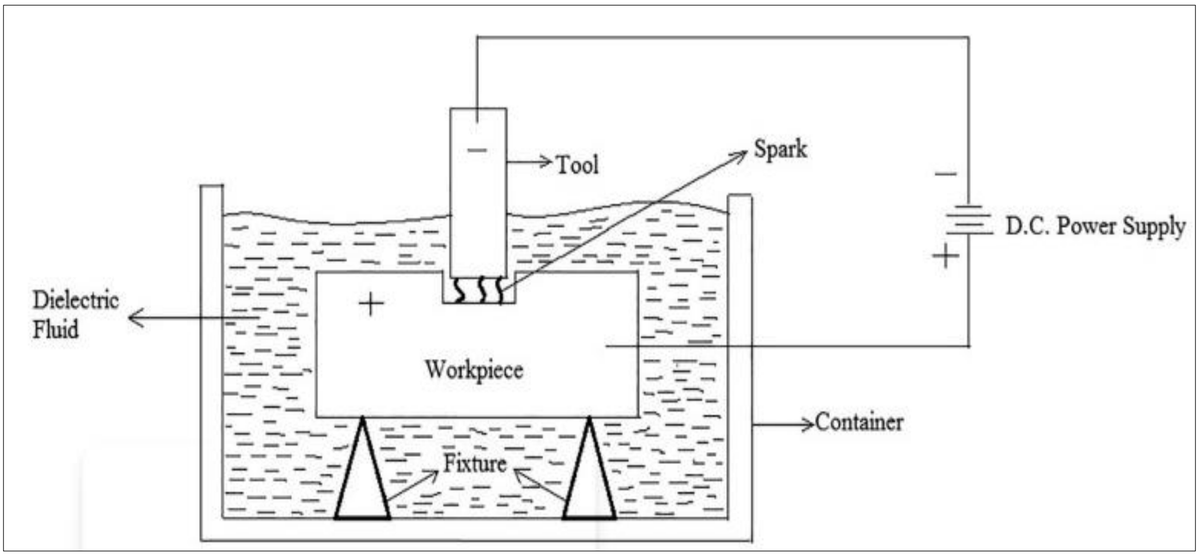

Figure 3.4.1: Working principal of EDM

- In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity.
- The tool and the work material are immersed in a dielectric medium.
- Gap is maintained between the tool and the workpiece.
- Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established.
- The tool is connected to the negative terminal of the generator and the workpiece is connected to a positive terminal.
- As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces.
- As they gain velocity and energy, and start moving toward the job, there would be collisions between the electrons and dielectric molecules

- Such collision results in ionization of the dielectric molecule depending upon the work. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions.

- This cyclic process increases the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap.

- Thus, all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool

- Such movement of electrons and ions can be visually seen as a spark

- The high-speed electrons then impinge on the job and lons on the tool •

- The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux.

- Such intense localized heat flux leads to an extreme instantaneous confined rise in temperature. Such a localized extreme rise in temperature leads to material removal.

- Material removal occurs due to instant vaporization of the material as well as due to melting

- The workpiece is made positive and the tool negative. Hence, the electrons strike the job leading to crater formation due to high temperature and melting, and material removal. Similarly, the positive ions impinge on the tool leading to tool wear

3.5 Experimental Set-up and Experimentation

In this present study, the rectangular plate of nickel-titanium-based shape memory alloy having a thickness of 5mm with a density equal to 6.5 g/mm^3 was utilized to machine the specimen using a copper electrode having a diameter of 10mm.

Three important machining parameters are pulse on time, current and flushing pressure. Material removal rate and surface roughness are the two output responses. The design of the experiment was based on Taguchi orthogonal design L27 with three control factors with three levels each which are listed in Table 3.5.1.

Table 3.5.1: Control parameters and their levels.

Machining Parameter	Levels		
	Level 1	Level 2	Level 3
Current (A)	5	6	8
Pulse on time(μS)	50	100	200
Flushing Pressure(Kg/Cm^2)	1.5	1.25	1.15

The material removal rate is calculated by using the difference in weight of the sample before and after machining divided by the time taken for machining.

$$\mathrm{MRR} = \frac{\Delta \mathrm{W} * 1000}{\rho * \mathrm{t}}$$

Where,

ΔW- weight loss from the workpiece,

t - duration of the machining process,

ρ – density of the workpiece.

Unit : mm^3/min

Table 3.5.2: Experimental Layout using L27(3^3) OA

Run	Current	Pulse on time	Flushing Pressure
1	5	50	1.5
2	5	100	1.25
3	5	200	1.15
4	5	50	1.25
5	5	100	1.15
6	5	200	1.5
7	5	50	1.15
8	5	100	1.5
9	5	200	1.25
10	6	50	1.5
11	6	100	1.25
12	6	200	1.15
13	6	50	1.25
14	6	100	1.15
15	6	200	1.5
16	6	50	1.15
17	6	100	1.5
18	6	200	1.25
19	8	50	1.5
20	8	100	1.25
21	8	200	1.15
22	8	50	1.25
23	8	100	1.15
24	8	200	1.5
25	8	50	1.15
26	8	100	1.5
27	8	200	1.25

Chapter 4

Results and Discussion

Results and Discussion

Table 4.1: Experimental values of MMR and SR.

Run	Current	Pulse on time	Flushing Pressure	MRR	SR
1	5	50	1.5	1.528	5.45
2	5	100	1.25	1.733	4.7
3	5	200	1.15	3.367	4.09
4	5	50	1.25	1.49	4.7
5	5	100	1.15	1.49	4.09
6	5	200	1.5	3.885	5.45
7	5	50	1.15	3.067	4.09
8	5	100	1.5	1.438	5.45
9	5	200	1.25	1.851	4.7
10	6	50	1.5	3.695	5.65
11	6	100	1.25	2.541	4.33
12	6	200	1.15	2.487	3.72
13	6	50	1.25	2.416	4.33
14	6	100	1.15	4.662	3.72
15	6	200	1.5	2.65	5.65
16	6	50	1.15	1.893	3.72
17	6	100	1.5	3.42	5.65
18	6	200	1.25	2.331	4.33
19	8	50	1.5	3.263	6.86
20	8	100	1.25	5.906	5.21
21	8	200	1.15	2.65	8.52
22	8	50	1.25	2.627	5.21
23	8	100	1.15	2.579	4.56
24	8	200	1.5	2.862	6.86
25	8	50	1.15	2.303	5.56
26	8	100	1.5	2.011	6.86
27	8	200	1.25	2.483	5.21

4.1 Effect of input process parameter on MRR.

The experimentally measured value of MRR for selected twenty-seven experimental trials is shown in Table 4.1. For higher productivity, a higher value of MRR is desirable outcome. Thus, MRR is in the category of the higher the better performance characteristics. Statistical software Minitab 17 was used for the experimental analysis. Fig 4.1.1 shows the main effect plot for MRR considering the variation of all input parameters. As the current increases the MRR is also increases and higher MMR observed at level 1 and level 3 of flushing pressure. In Table 4.1.2 the delta value of current is higher among pulse on time and flushing pressure. Hence current is most influential parameter on MMR.

S/N Ratio formula : (Larger is better)

$S/N = -10*\log (\Sigma (1/Y 2)/n)$

Table 4.1.1 Response Table for Signal-to-Noise Ratios (Larger is better)

Level	Current	Pulse On time	Flushing Pressure
1	6.217	7.483	8.279
2	8.938	8.141	7.602
3	9.014	8.545	8.289
Delta	2.797	1.063	0.687
Rank	1	2	3

Table 4.1.2 Response Table for Means (MRR)

Level	Current	Pulse On time	Flushing Pressure
1	2.205	2.476	2.722
2	2.899	2.864	2.598
3	2.965	2.730	2.750
Delta	0.759	0.389	0.153
Rank	1	2	3

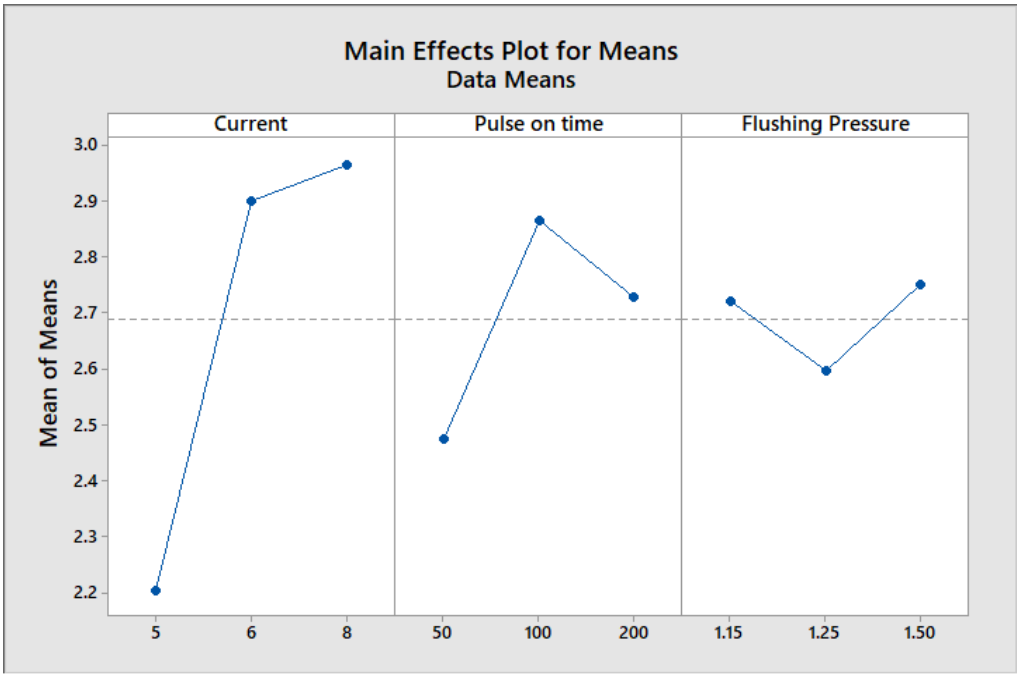

Figure 4.1.1: Main Effect Plot for Means (MMR)

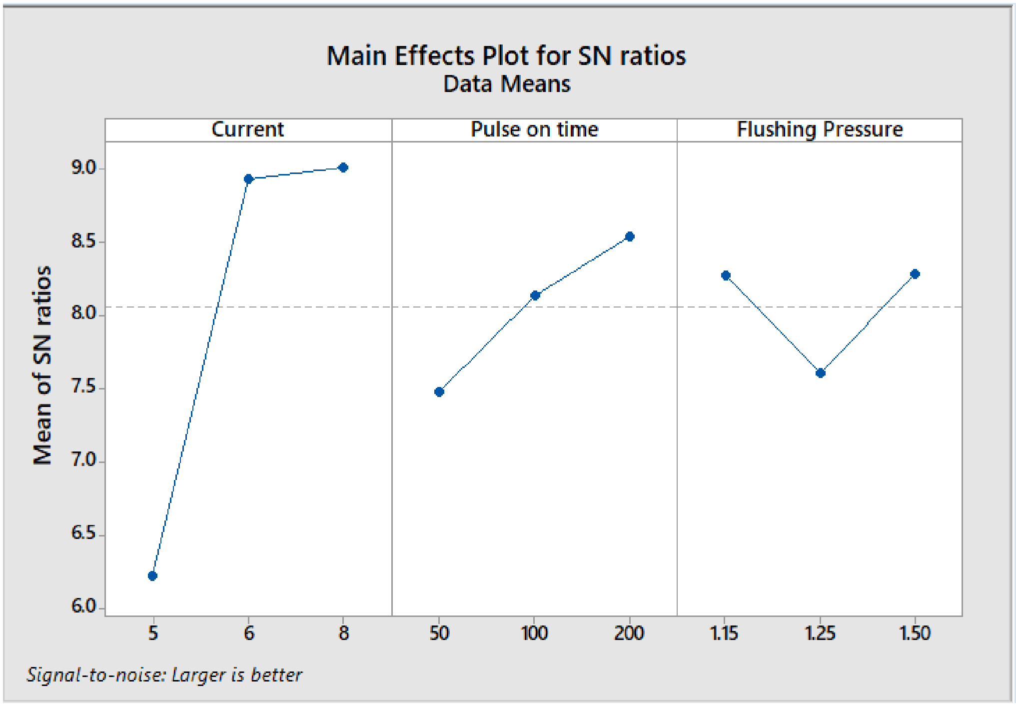

Figure 4.1.2: Main Effects Plot for SN ratio (MMR)

4.2 Effect of input process parameter on SR.

The experimentally measured value of SR for selected twenty-seven experimental trials is shown in Table 4.1. For a smooth surface, a lower value of SR is a desirable outcome. Thus, SR is in the category of the lower the better performance characteristics. Statistical software Minitab 17 was used for the experimental analysis. Fig 4.2.1 shows the main effect plot for SR considering the variation of all input parameters. When the current is at level 2 the lower surface roughness is observed which is desirable. At level 3 high value of surface roughness is observed which is not desired. Similarly, when the pulse on time is at level 2 the lower surface roughness is observed and high surface roughness is observed at level 3. In the case of flushing pressure lower surface roughness is observed at level 1 as the level increases the surface roughness also increases. In Table 4.2.2 the delta value of current is higher among pulse on time and flushing pressure. Hence current is the most influential parameter.

S/N Ratio formula : (Smaller is better)

S/N = −10*log (Σ (1/Y 2)/n)

Table 4.2.1 Response Table for Signal-to-Noise Ratios (smaller is better)

Level	Current	Pulse On time	Flushing Pressure
1	-13.47	-13.95	-13.07
2	-13.06	-13.76	-13.50
3	-15.54	-14.36	-15.50
Delta	2.48	0.60	2.43
Rank	1	3	2

Table 4.2.2 Response Table for Means (SR)

Level	Current	Pulse On time	Flushing Pressure
1	4.747	5.063	4.674
2	4.567	4.952	4.747
3	6.094	5.392	5.987
Delta	1.528	0.440	1.312
Rank	1	3	2

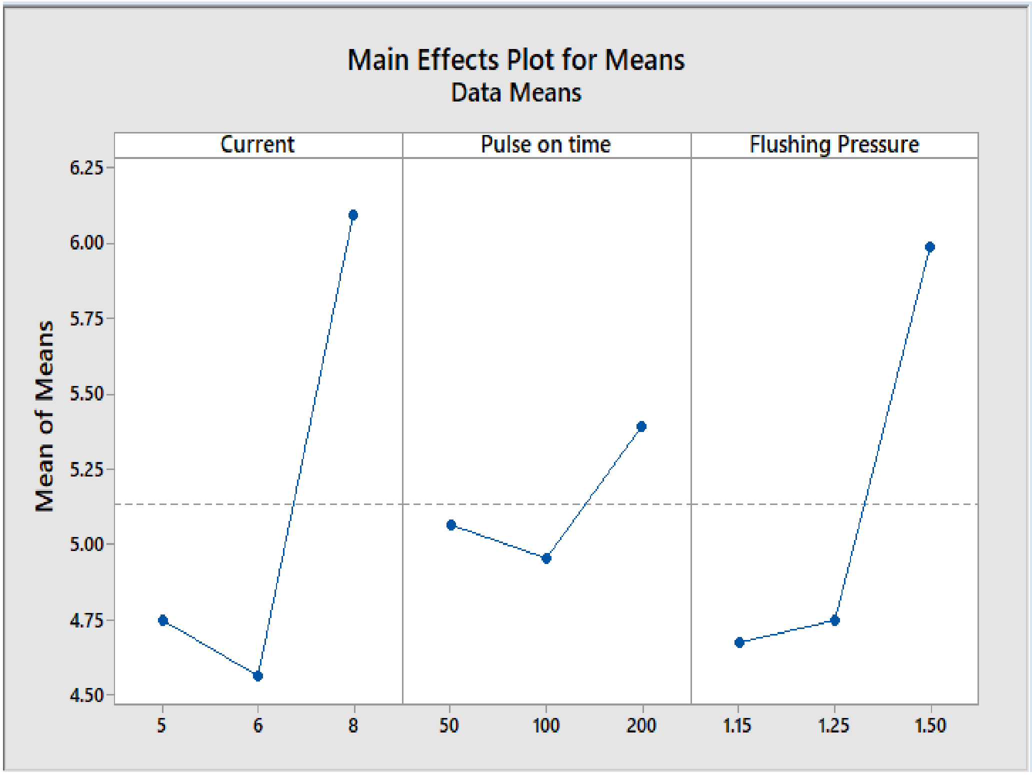

Figure 4.2.1: Main Effect Plot for Means (SR)

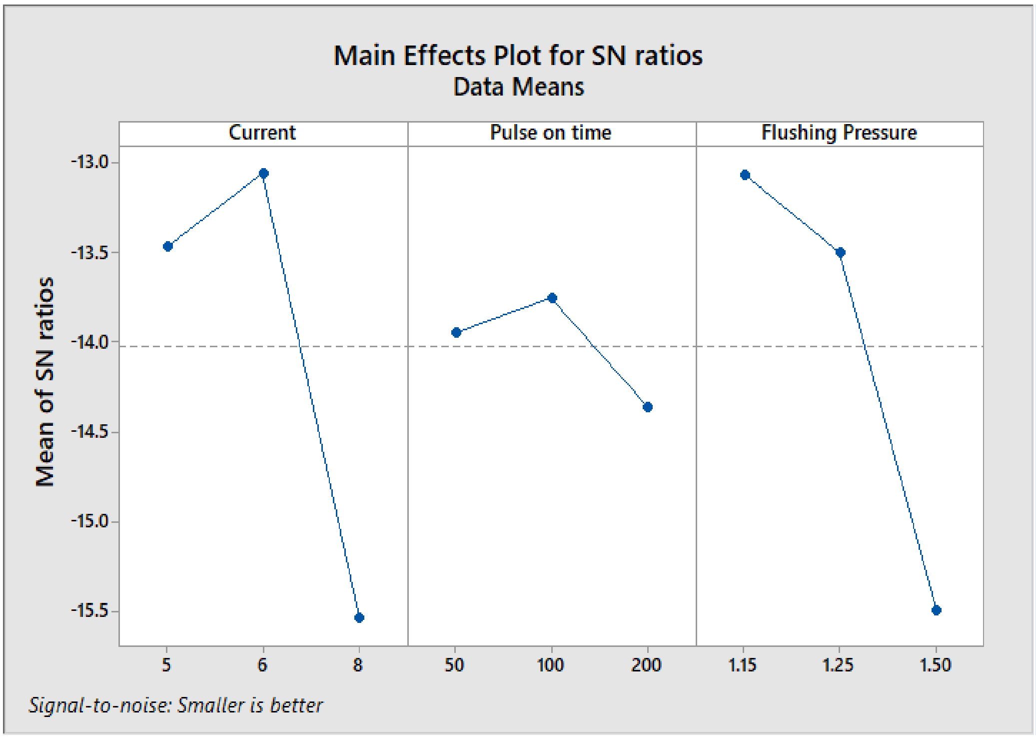

Figure 4.2.2: Main Effects Plot for SN ratio (SR)

Chapter 5

Conclusion

Conclusion

In this project, an attempt has been made to experimentally investigate the impact of the selected EDM process parameter such as current, pulse on time, and flushing pressure on output parameters and optimize the considered responses by using the Taguchi method. After the experimentation, the following conclusion can be made:

- Current has the most impact on output responses out of all considered input parameters.
- Material removal rate increases with an increase in current. The current made a large impact on the material removal rate followed by pulse on time and flushing pressure.
- Current at 8 A, pulse on time at 100µs, and flushing pressure at 1.50 kg/cm^2 give a higher value of material removal rate.
- As the flushing pressure increases surface roughness is also increases. Current at 6 A, pulse on time at 100µs, and flushing pressure at 1.15 kg/cm^2 give a lower value of surface roughness.
- The current made a large impact on the SR followed by flushing pressure and pulse on time.

Society/Community Utility :

- Firstly, in the medical industry, SMAs are used in various medical devices such as stents, orthodontic wires, and surgical tools. By optimizing the parameters for EDM of SMAs, the manufacturing process of these medical devices can be improved. This can result in more accurate and reliable medical devices, leading to better patient outcomes.
- Secondly, the aerospace industry can also benefit from the parametric optimization of SMAs on EDM. SMAs are used in various aerospace applications, such as actuation systems and structural components. By optimizing the EDM parameters, the manufacturing of these components can be improved, resulting in lighter and more efficient aerospace systems. This can lead to reduced fuel consumption and emissions, contributing to a more sustainable future.
- Thirdly, the automotive industry can also benefit from the parametric optimization of SMAs on EDM. SMAs are used in various automotive applications, such as brake

systems, suspension systems, and engine components. By optimizing the parameters for EDM of SMAs, the manufacturing process of these components can be improved. This can result in more durable and efficient automotive systems, leading to improved safety and reduced maintenance costs. the parametric optimization of nickel titanium based shape memory alloy on electrical discharge machining can have significant social utility in various fields. By improving the manufacturing process of SMAs, this technology can lead to better patient outcomes, more efficient aerospace systems, and safer and more durable automotive systems.

Chapter 6

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Chapter 7

Publication

Publication

Publication Details :

RAMMML- 2023 (RECENT ADVANCES IN MATERIALS, MANUFACTURING AND MACHINE LEARNING-2023):

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Certificate of Participation

This certificate is awarded to **Prajwal Chamat**, affiliated to **Yeshwantrao Chavan College of Engineering, Nagpur** for successfully presenting the manuscript titled **"A Mini-Review On Electro Discharge Machining of Aluminium Metal Matrix Composite Materials"** with manuscript ID: **84** in The 2nd International Conference on **"Recent Advances in Materials, Manufacturing and Machine Learning (RAMMML-2023)"** organized by **Department of Mechanical Engineering, Yeshwantrao Chavan College of Engineering, Nagpur,** Technically sponsored by **NPTC Group of Colleges, United Kingdom** held on **2nd – 4th February 2023.**

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