

STUDY ON WEDM PROCESS PARAMETERS ON MACHINING OF SS304

Submitted in partial fulfillment of the requirements for the award of
**Bachelor of Engineering Degree in
Mechanical Engineering**

By

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with grade "A" by NAAC

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BONAFIDE CERTIFICATE

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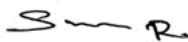
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ABSTRACT

Wire Electrical Discharge Machining (WEDM) is an advanced technique used for creating intricate shapes in conductive materials. Stainless Steel 304 (SS304) is a popular material used in various industries including aerospace, medical, electronic, semiconductor, tool, and die manufacturing. However, due to its limited heat conductivity and high built-up edge (BUE) affinity, traditional machining of SS304 can result in significant challenges such as excessive tool wear and high surface roughness values. To address this issue, this study focused on optimizing process parameters, including peak current, pulse on time, pulse off time, wire feed rate, and wire material, which impact output responses such as kerf width (K), material removal rate (MRR), and surface roughness Ra. Scanning Electron Microscope (SEM) images were used to study the surface morphology of the samples, and the impact of wire material and other WEDM process parameters were thoroughly discussed.

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LIST OF ABBREVIATION

CAD	-	Computer-Aided Design
CAM	-	Computer-Aided Manufacturing
CNC	-	Computer Numerical Control
EDM	-	Electrical Discharge Machining
HAZ	-	Heat-Affected Zone
I	-	Current
MRR	-	Material removal rate
PCBs	-	Printed Circuit Boards
PM-WEDM	-	Powder mixed wire electric discharge machining
Ra	-	Surface roughness
SS304	-	Stainless steel 304
Toff	-	Pulse off time
Ton	-	Pulse on time
WEDM	-	Wire electric discharge machining

CHAPTER 1

INTRODUCTION

In today's rapidly evolving manufacturing landscape, the demand for high-precision components with intricate designs has become increasingly prominent. Conventional machining methods often struggle to meet these demands due to limitations such as tool wear, material hardness, and complex geometries. However, a technology known as Wire Electrical Discharge Machining (EDM) has emerged as a solution. Wire EDM is a precision machining technique that utilizes a controlled electrical discharge between a wire electrode and the workpiece to remove material and create complex shapes with unmatched accuracy. The process involves a wire electrode, typically made of brass or copper, that is fed continuously through the workpiece while being submerged in a dielectric fluid. As electrical pulses are applied to the wire, sparks are generated, and the material is eroded, resulting in precise and intricate cuts. The working principle of Wire Electrical Discharge Machining involves the use of electrical sparks to erode material from a workpiece using a thin wire electrode. The wire electrode is guided by CNC and submerged in a dielectric fluid. High voltage electrical discharges generate sparks that melt and vaporize the material, which is then flushed away by the dielectric fluid. The wire electrode is continuously fed from a spool and guided by wire guides to maintain stability and accuracy. Wire EDM is a non-contact machining process that allows for precise machining of complex shapes and hard materials without tool wear or damage. The key parameters such as pulse duration, current, voltage, wire speed, and dielectric fluid properties are carefully controlled for optimal results.

Since its invention in the 1960s, Wire EDM has evolved significantly and has found applications in various industries, including aerospace, automotive, medical, and electronics, where the production of high-quality and complex parts is critical. The remarkable precision, versatility, and ability to machine different

materials make Wire EDM a preferred choice for manufacturing parts with challenging geometries, tight tolerances, and superior surface finishes. In this report, we will begin by providing an in-depth understanding of the basic principles behind Wire EDM, including the spark generation, wire movement, and the role of dielectric fluid. And its performance on different parameters and dielectric. For this experiment we have used different parameters obtained using minitab. And we have also used three different dielectric. And we also analyzed the results of the samples and have found out the parameter which gives better surface finish. Through this comprehensive report, we aim to provide a deep and comprehensive understanding of Wire EDM as a precision machining technique. We will explore its fundamental principles, advantages, applications, and analyzed result for better efficient machining, highlighting its significant impact on the manufacturing industry. With its unparalleled precision and versatility, Wire EDM has transformed the way complex parts are manufactured, and its potential for further advancements holds promise for the future of manufacturing.

1.1 WEDM SETUP

The machining process that we have chosen for machining in this project is wire electrical discharge machining.

1.1.1 *Major Components of WEDM System*

The wire electrical discharge machining consists of six components. They are

1. Machining tool.
2. Pulse generator.
3. Computer numeric control.
4. Power supply.
5. Dielectric system.
6. Coolant.

1.1.1.1 Machine Tool

- The machine tool consists of several components, including a work table commonly referred to as X, Y, and Z axis quill with motor, an automatic wire tension unit with rollers, and other elements.
- The work table moves along the X and Y axes with a precision of 1 micron, utilizing stepper motors for motion. Additionally, an auxiliary table that runs parallel to the X-Y table also moves using stepper motors.
- The machine incorporates multiple coordinate systems, allowing jobs to be programmed in either absolute or incremental modes, which saves programming time. For instance, multiple jobs can be set up on the worktable, with separate reference points or locations of these jobs stored in designated coordinate registers.
- The machine has the capability to produce taper cuts with an angle of ± 10 degree over a distance of 50 mm, thanks to the movement of the auxiliary table.

1.1.1.2 Pulse Generator

- The SC 01 generator is equipped with a user-friendly screen that operates on a Windows-based system, making it easy and convenient to operate the machine.
- The pulse generator unit generates a series of electrical pulses that are applied between the workpiece and the moving wire electrode, resulting in the electro-erosion of the workpiece material. As the material removal or machining progresses, the workpiece is displaced in the X-Y direction by the controller, following a predetermined path that is programmed into the controller. The path specifications can be supplied to the controller through a program.

- When the X-Y table moves along the predetermined path while the U-V table remains stationary, a straight cut with a predetermined pattern is created.
- One of the advantages of the SC 01 generator is that the user can draw a profile on the same PC while the spark mode is active.

1.1.1.3 Computer Numerical Control (CNC)

- In the world of precision manufacturing, Wire Electrical Discharge Machining (WEDM) has emerged as a cutting-edge technology for producing complex and intricate parts with unparalleled precision. Central to the success of WEDM is the incorporation of Computer Numerical Control (CNC), which has revolutionized the way wire EDM machines operate, providing enhanced accuracy, versatility, and efficiency in the manufacturing process.
- CNC technology has transformed the landscape of WEDM by automating the control of machine movements and operations through computer programming. With CNC, the traditional manual controls and limitations of WEDM have been replaced by advanced software-driven systems that offer superior precision and repeatability.
- One of the key advantages of CNC in WEDM is the ability to program and execute complex cutting paths with high precision. CNC allows for the creation of intricate part profiles, complex geometries, and precise angles, which would be challenging or impossible to achieve with manual control. The ability to program and automate these cutting paths not only ensures consistent and accurate results but also enables rapid prototyping and efficient production of complex parts with minimal operator intervention.
- Moreover, CNC in WEDM offers exceptional flexibility and versatility. With CNC programming, operators can easily switch between

different part designs, shapes, and sizes without the need for costly and time-consuming retooling or reconfiguration of the machine. CNC also enables the use of different cutting strategies, such as roughing and finishing, to optimize the machining process for specific materials, geometries, or surface finishes. This flexibility allows manufacturers to adapt quickly to changing production requirements and deliver customized parts with precision and efficiency.

- Additionally, CNC in WEDM enhances process control and monitoring. The CNC software provides real-time feedback and monitoring of various process parameters, such as cutting speed, wire tension, and spark gap, allowing for fine-tuning and optimization of the machining process. This level of process control ensures consistent quality and reduces the risk of errors or defects, leading to higher yield rates and improved overall productivity.
- Another significant advantage of CNC in WEDM is the ability to integrate with other manufacturing processes and software systems. CNC can seamlessly communicate with Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) software, allowing for seamless transfer of part designs and machining instructions to the WEDM machine. This integration streamlines the entire production process, eliminates the need for manual data input or translation, and minimizes the potential for errors or discrepancies.
- Furthermore, CNC in WEDM offers improved operator safety and ease of use. The automated nature of CNC minimizes the operator's exposure to hazardous cutting conditions, such as sparks, debris, and wire tension. The intuitive user interfaces of CNC software make it user-friendly and accessible, reducing the learning curve for operators and allowing for efficient and safe operation of the machine.

- CNC has changed the field of WEDM, transforming it from a manual, labor-intensive process to a highly automated and precise manufacturing technology. CNC in WEDM offers numerous advantages, including enhanced accuracy, versatility, flexibility, process control, integration with other manufacturing processes, and improved operator safety. As CNC technology continues to advance, it is expected to further propel the growth and innovation in the field of WEDM, enabling manufacturers to produce even more complex and precise parts with unprecedented efficiency and quality.

1.1.1.4 Power supply

One of the key components that directly affects the performance and efficiency of WEDM is the power supply. The power supply in WEDM serves as the source of electrical energy that is used to generate the sparks. It provides the necessary voltage, current, and pulse duration to create the electrical discharge that erodes the workpiece material. The power supply needs to be carefully calibrated and controlled to ensure optimal machining results.

One of the critical parameters in the power supply for WEDM is the pulse duration. The pulse duration determines the time duration of the electrical discharge, which in turn affects the material removal rate, surface finish, and accuracy of the machined part. The power supply should allow for precise control of the pulse duration to achieve the desired machining results.

Another important aspect of the power supply is the stability and consistency of the output voltage and current. Fluctuations in the power supply can result in variations in the spark intensity and discharge energy, leading to inconsistent machining results. Therefore, a stable and reliable power supply is crucial for maintaining the accuracy and repeatability of the WEDM process.

Additionally, the power supply in WEDM should also have proper safety features to protect the operator and the equipment. Since WEDM involves high voltages and electrical discharges, adequate safety measures such as short-circuit

protection, over-voltage protection, and ground fault detection should be incorporated in the power supply system.

In conclusion, the power supply plays a crucial role in WEDM by providing the necessary electrical energy for the machining process. It needs to be carefully calibrated, stable, and safe to ensure optimal machining results and protect the operator and equipment. Proper attention should be given to selecting and maintaining a reliable power supply for WEDM applications.

1.1.1.5 Dielectric system

The dielectric system in WEDM serves as a medium for the electrical discharge to occur between the wire electrode and the workpiece. It typically consists of a dielectric fluid, which acts as an insulator and a coolant during the machining process. The dielectric fluid is carefully selected based on its properties, such as dielectric strength, thermal conductivity, and viscosity, to ensure optimal machining results. One of the primary functions of the dielectric system is to facilitate the flushing of the eroded particles from the machining zone. As the electrical discharge occurs, the dielectric fluid is used to flush away the eroded particles and debris from the cutting zone, preventing them from interfering with the machining process. This flushing action helps to maintain a clean and debris-free machining zone, which is crucial for achieving accurate and precise machining results.

The dielectric system also plays a role in controlling the spark gap, which is the distance between the wire electrode and the workpiece. The dielectric fluid helps to maintain a stable and consistent spark gap by providing a medium for the electrical discharge to occur. This ensures that the sparks are generated at the desired location and with the desired intensity, which directly affects the accuracy and quality of the machined part.

Furthermore, the dielectric system also helps in regulating the temperature during the WEDM process. The dielectric fluid acts as a coolant, dissipating the heat generated during the electrical discharge, and helps to prevent overheating of the workpiece and the wire electrode. This helps to maintain a stable

temperature and prevent thermal damage to the workpiece, ensuring dimensional accuracy and surface finish of the machined part.

Powder Mixed WEDM (PM-WEDM)

Powder mixed wire electrical discharge machining (PM-WEDM) is a modern manufacturing process that combines traditional wire EDM with the use of conductive powder particles. In this process, a thin wire electrode is used to create an electrical discharge between the wire and the workpiece, which melts and vaporizes the material.

The key difference between PM-WEDM and traditional wire EDM is the addition of a conductive powder mixed with dielectric fluid to the gap between the wire and the workpiece. The powder particles help to erode the material, reducing the wear and tear on the wire electrode and increasing the material removal rate.

This process has several advantages over traditional wire EDM, including faster material removal rates, improved surface finish, and reduced wire electrode wear. Additionally, PM-WEDM can be used to machine complex shapes and intricate geometries, making it ideal for manufacturing parts used in the aerospace, medical, and automotive industries.

The use of powder particles in PM-WEDM also makes it suitable for difficult-to-machine materials such as titanium alloys and ceramics, where traditional machining techniques may not be effective. By using powder particles, the process can increase the material removal rate while maintaining precision and accuracy in the final product.

In conclusion, PM-WEDM is a promising technology that can improve the efficiency, accuracy, and surface finish of machined parts. Its ability to handle difficult-to-machine materials and intricate geometries makes it a valuable tool in modern manufacturing.

1.2.1.6 Coolant unit

One of the key functions of the coolant unit is to flush away the eroded particles and debris from the cutting zone. As the electrical discharge occurs between the wire electrode and the workpiece, material is eroded from the workpiece, creating debris. The coolant unit delivers a continuous flow of coolant to the machining zone, effectively carrying away the debris and preventing it from interfering with the machining process. This helps to maintain a clean and debris-free machining zone, ensuring accurate and precise machining results.

In addition to debris flushing, the coolant unit also plays a crucial role in regulating the temperature during the WEDM process. The electrical discharge generates heat, and the coolant acts as a coolant, dissipating the heat and preventing overheating of the workpiece and the wire electrode. This helps to maintain a stable temperature, preventing thermal damage and ensuring dimensional accuracy and surface finish of the machined part.

Furthermore, the coolant unit helps to improve machining efficiency by reducing wear and tear on the wire electrode. The continuous flow of coolant helps to lubricate the wire electrode, reducing friction and minimizing wear. This extends the lifespan of the wire electrode and improves machining efficiency, resulting in longer tool life and better machining performance.

In conclusion, the coolant unit is a crucial component in WEDM, providing a continuous and controlled supply of coolant to flush away debris, regulate temperature, and improve machining efficiency. Proper management of the coolant unit is essential for achieving optimal machining results in WEDM.

1.2.1.7 Keyboard and Control Panel Description

Functional Commands

- Pre Jog Pre jog is used to move the table to the position at which spark or dry run is halted.

- Pre Spark Pre-spark is very much similar to Pre-jog except table is moved like in spark mode.
- Centre Find Wire must be threaded through the hole/cavity for which centre find operation is to be performed.
- Edge Find Wire must be loaded before performing this operation. Edge find operation gets terminated whenever gap short conditions are detected. There are four modes of operation along X+,X-,Y+ and Y-.
- Wire Vertical It is used for vertical wire adjustment. For reference, wire vertical block is provided with the machine.
- Halt It is used to halt from functional spark, dry run, Pre-Jog, Pre-Spark, Centre find, Edge find and Wire vertical.

1.2 ADVANTAGES OF WEDM

- i. High Precision: WEDM is known for its exceptional accuracy in cutting complex shapes and achieving tight tolerances, making it ideal for precision machining applications.
- ii. Versatility: WEDM can cut a wide range of materials, including hard and tough materials like tool steels, titanium, and carbide, making it suitable for various industries and applications.
- iii. Complex Shapes and Fine Features: WEDM can cut intricate shapes and fine features with high precision, including tight inside radii, sharp corners, and small holes.
- iv. No Tool Contact: WEDM uses a non-contact wire electrode, eliminating the risk of tool wear, tool breakage, and material distortion.

- v. **Excellent Surface Finish:** WEDM produces smooth and burr-free surfaces, reducing the need for additional finishing operations.
- vi. **Minimal Heat Affected Zone (HAZ):** WEDM generates minimal heat during cutting, resulting in a small HAZ on the workpiece and minimizing the risk of material distortion.
- vii. **Material Hardness:** WEDM can cut materials with high hardness, which may be challenging or impossible with other cutting methods.
- viii. **Thin and Delicate Parts:** WEDM is suitable for cutting thin and delicate parts without causing distortion or damage.
- ix. **Accuracy and Repeatability:** WEDM offers high accuracy and repeatability, ensuring consistent results even for complex and repetitive cutting tasks.
- x. **Reduced Tooling Costs:** WEDM eliminates the need for expensive tooling, reducing overall production costs.
- xi. **Low Maintenance:** WEDM machines require minimal maintenance compared to traditional cutting methods, reducing downtime and production costs.
- xii. **Automation and Productivity:** WEDM machines can be automated for continuous and unattended operation, increasing productivity and reducing labor costs.
- xiii. **CAD/CAM Integration:** WEDM machines can be integrated with CAD/CAM software for efficient programming, optimized tool paths, and improved productivity.
- xiv. **Fast Cutting Speeds:** WEDM machines are capable of cutting at high speeds, reducing production cycle times.

- xv. **Reduced Material Waste:** WEDM generates minimal material waste due to its narrow kerf width, resulting in cost savings.
- xvi. **Flexibility:** WEDM allows for changes in cutting parameters during the machining process, providing flexibility in production.
- xvii. **Improved Machining Capabilities:** Advances in WEDM technology, such as adaptive control, multi-axis machining, and advanced wire threading, have expanded its capabilities and improved machining efficiency.
- xviii. **Small Part Production:** WEDM is suitable for producing small and intricate parts with high precision, making it ideal for micro-machining applications.
- xix. **Reduced Risk of Contamination:** WEDM uses dielectric fluid for flushing, reducing the risk of contamination on the workpiece and improving part quality.
- xx. **Environmental Friendliness:** WEDM uses de-ionized water as a dielectric fluid, making it an environmentally friendly cutting method compared to traditional cutting methods that may generate hazardous waste.

1.3 LIMITATIONS OF WEDM

- i. **Slow Cutting Speed:** WEDM typically has a slower cutting speed compared to some other cutting methods, which may result in longer production cycle times.
- ii. **High Initial Investment:** WEDM machines can be expensive to acquire and set up, requiring a significant initial investment.
- iii. **Complex Setup:** Setting up WEDM machines can be complex, involving precise alignment and calibration, which may require skilled operators.

- iv. Limited Material Thickness: WEDM is not suitable for cutting thick materials, and there may be limitations on the maximum material thickness that can be effectively cut.
- v. Material Conductivity: WEDM is not suitable for cutting highly conductive materials such as aluminum and copper, as they can cause wire breakage and other issues.
- vi. Consumable Costs: WEDM requires consumables such as wire electrode and dielectric fluid, which can add to the overall operating costs.
- vii. Wire Depletion: The wire electrode used in WEDM can wear out or break, requiring frequent replacements and causing downtime.
- viii. Recast Layer: WEDM can result in a recast layer on the workpiece surface, which may require additional post-machining operations for surface finishing.
- ix. Tapering: WEDM can result in slight tapering of the cut edges, which may require additional measures to achieve precise parallelism.
- x. Wire Threading Challenges: Threading the wire electrode through small holes or complex shapes can be challenging and time-consuming.
- xi. Corner Radius Limitations: WEDM may have limitations in achieving very tight inside corner radii due to wire electrode size.
- xii. Risk of Wire Deflection: Thin or delicate wires used in WEDM may deflect during cutting, affecting cutting accuracy and precision.
- xiii. Surface Discoloration: WEDM can result in discoloration or staining on the workpiece surface due to the use of dielectric fluid.

- xiv. Environmental Concerns: Disposal and management of used dielectric fluid can pose environmental challenges and require proper handling and disposal measures.
- xv. Operator Skill Requirements: Operating WEDM machines may require skilled operators with specialized training and expertise, adding to labor costs.

1.4 APPLICATIONS OF WEDM

- i. Aerospace Industry: WEDM is commonly used in aerospace manufacturing for cutting complex shapes, such as turbine blades, engine components, and aerospace alloys[1].
- ii. Automotive Industry: WEDM is used in the automotive industry for cutting intricate parts, such as gears, shafts, and molds for plastic components.
- iii. Medical Industry: WEDM is used in the medical industry for manufacturing surgical instruments, orthopedic implants, and dental prosthetics.
- iv. Electronics Industry: WEDM is used in the electronics industry for cutting intricate patterns in printed circuit boards (PCBs), lead frames, and micro-components.
- v. Tool and Die Industry: WEDM is used for producing dies, molds, and tooling components with high precision and intricate shapes.
- vi. Precision Machining: WEDM is used for precision machining of various materials, including hard and heat-resistant materials, where conventional machining methods may not be feasible.
- vii. Prototyping: WEDM is used for rapid prototyping and production of small batches of complex parts with tight tolerances.

- viii. Jewelry Industry: WEDM is used in the jewelry industry for cutting intricate patterns, designs, and molds for jewelry components.
- ix. Energy Industry: WEDM is used for manufacturing parts for energy-related applications, such as turbine blades, fuel cells, and electrical contacts.
- x. Micro Machining: WEDM is used for micro machining applications, such as cutting micro features, micro molds, and micro components in various industries, including electronics, medical, and aerospace.
- xi. Watchmaking Industry: WEDM is used in the watchmaking industry for cutting intricate watch components with high precision.
- xii. Optical Industry: WEDM is used for cutting intricate shapes in optical components, such as lenses, mirrors, and prisms.
- xiii. Dielectric Industry: WEDM is used for manufacturing components used in the dielectric industry, such as ceramic guides, spacers, and insulators.
- xiv. Textile Industry: WEDM is used for cutting intricate patterns and designs in textile molds and templates for the textile industry.
- xv. Packaging Industry: WEDM is used for manufacturing intricate cutting dies and molds for the packaging industry, including cartons, boxes, and packaging inserts.

1.5 FEATURES OF WEDM

- i. Precision Cutting: WEDM offers high precision cutting capabilities, allowing for the production of complex shapes with tight tolerances.
- ii. Non-Contact Cutting: WEDM uses a thin wire electrode to cut the material, which does not require direct contact with the workpiece, minimizing the risk of damage or distortion.

- iii. Ability to Cut Hard Materials: WEDM can cut hard and heat-resistant materials, such as stainless steel, titanium, and carbide, which are difficult to machine using conventional methods.
- iv. Fine Surface Finish: WEDM produces a fine surface finish on the cut edges, reducing the need for additional finishing processes.
- v. Minimal Material Waste: WEDM generates very little material waste, making it a cost-effective and environmentally friendly cutting method.
- vi. Complex Shapes and Intricate Designs: WEDM can cut complex shapes and intricate designs with high precision, allowing for the production of intricate parts and molds.
- vii. Versatility: WEDM can be used to cut a wide range of materials, including conductive and non-conductive materials, making it versatile for various applications.
- viii. High Productivity: WEDM machines can operate continuously for extended periods, resulting in high productivity and efficiency.
- ix. Wire Threading Capability: WEDM machines are equipped with wire threading capabilities, allowing for continuous cutting without the need for manual intervention.
- x. Multi-Axis Cutting: WEDM machines can cut in multiple axes, enabling the production of complex 3D shapes.
- xi. Automation: WEDM machines can be integrated with automation systems, allowing for unmanned operation and increased productivity.
- xii. Reduced Tooling Costs: WEDM does not require complex tooling, reducing the tooling costs associated with conventional machining methods.

- xiii. Excellent Corner Accuracy: WEDM offers excellent corner accuracy, allowing for precise cutting of sharp corners without rounding or burrs.
- xiv. Minimal Heat Affected Zone: WEDM produces minimal heat during the cutting process, reducing the heat-affected zone (HAZ) and minimizing material distortion or warping.
- xv. Wide Range of Wire Diameters: WEDM machines can accommodate a wide range of wire diameters, allowing for flexibility in cutting various material thicknesses.

CHAPTER 2

LITERATURE SURVEY

The research paper by Saha, Bhattacharyya, and Datta (2020) proposes a multi-objective optimization approach for wire electrical discharge machining (WEDM) of AlSiCp MMC using grey relational analysis. The study aims to optimize the WEDM parameters such as pulse on-time, pulse off-time, and wire tension to improve the machining performance in terms of material removal rate, surface roughness, and cutting width deviation. The results show that the proposed approach can effectively optimize the WEDM process and improve the machining performance of AlSiCp MMC.

The research paper by Tanaka and Goto (2018) investigates high-speed wire electrical discharge machining (WEDM) of fine and deep micro holes. The study explores the effects of WEDM parameters such as wire speed, pulse duration, and flushing pressure on the machining efficiency and quality of the micro holes. The results suggest that high-speed WEDM can achieve efficient and precise machining of fine and deep micro holes, providing a promising technique for microfabrication applications [21].

The research paper by Umer and Elbestawi (2019) investigates the influence of wire electrical discharge machining (WEDM) parameters on the surface integrity and subsurface microstructure of Ti-6Al-4V. The study explores the effects of WEDM parameters such as wire feed rate, pulse current, and pulse duration on the surface roughness, microhardness, and microstructure of the material. The results suggest that optimizing the WEDM parameters can improve the surface integrity and microstructure of Ti-6Al-4V, providing useful insights for optimizing the WEDM process.

The research paper by Venkatesan, Rajmohan, and Selvamani (2020) proposes a multi-objective optimization approach for wire electrical discharge machining (WEDM) using Taguchi-based grey relational analysis. The study aims to optimize the WEDM parameters such as pulse on-time, pulse off-time, and wire tension to improve the machining performance in terms of material removal rate, surface roughness, and cutting width deviation. The results show that the proposed approach can effectively optimize the WEDM process and improve the machining performance [23].

The research paper by Wang and Yan (2019) investigates high-efficiency machining of high-aspect-ratio micro hole arrays using wire electrical discharge machining (WEDM). The study explores the effects of WEDM parameters such as wire feed rate, pulse current, and pulse duration on the machining efficiency and quality of the micro hole arrays. The results suggest that WEDM can achieve high-efficiency machining of high-aspect-ratio micro hole arrays with good accuracy and surface quality, providing a promising solution for microfabrication applications [24].

The research paper by Xie, Tang, and Cui (2020) explores high-precision cutting of micro channels through wire electrical discharge machining (WEDM). The study investigates the influence of WEDM parameters such as wire tension, pulse current, and pulse duration on the cutting accuracy and surface quality of the micro channels. The results indicate that WEDM can achieve high-precision cutting of micro channels with an accuracy of up to $\pm 1.4 \mu\text{m}$ and a surface roughness of less than $0.4 \mu\text{m}$, making it a promising technique for microfabrication applications [25].

The research paper titled "An in-depth study of photocathodic protection of SS304 steel by electrodeposited layers of ZnO nanoparticles" investigates the photocathodic protection of SS304 steel using electrodeposited layers of ZnO nanoparticles. The study finds that the ZnO nanoparticle layer can significantly improve the photocathodic protection performance of SS304 steel under UV irradiation. The research employs various techniques such as scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), and electrochemical tests to analyze the morphology, composition, and performance of the ZnO nanoparticle layer. The paper provides valuable insights

into the use of ZnO nanoparticle layers for photocathodic protection of SS304 steel, which can have significant implications in various industrial applications, including corrosion prevention [26].

The research paper by Zhang, Guo, and Wei (2018) delves into the mechanism behind wire electrical discharge machining (WEDM) of titanium alloy using three-dimensional numerical analysis. The paper highlights the importance of optimizing the machining parameters to achieve better surface quality and efficiency. The authors used finite element method simulations to analyze the thermal and fluid dynamics during the WEDM process, providing insights into the material removal process and the formation of the recast layer. The study sheds light on the effects of pulse frequency, pulse duration, wire feed rate, and gap voltage on the machining performance, offering a basis for optimizing the WEDM process parameters [27].

CHAPTER 3

AIM AND SCOPE

3.1 AIM

Wire Electrical Discharge Machining (WEDM) is a process utilized to cut intricate shapes in electrically conductive materials. The primary objective of WEDM machining is to manufacture high-precision components with a fine surface finish and minimal mechanical stress or distortion in the workpiece.

During the WEDM process, a thin metal wire is utilized to cut the workpiece by creating a spark between the wire and the material being machined. This spark erodes the material and generates a narrow gap in the workpiece, which is then flushed away by a dielectric fluid. By precisely controlling the voltage, current, and movement of the wire, the shape of the cut can be accurately controlled.

The WEDM process is particularly useful for cutting complex shapes that would be difficult or impossible to achieve using traditional machining techniques. This makes it a preferred method for producing high-precision components for various industries, including aerospace, medical, and electronics. The aim of WEDM machining is to provide a cost-effective and accurate method for manufacturing intricate and precise parts with a high degree of consistency and accuracy.

3.2 SCOPE OF THE PROJECT

- I. The scope of Wire EDM includes the production of complex shapes and tight tolerances, making it ideal for parts in industries such as aerospace, medical, and electronics.

- II. Wire EDM can cut hard and brittle materials, such as ceramics and tungsten carbide, which are difficult to machine using traditional methods.
- III. The machining process is used to produce prototypes, tooling, dies, and molds, which are critical components in modern manufacturing.
- IV. Wire EDM can produce parts with fine surface finishes and excellent dimensional accuracy, making it an ideal method for producing parts that require minimal post-processing.
- V. Compared to traditional machining methods, Wire EDM is a cost-effective method for producing low-volume parts or parts that require high precision and accuracy, as it eliminates the need for expensive tooling and fixtures [5].
- VI. Wire EDM is ideal for producing intricate and complex shapes, such as gears, turbine blades, and fuel injection nozzles.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 MATERIALS FOR WEDM PROCESS

4.1.1 *Stainless steel 304*

The material that we have used for this experiment is stainless steel of grade 304. SS304 is a widely employed grade of stainless steel in diverse industries owing to its outstanding corrosion resistance, durability, and versatility. Stainless steel is renowned for its excellent performance in challenging environments and SS304 is particularly favored for its versatility and wide-ranging applications.

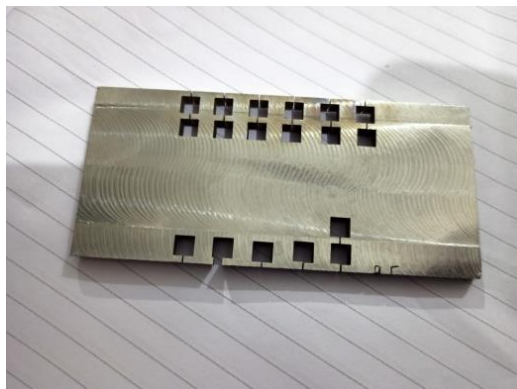


Fig. 4.1. SS304 material

4.1.2 *Properties of SS304*

SS304 is a member of the austenitic stainless steel family, known for its elevated levels of chromium (Cr) and nickel (Ni). Typically, SS304 comprises 18% chromium and 8% nickel, as well as trace amounts of carbon, manganese, and other elements.

Table 4.1 SS304 composition

Element	% Present
Carbon (C)	0.07
Chromium (Cr)	17.50 - 19.50
Manganese (Mn)	2.00
Silicon (Si)	1.00
Phosphorous (P)	0.045
Sulphur (S)	0.015b)
Nickel (Ni)	8.00 - 10.50
Nitrogen (N)	0.10
Iron (Fe)	Balance

These alloying elements give SS304 its unique properties, which include:

Corrosion resistance

SS304 possesses remarkable resistance to corrosion, rendering it well-suited for applications in diverse corrosive environments, including those with acidic, alkaline, or chloride-containing conditions. The substantial chromium content in SS304 prompts the formation of a passive oxide layer on its surface, providing effective protection against corrosion.

High temperature resistance

SS304 exhibits impressive heat resistance, retaining its strength and structural integrity even at temperatures as high as 870°C (1600°F). As a result, it is well-suited for use in applications that entail exposure to elevated temperatures, such as heat exchangers, exhaust systems, and furnace components.

Excellent formability

SS304 is highly malleable and can be easily shaped into different configurations and sizes using standard fabrication techniques like bending, welding, and machining. This versatility makes it well-suited for a wide range of manufacturing processes, including sheet metal fabrication, machining, and welding.

High strength

SS304 possesses favorable mechanical properties such as tensile strength, yield strength, and hardness, which make it well-suited for structural applications that demand strength and durability.

4.1.3 Dielectric Medium

We have used three different types of dielectric fluid for this machining process. They are

- Water
- Kerosene
- Graphite suspended kerosene (PMWEDM).

Water

Water is one of the commonly used dielectric mediums in wire electrical discharge machining (WEDM) due to its availability, low cost, and high dielectric strength. The dielectric medium in WEDM plays a crucial role in controlling the electrical discharge between the wire electrode and the workpiece, and it affects the performance of the process in various ways.

One of the main effects of using water as a dielectric medium in WEDM is its ability to dissipate the heat generated during the machining process. The heat generated by the electrical discharge is absorbed by the water and is carried away from the machining zone, which helps to prevent thermal damage to the workpiece.

Another effect of using water as a dielectric medium in WEDM is its ability to flush away the debris generated during the machining process. The debris is carried away by the water, which helps to keep the machining zone clean and reduces the chance of clogging or jamming of the wire electrode. The use of water as a dielectric medium in WEDM can also affect the surface finish of the machined parts. Water-based dielectric mediums tend to produce a rougher surface finish compared to oil-based dielectric mediums. However, the use of additives such as surfactants or deionizing agents can help to improve the surface finish.

Kerosene

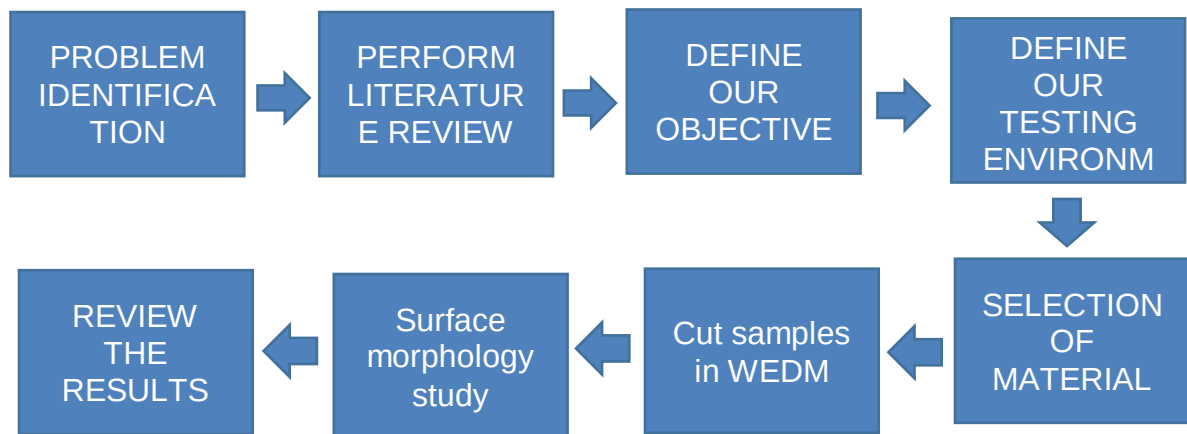
Main effects of using kerosene as a dielectric medium in WEDM is its ability to absorb and dissipate heat generated during the machining process. The heat generated by the electrical discharge is absorbed by the kerosene and is carried away from the machining zone, which helps to prevent thermal damage to the workpiece. Another effect of using kerosene as a dielectric medium in WEDM is its ability to provide lubrication during the machining process. The kerosene acts as a lubricant between the wire electrode and the workpiece, which reduces friction and wear on the wire electrode and improves the surface finish of the machined parts. The use of kerosene as a dielectric medium in WEDM can also affect the surface finish of the machined parts. Kerosene-based dielectric mediums tend to produce a smoother surface finish compared to water-based dielectric mediums. Additionally, kerosene-based dielectric mediums can also reduce the likelihood of rust or corrosion on the machined parts.

Graphite suspended kerosene (PMWEDM)

The addition of graphite particles to the dielectric medium can affect the performance of the process in various ways. One of the main effects of using graphite suspended kerosene in PMWEDM is its ability to improve the surface finish of the machined parts. The graphite particles act as an abrasive material that helps to remove material from the workpiece during the machining process. This results in a smoother surface finish compared to traditional WEDM using only kerosene as a dielectric medium. Another effect of using graphite suspended kerosene in PMWEDM is its ability to increase the material removal rate. The addition of graphite

particles to the dielectric medium enhances the electrical conductivity of the medium, which leads to more efficient and effective electrical discharge machining. This increases the rate of material removal from the workpiece and reduces the machining time. The use of graphite suspended kerosene in PMWEDM can also improve the accuracy and precision of the machined parts. The graphite particles act as an electrode and help to focus the electrical discharge on the desired location, which improves the accuracy of the machining process.

4.2 METHODOLOGY



4.2.1 *Preparatory Process*

4.2.2 *Milling*

This process involves the use of a milling machine to carefully remove a thin layer of material from the machined surface, revealing the underlying recast layer for examination under Scanning Electron Microscopy (SEM). One of the main reasons for performing the milling process for clear recast layer SEM analysis is to obtain a clear and undistorted view of the recast layer without any debris or residual material that may interfere with the SEM analysis. The recast layer is the layer of material that undergoes changes in its properties, such as melting and resolidification, due to the heat generated during the WEDM process.



Fig. 4.2: Milling machine

SEM analysis of the recast layer can provide valuable information about its thickness, composition, and microstructure, which can help in evaluating the effectiveness of the WEDM process and optimizing the machining parameters for improved results. For example, the thickness of the recast layer can provide insights into the amount of material that has been melted and resolidified, which can affect the overall integrity and properties of the machined component. Furthermore, SEM analysis of the recast layer can help in understanding the material behavior and the heat-affected zone during the WEDM process. This information can be crucial in determining the quality and reliability of the machined component, as well as identifying any potential issues or defects in the recast layer, such as cracks, voids, or irregularities.

It is important to note that the milling process for clear recast layer SEM analysis is an additional step in the machining process and may add to the production time and costs. Careful selection of milling parameters, such as feed rate, depth of cut, and tool material, is essential to avoid any potential damage or alteration to the recast layer during the milling process. Proper sample preparation techniques, such as avoiding contamination and maintaining a clean milling environment, should also be followed to ensure accurate and reliable SEM analysis results. In conclusion, the milling process for clear recast layer SEM analysis before machining in WEDM is a crucial step in evaluating the quality of the machined

surface and understanding the characteristics of the recast layer. It provides valuable insights into the performance of the WEDM process and aids in optimizing machining parameters for improved results. However, careful consideration of sample preparation techniques, milling parameters, and overall production needs is necessary to ensure accurate and reliable SEM analysis results.

4.2.3 Parameter Selection

By studying various literature papers related to WEDM. We have selected the parameters for machining. The literature survey helps in understanding the effect of various parameters such as pulse duration, pulse voltage, wire speed, and flushing pressure on the machining performance, such as surface roughness, material removal rate, and accuracy. The survey helps to identify the optimal parameter values for achieving the desired machining performance.

Table 4.2 Levels and parameters

Input factors and Levels			
Ton (μs)	108	112	-
dielectric medium	Water	Kerosene	Powder
Toff (μs)	25	30	35
I (A)	1	3	5
Wirefeed (m/min)	1.8	2	2.2

MINITAB was used to tabulate the parametric designs. Using Minitab for finding parameters for machining in WEDM (Wire Electrical Discharge Machining) can be a powerful tool in process optimization and parameter selection. Minitab is a statistical software that allows for data analysis and statistical modeling, making it useful for analyzing WEDM process data and identifying optimal machining parameters [2,3,6,7]. One of the key steps in using Minitab for finding parameters for machining in WEDM is to collect data from the WEDM machine during the machining process. This data may include parameters such as voltage, current, wire feed rate, flushing pressure, and other relevant process variables [4, 14-19, 22]. The collected

data can then be imported into Minitab for analysis. Once the data is imported into Minitab, various statistical tools and techniques can be applied to identify the optimal machining parameters.

Table 4.3 Experimental Results

S No	Ton (μ s)	Dielectric	Toff (μ s)	I (A)	WF (m/min)
1	108	Water	25	1	1.8
2	108	Water	30	3	2
3	108	Water	35	5	2.2
4	108	Kerosene	25	1	2
5	108	Kerosene	30	3	2.2
6	108	Kerosene	35	5	1.8
7	108	Powder	25	3	1.8
8	108	Powder	30	5	2
9	108	Powder	35	1	2.2
10	112	Water	25	5	2.2
11	112	Water	30	1	1.8
12	112	Water	35	3	2
13	112	Kerosene	25	3	2.2
14	112	Kerosene	30	5	1.8
15	112	Kerosene	35	1	2
16	112	Powder	25	5	2
17	112	Powder	30	1	2.2
18	112	Powder	35	3	1.8

These are the parameters were tabulated using Minitab for machining.

4.2.4 *Machining*

SS304 is being machined with the parameters in the above tabular column. It was being machined using water, kerosene and graphite suspended kerosene as dielectric. With a autocad diagram a square shaped piece of 5mm on each side is cut from the workpiece. The cut piece that was machined from the workpiece is used for further analysis of surface morphology.

CHAPTER 5

RESULT AND DISCUSIION

5.1 SEM ANALYSIS

SEM analysis is commonly performed on the machined surface of SS304 to examine its microstructure and surface characteristics, offering valuable insights into the machining process and surface quality. SEM analysis involves using a scanning electron microscope to obtain high-resolution images of the machined surface at a magnification range of several hundred to several thousand times. The SEM images reveal details such as surface topography, micro structural features, and the presence of any defects or contaminants. One of the primary advantages of SEM analysis is its ability to provide a three-dimensional view of the machined surface. SEM images can reveal the presence of tool marks, surface roughness, cracks, voids, and other surface irregularities that may affect the functional performance of the machined component. SEM analysis can also help identify the type and distribution of phases or inclusions in the SS304 material, which can impact its mechanical properties and corrosion resistance.

5.1.1 Recast Layer

The recast layer of the machined surface was studied using the SEM images. SEM analysis provides valuable insights into the microstructure and characteristics of the recast layer, which can impact the performance of machined components. SEM images of the recast layer in SS304 reveal details such as surface roughness, grain structure, residual stresses, and material deformation or melting. The recast layer is formed due to the thermal effects of machining, and its features depend on various factors such as machining parameters, tool material, and cutting conditions. SEM images can be used to measure the thickness of the

recast layer, which is important for assessing material damage. They can also reveal any defects or discontinuities in the recast layer.

The SEM images that we have taken from the cut samples are attached below. The images that we have taken from the lateral surface of the cut samples are used to study the recast layer are shown in fig 6.1, 6.2 respectively. It is inevitable to stop formation of recast layer in the samples machined using WEDM process. But we can reduce the thickness of recast layer by using the optimal parameter. During machining the material in contact with the wire melts due to the heat created by the high voltage. The molten material cools down and hardens on the surface. This layer of re-deposition of material is known as recast layer. Figure: a represent the recast layer of the sample cut using lower parameter, figure: 6.2 represents the recast layer of the sample cut using high parameter setting.

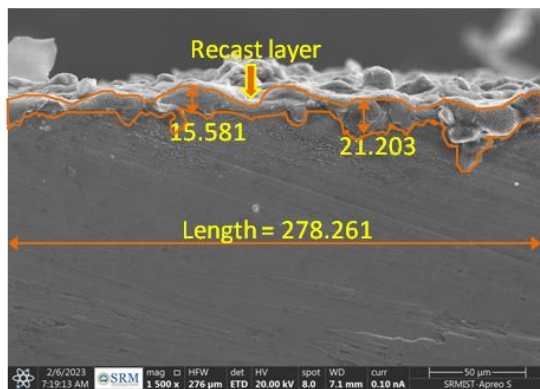


Fig. 5.1: Recast Layer 1

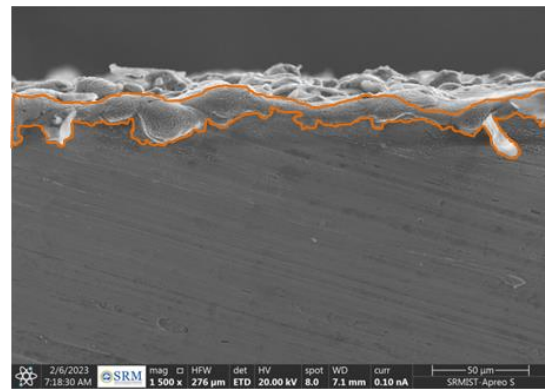


Fig. 5.2: Recast Layer 2

Recast layer obtained using (Fig: 5.1) low parameter setting (Fig.5.2) High parameter setting.

By analyzing the sem images we could conclude that the formation of of recast layer was found to be higher while machining with higher parameter setting and with lower parameter was found to be low[8,9].

5.1.2 Surface Morphology

SEM analysis provides valuable insights into the surface morphology of SS304, which can impact its performance and functional properties. SEM images of

the machined surface of SS304 reveal important details such as surface roughness, surface texture, grain boundaries, and presence of any contaminants or defects. The surface morphology of SS304 can be influenced by various factors including machining parameters, tool geometry, cutting conditions, and material properties. SEM images can be used to measure surface roughness parameters such as Ra, Rz, and Rq, which are critical for assessing the quality and functionality of the machined surface. They can also provide visual information about the surface texture, including the presence of grooves, scratches, or other surface features that may affect the performance of the component.

From Fig. 5.3 it is evident that while using higher parameter setting there is visible increase in the size of craters, micro-cracks, pockmarks and lumps of debris. From fig:6.4 it is evident that while using lower parameter setting there is a visible decrease in the size of craters, pockmarks, lumps of debris and micro-cracks[20,10].

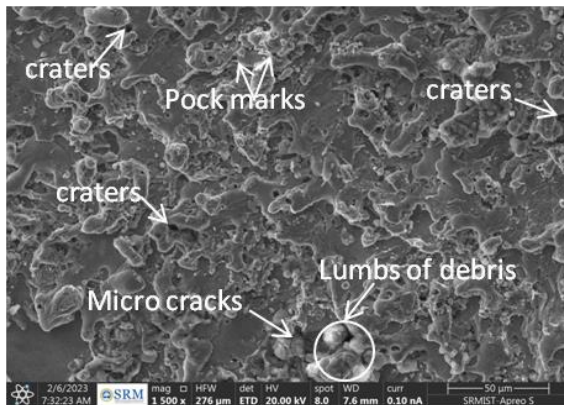


Fig. 5.3: Surface Morphology 1

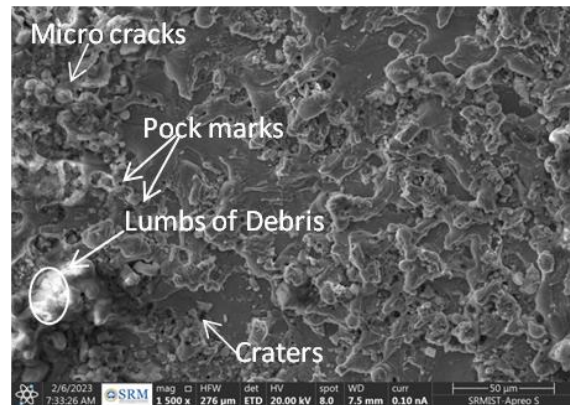


Fig. 5.4: Surface Morphology 2

Figure represents surface morphology for (5.3) high parameter setting (5.4) low parameter setting

5.2 SURFACE ROUGHNESS

Surface roughness analysis of SS304 is a crucial aspect of evaluating the quality and functionality of machined surfaces. It provides quantitative measurements of surface roughness parameters, allowing for objective

assessments of surface quality and optimization of machining processes. By ensuring that the machined surface meets the desired roughness specifications, manufacturers can ensure the performance, aesthetics, and functionality of SS304 components in various applications. The surface roughness of the samples was measured using a instrument.

Table 5.1 Surface roughness values

S No	Ton (μs)	Dielectric	Toff (μs)	I (A)	WF (m/min)	Ra (μm)
1	108	Water	25	1	1.8	2.62
2	108	Water	30	3	2	2.66
3	108	Water	35	5	2.2	2.54
4	108	Kerosene	25	1	2	2.94
5	108	Kerosene	30	3	2.2	2.73
6	108	Kerosene	35	5	1.8	2.66
7	108	Powder	25	3	1.8	3.39
8	108	Powder	30	5	2	2.97
9	108	Powder	35	1	2.2	2.36
10	112	Water	25	5	2.2	3.26
11	112	Water	30	1	1.8	2.76
12	112	Water	35	3	2	2.44
13	112	Kerosene	25	3	2.2	3.01
14	112	Kerosene	30	5	1.8	3.02
15	112	Kerosene	35	1	2	2.43
16	112	Powder	25	5	2	3.48
17	112	Powder	30	1	2.2	2.62
18	112	Powder	35	3	1.8	2.70

Ra Analysis

Table 5.2 Response Table for Signal to Noise Ratios (Ra)

Level	Ton	Dielectric	Toff	I	WF
1	-8.788	-8.633	-9.835	-8.349	-9.083
2	-9.061	-8.914	-8.913	-8.966	-8.939
3		-9.227	-8.025	-9.458	-8.751
Delta	0.272	0.594	1.810	1.110	0.333
Rank	5	3	1	2	4

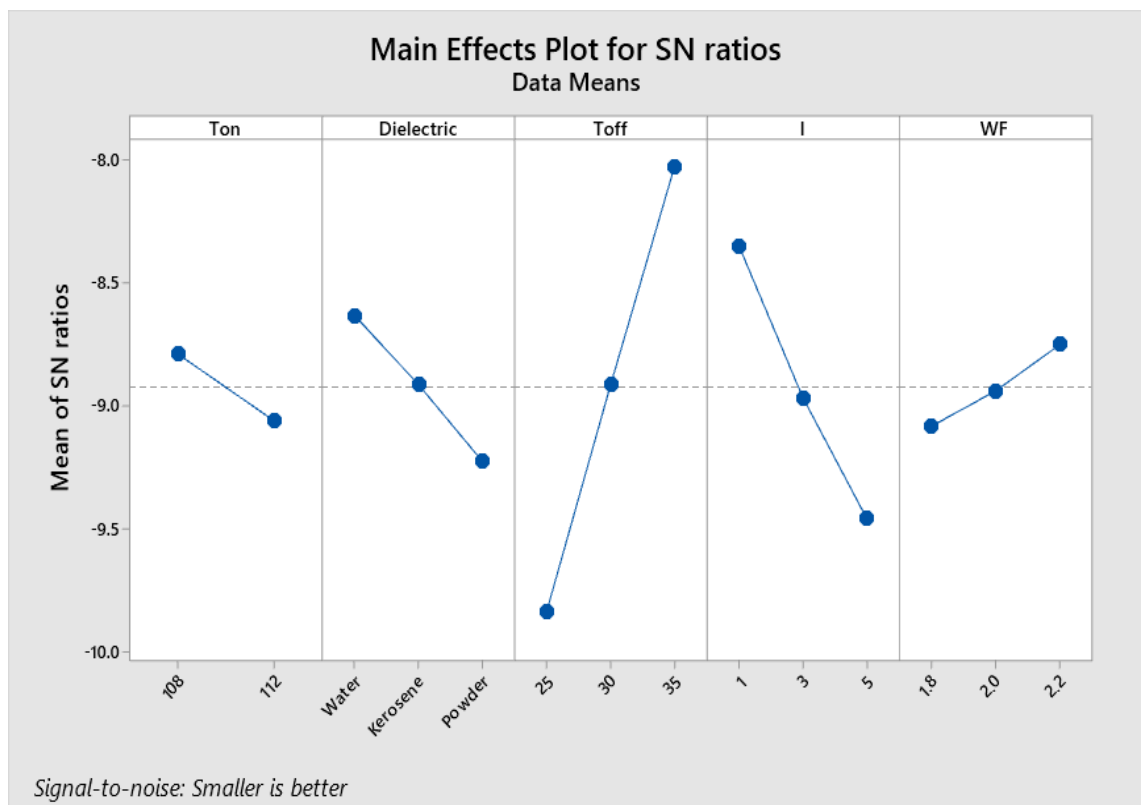


Fig. 5.5: Surface roughness graph

From the graph it is evident that the Toff plays a key role in surface roughness of the machined surface. While we machined with 35 as the Toff the highest parameter the Ra was found to be better. Higher pulse off time is known to

give better surface roughness in WEDM because it allows more time for the dielectric fluid to flush out the molten metal and debris generated during the electrical discharge process. When the electrical discharge occurs, the temperature in the gap zone rises rapidly, leading to the formation of a plasma channel. This plasma channel creates a molten pool on the surface of the workpiece, and the debris generated during the process gets mixed with the dielectric fluid. During the pulse off time, the dielectric fluid flushes out the molten metal and debris from the gap zone, preventing it from re-depositing on the workpiece surface. A longer pulse off time provides more time for the dielectric fluid to flush out the debris, resulting in a smoother surface finish and better surface roughness. Water gave better Ra compared to . Powder and kerosene. And 108 in Ton was found that it gave better Ra and 2.2 setting in wire feed gave better Ra. And current 1 was found to have better Ra. Eventhough every different parameter has different level of influence on the Ra of the machined surface. From the S/N ratio table, it is understood that pulse off time is the prime factor in finalising the surface quality of the machined surface followed by current, dielectric, wire feed and Ton [11, 13, 14].

5.3 MRR ANALYSIS

The material removal rate (MRR) is an essential performance parameter for wire electrical discharge machining (WEDM). The MRR represents the rate at which material is removed from the workpiece during the machining process. The MRR was calculated by using this formula

$$\text{MRR} = \text{cutting speed mm/min} \times \text{Kerf Width mm} \times \text{Thickness mm}$$

here, cutting speed refers to the time taken to cut 1mm in the work piece. Thickness of the sample is 7mm and time in minutes respectively.

Table 5.3 MRR values

S No	Ton (μs)	Dielectric	Toff (μs)	I (A)	WF (m/min)	MRR (mm ³ /min)
1	108	Water	25	1	1.8	1.9793
2	108	Water	30	3	2	2.0813
3	108	Water	35	5	2.2	2.5420
4	108	Kerosene	25	1	2	2.5522
5	108	Kerosene	30	3	2.2	2.6074
6	108	Kerosene	35	5	1.8	2.6185
7	108	Powder	25	3	1.8	3.3401
8	108	Powder	30	5	2	3.4812
9	108	Powder	35	1	2.2	2.6746
10	112	Water	25	5	2.2	4.2623
11	112	Water	30	1	1.8	3.5806
12	112	Water	35	3	2	3.5738
13	112	Kerosene	25	3	2.2	3.9988
14	112	Kerosene	30	5	1.8	4.2462
15	112	Kerosene	35	1	2	3.3945
16	112	Powder	25	5	2	5.1361
17	112	Powder	30	1	2.2	4.2496
18	112	Powder	35	3	1.8	4.2674

MRR Analysis

Table 5.4 Response Table for Signal to Noise Ratios (MRR)

Level	Ton	Dielectric	Toff	I	WF
1	8.342	9.189	10.565	9.479	10.168
2	12.148	10.006	10.289	10.145	10.205
3		11.540	9.882	11.111	10.362
Delta	3.806	2.351	0.683	1.632	0.194
Rank	1	2	4	3	5

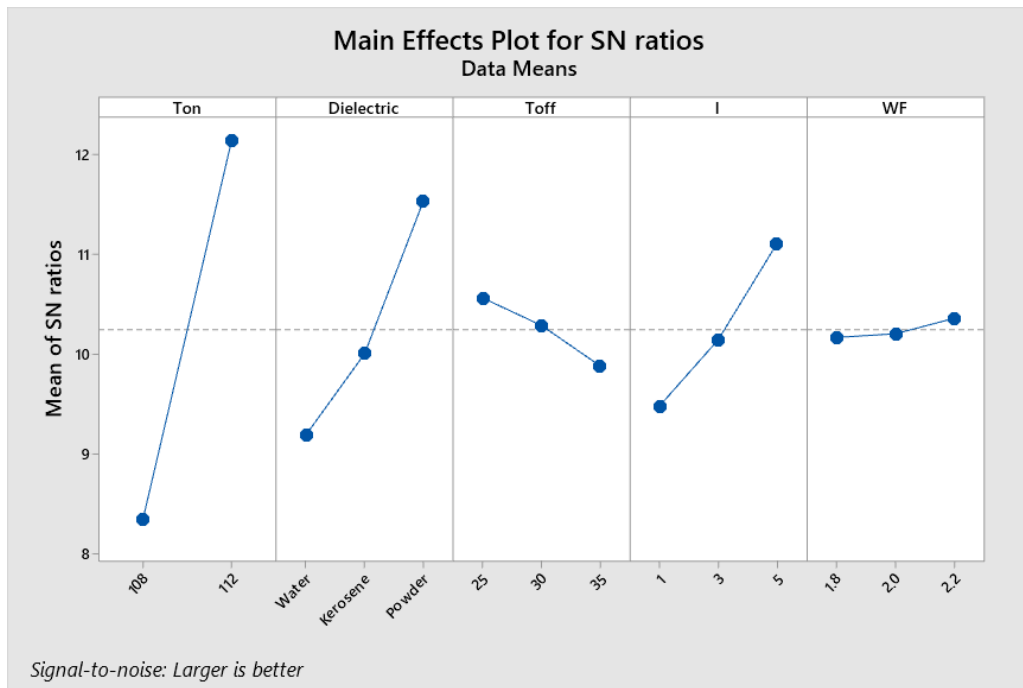


Fig. 5.6: MRR graph

From the graph it is evident that the Ton plays a key role in MRR of the machined surface. 112 was found to be the best pulse on time which has higher MRR. Higher pulse on time is known to give better MRR because it allows for a longer duration of electrical discharge, which results in more efficient material removal. During the pulse on time, a high-intensity electrical discharge pulse is applied to the workpiece, which generates a plasma channel and melts the workpiece material. A higher pulse on time allows for a longer duration of electrical discharge, which leads to a higher amount of material removal. This results in a higher MRR as more material is removed from the workpiece per unit time. Powder gave better MRR compared to water and kerosene. The addition of graphite powder to kerosene enhances the WEDM performance, particularly the material removal rate (MRR), due to several reasons. Firstly, GSK has improved thermal conductivity compared to pure kerosene. This increased thermal conductivity helps to dissipate the heat generated during the machining process more efficiently, which can result in a higher MRR. Secondly, GSK has an enhanced flushing capability due to the graphite powder increasing the viscosity and density of the fluid. This improved flushing capability helps to remove the debris and waste material from the machining zone more effectively, which can also result in a higher MRR. Thirdly, the graphite powder in GSK improves the spark erosion process by facilitating the formation of a

conductive layer on the surface of the workpiece. This conductive layer helps to maintain the electrical discharge and enhances the material removal efficiency, which can result in a higher MRR. And 25 in Toff was found that it gave better MRR and 2.2 setting in wire feed gave better MRR. And current 5 was found to have better MRR. Eventhough every different parameter has different level of influence on the MRR of the machined surface. From the S/N ratio table, it is understood that pulse on time (Ton) is the most significant factor in deciding the MRR followed by dielectric, current, Toff, and wire feed.

5.4 MICRO-HARDNESS

Micro-hardness testing is a non-destructive method used to measure the hardness of small areas or thin materials. In this test, a diamond indenter is pressed onto the surface of the material, creating an indentation that is measured under a microscope. The depth of the indentation is used to calculate the hardness of the material based on its resistance to deformation. Micro-hardness testing is commonly used to determine the hardness of thin films, coatings, and small parts where traditional hardness testing methods are not applicable. It is widely used in material science and engineering to evaluate the mechanical properties of materials at a small scale.

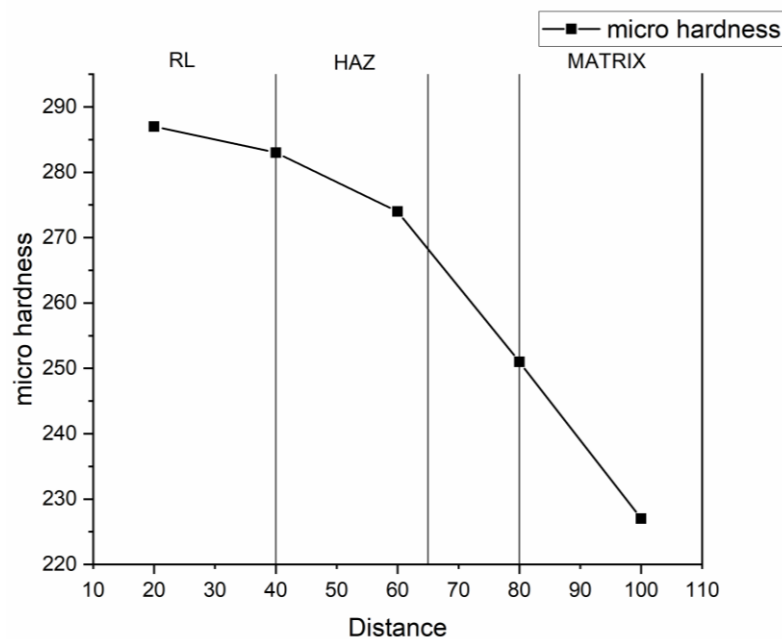


Fig. 5.7: Micro-hardness graph

The above figure 5.7 shows the micro-hardness results obtained with the help of graph for 5 indentations. Each indentation is taken at a distance of 20um. From the graph it is evident that micro-hardness value is higher at the recast layer and gradually decreases as we gradually move towards the base material.

CHAPTER 6

CONCLUSION

The influence of pulse on time, pulse of time, current and wire-feed on machining of SS304 was investigated using the WEDM method in this study. The major conclusions from the experimentation are given below.

1. When machining with higher parameters the thickness of the recast layer was found to be higher compared to machining with lower parameters.
2. The surface morphology of materials machined displays the existence of larger-sized clusters of debris, bigger indentations and holes, as well as irregular layer deposition, particularly for high discharge energy settings.
3. The highest value of MRR is obtained from the parameter input setting of Ton 112, Toff 25 and current 5 using dielectric fluid powder mixed kerosene. From the analysis we could understand that pulse on time (Ton) is the most significant factor in deciding the MRR.
4. Toff have greater impact on Ra. higher pulse-off time (Toff) in WEDM leads to a better surface finish with lower Ra values. The lowest value of Ra was obtained while machining with Ton 112 , Toff 35, current 1 , wirefeed 2 and dielectric as kerosene.
5. From the results it is evident that the recast layer has a higher hardness value than the base material. The hardness gradually decreases towards the center of the cut.

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