OPTIMIZATION OF MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS OF MOS_2 REINFORCED ALUMINIUM METAL MATRIX COMPOSITE IN WIRE EDM PROCESS

A Project report submitted in partial fulfillment of the requirements for the award of the

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ABSTRACT

In the present work, an attempt is made to study the effect of Wire Electric Discharge Machining (WEDM) parameters like pulse-on time, pulse-off time, peak current and % MoS_2 on Surface Roughness(Ra) and Material Removal Rate(MRR) in Aluminium Metal Matrix Composites(AMMCs). The composite material containing aluminium alloy 6082 as matrix, Molybdenum disulphide as reinforcement is produced by Stir casting technique with different weight percentages(0%,2%,4%).

Experimentation was conducted in a series of tests called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response using Taguchi design. The results showed that maximum material removal rate is obtained at 2% MoS_2 and minimum surface roughness is obtained at 4% MoS_2.

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CHAPTER 1

INTRODUCTION

1.1 Composite Materials

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness.

1.1.1 Classification

Based on the type of matrix material

- Polymer matrix composites
- Metal matrix composites
- Ceramic matrix composites
- Carbon composites

Based on the geometry of reinforcement

- Particulate reinforced composites
- Whisker/flakes reinforced composites
- Fiber reinforced composites

1.2 Metal matrix composites

A metal matrix composite is composite material with at least two constituent parts, one being a metal necessarily; the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite.

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminium to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fibre. To prevent this reaction, the carbon fibres are coated with nickel or titanium boride.

1.2.1 Matrix

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as Aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

1.2.2 Reinforcement

The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystaline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength.

1.3 Methods to prepare Aluminium Metal Matrix Composites

MMC manufacturing can be classified into three types –solid, liquid and vapour.

1.3.1 Solid state methods

- Powder blending and consolidation (powder metallurgy): Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment (possibly via hot isostatic pressing (HIP) or extrusion).
- Foil diffusion bonding: Layers of metal foil are sandwiched with long fibers and then pressed through to form a matrix.

1.3.2 Liquid state methods

- Stir casting: Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify.
- Pressure infiltration: Molten metal is infiltrated into the reinforcement through use a kind of pressure such as gas pressure.
- Spray deposition: Molten metal is sprayed onto a continuous fiber substrate.
- Reactive processing: A chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement.

1.3.3 Semi-solid state methods

Semi-solid powder processing: Powder mixture is heated up to semi-solid state and pressure is applied to form the composites.

1.3.4 Vapour deposition

Physical vapor deposition: The fiber is passed through a thick cloud of vaporized metal, coating it.

1.4 Stir Casting

Stir casting technique is simple and most commercial method of production of metal matrix composites .In preparing metal matrix composites by the stir casting method ,there are several factors that need to be considered including :

1.Difficulty in uniform distribution of the reinforcement material.

2.Wettability between the two main substances.

3.Porosity in the cast metal matrix composites and

4.Chemical reactions between the reinforcement material and material alloy.

In conventional stir casting method, reinforced particulate is mixed into the aluminium melt by mechanical stirring .Mechanical stirring is the most important element of this process . After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification .The essential thing is to create the good wetting between particulate reinforcement and aluminium melt. The distribution of reinforcement in the final solid depends upon the on the wetting condition of the reinforcement with the melt, relative density, rate of solidification etc. Distribution of reinforcement depends on the geometry of the stirrer , melt temperature and the position of the stirrer in the melt . Figure shows a schematic diagram of stir casting of stir casting process.

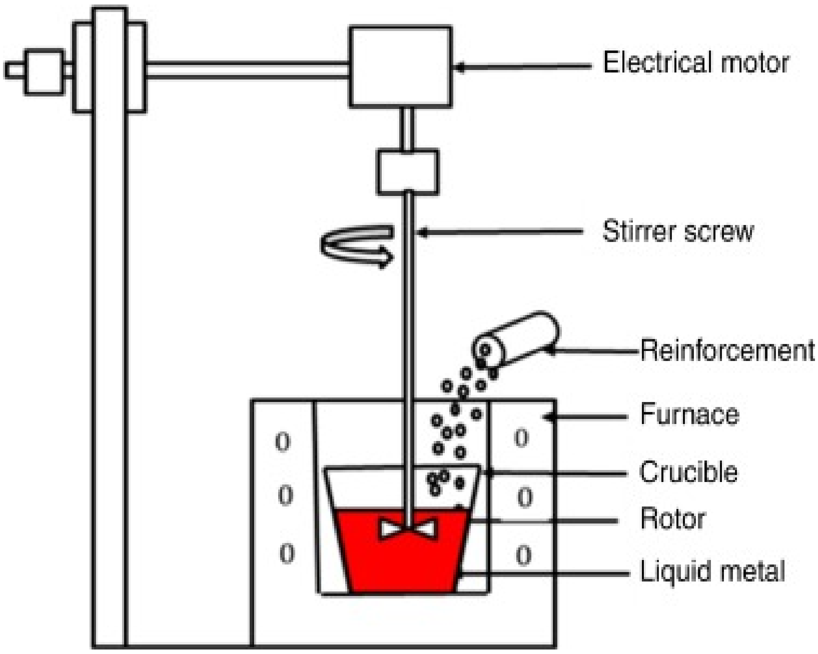


Fig 1.1 Stir Casting process

Fig 1.2 Stir Casting Equipment

Fig 1.3 Close view of Stir casting process

1.5 Wire EDM process

1.5.1 History of EDM

The historical roots of EDM date back to the discovery of electric discharges. Besides the discharges produced by natural phenomena, namely lightning, the production of artificial discharges has been closely related to the development of electrical energy sources. First investigations of electrostatic phenomena were performed with frictional machines, during the first half of the 18th century. After that, the first sparks and pulsed arcs were produced with Leyden jars, an early form of capacitor invented in Germany and in the Netherlands.

1.5.2 Theories of Material Removal in EDM

The removal of material in electrical discharge machining is based upon the erosion effect of electric sparks occurring between two electrodes. Several theories have been forwarded in attempts to explain the complex phenomenon of "**erosive spark**".

The following are the theories:

- Electro-mechanical theory

- Thermo-mechanical theory
- Thermo-electric theory

1.5.2.1 Electro-mechanical theory:

This theory suggests that abrasion of material particles takes place as a result of the concentrated electric field. The theory proposes that the electric field separates the material particles of the work piece as it exceeds the forces of cohesion in the lattice of the material. This theory neglects any thermal effects. Experimental evidence lacks supports for this theory.

1.5.2.2 Thermo-mechanical theory:

This theory, best-supported by experimental evidence, suggests that metal removal in EDM operation takes place as a result of the generation of extremely high temperature generated by the high intensity of the discharge current. Although well supported, this theory cannot be considered as definite and complete because of difficulties in interpretation.

1.5.3 Wire Cut Electric Discharge Machining

New materials created and/or demanded by space age technology sometimes cannot be economically cut using conventional cutting tools. Special, super-hard materials, normally quite expensive, are required. Synthetic diamonds or diamond compounds that are almost impossible to grind are very expensive, but are cut effectively by WEDM.

The process wastes very little work piece material due to its small kerf size, coupled with the fact that the process can accurately cut unusual shapes. In modern manufacturing industry, WEDM has been extensively used to machine complicated shapes on advanced materials with high accuracy. WEDM is one of the most extended non-conventional machining processes. It is widely used to machine dies and moulds aimed at producing components for many industries. The main advantage of WEDM is its capability for the production of high complexity shapes with a high degree of accuracy, independently of the mechanical properties of the material (especially, hardness, brittleness and resistance).

Wire EDM uses brass, tungsten, or copper as its material for the electrode tool wire. Deionized water is used for the dielectric fluid. Almost like the standard EDM, the wire is eroded and slowly fed.

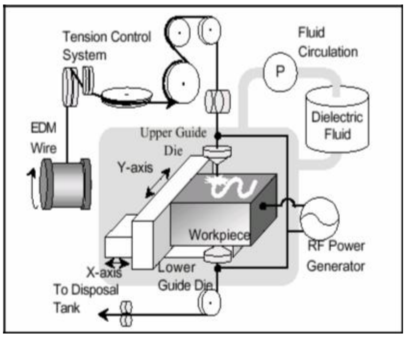


Fig 1.4 Wire Electrical Discharge machining system

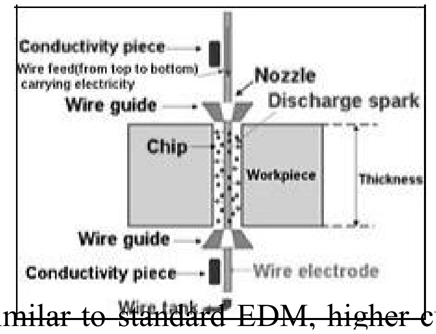


Fig 1.5 Close view of cutting zone in WEDM

Although it is similar to standard EDM, higher currents and lower rest times make this process ... le of WEDM process and Figure 1.3 shows t...

1.5.4 Wire EDM Working

WEDM is a special form of electrical discharge machining wherein the electrode is a continuously moving conductive wire. Material removal is effected as a result of spark erosion as the wire electrode is fed (from a spool) through the work piece. Figure 1.4 shows schematic view of generation of spark before the tool wire electrode starting the machining cycle.

Rapid DC electrical pulses are generated between the wire electrode and the work piece. Between the wire and the work piece is a shield of deionized water, called the dielectric fluid. Pure water is an insulator, but tap water usually contains minerals that cause the water to be too conductive for wire EDM. To control the water conductivity, the water goes through a resin tank to remove much of its conductive elements; this is called de ionized water.

Fig 1.6 Wire EDM equipment

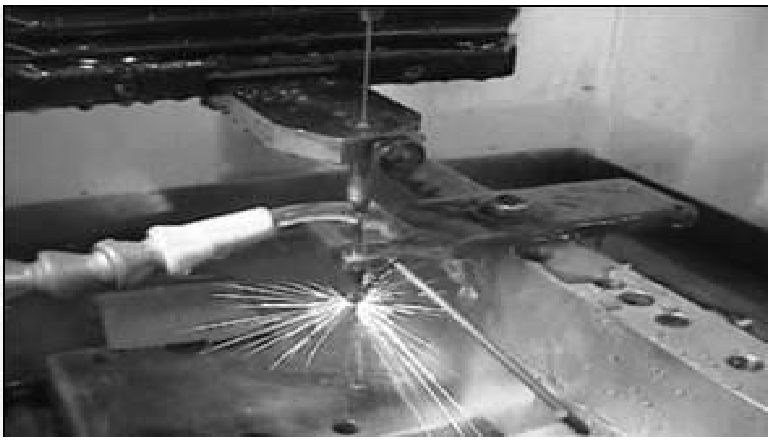


Fig 1.7 Generation of Spark in WEDM

When sufficient voltage is applied, the fluid ionizes. Then a controlled spark precisely erodes a small section of the work piece, causing it to melt and vaporize. These electrical pulses are repeated thousands of times per second. The pressurized cooling fluid, the dielectric, cools the vaporized metal and forces the re solidified eroded particles from the gap.

The dielectric fluid goes through a filter which removes the suspended solids. Resin removes dissolved particles; filters remove suspended particles. To maintain machine and part accuracy, the dielectric fluid flows through a chiller to keep the liquid at a constant temperature.

In this process, which is similar to contour cutting with the band saw, a slowly moving wire travels along the prescribed path, cutting the work piece, with the discharge sparks acting like cutting teeth. This process is used to cut plates as thick as 300mm and for making punches, tools and dies from hard metals. It can also cut intricate components for the electronic industry.

The tool wire is usually made up of brass, copper or tungsten; zinc-or brass-coated and multi-coated wires are also used. The wire diameter is typically about 0.30mm for roughing cuts and 0.20mm for finishing cut. The wire should have sufficient tensile strength and fracture toughness, as well as high electrical conductivity and capacity to flush away the debris produced during cutting.

The tool wire is generally used only once, as the wire gets deformed and loses its tensile strength. The wire travels at a constant velocity in range of 0.15 to 9.0 m/min, and a constant gap (kerf) is maintained during the cut. Figure 1.5 shows the path of wire generated by CNC automated computer system.

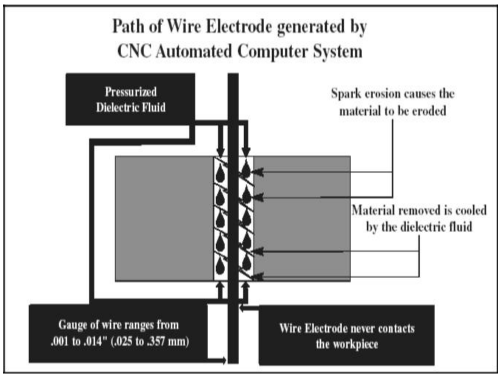


Fig 1.8 Path of Wire in WEDM

A DC or AC servo system maintains a gap from .002 to .003" (0.051 to 0.076mm) between the wire electrode and the work piece. The servo mechanism prevents the wire electrode from shorting out against the work piece and advances the machine as it cuts the desired shape. Because the wire never touches the work piece, wire EDM is a stress-free cutting operation.

1.5.5 Steps involved in Wire EDM process

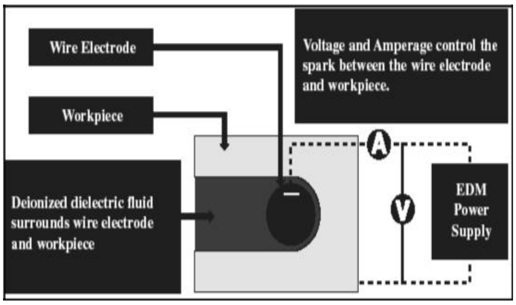
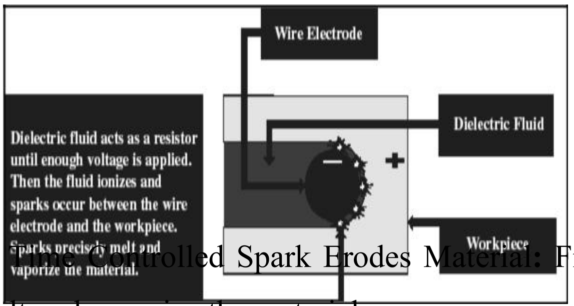


Fig 1.9 Power generation in WEDM

1.5.5.1 Power generation in WEDM

Power Supply Generates Volts and Amps**:** Deionized water surrounds the wire electrode as the power supply generates volts and amps to produce the spark. Figure 1.6 shows how power supply generates volts and amps



During ON Time Controlled Spark Erodes Material**:** Figure: 1.7 shows how Sparks precisely melt and vaporize the material.

Fig 1.10 Erosion of material in WEDM

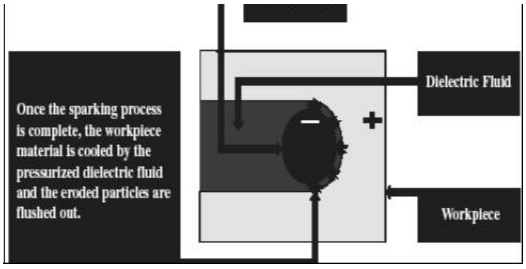


Fig 1.11 Removal of Eroded particles

1.5.5.2 Removal of Eroded Particles

Off Time Allows Fluid to Remove Eroded Particles: During the off cycle, the pressurized dielectric fluid immediately cools the material and f1ushes the eroded particles as shown in Figure

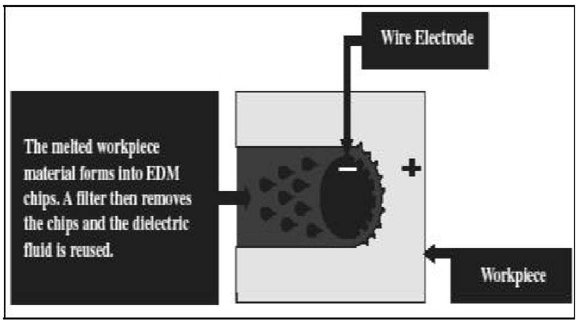


Fig 1.12 Chip removal by Filtration

1.5.5.3 Chip Removal by Filtration

Filter removes chips while the cycle is repeated. The eroded particles are removed and separated by a filter system.

1.5.5.4 Interface of WEDM Machine

Fig 1.13 Interface of WEDM Machine

Fig 1.14 Steps of cutting in WEDM

Fig 1.15 Castings cut in WEDM

Fig 1.16 Cicular holes obtained after cutting

Fig 1.17 Circular Pins obtained after cutting

1.5.6 Benefits of Wire EDM

- Efficient production capabilities.
- Production reliability
- Reduced Costs
- Stress-Free and Burr-Free Cutting
- Tight Tolerances and Excellent Finishes
- Program Files Downloadable

1.5.7 Process parameters in Wire EDM

WEDM is complex in nature and controlled by large number of parameters. These parameters have to be controlled for effective working of the cutting process. The parameters may be grouped into input parameters and output parameters. Input parameters are those variables which are required to run the cutting process. The output parameters are those which are the outcome of the process and are observed on the finished work after cutting. Some of the process parameters in WEDM process are:

- Wire material characteristics
- Effect of wire tension
- Effect of frequency
- Heat affected Zone

- Thickness of the Work piece
- Time ON
- Time OFF
- Current
- Voltage
- Gap size
- Surface finish
- Material of the work piece

1.5.8 Material removal rate (MRR):

Achieving an efficient MRR is not simply a matter of good machine settings. It also includes direct energy dissipated in the EDM process. This energy can be dissipated in three ways:

In the work piece: MRR is influenced by the thermal conductivity of the work piece. Copper for example has a low melting point but it also has a low MRR as it is a good conductor of heat. On the other hand steel has a high melting point but a low Thermal conductivity hence has a higher MRR.

In the gap**:** Particles in the work gap will contribute significantly to slowing down the MR

In the electrode**:** The MRR is also influenced by the electrode and the work piece selection.

1.5.9 Materials that WEDM can cut:

- Carbide
- Polycrystalline diamond
- Ceramics

1.6 Aluminium Metal Matrix Composites

Aluminium metal matrix composites are gaining widespread acceptance for automobile, aerospace, agriculture farm machinery and many other industrial applications because of their essential properties such as high strength, low density, good wear resistance compared to any other metal. The present study deals with the addition of reinforcements such as graphite, fly ash, silicon carbide, red mud, organic material etc. to the Aluminium matrix in various proportions. Each reinforced material has an individual property which when added improves the properties of the base alloy.

1.7 Advantages of AMMC

- Greater strength
- Improved stiffness
- Reduced density (weight)
- Improved high temperature properties
- Controlled thermal expansion coefficient
- Thermal/ heat management
- Enhanced and tailored electrical performance
- Improved abrasion and wear resistance
- Control of mass (especially in reciprocating applications)
- Improved damping capabilities.

1.8 Chemical composition of Aluminium 6082

- Aluminium: 95.2 to 98.3%
- Magnesium Silicide : 0.4 to 1.2%
- Iron : 0.4% to 1.0%
- Copper: 0.8% max
- Chromium: 0.25% max
- Titanium: 0.1% max
- Zinc: 0.2% max
- Residuals: 0.15% max

1.9 Properties

- High specific strength.
- Versatile light weight and highly durable.
- Wear resistance and strength equal to cast iron.
- Good surface finish.

1.10 Applications

- Aerospace – Engine Cylinders, pistons, crank shafts
- Defence
- Automotive engine cylinders
- Thermal management areas – containers, Vessels
- Sports and recreation

1.11 Surface roughness

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

Roughness plays an important role in determining how a real object will interact with its environment. In tribology, rough surfaces usually wearmore quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities on the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. For example, it is difficult and expensive to control surface roughness of fused deposition modelling (FDM) manufactured parts. Decreasing the roughness of a surface usually increases its manufacturing cost. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Roughness can be measured by manual comparison against a "surface roughness comparator" (a sample of known surface roughness), but more generally a surface profile measurement is made with a profilometer

1.11.1 Profile roughness parameters

Each of the roughness parameters are calculated using a formula for describing the surface. Standard references that describe each in detail are Surfaces and their Measurement.

The profile roughness parameters are included in BS EN ISO 4287:2000 British standard, identical with the ISO 4287:1997 standard. The standard is based on the ″M″ (mean line) system.

There are many different roughness parameters in use, but $\mathbf{R_a}$ is by far the most common, though this is often for historical reasons and not for particular merit, as the early roughness meters could only measure $\mathbf{R_a}$.

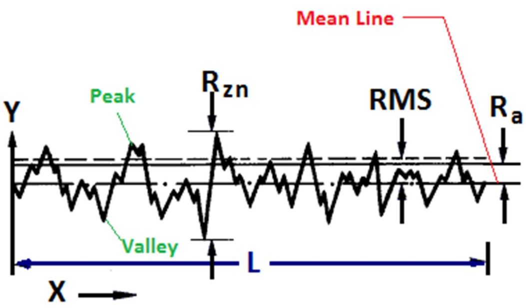


Fig 1.18 Surface Roughness profile

Other common parameters include , $\mathbf{R_z}$, $\mathbf{R_q}$ and $\mathbf{R_{sk}}$. Some parameters are used only in certain industries or within certain countries. For example, $\mathbf{R_{sk}}$ the family of parameters is used mainly for cylinder bore linings, and the Motif parameters are used primarily in the French automotive industry.

The MOTIF method provides a graphical evaluation of a surface profile without filtering waviness from roughness. A motif consists of the portion of a profile between two peaks and the final combinations of these motifs eliminate ″insignificant″ peaks and retains ″significant″ ones. Please note that $\mathbf{R_a}$ is a dimensional unit that can be micrometer or microinch.

Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered, how the mean line is calculated, and the physics of the measurement can greatly affect the calculated parameter. With modern digital equipment, the scan can be evaluated to make sure there are no obvious glitches that skew the values.

Because it may not be obvious to many users what each of the measurements really mean, a simulation tool allows a user to adjust key parameters, visualizing how surfaces which are obviously different to the human eye are differentiated by the measurements. For example, $\mathbf{R_a}$ fails to distinguish between two surfaces where one is composed of peaks on an otherwise smooth surface and the other is composed of troughs of the same amplitude. Such tools can be found in app format.

1.11.2 Amplitude parameters

Amplitude parameters characterize the surface based on the vertical deviations of the roughness profile from the mean line. Many of them are closely related to the parameters found in statistics for characterizing population samples. For example, R_a is the arithmetic average value of filtered roughness profile determined from deviations about the centre line within the evaluation length and$\mathbf{R_t}$ is the range of the collected roughness data points.

The arithmetic average roughness, $\mathbf{R_a}$ is the most widely used one-dimensional roughness parameter

1.12 Material removal rate

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the workpiece. The usefulness of this view can be seen in answering the following question. Since the depth of cut is changing the material removal rate changes continuously during the process.

In some cases this may be important. For example, if cutting forces and the resulting workpiece and tool deflections are of interest. The changing amount of material being removed along the tapered shaft means the cutting force and so the deflections will change during the process.

1.13 Calculation of MRR

Material Removal Rate (MRR) is calculated as the ratio of amount of material removed to the time in which material is removed.

MRR= $(2W_g+D)$ *t* V_c mm3 /min

Where:

- W_g = Spark gap,
- D = diameter of the wire = 0.25mm
- t = Thickness of the work piece in mm
- V_c = Cutting speed in mm/min

The cutting speed data (V_c, mm/min) is directly displayed on computer monitor of the machine tool.

1.14 Taguchi approach

Taguchi approach of an experiment. Therefore a method of calculating the signal-to-noise ratio we had gone for quality characteristics. They are

- Smaller the better
- Larger the better
- Nominal the best

Basically, experimental design methods were developed originally fisher however classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of experiments have to be carried out when the number of the process parameters increases, to solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only.

The experimental results are then transformed into a signal-to-noise(S/N) ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., the-lower –better, the-higher-better, and the nominal-better. The S/N ratio for each level of process parameter is compared based on the s/n ratio corresponds to better quality characteristics.

Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. There are 3 signal-to-noise ratios of common interest for optimization of Static problems.

- **Smaller the better**: The signal to noise ratio for the smaller the better is :

S/N=-10*log(mean square of the response)

S/N = −10 *log(Σ(Y^2)/n))

- **Larger the better**: The signal to noise ratio for the bigger- the- better is :

S/N = −10 *log(mean square of the inverse of the response)

S/N = −10 *log(Σ(1/Y^2)/n)

Where n=number of measurements in trial/row,in case n=1,2...........,9and $y_i$the**i**th measured value in a run/row. I=1,2,.........,27.

- **Nominal-the- best**: The S/Nequation for the Nominal-the Best is:

S/N = 10 *log(The square of the mean divided by the variance)

$$S/_N = -10 * \log_{10}\left(\frac{\bar{Y}^2}{\sigma^2}\right)$$

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminium alloy metal matrix composites

Meenaet.al,[1]made a study and experimentation on Aluminium(Al-6063)Silicon carbide reinforced particle metal-matrix composites (MMCs) which are fabricated by melt-stirring technique. The MMC bars and circular plates are prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, and 20%. The microstructure and mechanical properties like Proportionality limit(MPa), Tensile strength upper yield point (MPa), Tensile strength lower yield point(MPa), Ultimate tensile strength (MPa), Breaking strength(MPa), % Elongation,% Reduction in area, Hardness (HRB), Density (gm/cc), Impact Strength (N.m) are investigated on prepared specimens of MMCs. It was observed that the hardness of the composite is increased with increasing of reinforced particle weight fraction. The tensile strength and impact strength both are increased with rising of reinforced weight fraction.

Ravi Shankar et al., [2] studied that the variation has been carried out on the mechanical properties of Al-based alloy by varying amount of different constituent in Al alloys. The process through Sand Casting and Ferrous Casting is done on different Al-based alloy [Al-6Si-4Cu, Al-10Si-5Cu, Al-14Si-6Cu], and the research reveals the mechanical properties of Al alloy was improved by varying amount of each constituent and also by different types of casting. Each Al based alloy out of two was cast by different processes like Ferrous Casting and Sand Casting; and selected one by one from each phase of comparison of properties among related casting. After selecting three different Al alloy composition from different casting processes, the evaluation of the properties of each Al-alloy is done by comparing each other.

Gopal Krishna U Bet al,[3]made an effort to enhance the mechanical properties like tensile strength and hardness of AMCs by reinforcing AL6061matrix with B4C particles. Aluminium matrix was reinforced with boron carbide particulates of 37, 44, 63, 105, 250µ sizes by stir casting technique. The microstructure and mechanical properties of the fabricated AMCs was analysed. Based on the results obtained from tensile strength test of the metal matrix composites of different particle sizes, 105µ size B4C was chosen and varied the wt% of B4C with 6,8,10 and12wt%. The optical microstructure images reveal the homogeneous dispersion of B4C particles in the matrix. The reinforcement dispersion has also been identified with X-ray diffraction (XRD). The tensile strength and hardness was found to increase with the increase in the particle size and also with the increase in wt% of the reinforcement.

G.G.Hosmani et al [4] studied the wear characteristics, microstructure and the mechanical properties of cast silicon carbide (SiC) reinforced Aluminium matrix composites (AMCs). AMCs of varying SiC content (0, 3 and 7 wt.%) were prepared by stir casting process. Wear performance, microstructure, hardness, tensile strength and compressive strength of the prepared composites were analysed. Adding SiC reinforcements in Aluminium (Al) matrix increased wear resistance, tensile strength and compressive strength and 7 wt. % SiC reinforced AMC showed maximum wear resistance, tensile strength and compressive strength.

Paramasivam Suresh et.al,[5] prepared Aluminium Metal Matrix Composite by reinforcing 10 wt% and 20 wt% of wet grinder stone dust particles an industrial waste obtained during processing of quarry rocks which are available in nature. Dry sliding wear test was carried out using pin-on-disc apparatus on the prepared composites. The results reveal that increasing the reinforcement content from 10 wt% to 20 wt% increases the resistance to wear rate.

Ramarao et al,[6] examined that Aluminium alloy-Boron Carbide composites were fabricate by liquid metallurgy techniques with different particulate weight fraction (2.5,5 and 7.5%). Phase identification was carried out on Boron Carbide x-ray diffraction studies microstructure analysis was done with SEM a composites was characterised by hardness and compression tests. Compressive strength of composites was increased with increase in the weight percentage of Boron Carbide in the composites.

Balasivanandhaprabhu et al [7], investigated that better stir process and stir time. The high Silicon content Aluminium alloy-silicon carbide MMC material, with 10% SiC by using a variance stirring speeds and stirring time. The microstructure of the produced composite was examined by optical microscope and scanning electron microscope. The uniform hardness valued was achieved at 600rpm with 10min stirring, but above this stirring speed the properties degraded again .The study is to establish the trend between processing parameters such as stirring speed and stirring time with microstructure and hardness of composite.

Sozhamanna et al.[8] analysed that the methodology of microstructure based elastic-plastic finite element analysis of PRMMC. This model is used to predict the failure of two dimensional microstructure models under tensile loading conditions. Hence analysis were carried out on the microstructure of random and clustered particles to determine its effect on strength and failure mechanisms. The FEA models were generated in ANSYS using SEM images . The percentage of major failures and stress-strain responses were predicted numerically for each microstructure. Here the mixture material Al alloy , SiC.

Mahendra Boopathi et al,[9] reported that the development of Hybrid Metal Matrix composites was become an important area of research interest in materials science. In view of this, the present study was studied based on evaluating the physical properties of Aluminium 2024 in the addition of fly ash, Silicon carbide and their combinations. Stir casting method was used for the fabrication of aluminium MMC. The results show that the decrease in the density with increase in hardness and tensile strength was also observed but elongation of the Hybrid MMC in comparison with un-reinforced Aluminium decreased. Aluminium in the presence of SiC(10%)-Fly Ash(10%) was the hardest instead of Aluminium-Silicon and Aluminium-Fly ash composites.

2.2 AL6082 Reinforced With Mos2 Metal Matrix Composites

N.Ramanaiahet.al, [10] investigated the mechanical properties of molybdenum disulphide powders reinforced in Aluminium alloy (Al-2024) composite samples. MOS2 powders of approximately 40µm particle size were reinforced in an Aluminium alloy matrix to produce composite samples of ratios, 1, 2, 3, 4 & 5 weight % through stir casting technique. The fabricated composite specimens were subjected to a series of tests to evaluate the mechanical properties such as hardness and tensile strength. The same are compared with the base alloy. SEM and XRD analysis was carried out to analyse the microstructure and the dispersion of the reinforced particles in the alloy matrix. It was fairly observed from the results that, the hardness and tensile strength increased with the increase in wt. % of reinforcement particles in the matrix up to 4% addition of reinforcement and the hardness and tensile strength decreased for 5% addition of reinforcement in the matrix. The SEM and XRD results revealed the homogeneous dispersion of MOS2 particles in the matrix.

Rajesh Prabha.N.et al[11] investigated the mechanical properties like hardness, tensile strength and thermal evaluation for Aluminium alloy AA7075 reinforced with numerous percentages of TiC particles via the usage of high energy stir casting method additionally added with MoS2 as hybrid composite material. The addition of TiC improves the damage resistance of Aluminium composites. The outcomes confirmed that the mechanical residences, along with tensile electricity, spectrum examine expanded with the aid of the proportion of TiC present within the samples when compared with base Aluminium alloy. The outcomes of composites have a higher composition in addition with Al7075. The SEM-XRD analysis found out the occurrence of TiC in the metal matrix. The best composition of hybrid composite become found with nine 9wt% TiC composite in comparison to different compositions.

M.GeetaRaniet.al,[12] investigated the effect of Wire electrical discharge machining (WEDM) parameters such as pulse-on time (TON)pulse-off time (TOFF), peak current(Ip) and wire feed (WF) on material removal rate (MRR) and surface roughness (Ra) in metal matrix composites (MMCs) consisting of Aluminium alloy (Al6061) and MoS2. The Al6061 material is reinforced with MoS2 powder of 2 micron particle size with 4% weight ratio. The experiments are carried out based on design of experiments approach using L9 orthogonal array using CNC SPRINTCUT WEDM. The results were analysed and optimized using analysis of variance and response graphs.

Shreyas Pawaret al[13] studied based on the individual Aluminium alloy and combined effect of reinforcements on Aluminium alloy discussed. For preparation of composites Al6061 taken as a base metal and varying weight percentage of Molybdenum disulphide (MoS2). The composite of Al6061 and MoS2 is prepared by stir casting technique. A series of mechanical tests are conducted on fabricated composite specimen and compare the result of different compositions with the base alloy. Optical microscope is used for microstructure studies and grain size measurement. Mechanical and tribology properties like stiffness, tensile strength and hardness improved due to composite fabrication. Due to this Aluminium metal matrix composite with reinforcement increase application in aerospace, underwater, high temperature application and automobile.

Mitesh kumar et al ,[14] explained about the development of Al 6063 base hybrid metal matrix composite reinforced with 10 weight percentage of Aluminium Oxide (Al_2O_3) and varying weight percentage of Molybdenum disulphide (i.e. 3%,5%,7%& 9%). The composite was prepared by using stir casting technique. The density of Al6063 / MoS2/ Al2O3 were increasing when reinforcement of MoS2 increases from 3% to 9% .The ultimate tensile strength decreasing due to the additions of 3% to 9% of MoS2 and also reinforced with alumina (Al2O3) into the base matrix . It was seen that the while the Al6063 alloys shows the pre-dominantly ductile fracture (base matrix). The composite specimens (with a MoS2 addition) show an increase in the mixed mode (ductile and brittle region).Investigation also predicts that hardness increases due to varying addition of MoS_2. Micrographs are composite specimen are taken for the study of particular or overall behaviour of the material.

R.Ranjith kumar et al,[15] investigated on the optimization of dry sliding performances on the Aluminium hybrid metal matrix composites using Taguchi method. The parameters selected for this experimental study are applied load ,sliding velocity and sliding distance .Using a pin-on-disk operates dry sliding wear test is performed .The experiments were carried out using Taguchi technique with an L27 orthogonal array .The validity of the developed model is checked by applying analysis of variants (ANOVA) technique .The results reveal that with increasing applied load ,sliding distance and sliding velocity the wear rate also increasing .The molybdenum disulphide showed less wear in comparison to the MoS2 free composite.

Paras Mittal et.al.[16] Investigated the mechanical properties of aluminium 7075 with reinforcement of SiC, Red mud and Al2O3. The author revealed that hardness of composites having reinforcement of Al2O3 and red mud is more than the SiC reinforced composites and also increases with the percentage of reinforcement.

N. Krishnamurthy et.al.[17] developed Al_2O_3 and calciastabilized zirconia coating on Aluminium 6061 with the help of spraying method. By comparing the properties of both coatings, density of calcia-stabilized zirconia coatings was found to be denser than alumina coatings, which lead to less erosion of calcia-stabilized zirconia coating under erosion test. By comparing hardness, alumina coating is harder than calcia-stabilized zirconia coating. Strength, young modulus and strain hardening rate shows increment with the increase in reinforcement. They also observed decrease in percentage elongation with reinforcement.

Kumar et al. [18] studied the influence of SiC on the hardness of an Al6061–SiC composite. They found that the increase of SiC from 0 to 6 wt % leads to an improvement in the hardness of the composite by an amount of 67%. This improvement can be attributed to the reason that the SiC possesses higher hardness. The presence of SiC in the composite provides an improvement in its hardness. Some attempts have been made on preparing HAMMCs with SiC and other reinforcement materials.

Naveed and Khan [19] have successfully produced Al6061–SiC–Graphite hybrid composites by the vortex method with up to 4 wt % graphite and constant 7 wt % SiC. They observed from their experimental study that the ultimate tensile strength of Al6061 increases with the addition of 7 wt % SiC.

2.3 Manufacturing of AMMC's using stir casting Process

Himanshu Kala et.al,[20] presented a review on the mechanical and tri-bological properties of stir cast Aluminium matrix composites containing single and multiple reinforcement. Addition of alumina to Aluminium has shown an increase in its mechanical and tri-bological properties. Organic reinforcement like fly ash, coconut ash also improved the tensile and yield strength. Self-lubricating property of graphite improved the machinability of Aluminium.

M. Geeta Raniet.al,[21] prepared Aluminium MMC reinforced with MoS_2 powder of particle size of less than 2µm,with weight ratios of 1, 2, 3, 4, 5 & 5.5 %. Using stir casting technique. A series of tests were conducted to evaluate mechanical properties such as tensile strength, yield strength, impact strength and hardness for the specimen. The results were compared with base alloy. The results are revealing that the hardness and tensile strength increased with increase in wt. %

of reinforcement particles in the matrix up to 4% and the hardness and tensile strength decreased for 5 % , 5.5% addition of reinforcement in the matrix. Investigations show that the MMC with 4% of MoS2 have better mechanical properties i.e. hardness and tensile strength yield strength.

Kandpal etal,[22] made a composite using Aluminium 6063 as a matrix component and alumina (Aluminium oxide, Al2O3) as a reinforcement using stir casting technique. The results confirmed that stir formed Al alloy 6063 with Al_2O_3 reinforced composites is clearly superior to base alloy Al alloy 6063 in the comparison of Tensile Strength, Impact Strength as well as hardness. Dispersion of Al_2O_3 particles in Aluminium matrix improves the hardness of matrix material. It is found that elongation tends to decrease with increasing particles weight percentage, which confirms that alumina addition increases brittleness. Aluminium matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of Al_2O_3particals. It appears from this study that UTS and yield strength trend starts increases with increase in weight percentage of Al2O3 in the matrix

2.4 Optimisation of Cutting Parameters in WEDM process

Sankara Narayanan Get.al,[23] investigated the effect of process parameters on the thickness of the work piece, time and wear and developed mathematical relationships using Artificial Neural Networks. From that they developed Algorithm for the input parameters and the process parameters by using Wire Cut Electric Discharge Machining.

Pragya Shandilyaet.al,[24] optimized the process parameters during machining of Al6061/ Sic MMC by WEDM . The input parameters of WEDM namely pulse-on time, pulse- off time, wire feed were chosen as variables. ANOVA results were used to find out the contribution of parameters on MRR and Surface roughness.

Ashish Srivastavaet.al,[25] presented an experimental study on composite of Al2024 reinforced with SiC to investigate the effects of WDEM and Response Surface methodology was applied to optimize the machining parameters for maximize the MRR and Surface finish

Sarcaret.al,[26] optimized the trim cutting operation of WEDM of γ-TiAl alloy for a given machining conditions by desirability function approach. Response Surface Methodology (RSM) was used to develop a prediction model of surface roughness for machining mild steel.

B.Nagaraju et.al,[27] made an attempt to study the effect of Wire Electric Discharge Machining (WEDM) parameters like pulse-on time, pulse-off time and peak current on Surface Roughness(Ra)and Material Removal Rate(MRR) in Aluminium Metal Matrix Composites(AMMCs). The composite material containing alumina alloy as matrix, silicon carbide as reinforcement is produced by Stir casting technique. Experimentation was conducted in a series of tests called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response using Response Surface Methodology.

2.5 Optimisation of WEDM Parameters using Taguchi Method

Tirumavalan, ket.al,[28] optimized the process parameters during machining of AA6061 by Severe Surface Mechanical Treatment (SSMT). By using Taguchi design of experiments the process parameters were optimized. ANOVA is used to analysis of the results.

Sateesh Kumar Reddyet.al,[29] made an attempt to find the optimization of wire electrical discharge machining of Al/SiC MMC. The experiments were carried out to find the best affecting parameters to maximize MRR & Surface Roughness. Taguchi method was used as the Design of Experiment and for the analysis. ANOVA is used for the development of mathematical correlation equation.

Mahapatraet.al,[30] made an attempt to determine the important machining parameters for performance measures like material removal rate, surface finish and kerf width separately in the WEDM process.

CHAPTER 3

DESIGN OF EXPERIMENTS

3.1 Design of experiments (DOE) overview

Design of experiments (DOE) is defined as a branch of applied statistics deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. DOE is a powerful data collection and analysis tool that can be used in a variety of experimental situations.

In Industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, direct field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well designed experiments can produce significantly more information and often require fewer than haphazard or unplanned experiments. A well-designed experiment identifies he effects that are important. If there is an interaction between two or more input variables, they should be included in design rather than doing a "one factor at a time" experiment. As interaction occurs, when the effect of one input variable is influenced by the level of another output variable.

Design of experiments are often carried out in four phases: planning, screening (also called process characterisation), optimization and verification.

3.1.1 Planning

Careful planning helps in avoiding problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of your system can affect your ability to complete the experiment. The preparation required before beginning of the experimentation depends on the problem. Here are some steps that need to go through:

- **Define the problem.** Developing a good problem statement helps ensure that you are studying the correct variables.
- **Define the objective.** A well-defined goal will ensure that the experiment answers the correct questions and yields practical, usable information. At this step, you define the goals of the experiment.
- **Develop an experimental plan that will provide meaningful information.** Relevant background information, such as theoretical principles, and knowledge obtained through observation or previous experimentation should be considered.
- **Make sure the process and measurement systems are in control.** Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system. Minitab provides numerous tools to evaluate process control and to analyse your measurement system.

3.1.2 Screening

In many process development and manufacturing applications, potentially influential variables are numerous. Screening (process characterization) is used to reduce the number of factors by identifying the most important factors that affect product quality. This reduction helps in concentrating on process improvement efforts on the most important factors. Screening suggests the "best" optimal settings for these factors.

The following methods are used for screening:

- Two level full and fractional factorial designs are used extensively in industry.
- Plackett-Burman designs have low resolution, but their usefulness in some screening experimentation and robustness testing.
- General full factorial designs (design with more than two levels) may also be useful for small screening experiments.

3.1.3 Optimization

After identifying the vital variables by screening there is no need to determine the best or optimal values for these experimental factors. Optimal factor values depend on the process objectives.The optimization methods available in Minitab include general full factorial designs (designs with more than two levels), response surface designs, mixture designs, and Taguchi designs.

- Factorial designs overview describes methods for designing and analysing general full factorial designs.
- Response surface designs overview describes methods for designing and analysing central composite and Box-Behnken designs.
- Mixture designs overview describes methods for designing and analysing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of components (factors), rather than their magnitude are important
- Response optimisation describes methods for optimising multiple responses. Minitab provides numerical optimisation, an interactive graph, and an overlaid control plat to help to determine the "best" settings to simultaneously optimisw multiple responses.
- Taguchi designs overview describes methods for analysing designs. Taguchi designs may also be called orthogonal array designs, robust designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4 Verification

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

3.2 Advantages & Disadvantages of DOE

DOE became a more widely used modelling technique superseding its predecessor one-factor-at-time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible characteristics.

Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation.

DOE function in such a manner that the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have error occurring.

Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behaviour. However, when it comes to non-linear behaviour, DOE does not give best results.

3.3 To create a Taguchi Design

Step 1: Stat> DOE > Taguchi > Create Taguchi Design

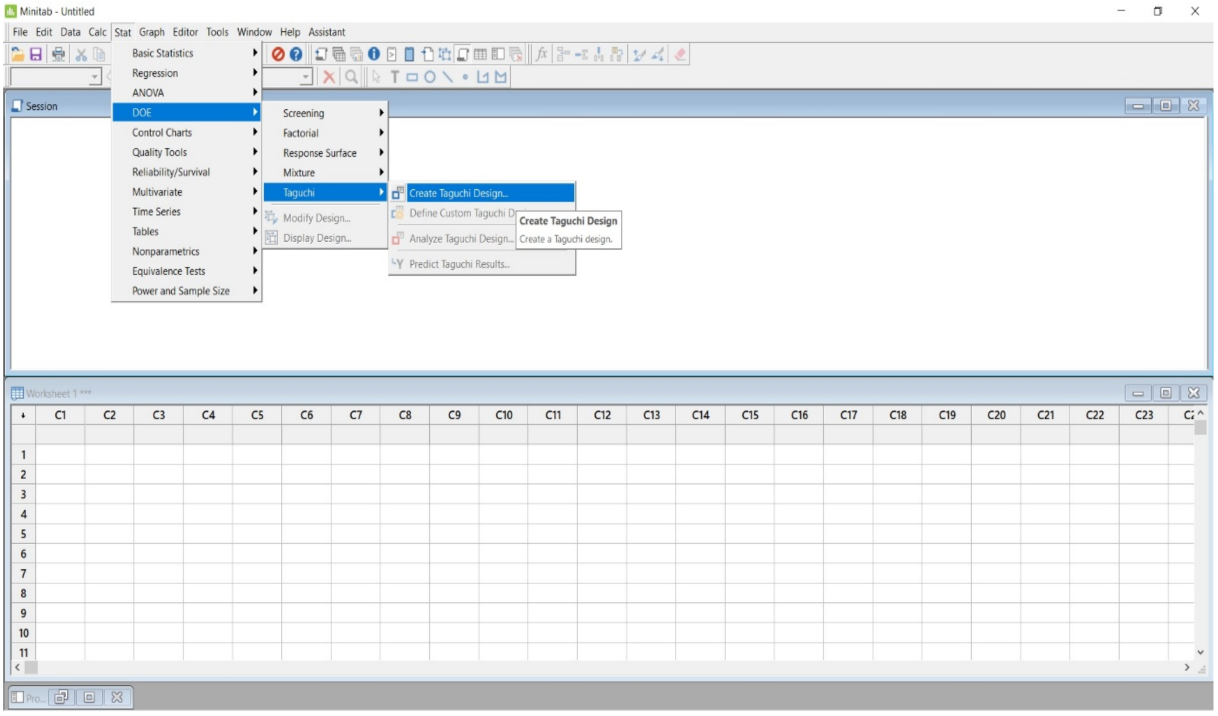


Fig 3.1 Taguchi Design

Step 2: Choose 3 level design (2 to 5 factors)

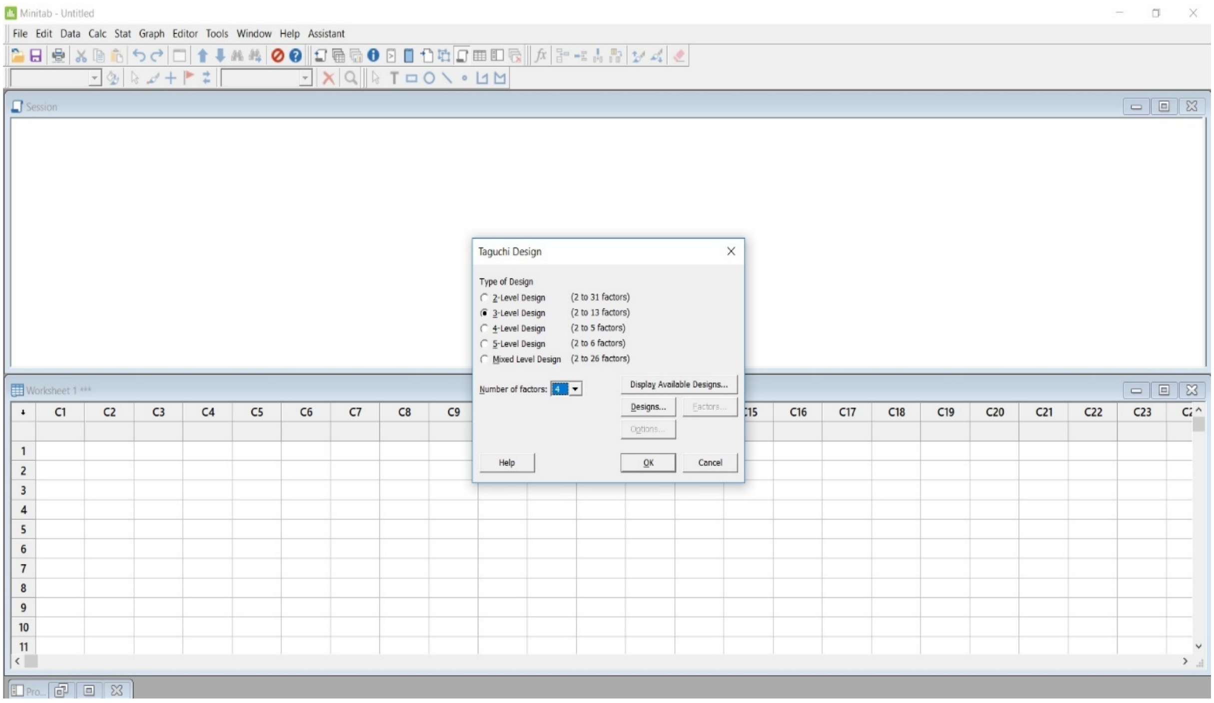


Fig 3.2 Creation of Taguchi design

Step 3: Choose number of factors as 4; shown in fig

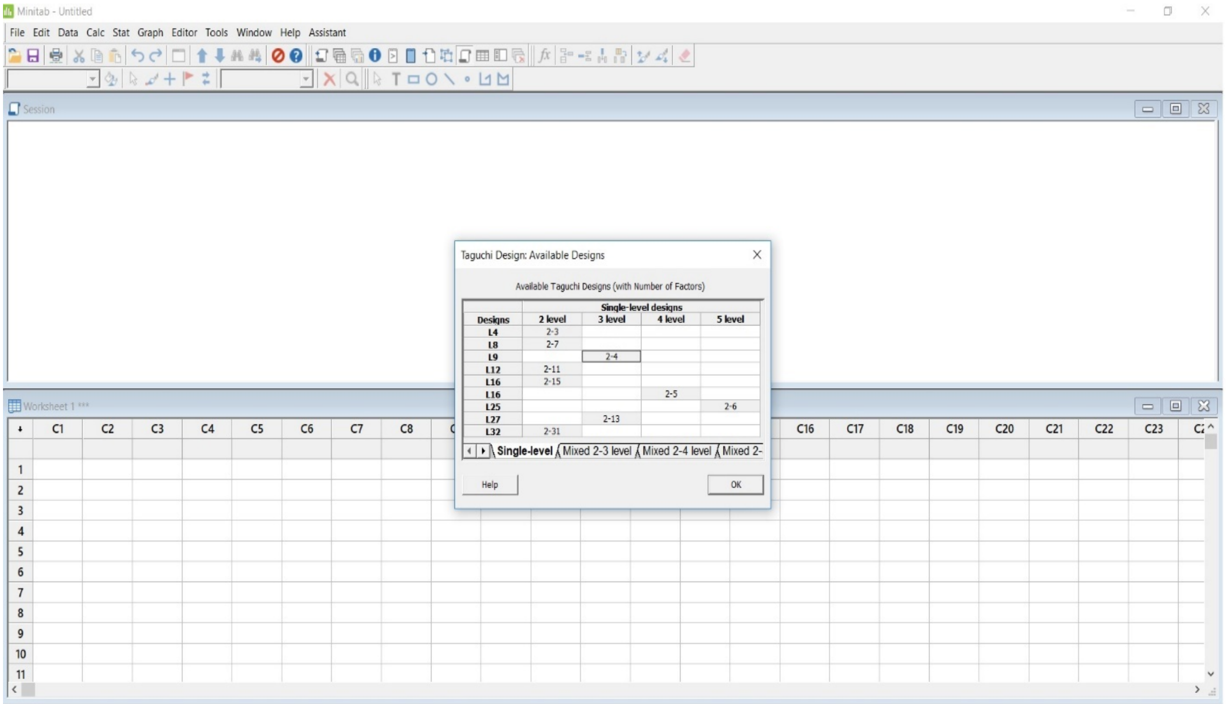


Fig 3.3 Choosing No. Of factors

Step 4: Stat > DOE > Taguchi > Create Taguchi Design > Display available designs

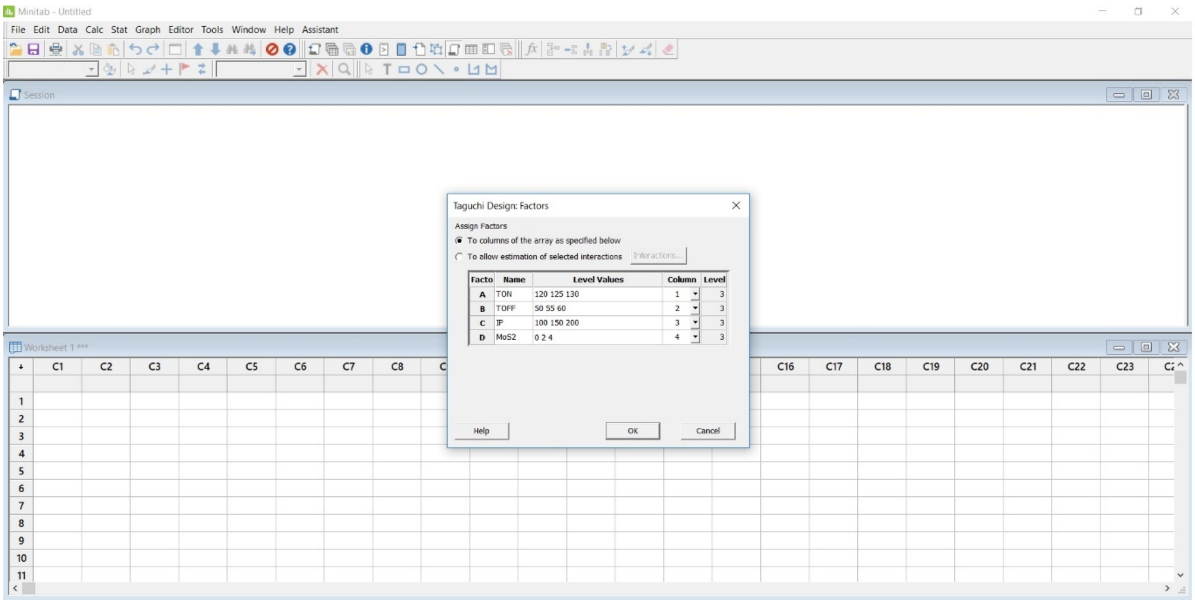


Fig 3.4 Dialog box for entering parameters

Step 5: Stat > DOE > Taguchi > Create Taguchi Design > **Factors**

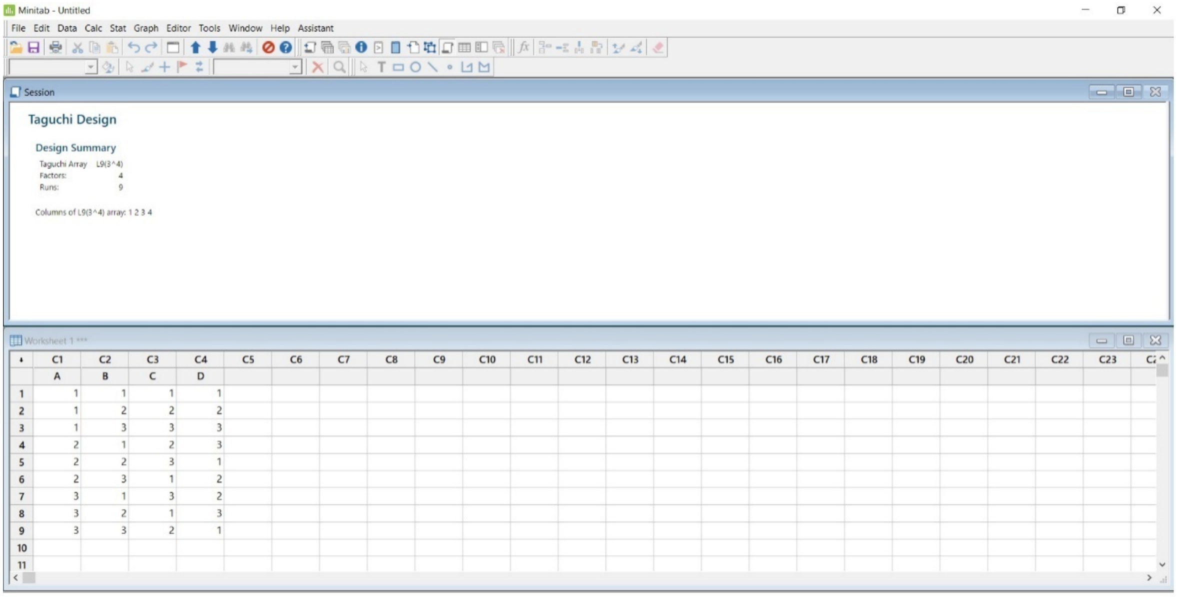


Fig 3.5 Coded form of DOE

Step 6: Stat > DOE > Taguchi > Create Taguchi Design >**Options**

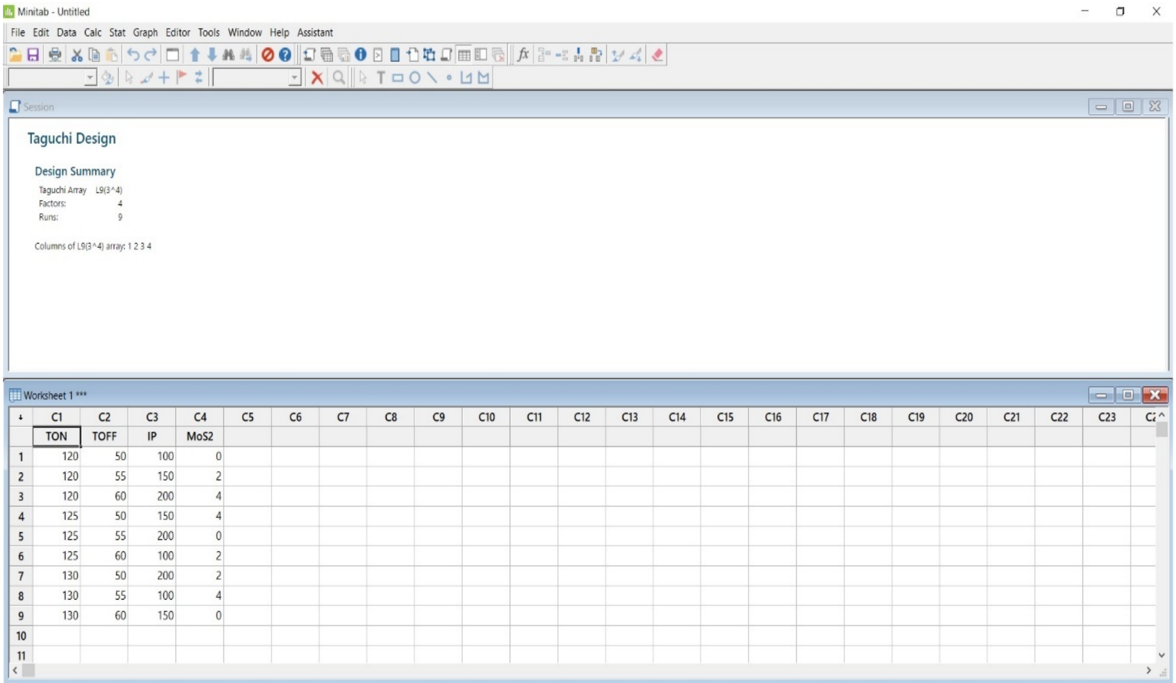


Fig 3.6 Taguchi design in MINITAB

Step 7: Stat > DOE > Taguchi > Create Taguchi Design >**Ok**

3.4 Selection of Levels

Since it is a three level design, by observing the parameters taken in various projects, the level of factors are designed as follows

Table 3.1 Selection of process variables

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
TON	120	125	130
TOFF	50	55	60
IP	100	150	200
MOS_2	0	2	4

3.5 Coded Form of DOE

Table 3.2 Coded form of DOE

S.NO	TON	TOFF	IP	MOS_2
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.6 Decoded Form of DOE

Table 3.3 Decoded form of DOE

S.NO	TON	TOFF	IP	MOS_2
1	120	50	100	0
2	120	55	150	2
3	120	60	200	4
4	125	50	150	4
5	125	55	200	0
6	125	60	100	2
7	130	50	200	2
8	130	55	100	4
9	130	60	150	0

3.7 Selection of Material

By studying various literature reviews, Aluminium is selected for this project. The composition of Aluminium-6082 which is used in this project is

- Aluminium: 95.2 to 98.3%
- Magnesium Silicide : 0.4 to 1.2%
- Iron : 0.4% to 1.0%
- Copper: 0.8% max
- Chromium: 0.25% max
- Titanium: 0.1% max
- Zinc: 0.2% max
- Residuals: 0.15% max

3.8 Measurement of Surface Roughness

Surface roughness of the pins that are cut by Wire EDM is measured using a Surface roughness. It has a stylus which have Diamond tip. The Diamond tip stylus is placed on the surface whose roughness is to be measured. Then the stylus moves in to and fro direction between a certain given length. While it is moving the display shows a graph and at the end of measurement the required Surface Roughness value in microns is displayed on the screen. For this experiment we have used a Mitutoyo Portable Surface Roughness Tester SJ-210 which is shown in the figure.

Fig 3.7 Surface Roughness meter

3.9 Preparing the Specimen

Aluminium is purchased in the form of a rectangular rod and the reinforced material i.e., Molybdenum Disulphide (MoS_2) in the form of powder (5 microns). The rectangular rod is cut using a Power Hack Saw to a specified length based on the required weight for each specimen i.e., 600gm.

Then using Stir Casting process composite material is prepared in the shape of a rectangular prism of dimensions 140mm x 50mm x 10mm. 9 holes are cut on specimens having different percentages of MoS_2 i.e., 0%, 2% and 4% in Wire EDM machine. The pins thus obtained after cutting are used as specimens in determining the Surface Roughness.

3.10 List of experimental MRR and Surface Roughness values

The MRR values and Surface roughness values which are calculated and measured are tabulated as follows:

Table 3.4 Experimental values of MRR

S.No	Ton	Toff	IP	Mos2	Cutting ɛed(mm/min)	MRR(mm^3/min)
1	120	50	100	0	0.83	24.07
2	120	55	150	2	1.9	55.1
3	120	60	200	4	1.8	52.2
4	125	50	150	4	1.13	32.77
5	125	55	200	0	2.42	70.18
6	125	60	100	2	1.85	53.65
7	130	50	200	2	1.51	43.79
8	130	55	100	4	1.64	47.56
9	130	60	150	0	2.19	63.51

Table 3.5 Experimental values of Ra

S.No	Ton	Toff	IP	Mos2	Ra
1	120	50	100	0	2.46
2	120	55	150	2	3.54
3	120	60	200	4	2.63
4	125	50	150	4	2.31
5	125	55	200	0	3.36
6	125	60	100	2	3.55
7	130	50	200	2	3.64
8	130	55	100	4	3.42
9	130	60	150	0	3.32

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Methodology

Select the three levels of TON, TOFF, IP and MoS_2 for experimental analysis. By using MINITAB software, create the Taguchi design of 9 runs. Cutting operations are performed on Wire EDM process in the order of the matrix given by Taguchi design. Surface Roughness of the pins obtained after cutting is to be measured by using a Tally Surf roughness tester .The MRR of Wire EDM is calculated using equation.

4.2 RESULTS

4.2.1 MRR

Table 4.1 Table for S/N ratio

S.No	Ton	Toff	IP	Mos2	Cutting speed (mm/min)	MRR (mm^3/min)	SNRA1
1	120	50	100	0	0.83	24.07	27.6295
2	120	55	150	2	1.90	55.10	34.8230
3	120	60	200	4	1.80	52.20	34.3534
4	125	50	150	4	1.13	32.77	30.3095
5	125	55	200	0	2.42	70.18	36.5577
6	125	60	100	2	1.85	53.65	34.5914
7	130	50	200	2	1.51	43.79	32.8275
8	130	55	100	4	1.64	47.56	33.5448
9	130	60	150	0	2.19	63.51	36.0568

Table 4.2 MRR & S/N ratios

S.No	Ton	Toff	IP	MoS2	Cutting speed (mm/min)	MRR (mm^3/min)	S/N	S/N Predict
1	120	50	100	0	0.83	24.07	27.62952	27.62952181
2	120	55	150	2	1.9	55.1	34.82303	34.82303198
3	120	60	200	4	1.8	52.2	34.35341	34.35341006
4	125	50	150	4	1.13	32.77	30.30953	30.30952883
5	125	55	200	0	2.42	70.18	36.55772	36.55771966
6	125	60	100	2	1.85	53.65	34.59139	34.59139453
7	130	50	200	2	1.51	43.79	32.8275	32.8274989
8	130	55	100	4	1.64	47.56	33.54484	33.54483692
9	130	60	150	0	2.19	63.51	36.05684	36.05684225

Table 4.3 Response table for S/N ratio

Level	Ton	Toff	IP	MoS_2
1	32.27	30.26	31.92	33.41
2	33.82	34.98	33.73	34.08
3	34.14	35.00	34.58	32.74
Rank	3	1	2	4

4.2.1.1 Predicting the optimum performance

Predicted S/N Ratio is given by

$$S/N_{predict} = S/N_{Total\,mean} + \sum_{i=1}^{n} (S/N_{mean\_opt\_factor} - S/N_{Total\,Mean})$$

$$\begin{aligned} S/N_{predict} = S/N_{Total\,mean} &+ (TON_3 - S/N_{Total\,mean}) \\ &+ (TOFF_3 - S/N_{Total\,mean}) + (IP_3 - S/N_{Total\,mean}) \\ &+ (MoS2_2 - S/N_{Total\,mean}) \end{aligned}$$

Predicted S/N Ratio = 37.568 dB

Material removal rate = 75.5 mm^3/min

4.2.2 Surface Roughness

Table 4.4 Table for S/N ratio

S.No	Ton	Toff	IP	Mos2	Ra (μm)	SNRA1
1	120	50	100	0	2.46	-7.8187
2	120	55	150	2	3.54	-10.9801
3	120	60	200	4	2.63	-8.3991
4	125	50	150	4	2.31	-7.2722
5	125	55	200	0	3.36	-10.5268
6	125	60	100	2	3.55	-11.0046
7	130	50	200	2	3.64	-11.2220
8	130	55	100	4	3.42	-10.6805
9	130	60	150	0	3.32	-10.4228

Table 4.5 Response table for S/N ratio

Level	Ton	Toff	IP	MoS_2
1	-9.066	-8.771	-9.835	-9.589
2	-9.601	-10.729	-9.558	-11.069
3	-10.775	-9.942	-10.049	-8.784
Delta	1.709	1.958	0.491	2.285
Rank	3	2	4	1

4.2.2.1 Predicting the optimum performance

Predicted S/N Ratio is given by

$$S/N_{predict} = S/N_{Total\ mean} + \sum_{i=1}^{n} (S/N_{mean\_opt\_factor} - S/N_{Total\ Mean})$$

$$S/N_{predict} = S/N_{Total\,mean} + (TON_1 - S/N_{Total\,mean}) + (TOFF_1 - S/N_{Total\,mean}) + (IP_2 - S/N_{Total\,mean}) + (MoS2_3 - S/N_{Total\,mean})$$

Predicted S/N Ratio = -6.737dB

Surface Roughness = 2.17 µm

4.3 GRAPHS (MRR)

Main effects plot of S/N ratio

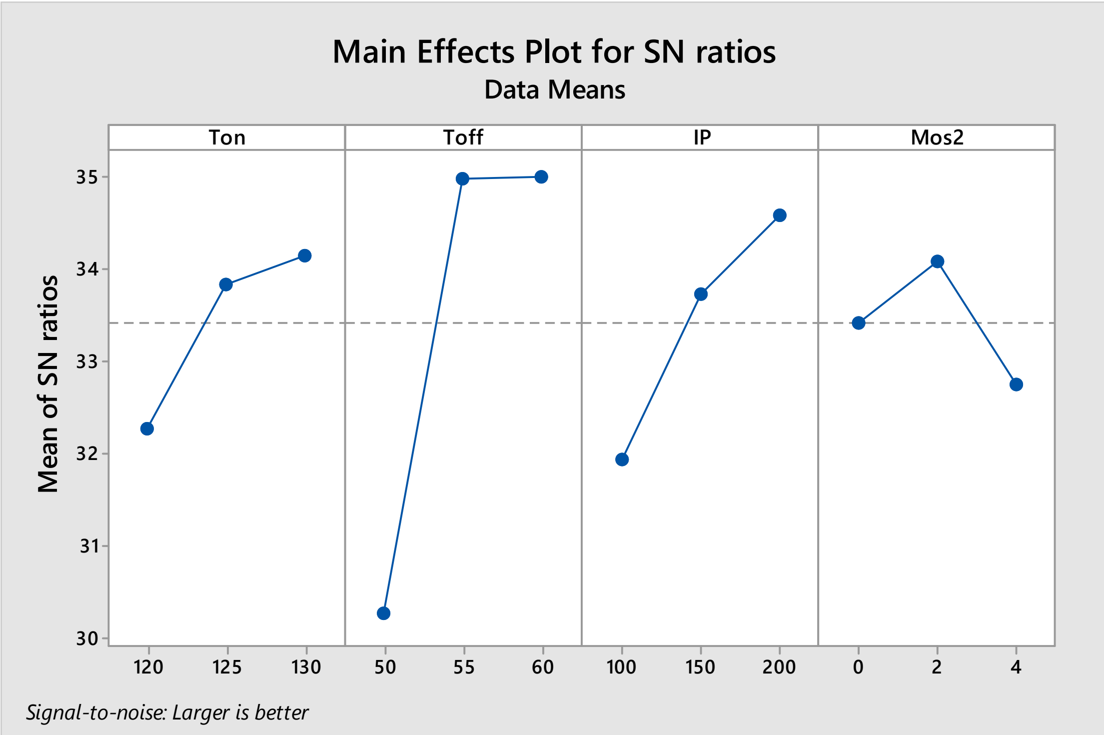


Fig 4.1 Main effects plot of S/N ratio

Main effects plots show how each factor affects the response characteristic (S/N ratio, means, Slopes, Standard deviations). A main effect exists when different levels of a factor affect the characteristic differently. For a factor with 3 levels you may identify that one level increases the mean compared to the other level. This difference is the main effect.

Table 4.6 Optimum Factors based on Main effects Plot

S.No	Factor	Level	Value of corresponding optimum level	Mean of S/N dB
1	TON	3	130	34.14
2	TOFF	3	60	35
3	IP	3	200	34.58
4	MoS_2	2	2	34.08

4.4 GRAPHS (Surface Roughness)

Main effects of S/N ratio

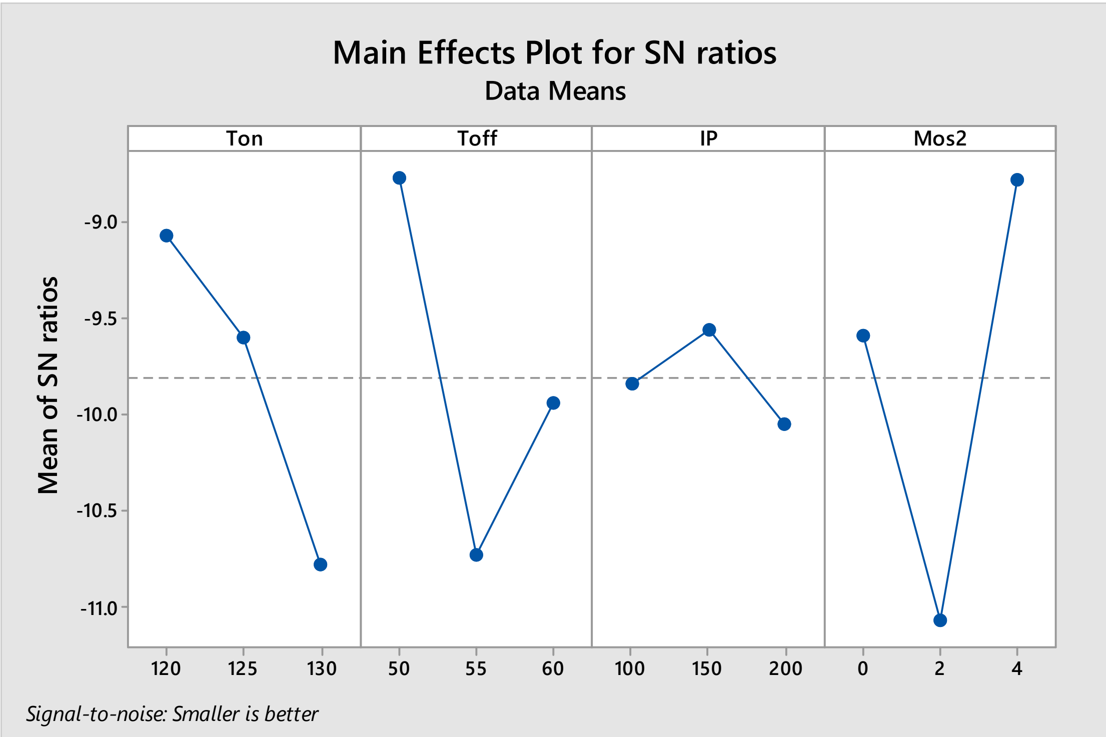


Fig 4.2 Main effects plot of S/N ratio

Main effects plots show how each factor affects the response characteristic (S/N ratio, means, Slopes, Standard deviations). A main effect exists when different levels of a factor affect the characteristic differently. For a factor with 3 levels you may identify that one level increases the mean compared to the other level. This difference is the main effect.

Table 4.7 Optimum Factors based on Main effects Plot

S.No	Factor	Level	Value of corresponding optimum level	Mean of S/N dB
1	TON	1	120	-9.066
2	TOFF	1	50	-8.771
3	IP	2	150	-9.558
4	MoS_2	3	4	-8.784

4.5 Confirmation experiment

The confirmation experiment is very important in parameter design. The purpose of the confirmation experiment in the present work is to validate the optimum factors viz., Pulse on-time, Pulse of-time, Input Current and Percentage of MoS_2.The experimental results of the confirmation experiments is listed in the tables.

4.5.1 For Material Removal Rate

Table 4.8 Results of Confirmation Experiment for MRR

TON	TOFF	IP	%MoS_2	MRR	S/N Ratio	Predicted S/N ratio	% Error
130	60	200	2	70.18	36.55	37.568	2.78

4.5.2 For Surface Roughness

Table 4.9 Results of Confirmation Experiment for Ra

TON	TOFF	IP	%MoS_2	Ra	S/N Ratio	Predicted S/N ratio	% Error
120	50	150	4	2.31	-7.16	-6.737	5.91

CHAPTER 5

CONCLUSIONS

This study has presented the application for minimizing surface Roughness and maximizing material removal rate in Wire EDM machine. The following conclusions from the experimental and predicted results.

1. Optimum parameters for maximizing Material Removal Rate in wire EDM are obtained i.e., TON-130, TOFF-60, IP-200, MoS2-2%.
2. Optimum parameters for minimizing Surface Roughness of pins obtained after machining the specimen in Wire EDM, i.e., TON 120, TOFF 50, IP 100, MoS2 4%
3. Predicted S/N Ratio of Material removal rate has been obtained as 37.568dB at optimum parameters. Confirmation experiment for material removal rate was conducted at optimum parameters and S/N Ratio was obtained as 36.55dB. The predicted values and experimentally measured values are good in arrangement with 2.78% error.
4. Predicted S/N Ratio of surface roughness has been obtained at -6.737dB at optimum parameters. Confirmation experiment for Surface roughness was conducted at optimum parameters and S/N Ratio was obtained as -7.16dB. The predicted values and experimentally measured values are good in arrangement with 5.91% error.

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