Using Wire EDM to Predict Process Parameters for Surface Roughness on an Aluminium Metal Composite

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ABSTRACT

One of the unconventional machining techniques is wire EDM. The objective of the current inquiry is to analyse the surface roughness of composites made of aluminium and silicon carbide that contain silicon carbide particles. Conventional machining techniques are now being replaced by non-traditional machining techniques because of the rising demands for high surface finishes and the processing of complicated form geometries. This useful technology of the WEDM procedure is based on the typical EDM sparking phenomenon and makes use of the commonly used non-contact material removal method. The finest choice for producing micro-scale parts with the highest level of dimensional precision and surface finish quality is WEDM, which has been utilized for generating tools and dies in a straightforward manner. To determine their influence on the output parameter, namely the surface roughness of aluminium/SiC composites containing SiC particulates, it has been investigated how different WEDM parameters such as pulse on time (Ton), pulse off time (Toff), servo voltage (SV), and wire tension (WT) affect each other. To explore the effects of the factors and afterwards anticipate sets of optimal parameters for minimizing the surface roughness, an experimental plan is carried out using the Taguchi technique. Moreover, Analysis of variance (ANOVA) is used to determine how specific elements affect the work piece's surface roughness.

Key words: WEDM ANOVA, Surface roughness.

1202

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

1. Introduction

1.1 manufacturing

Manufacturing is the process of turning raw materials into finished goods in the broadest sense. It includes everything from the product's design to the choice of raw materials to the order in which the product will be constructed.

Additionally, there are processes involved in manufacturing where the final product is used to create other items. Large presses used to shape sheet metal for vehicle bodies, equipment used to create bolts and nuts, and sewing machines used to create garments are a few examples of these products. The classification is in figure:1.1.

Primary manufacturing processes and secondary manufacturing processes are the two basic categories into which manufacturing processes can be categorized. According to the needs of the designer, the first ones provide the material a basic shape and size. Such operations include casting, forming, and powder metallurgy, to name a few. The final shape and size are produced using secondary production techniques, which offer greater control over dimension, surface properties, etc. The secondary manufacturing processes are mostly those that involve material removal.

Once more, there are two basic categories into which material removal operations can be subdivided: "Conventional Machining Processes" and "Non-Traditional Manufacturing Processes."
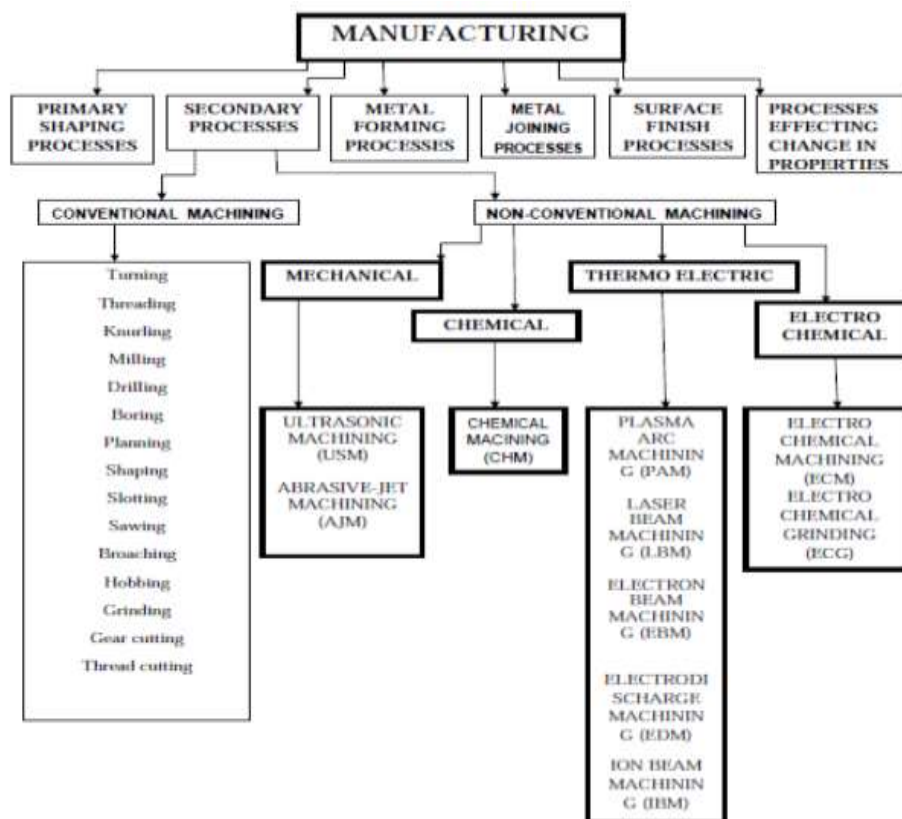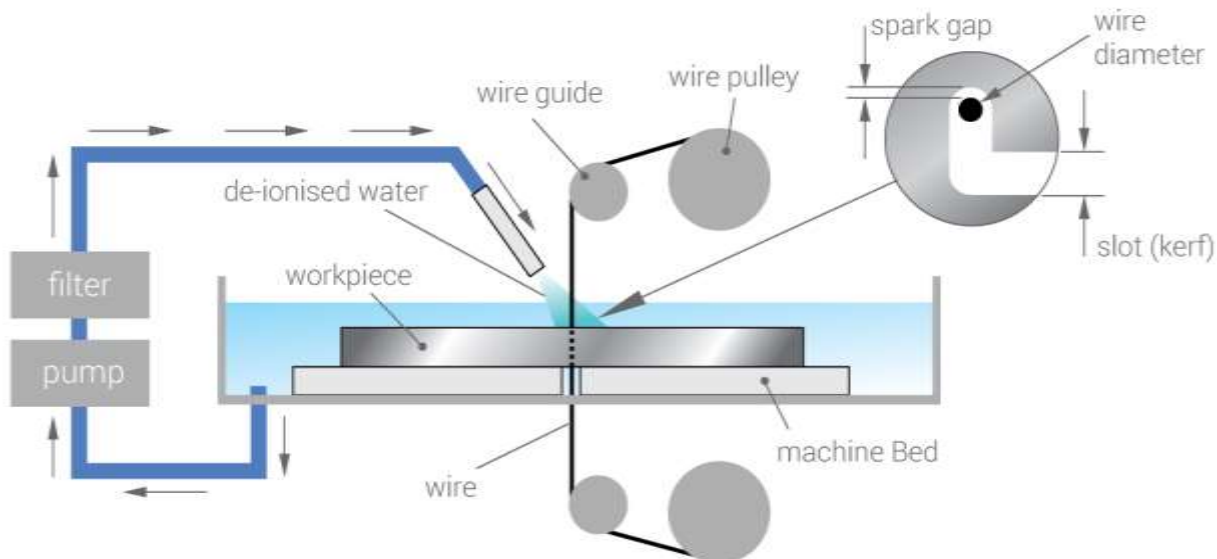

FIGURE 1 Classifications of Manufacturing Processes

1203

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

My main discussion on this project being on the Non-Traditional machining.

## 1.2 ELECTRIC DISCHARGE MACHINING (EDM) AND WIRE EDM

FIGURE 2 CNC Wire Cut EDM

FIGURE 3 Machining in WIRE EDM

It has many benefits to give and is perhaps the most interesting and versatile machine tool created for this industry in the previous fifty years. EDM is frequently used to cut materials, ranging from everyday materials. Every material can be easily machined as long as it is electrically conductive, regardless of how tough it is. In contrast to milling cutters and grinding wheels, cutting wires impart no cutting pressure or mechanical stresses to the work piece because they do not make contact with it. Also, holding small, delicate, or thin fragile parts only requires a very little amount of clamping pressure, preventing distortion. The process is significantly simpler to estimate because of the accuracy, surface polish, and time needed.

1204

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218
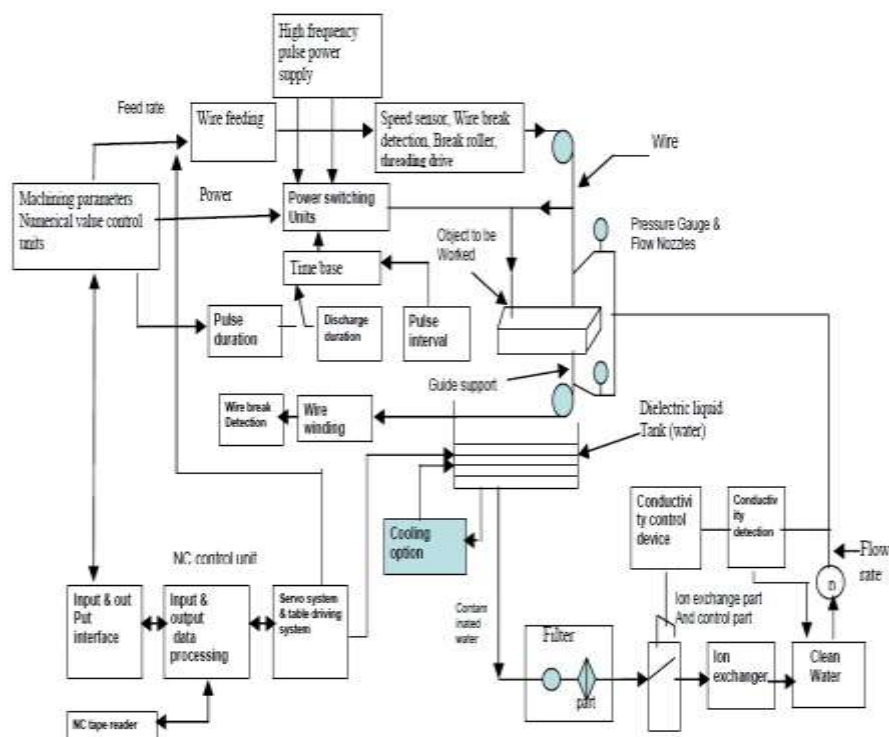
FIGURE 4   A Typical Block Diagram of CNC-WIRE EDM Machine

Using wire EDM, there are no lingering burrs on the work piece, avoiding time- and money-saving subsequent deburring procedures. In addition, unlike the marks produced by grinding and milling processes, Wire EDM leaves no tooling marks because the surface has a homogeneous, random pattern. Moreover, Wire EDM allows management more control over manufacturing and designers more freedom when creating dies. You don't need to use various equipment or rely on people with different skill levels to work on parts with complex geometry and tight tolerances. When the machining is unattended, significant productivity gains are made possible by the operators' ability to work on other tasks. The majority of machines operate in a "lights-out" environment at night. Shorter jobs are scheduled during the day, while long-running jobs are terminated overnight or over the weekend. On the worktable, many jobs are frequently configured and connected using various programs. For instance, the machine may automatically thread the wire and cut the punches needed for the work in a much thicker piece of material once the die apertures and dowel pin holes have been produced on a one-inch thick die block. Most work components exit the machine as finished parts, necessitating no further processing. It only only one step! The ability to repeat parts is yet another crucial aspect of wire EDM. Short production runs or prototype items are cut one at a time or by laminating stacks of material. Even if the sections are cut again six months later, they will be the same.

1.3 A REVIEW OF THE LITERATURE
Electrical sparks on the surfaces of the machines formed a lot of craters. The surface quality will be worse the more electrical energy is discharged. A significant amount of energy will cause the surface to ripple, alter the structure and physical characteristics of the materials, and cause

1205

surface fissures and residual strains. Eventually, the work piece's life and surface quality will both decline. Many studies were done in this region to try to get a fine surface quality. This is a list of some of the important ones.

The impact of WEDM is discussed by Han J, Jiang J, and Yu D [1]. The results of the experiments showed that by reducing the discharge current and pulse time, the surface roughness can be increased. Short and long pulses will produce the same surface roughness but differing surface morphologies and material removal rates when the pulse energy per discharge is constant. While using short pulse duration, the removal rate is significantly higher than when using lengthy pulse duration. Also, we discovered from the single discharge trials that, after the pulse energy was decreased to a certain level, a lengthy pulse duration combined with a low peak value could no longer create craters on the work piece surface.

HSLA is used as the workpiece in Neeraj Sharma et al's [2] investigation of the influence of factors on metal removal rate for WEDM. HSLA is a material used in vehicles such as cars, trucks, cranes, bridges, roller coasters, and other constructions that are made to withstand a lot of stress. A mathematical model developed by Responsive Surface Methodology links the independent process variables to the target metal removal rate and surface roughness. In order to produce a precise piece of work, metal removal rate (MRR) and surface finish (SF) improvement are desired.

Amar Patnaik et al. [3] deemed rough cutting operation in WEDM to be a tough one. Significant machining parameters influencing the performance measurements have been determined using Taguchi's parameter design, including discharge current, pulse length, pulse frequency, wire speed, wire tension, and dielectric flow.

M. Durairaj et al.[4] cover in order to improve the cutting parameters in Wire EDM for SS304. The goal of optimization is to achieve the smallest kerf width and the best surface quality simultaneously and independently. Brass wire with a 0.25 mm diameter is utilized as a tool, distilled water is employed as the dielectric fluid, and stainless steel 304 is used as the work piece in this investigation. Taguchi L16 experimentation has made use of an orthogonal array. Gap voltage, wire feed, pulse on time, and pulse off time have been chosen as the input parameters for optimization.

Ramakrishna et al. [5] designed for wire electrical discharge machining (WEDM) operations. Planning for the experiment followed Taguchi's L16 orthogonal array. Different cutting conditions, such as pulse on time, wire tension, delay time, wire feed speed, and ignition current intensity, were used for each experiment. For each experiment, three responses—material removal rate, surface roughness, and wire wear ratio—were taken into account.

Biranchi Narayan Panda et al. [6] viewed rough cutting operation in WEDM to be a tough one. Dielectric current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow rate are identified as significant machining parameters affecting the performance measures using the Tauguchi's parameters design. Machining performance measurements include surface finish and material removal rate.

Saurav Datta and Siba Sankar Mahapatra [7]. Six process parameters have been tested, with three levels of variation for each of the following: discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow rate. For each of the experimental runs,

1206

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

which correspond to randomly selected distinct factor setting combinations, data relating to the process responses, including material removal rate (MRR), roughness value of the working surface (a measure of surface finish, SF), and kerf, have been measured. This data have been used to develop a quadratic mathematical model (Response Surface Model) that may be seen as a function of the aforementioned six process parameters for each of the replies.

J.T. Huang, Y.S. Liao, and W.J. Hsue [8] conducted a study. The surface of the machined work piece is measured and evaluated for the gap width, surface roughness, and white layer depth. The pulse-on duration and the separation between the wire perimeter and the work piece surface are two important elements impacting the machining performance, according to the Taguchi quality design technique and numerical analysis. Regression analysis is utilized to build mathematical models that link machining parameters and performance, and non-linear programming with the Feasible-direction technique was used to find the ideal machining parameters.

S. Balasubramanian's [9] study's primary goals were to increase material removal rate (MRR) and decrease surface roughness. The six control factors are ton, T off, applied current, gap voltage, wire tension, and wire feed rate, each taken at a different level. The grey relational analysis is utilized because the process has various performance criteria. The conflicting performance indices are normalized by the grey relational grade.

J. T. Huang and Y. S. Liao [10] used grey relational analysis to find the best selection of machining settings. For a system when the model is uncertain or the data is lacking, the Grey theory can offer a solution. Also, it offers an effective solution to the problem of uncertainty, multiple inputs, and discrete data.

N.Ozdemer et al. [11] investigated the machinability of standard GGG40 nodular cast iron. The primary goal of the study was to look at how the machining input parameters affected the surface roughness, cutting rate, and surface microstructure of nodular cast iron on WEDM. According to the findings, as discharge energy rose due to an increase in current and pulse duration, surface roughness and cutting rate also increased. This is because larger and deeper discharge craters are produced when discharge current is raised.

Spedding and Wang [12]. Even though NN has been used extensively to model the process, it has several limitations. NN operates in a manner resembling a black box. It is unable to establish the quantitative relationships between the input variables and the output parameters, making it impossible to precisely choose and regulate the input variables for the best performance.

2. Problem definition

The current investigation's goals are to create an aluminium matrix with SiC reinforcement and to examine the surface roughness of the created MMC. Aluminum alloy was used as the matrix material in this experiment. Of all the aluminum alloys, aluminum alloy offers the highest strength and ductility, as well as outstanding machinability, good bearing, and wear qualities. Liquid metallurgy, also referred to as the "vortex method," is the primary technology used to create the majority of particle reinforced metal matrix composites. SiC particles have been employed as candidate reinforcements of particulate with a 400 mesh size and are added to the vortex generated in the aluminium melt above its liquidus temperature in the current work, which uses the "vortex

1207

method" to create AMCs. The MMC is first prepared, and then it is machined utilizing wire electrical discharge machining.

It may be argued that only a WEDM can easily produce extremely complicated and complex shapes and profiles. Several industries, including those that manufacture tool and dies, space applications, and the automobile industry, use WEDM extensively. The development of the governing relationships between the process parameters and surface roughness is the main goal of the work. The current research suggests using the traditional regression analysis to model WEDM. In this experiment, the input parameters chosen were SERVO VOLTAGE, WIRE TENSION, PULSE ON TIME, and PULSE OFF TIME. The operator's experience and a literature review are used to determine the input parameters in the conventional manner. Surface Finish (Ra), one of the most important output characteristics that determines how well a machining process performs, is one of the output parameters. Process variables such as pulse on and off times, wire tension, and servo voltage act as the input variables for surface finish prediction.

The decision parameters and other parameters are treated as constants across the experiment domain in the current work. The studies were carried out using a five axis high precision CNC-Wire Electrical Discharge Machine with the model number ULTRA CUT S1 from Electronica Machine Tools in India. Wire, a work table, a servo control system, a power supply system, and a dielectric supply system make up the essential components of a WEDM machine. Every time an experiment was run, a certain set of input variables was selected, and a work piece was cut with a 05mm length of cut and a 20mm thickness. The vertical configuration of a 0.25 mm diameter uncoated brass wire was selected and discarted after use. A surface roughness tester is used to determine surface roughness. Response value was calculated as the average of three measurements taken in three separate locations. The relationships between surface roughness variations and process factors are finally concluded.

3. Mechanisms

3.1 The Taguchi method

The modern quality movement and the adoption of the Taguchi Techniques in the United States can be traced back to the industrial competitive crisis of the 1970s and 1980s. Taguchi's approach to engineering design for quality improvement is known as the "Method." The term "Taguchi Methods" is used to describe a set of guidelines that serve as the basis for an ever-evolving strategy toward excellence. The loss function, signal-to-noise ratio, and orthogonal arrays form the backbone of the Taguchi Methods of Quality Engineering's design, and they are all intimately connected to the concept of quality. Taguchi argues that there is no clear boundary between two states. As the design parameter deviates from its optimal value, performance gradually decreases. Thus, he recommended using the margin of error to quantify the loss function. The line in the illustration shows that this function is continuous. When the parameters used in the design stray from the ideal or the goal value, the product's performance suffers. The simplest quadratic form of this loss function is as follows.

$$L(x) = k(x-m)^2 \text{ - - -}$$

1208

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

In this equation, L represents the monetary loss, m is the optimal setting point, x represents the actual setting point, and k is a constant that varies with the magnitude of the characteristic and the unit of currency.

According to the quadratic loss function, the overall loss exhibits a parabolic rise in conjunction with an increase in the degree of departure from the ideal value. A continuous function is represented by this deterioration. Good quality is currently defined as keeping the product characteristic on target with minimum volatility, therefore this shows that manufacturing a product inside the specification bounds is not sufficient to guarantee its quality. Taguchi places an emphasis on designing goods that consistently meet the intended value. Taguchi's approach to quality control centres primarily on reducing variation around a set target value.

4. EXPERIMENTAL PROCEDURE

4.1 FABRICATION OF MMC

Metal matrix composites are made with pure aluminium that is readily accessible on the market as the matrix alloy. This matrix alloy was selected because to its high strength-to-temperature-degradation characteristics. Reinforcements for the metal matrix composite were the SiC particles. (Table 4.1).

TABLE 4.1 Chemical composition of aluminium alloy matrix in wt. %

Element in %	Si	Mg	Fe	Cu	Zn	Cr	Ni	Ti	Mn	Al
Content	0.40	2.1	0.5	1.3	5.21	0.18	0.028	0.2	0.3	89.78

Figure 5 Induction furnace used for the preparation of MMCs

1209

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

The block diagram of Wire Electrical Discharge Machine (WEDM) used for the study is shown in Figure 6.
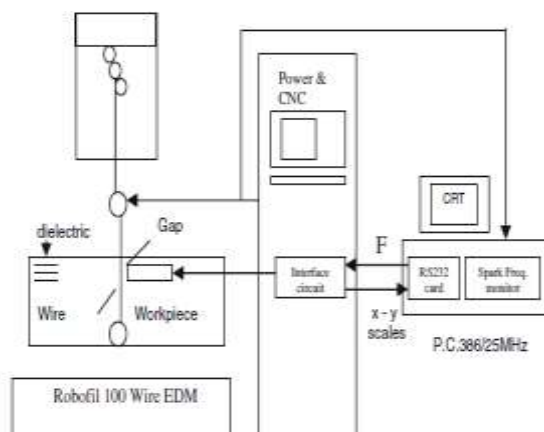
FIGURE 6   Block Diagram of WEDM used for the Study

5. RESULTS

A total of 16 experiments were conducted by varying the input control variables within the feasible ranges. The machining was performed with a five axis high precision CNC-Wire Electrical Discharge Machine, model number ULTIMA 1F, manufactured by Electronica Machine Tools, India. Table 6.1 shows that, all the 16 experiments are use to develop a mathematical model for surface roughness (Ra). The same readings are used to validate the linear regression models. Regression analysis is carried out using MINITAB Version 14. A linear mathematical model for surface roughness as a function of process parameters using conventional regression analysis and is given by the Equation 1.

Ra=39.53-0.0007*SV-0.9750*WT-0.7170*Ton+0.1275*Toff+0.0002*SV*SV-0.0058*WT*WT+0.0025*Ton*Ton-0.0009Toff*Toff+0.0007*SV*WT-0.0005*SV*Toff+0.0154*SV*WT-0.0105*WT*Toff+0.009*Ton*Toff   ------------ (1)

All the control input variables as selected such that they are in the feasible ranges of the machine and cause no burning marks during machining. The feasible ranges for the control variables are as shown in Table 5.3.

TABLE 5.3   Feasible bounds of control input variables

S.No	VARIABLE	LOWER RANGE	UPPER RANGE
1	Servo voltage	*20*	*80*
2	Wire tension	*2*	*14*
3	Pulse-on time	*100*	*112*
4	Pulse-off time	*45*	*60*

Using the above feasible bounds of the control variables and with the experience of the operator control variables were selected and have been divided into five control levels. The actual and coded values are given in TABLE 5**.**4.

TABLE 5.4   Control factors and their levels

S.NO	CONTROL FACTOR	SYMBOL USED	LEVELS				UNITS
			1	*2*	*3*	*4*	
1	Servo voltage	*SV*	*20*	*40*	*60*	*80*	*V*
2	Wire tension	*WT*	*8*	*10*	*12*	*14*	*N*
3	Pulse-on time	*Ton*	*100*	*104*	*108*	*112*	μs
4	Pulse-off time	*Toff*	*45*	*50*	55	*60*	μs

The most important performance measurements in WEDM are the SURFACE ROUGHNESS (Ra). Surface roughness is calculated using a surface roughness tester at a 0.8mm cutoff value. An average of three measurements at three different places was recorded as response value. With the above control values 16 experiments were conducted. The input values in each case are shown in TABLE 5.5.

TABLE 5.5   Selected Input Values

Experiment Number	SV	WT	T on	T off
1	20	8	100	45
2	20	10	104	50
3	20	12	108	55
4	20	14	112	60
5	40	8	104	55
6	40	10	100	60
7	40	12	112	45
8	40	14	108	50
9	60	8	108	60
10	60	10	112	50
11	60	12	100	45
12	60	14	104	45

1211

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

13	80	8	112	50
14	80	10	108	45
15	80	12	104	60
16	80	14	100	55

5.3 CALCULATION FOR SURFACE ROUGHNESS

Table 5.6 shows surface roughness values at 3 different locations and their average values for each experiment. Surface roughness has been measured by using surface roughness tester show in Figure 5.4

Table 5.6 Table for surface roughness

S.NO	SV	WT	T on	T off	Ra
1	20	8	100	45	1.501
2	20	10	104	50	1.625
3	20	12	108	55	1.75
4	20	14	112	60	2.061
5	40	8	104	55	1.721
6	40	10	100	60	1.616
7	40	12	112	45	2.09
8	40	14	108	50	1.88
9	60	8	108	60	1.823
10	60	10	112	50	1.621
11	60	12	100	45	1.909
12	60	14	104	45	1.83
13	80	8	112	50	1.941
14	80	10	108	45	2.098
15	80	12	104	60	1.69

1212

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

16	80	14	100	55	1.49

6. DISCUSSIONS

ANOVA for Surface roughness: Using the MINITAB software, an ANOVA was conducted to determine which factors substantially affect the quality. In order to analyze how process parameters, affect surface roughness, actual data of value were used. The surface roughness is influenced by the control factors Ton and Toff, whereas the other two variables have less of an impact overall, as can be shown from a study of Table 6.2. When the percentage of contribution is roughly the same as the corresponding mistake, the variables do not have a physical meaning. As a result, it was discovered in this study that all control variables had physical significance. In Figure 6.1, each variable's impact on surface roughness was visually depicted.

Table 6.1 Surface roughness values calculated and experimental:

S. NO	SV	WT	T on	T off	Ra Experimental	Ra calculated
1	20	8	100	45	1.501	1.538
2	20	10	104	50	1.625	1.686
3	20	12	108	55	1.75	1.835
4	20	14	112	60	2.061	1.983
5	40	8	104	55	1.721	1.666
6	40	10	100	60	1.616	1.520
7	40	12	112	45	2.090	2.035
8	40	14	108	50	1.88	1.889
9	60	8	108	60	1.823	1.813
10	60	10	112	50	1.621	1.592
11	60	12	100	45	1.909	2.033
12	60	14	104	45	1.83	1.776
13	80	8	112	50	1.941	2.014

1213

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

14	80	10	108	45	2.098	1.903
15	80	12	104	60	1.69	1.721
16	80	14	100	55	1.49	1.610

Table 6.2 ANOVA table for Surface Roughness

Source	DF	SS	MS	F	% contribution
SV	3	0.00399	0.00133	0.086084142	0.699288
WT	3	0.01193	0.003976667	0.257389428	2.090855
Ton	3	0.44955	0.14985	9.699029126	78.78825
Toff	3	0.01241	0.004136667	0.267745415	2.17498
Error	6	0.0927	0.01545	0.086084142	16.24663

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, $P < 0.05$ - determines significance of a factor at 95% confidence level
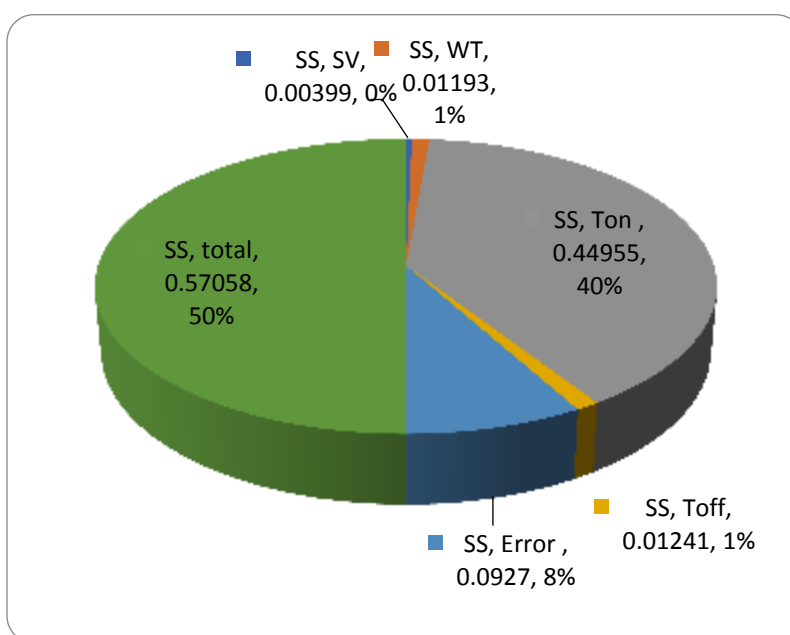

Figure 6.1 Percentage contributions of parameters on Surface roughness

1214

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

Mean of Ra:

Figure 6.2 shows the main effect plots for means of surface roughness values. From the graph it can be observed from the plot of surface roughness with process parameters that surface roughness increases pulse on time. Surface roughness is drastically decreases up to a point, then increases to point increase of pulse off time. Surface roughness slightly increases to a point and then decreases with servo voltage. Surface roughness is slightly increased up to a point, then decrease to point, and finally increase with increase of Wire tension. From figure 6.2 mean effect plots lowest surface roughness values were achieved at SV1, WT 1, T on1 and T off 3
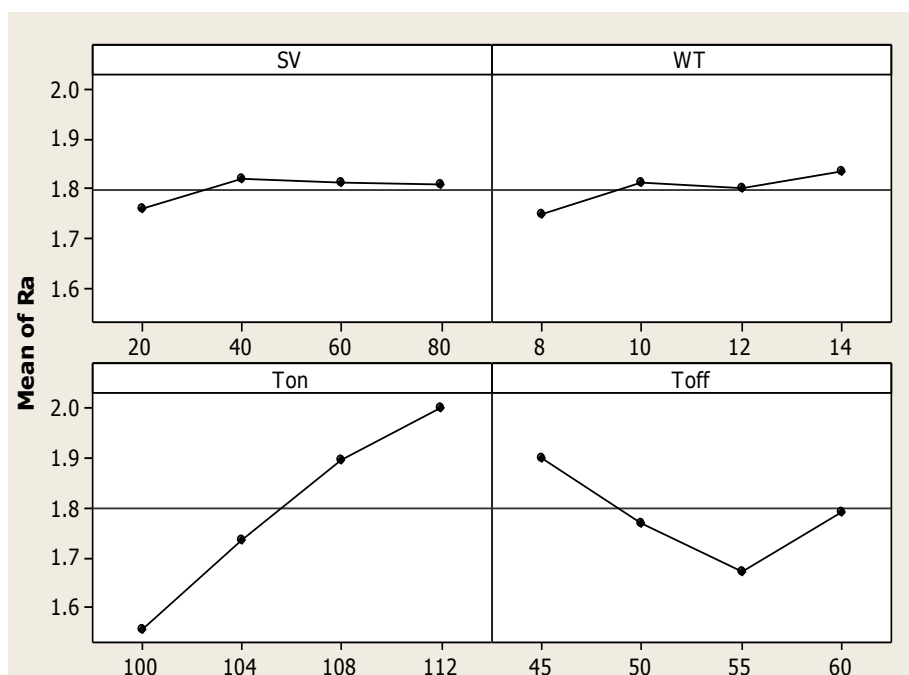
Figure 6.2 Main effect plots for means

SN Ratio for surface roughness:

The median Signal-to-noise ratio (SNR) is shown in Figure 6.3. These charts make it easy to pinpoint the precise settings for these regulators. The graph depicts the variation in SNR between two different control factor settings. At greater SNR values, the response graph showed the best value. Figure 6.3 shows that the best surface roughness is achieved at values of SV2, WT4, Ton4, and Toff1.
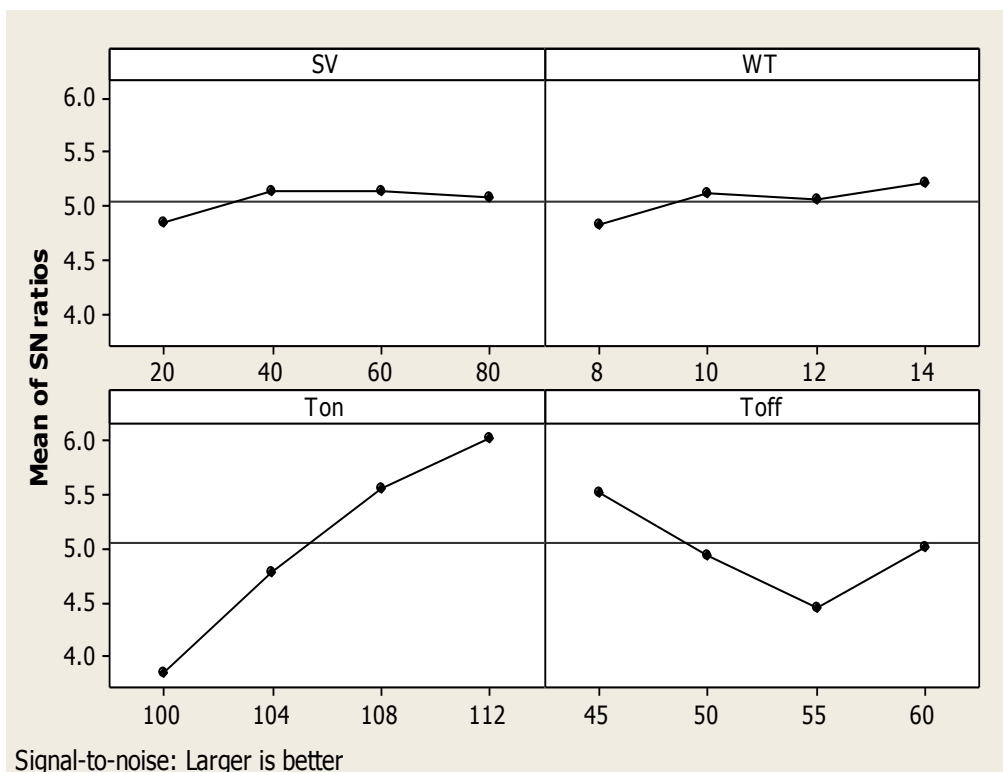
1215

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

Figure 6.3 Main affects plots for SNR means

Table 6.3 Process parameters for optimum surface roughness from SN Ratio

SV	WT	Ton	Toff
40	14	112	45

CONCLUSIONS

In the present work detailed investigation was carried out on surface roughness of the aluminum metal matrix composite. The investigation includes preparing of aluminum metal matrix composite and evaluation of surface roughness according to L16 orthogonal array. The major contributions drawn from the investigation are summarized as below

➢ The aluminum - SiC composites were prepared by the vortex method.
➢ It has been observed from the plot of surface roughness with process parameters that surface roughness increases pulse on time. Surface roughness is drastically decreases up to a point, then increases to point increase of pulse off time. Surface roughness slightly increases to a point and then decreases with servo voltage. Surface roughness is slightly increased up to a point, then decrease to point, and finally increase with increase of Wire tension.
➢ From above Mean effect plot it shows minimum surface roughness values at SV1,WT1,Ton1and Toff3

1216

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

➢ Taguchi method was applied successfully in order to identify the optimized values of surface roughness. Based on the analysis it was identified that the optimum surface roughness will be obtained at SV2, WT4, Ton4 and Toff5 levels.

➢ Based on ANOVA results of tensile strength, it can be observed that the control variables Ton (78.7%), Toff (2.17%) influence the surface roughness, whereas the SV (0.69%) and WT (2.09%) when compared to remaining variables.

SCOPE OF FUTURE EXTENSION

➢ In this project the mathematical model was formulated using the regression analysis. But other techniques like ANFIS, artificial neural networks can also be adopted to develop the mathematical model and thereby calculating the accuracy of the models formed.

➢ This technique can be extended to other manufacturing processes like Abrasive jet machining, laser beam welding, ultrasonic machining etc. Models for other machining processes can also be formulated.

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1217

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218

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1218

Eur. Chem. Bull. 2023,12(Special Issue 4), 1202-1218