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EXPERIMENTAL ANALYSIS ON NICKEL ALUMINIUM ALLOY BY ELECTRIC DISCHARGE MACHINE USING TAGUCHI MODEL

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***Abstract*— Advanced structural ceramics, such as Silicon Carbide (Sic), Silicon Nitride (Si3N4), Alumina (Al2O3) and Zirconia (ZrO2) are attractive materials for many applications ranging from aero engines to dental restoration and is possible due to high hardness and strength, wear resistance, resistance to chemical degradation and low density. Various applications of these ceramic materials demand shaping to a high degree of surface finish and dimensional accuracy. These materials difficult to machine because of high hardness and abrasive nature of reinforcing elements like alumina particles. In this study, homogenized (4%, 6%, and 8%) by weight of alumina aluminum metal matrix composite materials were fabricated and selected as work piece for experimental investigations of surface roughness and metal removal rate.**

Among the machining processes used for shaping advanced ceramics, grinding is the most widely used machining process as it gives reasonably good rate of material removal. However, the high cost of diamond grinding and difficulty in machining complex shapes and 3D surfaces have promoted research into alternative methods of ceramics machining like ultrasonic machining, abrasive water jet machining, electrical discharge machining and laser beam machining.

Electrical-discharge machining (EDM) is an unconventional, non-contact type machining process where metal removal is based on thermal principles. In this process, the material removal mechanism is based on the conversion of electrical energy into thermal energy through a series of discrete electrical discharges that occur between the electrode and work piece immersed in an insulating dielectric liquid. The concentrated heat of spark generates a channel of plasma between the cathode and anode at a temperature in the range of 8000 to 12,000 °C, initializing a substantial amount of heating and melting of material at the surface of each pole. When the direct current supply is turned off and the potential reaches above the breakthrough voltage of dielectric, the plasma channel breaks down.

***Index Terms*— Ni-Al Alloy, EDM, Taguchi Method, Mechanical Properties.**

I. INTRODUCTION

A. Overview of composite materials

Aluminum-based Ni-Al particle reinforced MMC material have become useful engineering materials due to their properties such as low weight, heat-resistant, wear-resistant and low cost. These are found in various engineering applications such as cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames etc. These materials are known as the difficult-to-machine materials, because of the hardness and abrasive nature of reinforcement element like nickel particle. These composites can be produced through a number of routes including melt processing and powder metallurgy. Compared with powder metallurgy, melt processing has some important ad vantages, e.g. better matrix particle bonding, easier control of matrix structure, simplicity, low cost of processing. There are many types of composite materials and several methods of classifying them. One such method is based on geometry and consists of three distinct families: laminar or layered composites, particulate composites, and fiber- reinforced composite.

B. Electro-Discharge Machining (EDM)

Electrical discharge machining (EDM) is a non-traditional manufacturing process where the material is removed by a succession of electrical discharges, which occur between the electrode and the work piece. These are submersed in a dielectric liquid such as kerosene or de- ionized water. The electrical discharge machining process is widely used in the aerospace, automobile and molds industries to machine hard metals and its alloys.

1) Types of EDM

- Die Sinker EDM
- Wire Cut EDM
- Drill EDM
- Disintrigated EDM

2) EDM Basic and Principle

In electrical machining processes, electrical energy is used directly to cut the material to final shape and size. Efforts are made to utilize whole of the energy by apply it at the exact spot where the operation is to be carried out. Another advantage of these methods is that no complicated fixtures are needed for holing the job and even very thin jobs can be machined to the desired dimensions and shape.

3) Die Sinking EDM

In the Die -Sinker EDM Machining process, two metal parts submerged in an insulating liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two parts are brought together to within a minimum Gap, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consists of an electrode and work piece submerged in an insulating liquid such as, oil or, less frequently, other dielectric fluids.

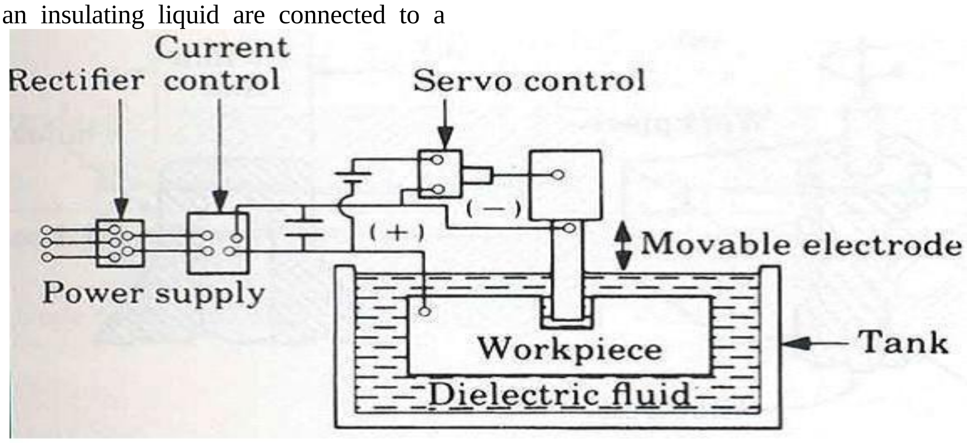

Fig.1.1:- Sinker EDM Set-up

Die-sink electric discharge (ED) machining is a machining method with which it is possible

i. To produce relatively sharp internal corners and deep narrow shapes with drafted walls.
ii. Machine hardened steel and other difficult materials.

For a long time ED machining was the only possible method for hardened steels. High speed technologies have improved the potentials of a milling method, but the shape depth still sets certain limits: The deeper the shape, the larger cutter diameter must be selected because of the cutting force and vibrations caused by the rotating movement. Die-sink ED machining technology does not set this kind of limit, because there are table mechanical stresses on the cutting tool.

The basic elements in the die-sink ED machining method are: electrode, die electric medium and work piece. The ED machine moves electrode and/or work piece three dimensionally and in some machine types rotationally. (See images) The three dimensional axes are named as X, Y and Z and the rotational axis as C.

Fig. 2:- Die Sinking EDM Experimental set up

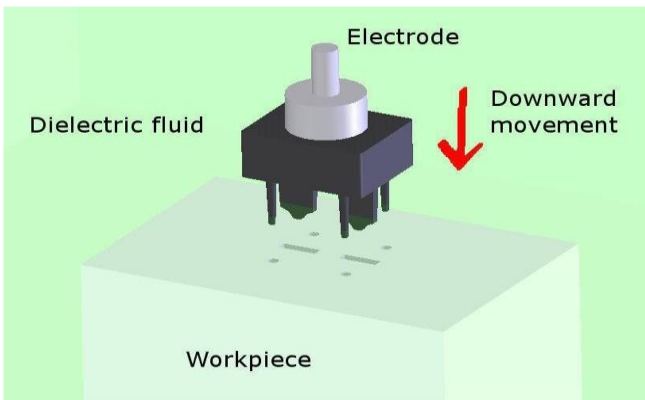

Fig. 3: -The simplest configuration of movement of electrode

The electrode moves with a slow downward movement. The aim is to produce deep small radius holes and grooves to the work piece. Work piece is in fixed position. The electric discharge machining process is rather simple. The EDM produces scraped and regular changes in electric potential between the electrode and the work piece. Depending on the electrode and the work piece materials either one can be set as positive pole. The change in potential causes the liquid medium to change from an insulator to a conductor and a spark occurs between the Electrode and the work piece at the moment the electrode is near enough to the work piece. The spark causes the work piece surface to melt in a very small round area. The work piece surface will become pitted. (See image.) There is a servo system in the electric discharge machine, which prevents the electrode to touch the work piece. Touching would short circuit the system and no machining would take place. Between the sparks the work piece surface cools down. The melted work piece material forms a round chip, which is flushed away with the dielectric fluid.

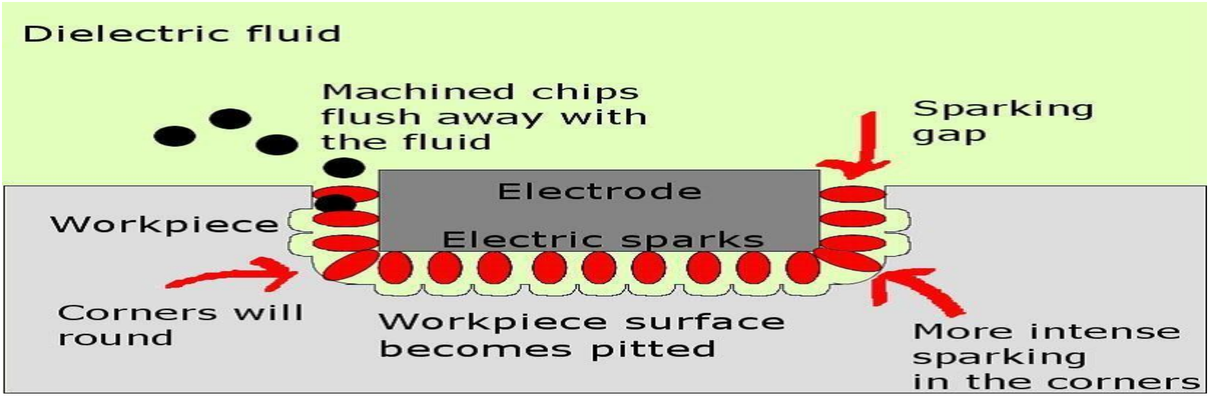

Fig. 4:- Spark generation mechanism

C. EDM tool material

Rate of material removal is very slow. Tool material used is any conducting material generally brass or copper or aluminum of copper or cast iron. These materials can be easily shaped to the required profile. Where high accuracy and long electrode life are required higher melting point materials such as copper-tungsten, graphite or tungsten carbide are used. As the tool does not come into contact with the work, life of tool is long and less wear and tear takes place.

The selection of proper tool material is influenced by:

- Size of electrode and volume of material to be removed,
- Surface finish required
- Tolerances desired,
- Nature of coolant application etc.

II. LITRATURE REVIEW

The review presented in this section is based on current EDM research trends. Few researches have been investigated in areas discussed.

Lokesh Upadhyay et al. [1] have been concluded that microstructure of MMC's indicates the homogenous mixture of the alumina in the composite. Surface roughness increases with the process variables except the speed, speed made adverse effect on surface roughness. MRR increases with the process parameters except the concentration of reinforced particles due to presence of hard ceramic particles.

Lokesh Upadhyay et al. [2] have studied surface finish increases as the cutting speed icreases. With increase in reinforcement ratio the hardness and tensile strength of composite material found to be increased.

Pradhan et al. [3] have studied three different parameters namely pulse current, discharge time and pulse time and pause time for EDM process of AISI D2 steel using response surface method. It was found that all the three machining parameters and some of their interactions have significant effect on MRR.

Ryota Toshimitsu et al. [4] have studied a new EDM surface finishing method using chromium powder mixed fluid was proposed and the finished surface characteristics were experimentally discussed.

Syed, Palaniyandi et al [5] worked on addition of aluminium metal powered I distilled water resulted in high MRR, good surface finish and minimum white layer thickness when compared with pure distilled water.

Singh et al [6] investigated that negative polarity of tool electrode is desirable lowering of surface roughness and addition of powder particles I dielectric fluid decreases surface roughness of specimen in EDM process.

Rozeek et al. [7] was found that application of powder I the dielectric lead to reduce surface roughness. The investigation result showed that there were chances for replacing the convetioal dielectric powder suspended deionized water and that would imply considerable economic and ecology advantages.

Biswas et al. [8] investigated that surface roughness is directly proportional to linear effect of pulse current and pulse on time.

Singh et al. [9] concluded that dry EDM have several advantages such as low tool electrode wear ratio, better surface roughness and waste from the dielectric liquid as in case of EDM with oil.

III. METHODOLOGY

The recent advancement in various technological field demands the development and use of new materials, which can sustain external loads at extremely high temperatures and corrosive environments. The use of thermoelectric source of energy in developing the nontraditional techniques has greatly helped in achieving an economic machining of extremely low machinability materials and jobs with complex geometries. There are many processes in which metal removal is based on thermal principles and Electrical Discharge Machining (EDM) is one of them EDM is a process that is based on removing material from a conducting work piece by means of a series of repeated electrical discharges between tool electrode (cathode) and the work piece (anode) in the presence of a dielectric fluid. The electrode is moved towards the work piece by servo controlled feed until the gap is small enough in the range of 10 - 100 μm so that the applied voltage ionizes the dielectric. Short duration discharges are generated in a liquid dielectric gap. The material is removed with the erosive effect of the electrical discharges from tool and work piece. Thermal energy generates a channel of plasma between the cathode and anode at a temperature in the range of 8000 to 20000°C initializing a substantial amount of heating and melting of material at the surface of each pole. When the pulsating direct current supply of approximately 20000–30000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the pole surfaces in the form of microscopic debris. EDM does not make direct contact between the electrode and the work piece whereby it can eliminate mechanical stresses chatter and vibration problems during machining. Although this does not mean that induced stresses and metallurgical effects on the work piece are necessarily absent.

A. Selection of Work Piece and Tool Material

The manufacturing of the composite material we select two materials. The Al 2024 alloy is used as base metal and nickel is used as reinforcement material for manufacturing. The range of particle size of nickel is 16-30 µm and average particle size is 25µm.The general properties of aluminum are non-toxic, impervious, non-magnetic, non-sparking, easily machined, low density, corrosion resistant, electricity conductor, and non-magnetic, malleable and other physical properties given in table 1.

Nickel is the most cost effective and widely used material in the family of engineering ceramics. It has many desirable characteristics like hard, wear resistant, good thermal conductivity, high strength and stiffness, excellent size and shape capability and other physical properties are given in table 1.

Table 1:- Physical properties of Nickel

Properties	Units of Measure	Values
Density	gm/cc^3	8.9
Color	—	Silvery White
Elastic Modulus	GPa	300
Hardness	Kg/mm^2	1175
Melting point	°C	1453
Thermal Conductivity	W/m-°K	18
Coefficient of Thermal Expansion	10^{-6}/°C	8.1
Specific Heat	J/Kg-K	880
Maximum Use Temperature (no load)	°C	2700

The copper has chosen as tool material of 8 mm diameter for Electric discharge machining.

B. Manufacturing of Ni-Al composite

The Ni-Al reinforced Al composite was produced by sand casting in foundry shop. The dimensions of final product were 45mm in diameter and 300mm length. In order to obtain matrix material at the beginning phase of the production, 99.9% pure aluminum was melted in the crucible at 700°C in muffle furnace. Then the nickel was added in the crucible and steered continuously. In order to increase wetting capability of reinforcement, 2% of Mg was added. In our experiment three types of nickel particles reinforced metal matrix composites were casted. In the first type 15% by weight nickel and remaining aluminum and could able to mix 4% by weight alumina in the final cast product.

In type second 20% by weight nickel and remaining aluminum and could able to mix 6% by weight nickel in the final cast product. In third type 25% by weight nickel and remaining aluminum and could able to mix 8% by weight nickel in the final cast product. The dimension of work piece was 30 mm x 30 mm x 10 mm.

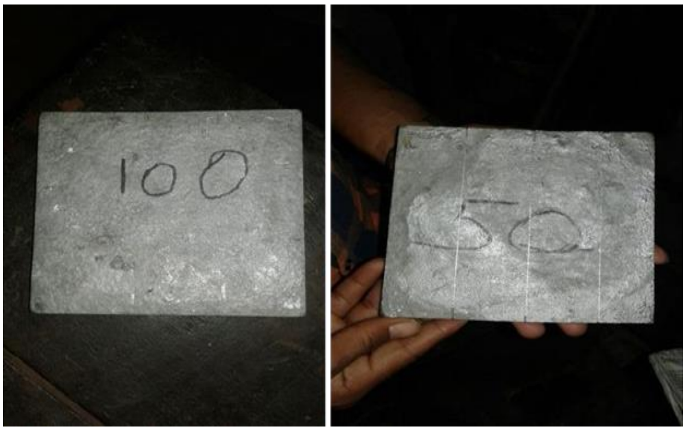

Fig 3.1:- Work piece of composite

1) Characterization of work piece material

Hardness, tensile strength and scanning electron microscope images have been characterized of work piece material. Hardness of composite is tested on the Rockwell hardness testing machine .The model of machine is Fine Engineering industries, S No. NR S. and pressure imposed capacity is 50kgf, 100kgf, 150kgf.

We had applied 100kgf at B scale 1/16’’ ball penetration, of pressure on our three specimens of 15%, 20% &25% by weight in nickel particles reinforced aluminum metal matrix composite. Tensile strength of composite specimen is measured by universal testing machine. The maximum capacity of our UTM is 40,000 Kgf. When the composite specimens obtained from casting, their microstructure of 4%, 6%, and 8% will examined with the scanning electron microscope (SEM). The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern.

2) Hardness

The hardness of the work piece material for 15%, 20% and 25% reinforcement of Nickel given in table 2 and tensile strength is given in table 3.

Hardness Value (HRB)				
S.NO	Trail no.	Percent of Nickel by weight		
		15%	20%	25%
1	Trial-1	97	111	118
2	Trial-2	98	113	121
3	Mean	97.5	112	119.5

Table 2: Hardness of Composite

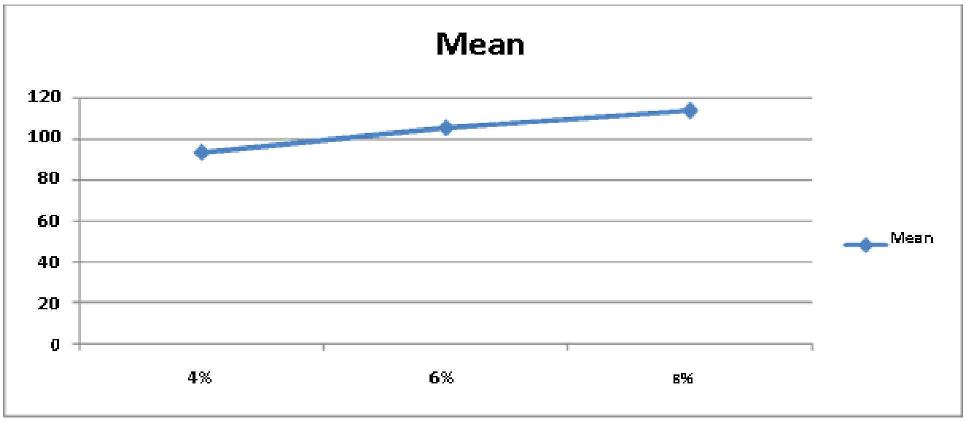

Fig 3.2:- Hardness Vs. reinforcement ratio curve

From main effect plot of hardness (figure 3.1), it has been observed that hardness of composite increases with increasing the reinforcement ratio. This is due to the fact that alumina is very hard and brittle material, so reinforcement of alumina increases the hardness of the composite material.

3) Tensile strength

Tensile Strength (Kgf)				
S.NO	Trail no.	Percent of Nickel by weight		
		15%	20%	25%
1	Trial-1	1270	1440	1800
2	Trial-2	1290	1455	1795
3	Mean	1280	1447.5	1977.5

Table 3 Tensile Strength Of Composite

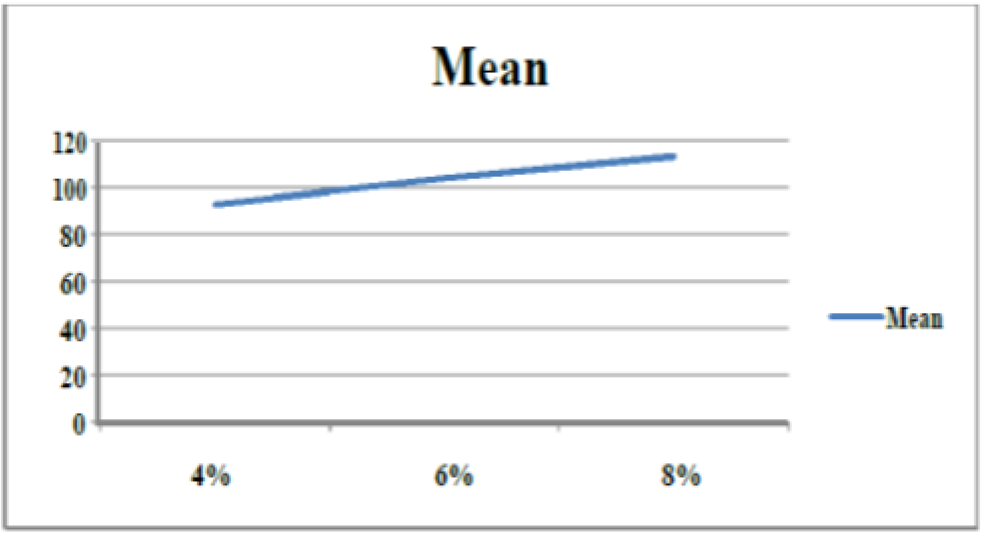

Fig 3.3:- Tensile Strength Vs. Reinforcement Ratio Curve

From main effect plot of hardness (figure 3.1), it has been observed that hardness of composite increases with increasing the reinforcement ratio. This is due to the fact that alumina is very hard and brittle material, so reinforcement of alumina increases the hardness of the composite material.

IV. RESULT & DISCUSSION

A. Experimentation on EDM with EDM oil as Di-Electric fluid Medium

Die sinking EDM experiments have been carried out on EDM machine (Model Spark nix, India). In all the experiment, Nickel reinforced aluminum composites of 8% composition of Nickel powder used because its tensile strength and hardness value was better than other two composites. In all the experiments, EDM oil has been used as dielectric medium. Total 18 experiments have been performed using CCRD with independent variables at 5 different levels. Machining time for each work piece in the experiments has been kept 60 minutes.

After EDM, Nickel reinforced aluminum composites (8%) samples have been cleaned with acetone. A high precision electronic weighing balance with least count 0.01 mg has been used to measure the weight loss of work piece and electrodes after each experiment. The surface finish after machining was measured using Talysurf 6 (Rank Taylor Hobson, England). A traverse length of 3 mm with a cut-off evaluation length of 2 mm was used. The Centre line average value of the surface roughness (SR) is the most widely used surface roughness parameter in industry, was selected in this study. Each sample was measured three times and the average was taken as the response. Measurement of out of roundness of the electrode was performed before and after machining so as to determine the actual change in the shape of the electrode. This measurement was performed on Carl Zeiss Coordinate Measuring Machine and Calypso software. The change in roundness of the tool has been considered as the response in the study to represent the shape of the tool.

MRR has been defined, as the ratio of the wear weight of work piece to the machining time.

$$\textbf{MRR} = \frac{\textbf{Initial Volume} - \textbf{Final Volume}}{\textbf{Time taken during turning}}$$

Table 4: Design for Experiments

Exp. No	IP	TON	DC	%Ni	MMR	SR
1	4	270	0.75	15	.0266	1.3945
2	4	320	0.78	20	.0385	1.2435
3	4	370	0.81	25	.0695	1.5898
4	5	270	0.78	25	.0573	1.896
5	5	320	0.81	15	.0411	0.9578
6	5	370	0.75	20	.1120	1.7356
7	6	270	0.81	20	.1266	1.9486
8	6	320	0.75	25	.1130	2.0236
9	6	370	0.78	15	.1331	2.0856

B. Analyzing Experimental data for MRR

Conducting three trails for each experiment, the data below was collected. Compute the SN ratio for each experiment for the target value case, create a response chart, and determine the parameters that have the highest and lowest effect on the processor yield.

Exp. No.	IP	TON	DC	%AL2O3	TRIAL 1	TRAIL 2	MEAN
1	4	270	0.75	15	0.0276	0.0257	0.0266
2	4	320	0.78	20	0.0425	0.0346	0.0385
3	4	370	0.81	25	0.0612	0.0781	0.0696
4	5	270	0.78	25	0.0339	0.0807	0.0573
5	5	320	0.81	15	0.0459	0.0363	0.0411
6	5	370	0.75	20	0.0857	0.1384	0.1120
7	6	270	0.81	20	0.1176	0.1357	0.1266
8	6	320	0.75	25	0.0625	0.1636	0.1130
9	6	370	0.78	15	0.1538	0.1125	0.1331

Shown below is the calculation and tabulation of the SN ratio.

$Sm1 = (0.0269+0.0257)^2 \div 2 = 0.001383$

$St1 = (0.0269)^2 + (0.0257)^2 = .6677$

$Se1 = St1 - Sm1 = .6535$ $Ve1 = Se1 / (N-1) = .06535$

SN1= 10log (1/N)(Sm1-Ve1)

Ve1

SN1 = .00418

Similarly, SN2 = .00147

SN3 = .00478

SN5 = .00166

SN6 = .01186

SN7 = .01596

SN8 = .01022

SN9 = .01729

Exp. No.	IP	TON	DC	%Ni	TRIAL 1	TRAIL 2	MEAN	SN
1	1	1	1	1	0.0276	0.0257	0.02665	.00418
2	1	2	2	2	0.0425	0.0346	0.03855	.00147
3	1	3	3	3	0.0612	0.0781	0.06965	.00478
4	2	1	2	3	0.0339	0.0807	0.0573	.00273
5	2	2	3	1	0.0459	0.0363	0.0411	.00166
6	2	3	1	2	0.0857	0.1384	0.1120	.01186
7	3	1	3	2	0.1157	0.1357	0.1266	.01596
8	3	2	1	3	0.0625	0.1636	0.1130	.01022
9	3	3	2	1	0.1538	0.1125	0.1331	.01729

Shown below is the response table. This table was created by calculating an average SN value for each factor.

Exp. No.	IP	TON	DC	%Ni	SN
1	1	1	1	1	.00418
2	1	2	2	2	.00147
3	1	3	3	3	.00478
4	2	1	2	3	.00273
5	2	2	3	1	.00166
6	2	3	1	2	.01186
7	3	1	3	2	.01596
8	3	2	1	3	.01022
9	3	3	2	1	.01729

A sample calculation is shown for Factor IP (Discharge current).

SN1= (.00418+.00147+.00478)/3 = .003476
SN2= (.00273+.00166+.01186)/3 = .00541 SN3= (.01596+.01022+.01729)/3 =.01449

The effect of this factor is then calculated by determining the range:
=Max-Min=.01449-.00347=.01102

Table:-Confirmation Experiment of MRR

LEVEL	%Ni	DC	TON	IP
1	17.28	13.65	16.25	.00347
2	16.07	17.89	13.14	.00541
3	14.69	16.50	18.65	.01449
	2.58	4.24	5.51	.01102
Rank	4	3	2	1

It can be seen that % Ni has the largest effect on the processor yield and that impulse current has the smallest effect on the processor yield. Due to increases the %Ni and material removal rate increases. Due to the vibrational effect of tool and on increases the %Ni the abrasive particle provide better effect.

C. Analyzing Experimental data for SR

Conducting three trails for each experiment, the data below was collected. Compute the SN ratio for each experiment for the target value case, create a response chart, and determine the parameters that have the highest and lowest effect on the processor yield.

Exp. No.	IP	TON	DC	%Ni	TRIAL 1	TRAIL 2	MEAN
1	4	270	0.75	15	1.494	1.140	1.317
2	4	320	0.78	20	1.163	1.237	1.200
3	4	370	0.81	25	1.869	1.719	1.794
4	5	270	0.78	25	1.475	1.595	1.535
5	5	320	0.81	15	1.697	1.877	1.787
6	5	370	0.75	20	1.125	0.965	1.045
7	6	270	0.81	20	1.866	1.910	1.888
8	6	320	0.75	25	1.023	1.303	1.163
9	6	370	0.78	15	1.754	1.785	1.769

Shown below is the calculation and tabulation of the SN ratio.

Sm1 = $(1.494+1.140)^2 \div 2 = 3.4689$

St1 = $1.494^2+1.140^2 = 3.5316$

Se1= St1─ Sm1 = .06273 Ve1 = Se1 / (N-1) = 0.06273

SN1= 10 log (1/N)(Sm1-Ve1)

Ve1

SN1 = 10.25

Similarly, SN2 = 12.45

SN3 = 24.88

SN4 = 9.33

SN5 = 17.93

SN6 = 15.96

SN7 = 16.19

SN8 = 10.53

SN9 = 19.49

Exp. No.	IP	TON	DC	%Ni	TRIAL 1	TRAIL 2	MEAN	SN
1	1	1	1	1	1.494	1.140	1.317	10.25
2	1	2	2	2	1.163	0.237	1.200	12.45
3	1	3	3	3	1.863	1.719	1.794	24.88
4	2	1	2	3	0. 475	0.595	0.535	9.33
5	2	2	3	1	1.697	1.877	1.787	17.93
6	2	3	1	2	1.125	0.965	1.045	15.96
7	3	1	3	2	1.866	1.910	1.888	16.19
8	3	2	1	3	1.023	1.303	1.163	10.53
9	3	3	2	1	1.754	1.785	1.769	19.49

Shown below is the response table. This table was created by calculating an average SN value for each factor.

Exp. No.	IP	TON	DC	%Ni	SN
1	1	1	1	1	10.25
2	1	2	2	2	12.45
3	1	3	3	3	24.88
4	2	1	2	3	9.33
5	2	2	3	1	17.93
6	2	3	1	2	15.96
7	3	1	3	2	16.19
8	3	2	1	3	10.53
9	3	3	2	1	19.49

A sample calculation is shown for Factor IP (Discharge current).

SN1= (10.25+12.45=24.88)/3 =18.36
SN2= (9.33+17.93+15.96)/3 = 14.40 SN3= (16.19+10.53+19.49)/3 = 15.40

The effect of this factor is then calculated by determining the range:
=Max-Min=18.36-14.40= 3.96

Table: Confirmation Experiment of SR

LEVEL	%Ni	IP	DC	TON
1	18.39	18.36	14.34	14.42
2	14.86	14.40	13.75	13.63
3	14.91	15.40	19.66	20.11
	3.53	3.96	5.91	6.48
Rank	4	3	2	1

It can be seen that %Ni has the largest effect on the processor yield and that Pulse ON Time has the smallest effect on the processor yield. Due to the increase of abrasive particle provide better cleaning cutting of piece.

V. CONCLUSION

In this work, EDM has been successfully performed on nickel reinforced aluminum composite material. Statistical models have been developed for predicting MRR and SR in EDM by correlating the input parameters, namely, discharge current, pulse-on time, duty cycle, and % of Ni. In EDM process, significant parameters have been identified and Taguchi was used to establish the adequacy of the model.

It has been observed that MRR is significantly affected by discharge current, pulse-on time and duty cycle. It has been found that MRR increases with the increase in discharge current. It is also observed that MRR decreases with the increase in pulse-on time initially but after a certain value of pulse-on time, MRR increases. MRR is found to be increasing with an increase in the duty cycle. The second order model developed for SR is statistically significant. It has been observed that discharge current and pulse-on time are significant parameters affecting SR. It has been observed that SR increases with increase in discharge current. An increase in pulse-on time increases the SR.

VI. SCOPE FOR THE FUTURE WORK

The work presented in this thesis may be extended further in the following ways:

In place of Nickel reinforced Aluminum composite, investigate another composite such as AL Sic, Silicon Carbide (Sic), Silicon Nitride (Si_3N_4), etc. on EDM with different types of di- electric fluids.

We use dielectric fluid in place of Silicon oil and the MRR because due to the abrasive particle it provides better cleaning of cutting pieces. This process we will study in our future investigation.

We also think how to improve the MRR then we decided to design and construct the Rotational types electrode holder, this types of holder arrangement we are construct and also check it

.at the same times the MRR is increases more due to vibrational effect .and surface finishing is not affected more but it is also maintained that.

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