Surface Evaluation of 316L Stainless Steel with HAp mixed EDM

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Abstract: In this work, the impact of processing parameters on HAp mixed electric discharge machining (NPMEDM) of 316L stainless steel is examined. A commercial grade electrode of copper tungsten with reverse polarity is used. The responses were analyzed using an orthogonal array L18 experimental design in terms of material removal rate, tool wear rate and surface roughness. It was revealed that current is the most important variable boosting material removal rate (0.33 mg/min) with pulse on time (200), pulse off time (60) and voltage (80). Due to the copper tungsten electrode's low wear rate, there was little tool wear. The use of x-ray diffraction methods was used to examine the surface morphology of machined samples. The stability of the machining process and the mechanism for material transfer were found to be improved by adding nano powder to the dielectric.

1. Introduction

In contrast to the conventional structural materials, there has been a significant development in novel materials in recent years that have a variety of mechanical and thermal properties. Conventional machining techniques have proven less effective in processing these more difficult materials, leading to the development of a number of non-traditional machining technologies. This investigation on copper electrode performance when EDMing AISI H13 tool steel is being done. Peak current, pulse ON/OFF time, and pulse duration are the variables taken into account. According to the results, putting the peak current at a low level produced the best surface roughness, while a high peak current produced the best MRR. and low pulse-OFF time, medium pulse-ON time, and vice versa. [1]
Using Taguchi approach, cutting Tungsten Carbide ceramic by electro-discharge machining (EDM) with a graphite electrode demonstrates that, in general, the peak current has a considerable impact on the EWR and SR, but the pulse duration mostly influences the MRR [2].Researcher focused on the rate of electrode wear, machining polarity, peak current, auxiliary current at high voltage, pulse duration, and no load voltage. [3]
A study looks into the viability of employing graphite nanopowder-mixed dielectric to enhance surface properties when micro-EDMing cemented tungsten carbide. The surface finish, MRR, and EWR can all be greatly improved with the use of nanopowders. [4]
In the current study, the effect of tungsten powder mixed in with the dielectric medium on three die steel materials' responses to surface modification by EDM was examined. The fact that tungsten carbide (WC and W2C) is present suggests that it is forming in the plasma channel. For all three die steels, the identical machining parameters gave the best micro-hardness value. [5]
The output characteristics of EDM, including material removal rate, electrode wear, and surface roughness, rise as the pulsed current does. According to the findings, copper electrodes successfully removed large amounts of material at high rates, whereas copper-tungsten electrodes produced less electrode wear, a smooth surface finish, and good dimensional accuracy [6].An investigation on the hybrid ED machining procedure carried out in a magnetic field to enhance process performance. Results indicate a reduction in Recast layer development at higher spark energies in a magnetic field environment and an improvement of 12.9% MRR [7].
The numerous research projects on Ti alloy surface modification by electric discharge machining are reviewed in this article. Additionally, machining performance for surface modification has been introduced, with a focus on biocompatibility and surface quality of biomaterials [8]. The purpose of this study is to add Ti nanopowder to AISI D2 steel that has been surface-machined using EDM to improve its properties. The properties of the machined surface, including surface roughness, surface morphology, and surface micro-defects, were revealed using a surface roughness profilometer, FESEM, and AFM analysis. With the exception of Ton = 340 s, the greatest improvement was seen for these machining parameters [9].
Low material removal rates (MRR), high tool wear, and poor surface quality all hinder electrical discharge machining. Powder mixed electrical discharge machining is used to get around this problem. When compared to no-powder machining, a 20 g/l powder concentration enhanced the MRR by 42.1% [10]. It was discovered that the spark energy of EDM and the matrix phase reinforcement structures have a substantial impact on this layer's creation [11].
According to the experimental findings, machining in a magnetic field with more spark energy had a noticeable impact on MER and surface finish as well as a decrease in microhardness values and a reduction in recast layer thickness [12]. Traditional Electrical Discharge Machining was used in the process of machining in a magnetic field (EDM). According to the experimental findings, the recast layer's thickness and microhardness values decreased, and there was a considerable impact on the MER and surface finish[13].
One such material, Inconel 825, has use in the nuclear power industry as well as petrochemical, chemical, missile, and very corrosive environments. Peak current (IP), pulse on time (TON), and gap voltage have been discovered to have a significant impact on MRR, SR, and TWR (GV) [14]. Electrical discharge machining (PMEDM) is a practical advanced machining technique for treating conductive materials that are challenging to cut. Current, pulse on time, and gap voltage are found to have the greatest effects on MRR, SR, and TWR [15].
Using a graphite electrode with reverse polarity, MWCNTs mixed hydrocarbon oil was employed as the dielectric medium to manufacture Ti-6Al-4V alloy. Material erosion rate, electrode wear, and surface integrity were evaluated as the output responses [16]. The current paper concentrated the alloy of duplex stainless steel (DSS-2205) that was machined using an electric discharge and had three different types of electrode material (Electrodes made of graphite, copper-tungsten, and tungsten). High spark energies in EDM oil revealed porosity, oxide production, and intermetallic compounds on the machined surface. It is applicable to a variety of biomedical and commercial applications. [17]

Comparing EDM treated samples to bare metal, the corrosion resistance showed a noticeable improvement. The electrode (28.27%) and current (67.24%) had the biggest effects on the surface roughness of the machined Co-Cr alloy (1.080 m) [18]. The performance of copper and tungsten electrodes for the edm of SUS-316L was investigated. It was discovered that the two variables most strongly influencing each of the three responses were the current and electrode [19].

Edm was used in the current work to modify the surface of duplex stainless steel (DSS 2205). The maximum MRR (0.271 mg/min), which was measured using 16 Amp discharge current, 150 s pulse on time, 60 s pulse off time, and 80 V voltage [20]. The objective of this study is to ascertain the effects of 316L when used in HAp powder mixed EDM. XRD technique was also used to investigate the altered morphology of the machined samples.

2. Experimental Methodology

2.1 Material

From Rexton Steel and Alloys, Mumbai, Maharashtra, a rectangular block of 316L stainless steel measuring 100 mm x 80 mm x 5 mm was purchased. The tool for the current experiment was a copper tungsten electrode with a 10 mm diameter. To improve the machining properties, Hydroxyapite Nanoparticles (HAp; particle size <50nm; obtained from Nano Research Lab, Jamshedpur, Jharkhand) was combined with dielectric medium. The chemical composition of 316L stainless steel is presented in (Table 1).

Table 1: Showing the Composition of Duplex Stainless Steel (DSS 2205)

Grade		C	Mn	Si	P	S	Cr	Mo	Ni
316L	Min	-	-	-	-	-	16	2	10
	Max	0.03	2	0.75	0.045	0.03	18	3	14

2.2 Method

Using the Minitab 18 software and the Taguchi L18 orthogonal array, the design of experiment was created to reduce the number of experimental runs. Through experiments, the impact of a number of machining factors, including discharge current, pulse-on time, pulse-off time, and voltage, each with three levels was determined. Minitab was used for the analysis of the output replies. The chosen machining variables utilized for experimentation are shown in (Table 2).

Table 2: Experimental Machining Parameters

Input Parameters	Discharge Current	Pulse-on time	Pulse-off time	Voltage
	Amp (I)	(µs)	(µs)	(V)
Level I	5	60	60	40
Level II	10	150	150	60
Level III	16	200	200	80

2.3 Experimentation

The full experiment was carried out in order to calculate the output responses, including MRR, TWR, and surface integrity of the machined work piece. Each experiment combination was run twice to ensure accuracy, and the average of the findings was displayed. A locally constructed powder mixed EDM system (Figure 1) with a stirrer and pump was used for effective mixing and flushing of powder particles. Each run's machining duration (40 minutes) and cut depth (1.0 mm) were kept constant by using reverse polarity. Using a digital weighing balance, the work piece's initial and ending weights were calculated (Citizen, model CY220). A digital weighing balance was used to determine the work piece's initial and final weights (Citizen, model CY220). The roughness of the surface was measured with an SJ-400 (Mitutoyo, Germany) roughness tester.

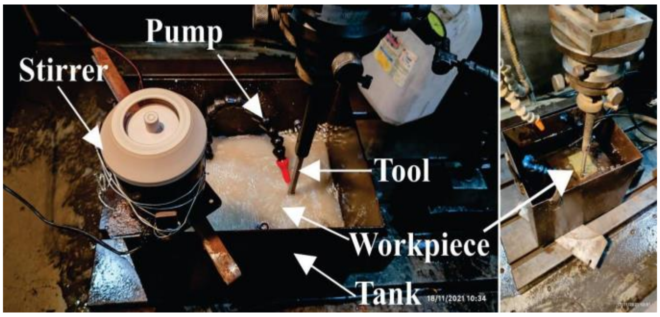

Fig. 1: Setup for the experiment on powder mixed EDM machining.

3 Results and Discussion

(Table 3) presented the average responses from the L18 orthogonal array. The findings show that surface roughness (SR) and material removal rate (MRR) both increased when applied current intensity increased. It was found that the tungsten electrode's calculated tool wear was negligible.

Table 3: Design and results of the experiment.

Exp. N.	Dielectric used	Current (I)	Pulse on Time	Pulse Off Time	Voltage (V)	Avg. MRR	Avg. TWR	Avg. SR
1	EDM Oil as Dielectric	5	60	60	40	0.03049	0.00118	1.73667
2	EDM Oil as Dielectric	5	150	150	60	0.03461	0.00000	1.67667
3	EDM Oil as Dielectric	5	200	200	80	0.01840	0.00015	1.35167
4	EDM Oil as Dielectric	10	60	60	60	0.09831	0.00228	2.49333
5	EDM Oil as Dielectric	10	150	150	80	0.08817	0.00192	2.14667
6	EDM Oil as Dielectric	10	200	200	40	0.12769	0.00189	2.84333
7	EDM Oil as Dielectric	16	60	150	40	0.11418	0.00421	2.78500
8	EDM Oil as Dielectri	16	150	200	60	0.17196	0.00243	3.19333

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9	EDM Oil as Dielectric	16	200	60	80	**0.33337**	0.00227	2.61500
10	HAp mixed EDM Oil	5	60	200	80	0.01163	0.00063	1.85833
11	HAp mixed EDM Oil	5	150	60	40	0.05600	0.00081	1.46500
12	HAp mixed EDM Oil	5	200	150	60	0.02606	0.00038	**1.32500**
13	HAp mixed EDM Oil	10	60	150	80	0.03482	0.00076	2.31667
14	HAp mixed EDM Oil	10	150	200	40	0.07661	0.00060	3.03333
15	HAp mixed EDM Oil	10	200	60	60	0.19275	0.00268	2.29333
16	HAp mixed EDM Oil	16	60	200	60	0.07832	0.00298	2.57667
17	HAp mixed EDM Oil	16	150	60	80	0.30482	0.00680	3.52500
18	HAp mixed EDM Oil	16	200	150	40	0.25014	0.00166	3.11500

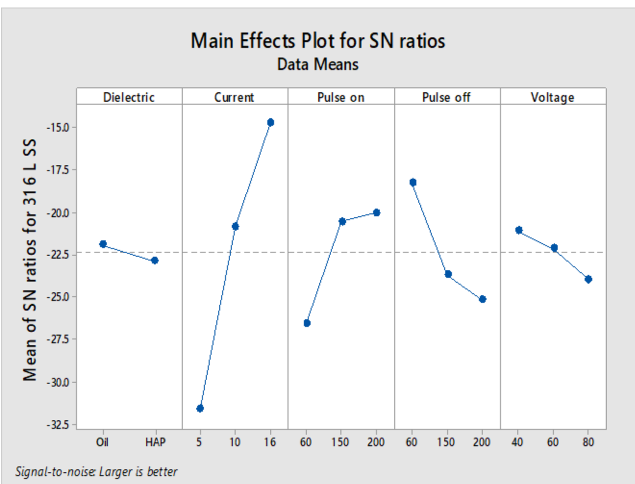

Fig. 2: SN Ration for MRR from Minitab

3.1 Influence of machining factors on MRR of DSS 2205

The S/N ratio plot for MRR is generated with Minitab software and Taguchi's approach under the "Larger is better" condition is shown in Figure 2. Increases in discharge current result in higher S/N ratios for material removal rates. The amount of metal removed rises with current because more heat energy is being transmitted to the area between the electrode and the work piece. Peak current, followed by pulse-on time and pulse-off time, was the factor that had the greatest impact on MRR, according to the plot (Figure 2).

Table 4: Analysis of Variance for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Dielectric	1	0.000011	0.01%	0.000011	0.000011	0.01	0.925
Current	2	0.097450	58.47%	0.097450	0.048725	42.04	0.000
Pulse on	2	0.028707	17.22%	0.028707	0.014354	12.38	0.004
Pulse off	2	0.028052	16.83%	0.028052	0.014026	12.10	0.004
Voltage	2	0.003175	1.90%	0.003175	0.001587	1.37	0.308
Error	8	0.009273	5.56%	0.009273	0.001159		
Total	17	0.166668	100.00%				

3.2 Influence of machining factors on Surface roughness of DSS 2205

The influence of input machining process parameters on surface roughness is seen in (Figure 3). S/N ratios were chosen to calculate surface roughness using the smaller-is-better principle. The surface roughness of the work piece rises with an increase in discharge current and pulse-on time values, proving that the relationship between surface finish and spark energy is inverse. A forceful explosion results from intense energy being applied to the gap between the electrode and the work piece due to greater machining factors. This causes deep craters to develop on the surface, which raises the surface roughness.

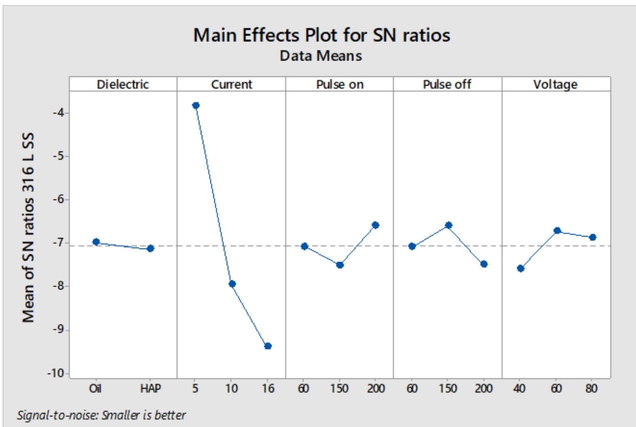

Fig. 3: SN Ration for SR from Minitab

Table 5: Analysis of Variance (ANOVA) for SR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Dielectric	1	0.02469	0.32%	0.02469	0.02469	0.22	0.655
Current	2	6.13036	79.97%	6.13036	3.06518	26.73	0.000
Pulse	2	0.217	2.83%	0.217	0.108	0.95	0.427

on		29		29	65		
Pulse off	2	0.185 46	2.42%	0.185 46	0.092 73	0.81	0.479
Voltag e	2	0.191 04	2.49%	0.191 04	0.095 52	0.83	0.469
Error	8	0.917 26	11.97%	0.917 26	0.114 66		
Total	1 7	7.666 09	100.00%				

The most crucial factor for a good surface finish, according to (Figure 3), was voltage, followed by the dielectric medium and pulse-off duration. A higher degree of provided voltage in conjunction with mixed HAp dielectric produces good surface quality when machining 316L stainless steel using a tungsten electrode.

3.3 Surface morphology of machined surface

The machined zone's XRD phase generation pattern in EDM oil and powder-mixed EDM oil is shown in Figure 5.

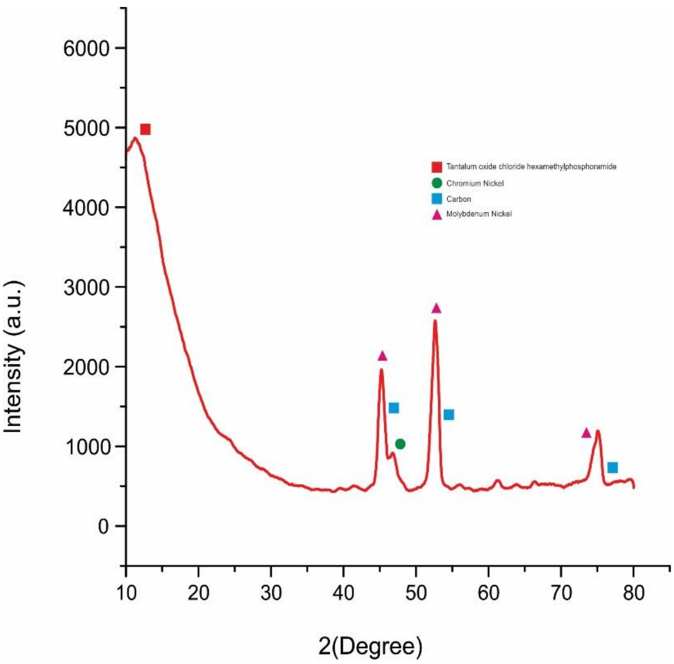

Fig. 5: XRD Analysis (Pattern 1)

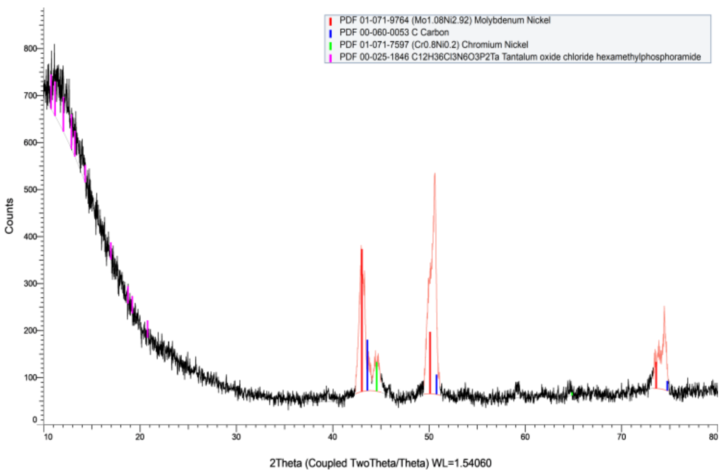

Fig. 6: XRD Analysis (Pattern 2)

From the findings, it was evident that several intermetallic compounds were created on the surface during the machining of 316L stainless steel powder mixed dielectric. On the matrix, some significant peaks on the XRD pattern were seen for the elements carbon, chromium nickel and molybdenum nickel. Carbides are created during the machining process as a result of the injection of broken carbon particles from the EDM fluid. HAp nanopowder mixed EDM was used to modify the work piece's material's surface in this manner.

4. Conclusions

The impact of nano-sized HAp powder combined with EDM on stainless steel 316L machining is discussed in the current paper employing copper tungsten electrode. The inferences that arose from the results were drawn.

The findings showed that the most crucial variables in increasing the MRR were the pulse-on time, which contributed 16.83%, the pulse-off time, which contributed 17.22%, and the discharge current, which contributed 58.47%. The optimal machining parameters for producing the highest MRR (0.333 mg/min) when using EDM Oil were discharge current 16 Amp, pulse on time 200 s, pulse off 60 s, and voltage 80 V.

Discharge current of 16 Amp, duration of 150 s, pulse duration of 60 s, and voltage of 80 V were the optimum machining parameters for NPMEDM in order to achieve the highest MRR (0.304 mg/min). When using combined electric discharge machining with nanoparticles, MRR is reduced by 8.7%.

The tool wear rate was very minimal in the chosen machining conditions. The fine surface smoothness (1.34 m) was achieved using NPMEDM at discharge current 5Amp, pulse on 200 s, pulse off 150 s, and voltage 60V. XRD substantiated the surface modification of DSS 2205, demonstrating the expression of a number of intermetallic compounds on the machined surface with mixed dielectric.

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