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ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Factura '20 - National Conference On Emerging Trends In Manufacturing
NSS College of Engineering, Palakkad, Kerala, India
Vol. 7, Special Issue 1, August 2020

Comparison of the Effect of Chromium and Nickel Powders on Surface Modification Using Powder Mixed EDM

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Abstract: Electrical Discharge Machining (EDM) has established itself as one of the most versatile machining process in the manufacturing of dies, press tools and punches. In this process, a tool (electrode) cuts the work material by a series of electrical sparks generated in a dielectric medium and produces a mirror image of itself by advancing into the workpiece. Though EDM is essentially a material removal process, a number of phenomena observed during machining make it a suitable technology for application in the field of surface improvement. Suitable alloying elements may be introduced in the tool electrode materials or added to the dielectric medium in the form of fine powders for specific surface modifications. These elements may migrate to the machined surface either in free form or as carbides by combining with carbon generated from the breakdown of the hydrocarbon dielectric. The present work investigates the comparison of the response of OHNS material to surface modification by chromium and nickel powders using EDM method. Surface Modification was carried out using L18 orthogonal array of Taguchi experimental design. Micro-hardness measurements were carried out on all the machined samples and the data was analyzed as per Taguchi method to find out the best values of input process parameters. It was reported that surface modified using chromium powder has more hardness compared to surface deposited with nickel powder and has shown good surface characteristics, such as high hardness, high corrosion resistance and so on.

Keywords: EDM, Powder mixed EDM, Surface Modification, OHNS Steel, Chromium and Nickel powders.

I. INTRODUCTION

The last decade has seen an increasing interest in the application of Electrical Discharge Machining (EDM) process, with particular emphasis on the potential of this process for surface modification. Since EDM is widely used for the manufacturing of press tools, dies and punches where a hard and abrasion-resistant machined surface is a major requirement, researchers are exploring various ways to adapt this technique for surface hardening of workpieces. Efforts are being made to create new, harder alloys on the surface of machined components with the aim of increasing their working life and wear resistance with the advancement of technology, there is an ever-increasing need for harder materials with surfaces that are able to withstand stringent applications. The purview of surface modification may be stated to include:

a) Improving the surface characteristics by varying the input machining parameters within the existing process.
b) Altering the microstructure by changing the rate of melting and cooling.
c) Deposition of new metals and compounds (such as carbides and nitrides) on the machined surface.

A number of phenomena observed during the EDM process make it a high potential technology for application in the field of surface modification. Each spark generates a temperature of the order of 8,000 to 12,000°C and creates a plasma channel, causing fusion or partial vaporization of the workpiece, tool electrode and the dielectric fluid at the point of discharge. While removing material from the workpiece surface, the spark also erodes some material from the tool electrode. Most of this material is carried away by the dielectric but some of it gets deposited back on the workpiece and the tool electrode.

As the dissolution of the electrode takes place during the process, the constituents of the electrode material may be deposited on the machined surface by varying the process parameters towards the end of the machining cycle for specific surface modifications. Suitable alloying elements may also be added to the dielectric in the form of fine metal powders and they may get deposited on the machined surface either in the free form or as carbides by combining with carbon from the break-down of the dielectric. Thus surface finish and coating of the dies play an important role in improving lubrication, metal flow and operational life of the die.

Surface modification can been defined as the act of modifying the surface of a material by bringing physical, chemical, biological characteristics different from the ones originally found on the surface of material. Surface modification may be necessary to:

- Improve resistance to wear, erosion and indentation.
- Reduce friction, improve lubrication.
- Improve resistance to corrosion and oxidation.
- Improve fatigue resistance.

A vast number of engineering components degrading or failing catastrophically in service, due to surface related phenomena such as wear, fatigue, corrosion etc. can be made to serve longer by the optimal use of surface modification.

II. OBJECTIVES

The objectives are:

- Fabrication of tank to enable proper mixing of powder in dielectric.
- To modify the surface of OHNS steel using powder mixed electrical discharge machining.
- To investigate the effect of type and concentration of powder on micro hardness.
- To compare the surface topography using machine vision technique.
- To arrive at the best parameters at which surface quality of the modified surface is maximised.

III. EXPERIMENTATION

A smaller tank made of SS304 was placed in the main machining tank for conducting the experiments. This tank was provided with a stirrer to keep the powder suspended uniformly in the dielectric throughout the machining cycle. EDM oil is used as the dielectric medium. For carrying out machining in powder-suspended dielectric, the following important points are to be kept in consideration:

- ➢ The powder should not enter the main dielectric tank and the filtering system.
- ➢ The machining in powder-suspended dielectric should be confined to a small volume so as to avoid wastage of powder.
- ➢ The dielectric should be continuously stirred to prevent settling of the powder.
- ➢ Proper conductivity at the tool electrode and work piece interface must be maintained.

In view of these points, a specially designed tank was used for this stage of experimentation. The box is made up of SS304 material with a dimension of 40cm*20cm*20cm. Capacity of the tank is approximately 16 litres. Machining of the work pieces was then carried out on Electric Discharge Machine RATNAPARKHI EDM 5530. After mounting the workpiece on the fixture, the tank is filled with the dielectric. The level of the dielectric in this tank is same as that of the main tank. Copper electrode was mounted in the tool holder. Desired quantity of one of the powders was then mixed in the dielectric and stirred properly. The values of pulse on-time, pulse off-time and peak current were set from the control panel of the machine according to the control log. Copper electrode was brought near the workpiece and sparking was switched on. The set of nine experiments have been repeated two times for each set of powders. Negative polarity of the tool electrode and EDM oil dielectric with side flushing was used for all the experiments. Figure 1 shows the arrangement of dielectric tank, Work piece and tool on the EDM machine. Time for each machining cut was fixed at 10 minutes. Since very little work material was removed during the machining cycle and the purpose of the experimentation was to deposit the products of sparking and the suspended powder, dielectric flushing was switched off.

Fig. 1 Dielectric tank fitted on the EDM machine

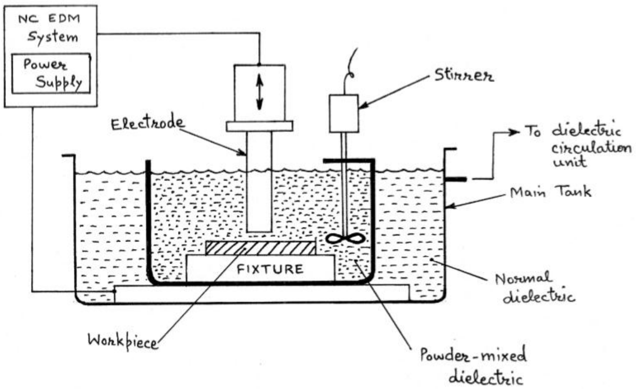

Fig. 2 Schematic diagram of machining setup

The turbulence caused by the stirrer was sufficient to keep the dielectric in motion near the machining area. Schematic diagram of machining setup is shown in figure 2.The effect on the response parameter micro-hardness has been studied and presented in this chapter. For calculating S/N ratios, the criteria of “higher-the-better” for micro-hardness as defined in the Taguchi method have been used. The input machining parameters and their levels used for experimentation are given in Table I.

TABLE I: INPUT PROCESS PARAMETERS AND THEIR LEVELS

Parameter	Levels		
	L1	L2	L3
Powder	Chromium	Nickel	
Peak current(Amperes)	2	4	6
Pulse on time (µsec)	5	10	15
Pulse off time (µsec)	4	6	9
Powder concentration(g/l)	5	8	12

The experimental data has been analyzed to find out:

- Optimum values of input process parameters.
- The percentage contribution of each factor and its significance from ANOVA (Analysis of Variance) of the S/N data.
- The theoretical estimated values of response characteristics for the set of optimum parameters thus obtained.

After 10 minutes of operation, the machine is switched off. The powder mixed dielectric is transferred to a separate container and the workpiece was replaced by a new one. Copper electrode is also replaced. The powder-mixed dielectric was filled back and machining was started with the new set of values of the three input process parameters. Different powder is used after completion of nine experiments. The set of nine experiments were repeated two times for each powder. Thus, a total of 18 sets of experiments were conducted. The experimental data was analyzed using Taguchi method to find out the optimum machining parameters for the response characteristic, their significance and percentage contribution.

IV. ANALYSIS AND DISCUSSION OF THE RESULTS

During the experimentation, OHNS steel material is machined using copper electrode and two different powders suspended in the dielectric medium under process conditions favouring material transfer to the workpiece surface. Machining was done by varying peak current, pulse on-time, pulse off-time and powder concentration according to L18 orthogonal array of Taguchi design of experiments. All the machined surfaces were subjected to micro-hardness measurement. Pictorial views of some samples machined using chromium powder mixed dielectric are shown in Fig. 3.

Fig. 3 Pictorial views of the samples machined using chromium

Pictorial views of some samples machined using nickel powder mixed dielectric are shown in Fig. 4.

Fig. 4 Pictorial views of the samples machined using nickel

Comparison of micro-hardness before and after machining is shown in table II. The hardness also depends on the type of powder deposited. Here the value of hardness is higher for chromium coated surface when compared to nickel coated surface. From the above table, we can observe that after machining with chromium powder hardness is improved in the range of 29.24% to 51.96% and when machining with nickel powder, hardness is improved by 8.16% to 31.2%.

TABLE II: COMPARISON OF MICRO-HARDNESS BEFORE AND AFTER MACHINING

Work Piece Material	Micro-hardness (HV)		
	Before Machining	After Machining	
		Chromium Powder	Nickel Powder
OHNS	612	791 - 930	662-803

A. Analysis Of Variance And Taguchi Analysis For Micro Hardness

Analysis of variance and Taguchi’s response table were used to identify the significant input parameters that affect micro hardness. Taguchi’s response table was also used for calculating signal to noise ratio values. For micro hardness, main effect and interaction plots were drawn based on the calculated signal to noise ratio values. Analysis of variance was carried out with a level of significance of 0.1. Table III shows the analysis of variance table for micro hardness for signal to noise ratio with ‘F-ratios’ and probability values. To find out the significant input parameters, the value of 'α' is considered as α = 0.1. When the calculated p-value is less than α = 0.1, then that input parameter is considered as a significant parameter. Table 4.7shows that the p-values are less than 0.1 for Powder (0.000) followed by powder concentration (0.000) peak current (0.020) and pulse off-time (0.0445). These are thus significant factors that influence the surface micro hardness.

TABLE III: ANALYSIS OF VARIANCE FOR MICRO-HARDNESS

Source	DF	Adj SS	Adj MS	Contribution	F-Value	P-Value
Powder	1	83913.4	83913.4	48.59%	411.31	0.000
Peak current	2	804.0	402.0	9.55%	1.97	0.020
Pulse-on time	2	940.3	470.2	0.65%	2.30	0.162
Pulse-off time	2	364.3	182.2	4.25%	0.89	0.0445
Powder concentration	2	58050.3	29025.2	35.84%	142.27	0.000
Error	8	1632.1	204.0	1.12%		
Total	17	145705		100.00%		

The data was analysed to find out the desirable combination of levels of the five input process parameters, their significance and relative contribution. The results of experimentation with different input parameters and powders are presented in this chapter. Table IV represents the response for surface micro hardness for signal to noise ratio. For achieving maximum micro hardness, the quality characteristics were set as larger-the-better. In this method, ranks are used to find out the relative importance of each factor towards surface micro hardness. To award ranks to each factor, first delta values are calculated for each factor. A delta value is calculated by subtracting lower value of signal to noise ratio from the highest value of signal to noise ratio. The highest delta value is assigned the first rank and the subsequent ranks are assigned to all factors based on the delta values. Table IV shows the delta values and the subsequent ranks for various parameters. Type of Powder emerged to be the most significant parameter at rank 1 followed by powder concentration at rank 2 and Peak current at rank 3. The significant factors are the same as that of obtained from analysis of variance.

TABLE IV: RESPONSE TABLE FOR MICRO-HARDNESS

Level	Powder	Peak current	Pulse on time	Pulse off time	Powder concentration
1	58.50	57.76	57.67	57.82	57.19
2	56.95	57.83	57.73	57.71	57.36
3		57.59	57.77	57.64	58.62
Delta	1.56	0.23	0.11	0.18	1.42
Rank	1	3	5	4	2

Figure 5 shows the main effects plot for surface micro hardness for signal to noise ratio. From the main effects plot for signal to noise ratio, it can be observed that deposition of chromium powder results in more hardness and micro-hardness increase with reduced peak current, moderate pulse on time, increased pulse-off time and increased powder concentration.

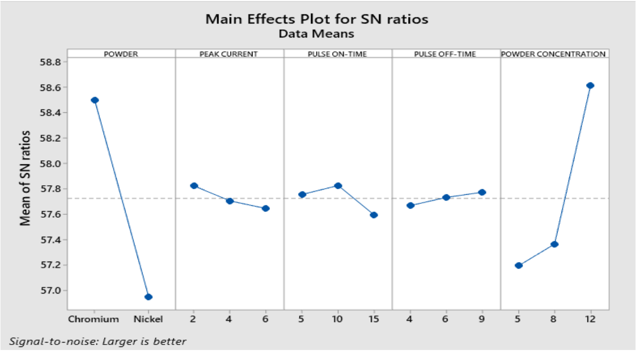

Fig. 5 Effects of process parameters on micro-hardness

As micro hardness is to be maximized, the quality characteristic is set at higher-the-better. From figure 5, the optimal settings of input parameters are made. These are chromium powder, first level of peak current, the second level of pulse on time, the third level of pulse off time and the third level of powder concentration. This combination of parameters is expected to result in maximum values of micro-hardness. Figure 6 represents the residual plots for signal to noise ratio for micro hardness. For the present study, the data is distributed along the straight line in normal probability plot. Approximately symmetric nature of curve is observed in the histogram plot indicating that the residuals were properly distributed. In residual versus the fitted values plot, the data indicates a near uniform variation about zero. In the residual versus observation order plot, no straight pattern was observed. This analysis confirms that there was no error during data collection due to the time factor.

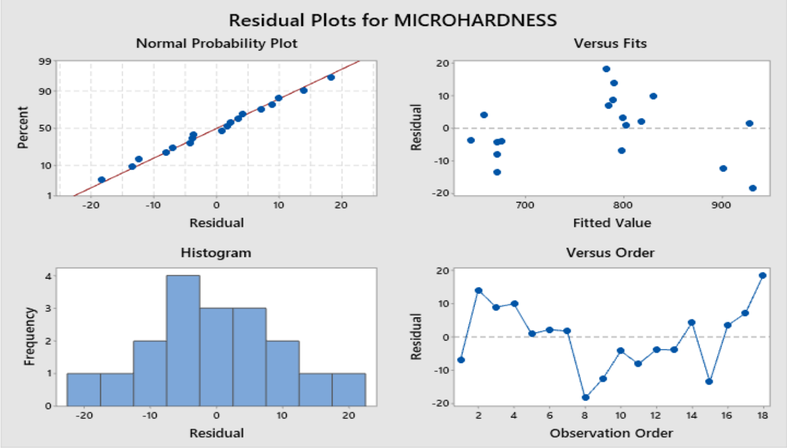

Fig. 6 Residual plot for micro-hardness

B. Surface Morphology Using Imagej

An attempt is made to study the changes in surface morphology after surface modification. For this purpose histogram, plot profile and surface plot of work piece before and after the modification is compared. Further analysis of the machined surfaces after modification was done on imageJ software to find out gray values and intensities of pixels in a gray scale and it has been presented in this chapter. Before the start of experimentation, Histogram, Plot profile and Surface plot of the image is taken using imagej software. Histogram of non machined part is shown in figure 7. Calculates and displays a histogram of the distribution of gray values in the active image. The x-axis represents the possible gray values and the y-axis shows the number of pixels found for each gray value. The total pixel count is also calculated and displayed, as well as the mean, modal, maximum and minimum gray value. The horizontal LUT bar below the x-axis is scaled to reflect the display range of the image.

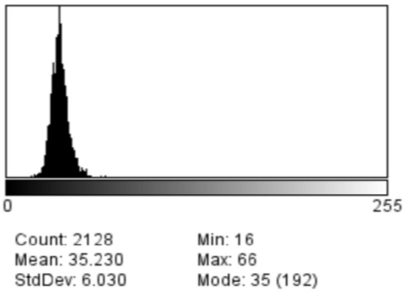

Fig. 7 Histogram of non machined part

In an image processing context, the histogram of an image normally refers to a histogram of the pixel intensity values. Each of the pixels that represent an image stored inside a computer has a pixel value which describes how bright that pixel is, and/or what colour it should be. For a gray scale images, the pixel value is a single number that represents the brightness of the pixel. The most common pixel format is the byte image, where this number is stored as an 8-bit integer giving a range of possible values from 0 to 255. Typically zero is taken to be black, and 255 are taken to be white. In-between values make up the different shades of gray. This histogram is a graph showing the number of pixels in an image at each different intensity value found in that image. For an 8-bit gray scale image there are 256 different possible intensities, and so the histogram will graphically display 256 numbers showing the distribution of pixels amongst those gray scale values.Surface plot of non machined part is shown in figure 8. Displays a three-dimensional graph of intensities of pixels in a gray scale or pseudo colour image (non-RGB images). The plot is based on the existing rectangular selection or on the entire image if no selection is present.

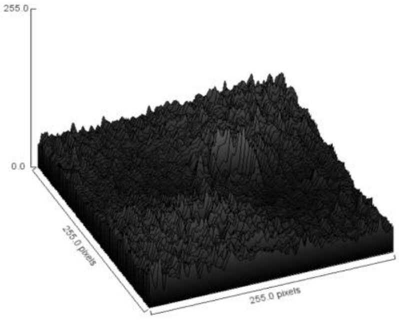

Fig. 8 Surface plot of non machined part

1. Response of Chromium Powder Mixed Machining

The response of OHNS die steel in terms of improvement in micro-hardness after machining with chromium powder is shown in Table V and comparison has been done with the original value of micro-hardness recorded before the start of experimentation. It can be seen that all the experiments result in an increase in micro-hardness, ranging from 29.24 % to 51.96%.

TABLE V: COMPARISON OF MICRO-HARDNESS

Work Piece Material	Micro-hardness (HV)	
	Before Machining	After Machining
OHNS	612	791 - 930

This increase in micro-hardness can be attributed to three reasons:

- More heating and quenching of the work surface results in more hardening.
- The increase in carbon in the work surface results in formation of more cementite which has high hardness.
- Transfer of alloying elements to the work surface results in formation of their solid solutions in ferrite and cementite phases or their independent hard carbides or both. This aspect has been analyzed with more details later in this chapter when migration of individual alloying elements is taken up for discussion.

The best value of peak current is found to be 2A. It means that very little transfer of material is taking place at 4A and 6A value of peak current. Low value of peak current means less energy in the discharge channel and also less heating and quenching effect. The best value of pulse on-time is found to be 10 µsec. higher values of pulse on-time means that heat energy in the discharge channel is available for a longer period of time. But the value of pulse on time should not be too high or small. The best value of pulse-off time is found to be 9 µsec. That means more time is permitted for the deposition of suspended particles. Higher powder concentration results in higher hardness, this is due to availability of more powder for deposition. The histogram of surface deposited with chromium powder is shown in Figure 9.

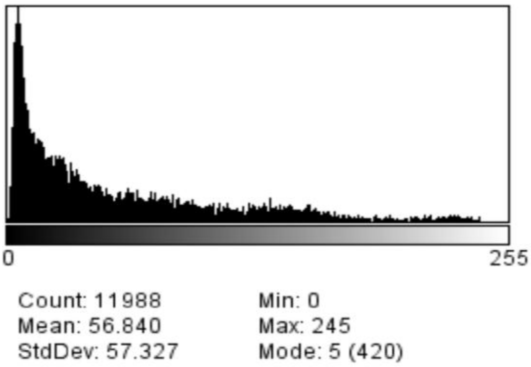

Fig. 9 Histogram of surface deposited with chromium powder

The surface plot for the surface deposited with chromium powder is shown in Figure 10.

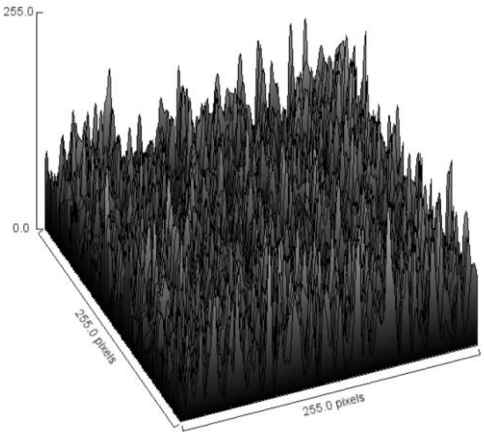

Fig. 10 Surface Plot for the surface deposited with chromium powder mixed EDM

2. Response of Nickel Powder Mixed Machining

The response of OHNS die steel in terms of improvement in micro-hardness after machining with nickel powder is shown in Table VI and comparison has been done with the original value of micro-hardness recorded before the start of experimentation. It can be seen that all the experiments result in an increase in micro-hardness, ranging from 8.16% to 31.209%.

TABLE VI: COMPARISON OF MICRO-HARDNESS

Work Piece Material	Micro-hardness (HV)	
	Before Machining	After Machining
OHNS	612	662-803

The histogram of surface deposited with nickel powder is shown in Figure 11.

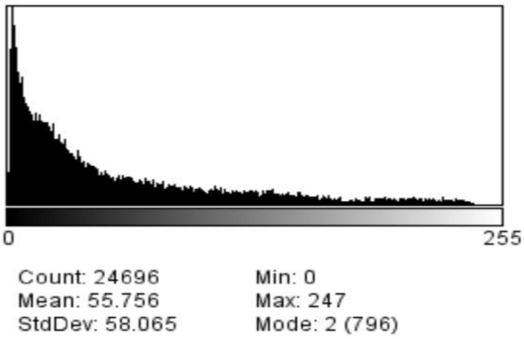

Fig. 11 Histogram of surface deposited with nickel powder

The surface plot for the surface deposited with nickel powder is shown in Figure 12.

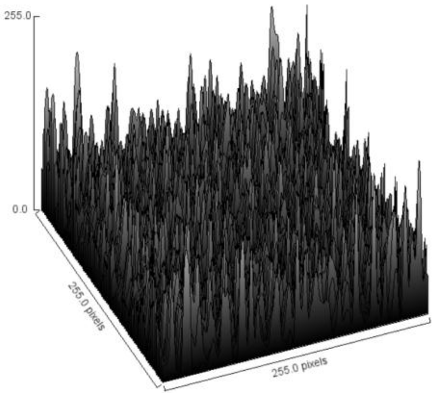

Fig. 12 Surface Plot for the surface deposited with nickel powder.

V. CONCLUSIONS

Experimental investigations were conducted into the phenomenon of material transfer during electrical discharge machining of OHNS steel using copper tool electrodes and two powders suspended in the dielectric medium. The important conclusions drawn from this research work are:

- Under appropriate conditions, significant amount of material transfer can take place from the powder suspended in the dielectric medium to the work material. It can be concluded that surface modification is possible by EDM method.
- Chromium containing layer can be formed on the EDM finished surface by using a chromium powder mixed fluid and similarly nickel containing layer can be formed by using nickel powder mixed fluid.
- Based on the experimental results, micro-hardness increased in all the experiments. Using chromium powder mixed edm, the maximum micro-hardness achieved was 930HV and with nickel powder mixed edm, the maximum micro-hardness achieved was 803HV. Surface hardness has a direct bearing on abrasion resistance, therefore the life of the dies and other press tools can be substantially improved by this method.
- The favorable machining conditions for material transfer by EDM were found to be low discharge current, shorter pulse on-time, longer pulse off-time, increased powder concentration and negative polarity of the tool electrode. In general, it was observed that within the given conditions, less current and more pulse on-time were required for material transfer from suspended powders as compared to material transfer from tool electrode bodies.

Finally, it can be concluded from this research work that the method of surface modification by electrical discharge machining is technically feasible and has the potential of becoming a cost effective and time saving alternative to the surface modification techniques currently being used by the tool and die making industry. It is pertinent to note that EDM process is already being used in the industry for machining hardened work materials, and simple modifications in the existing setup can lead to substantial improvement in surface properties. Consequently, the working life of dies and press tools can be significantly enhanced.

VI. RECOMMENDATIONS AND SCOPE FOR FUTURE WORK

- In this experimental work, the effect of type of powder and concentration of powder was established for the response parameters. However, the electrode material, work piece material, electrode size and powder size was kept constant for the study. It is well known fact in EDM process that inter-electrode gap depends on gap voltage, electrode area and powder size. This affects the discharge process. Hence, there is a need to study the effect of electrode material, work piece material and electrode size on the response parameters.
- Other important alloying elements in tool and die steels namely, tungsten, cobalt, molybdenum and vanadium can be used as powder material in the dielectric. Like inconel, some other readily available alloys of desirable elements can be tried as electrode materials for this application. Examples of such materials are Haynes alloy (containing cobalt, chromium and molybdenum), Hastalloyn(containing nickel, chromium, molybdenum and iron), Cupronickel (containing copper and nickel) and Silicon Bronze (containing copper, silicon and manganese) etc.
- This study did not consider the productivity aspects (MRR and TWR) of the EDM process as a lot of work is reported in the literature. And present study was aimed at establishing the optimal parameters of EDM process for surface modification that was less attempted and addressed in the literature.
- In this experimental work, the effect of powder mixed EDM process parameters were not studied on the surface crack development during the machining process. These surface cracks affect the fatigue strength of the machined surface. This can be an exciting area which can be explored. The fatigue strength of the machined surface can be checked by shot penning operation.
- Some organic liquids or deionized water or other environment friendly dielectric fluid can be tried as dielectric medium. In such a medium, graphite electrode can be used as source for providing carbon with different combinations of powders in the dielectric such as tungsten, silicon carbide, chromium, cobalt, nickel, molybdenum and vanadium.
- Taguchi technique and ANOVA were used to investigate the effect of the PMEDM process parameters and subsequently to predict sets of parameters for optimum values of responses. Different algorithms can be used to predict the optimal settings of EDM process parameters.

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