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Surface Modification of W304 Die Steel by EDM with Chromium Powder Suspended Dielectric

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Abstract—Electric Discharge Machining (EDM) is quite extensively used for machining of hard materials due to controlled erosion through a series of electric spark. This paper investigates the material removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR) hardens of material (KgF) of W304 (die steel) with electrolytic copper Electrode using D7120 electric discharge machine. The dielectric used for the present study is chromium powder suspended EDM Oil Fluid. The attempt shows promising results for MRR, EWR, SR and hardness of material at higher current, higher pulse on time (T_{on}) and higher pulse off time (T_{off}).

1. INTRODUCTION

Electric Discharge Machine (EDM) is one of the most widely used advanced machining methods for the manufacturing of the press tool, die casting and various dies. Electric Discharge Machining (EDM) is an unconventional electro thermal machining process used for manufacturing material parts that are extremely difficult-to-machine by conventional machining process. Electric Discharge Machining (EDM) is the removal of materials conducting electricity by electrical discharges between the two electrodes (work piece electrode and tool electrode), a dielectric fluid being used in the process.This removes (erodes) very tiny pieces of metal from the work piece at a controlled rate.

Powder mixed EDM (PMEDM) has a different machining mechanism from the conventional EDM. In this process, a suitable material in the powder form was mixed into the dielectric fluid either in the same tank or in a separate tank. For better circulation of the powder mixed dielectric, a stirring system was employed. For constant reuse of powder in the dielectric fluid, a special circulation system was used. The various powders that can be added into the dielectric fluid include aluminum, chromium, graphite, copper or silicon carbide. The spark gap was filled up with additive particles. When a voltage of 80-320 V was applied between the electrode and the work piece facing each other with a gap of 25-50 µm, an electric field in the range 105-107 V/m was created. The powder particles get energized and behave in a zigzag fashion. Under the sparking area, the particles come close to each other and arrange themselves in the form of chain like structures between both the electrodes. The interlocking between the different powder particles occurred in the direction of flow of current. The chain formation helps in bridging the discharge gap between both the electrodes. Due to bridging effect, the insulating strength of the dielectric fluid decreased. The easy short circuit takes place, which causes early explosion in the gap. As a result, a 'series discharge 'starts under the electrode area. The faster sparking within a discharge takes place, which caused faster erosion from the work-piece surface and hence increased the MRR. At the same time, the added powder modifies the plasma channel. The plasma channel becomes enlarged and widened. The sparking is uniformly distributed among the powder particles, hence electric density of the spark decreased. Consequently, uniform erosion (shallow craters) occurred on the work piece surface. This results in improvement in surface finish.

2. LITERATURE REVIEW

It can be easily observed from the available literature that considerable efforts have been directed to improve the material removal rate and the surface quality by suspending powder particles in the dielectric of EDM.

Toshimitsu et al [1], 2016 investigated the effect of chromium powder in Dielectric fluid. They used the material SKD11 and electrolyte copper and found chromium containing layer on the surface by mixing the powder in fluid.

Ojha et al. [11], 2011 investigated the effect of nickel micro-powder suspended dielectric on EDM performance measures of EN-19 steel using Response Surface Methodology (RSM). Peak Current, pulse on time, diameter of electrode and concentration of micro-nickel powder added into the dielectric fluid of EDM have been chosen as process parameters to study the PMEDM performance in terms of MRR, EWR and SR. Maximum MRR is obtained at high current. MRR is found to increase with duty cycle and powder concentration. Powder concentration has much significant effect on MRR. Also, current is important parameter affecting the EWR.

Rathi et al [4], 2014 studied the influence of Graphite, silicon carbide and aluminum oxide powder on Inconel 718 by using conventional EDM and reported the MRR, EWR and optimized the result by using ANOVA and Taguchi method.

Singh et al [3], 2015 studied to enhance the result of different types of powder on different types of work material and optimized the result for the material.

Kumar et al. [9], 2012 investigated the effect of surface modification of die steel material by EDM method using tungsten powder mixed dielectric. Considering the parameters namely Peak current, pulse on time, pulse off time, powder concentration and micro hardness. Undergoing X-Ray diffraction and spectrometric analysis.

Yadav et al [7], 2016 investigated the improvement of material properties of the work piece, with the effect of different input parameter (current, dielectric material work piece material, Pulse on time, pulse off time, powder concentration) on the MRR, EWR and SR of W304 die steel by using electrolyte copper electrodes has been analyzed.

Abrol et al. [2], 2015 used chromium powder for the research of PMEDM in machining with the work material AISI D2 Die steel, with the process parameter (peak current, pulse on time, pulse off time, and concentration of powder), and analyzed the MRR, EWR and SR by using the Taguchi method. Bin Idris [6], 2015 taking the same parameter he further discussed on the responses of surface morphology, micro hardness and recast layer under the same machining conditions.

Manoharan et al. [8], 2013 analyzed the EDM process by using different electrode material. The Material Removal Rate (MRR), Electrode Wear Rate (EWR) and Surface Roughness (SR) is measured and recorded for detailed analysis on different electrode.

Hua et al. [10], 2013 studied the surface properties machined by using powder mixed EDM. Decrease in roughness and increase in hardness was observed.

3. PROCESS PARAMETER

(**Fig. 1**) shows the schematic illustration of EDM finishing equipment. The machine Electrode used for the experiments was D7120 die sinker EDM (**Fig 2**). A cylindrical copper of 15mm in diameter was used as electrode. The work piece material was Die Steel W304 in JIS specifications, which is widely applied for Die Making. Work piece specifications are listed in (**Table 1**). EDM Machine Specification is shown in (**Table 2).** In order to prevent the powder precipitation in the fluid, the working fluid was stirred with a rotating screw during EDM. The concentration of mixed chromium powder varied from 3 to 5 g/L. The chromium powder grain size was about 5μm in diameter. To increase the spark gap and to reduce the insulating strength of dielectric fluid the chromium powder suspended EDM oil has been used. These are based on the EDM maker recommended conditions for finishing using Chromium powder mixed fluids. These powder mixed fluids have been practically applied as working fluid to obtain very small surface roughness and high Hardness.

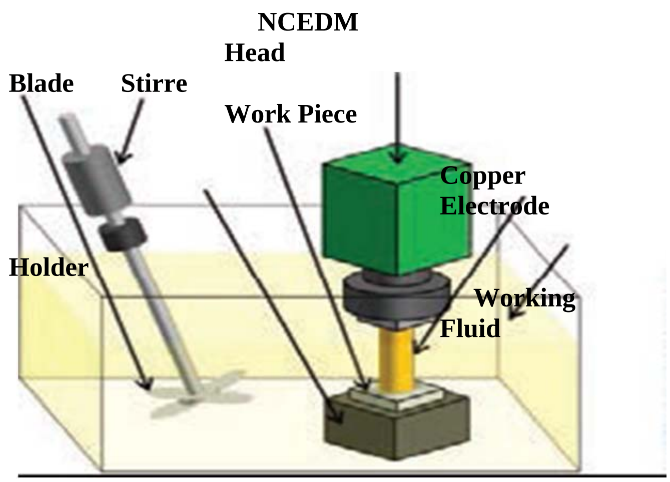

Fig. 1 schematic illustration of Experimental Setup

Fig. 2: D7120 Die Sinker EDM

The sample of work piece was 20mm×40mm×6mm. The chemical composition of W304 is shown in (Table 1) below:-

Table 1: Composition of W304

Elements	Percentage
Nickel	8-12%
Carbon	0.08%
Chromium	18-20%
Manganese	2%
Phosphorus	0.045%

Table 2: Machine Specifications

Specification	D7120		
X,Y travel size (mm)	200×160		
Working table size (mm)	400×250		
Principal axis travel (mm)	200		
Head travel of principal axis (mm)	——		
Principal axis load (kg)	25		
Max. work piece weight (kg)	150		
Chief axis connect board to working table (mm)	420		
Work tank internal size (mm)	650×400×230		
Overall weight (kg)	700		
Overall Dimensions (mm)	1200×1000×1800		
Electric Cabinet Parameter and Specification	BH20AMP		
Max. processing current (A)	20		
Max. processing speed (mm/min)	100		
Min Electrode Consumption	≤0.2%		
Optimum roughness (um)	Ra<0.3		
Max. power Consumption (kw)	2		
Net weight (kg)	——		
Overall dimensions (mm)	——		

The Hardness of Work piece W304 has been recorded with the help of Rockwell Hardness Machine. The specification of Rockwell Hardness machine is shown in **Table 3:-**

Table 3: Specification of Rockwell Hardness Machine

Capacity	250Kgf
Major Load	150KgF
Minor Load	10KgF
Indenter Type	Steel Ball Indenter
Diameter of Indenter	1.5875 mm

4. EXPERIMENTAL DESIGN

Taguchi method known to be a simple, efficient and systematic method is used for the design of the experiment. This method uses a special design of orthogonal array to study the entire process parameter space with lesser number of experiments. L9 OA was used to optimize the machining parameters for die steel in order increase the MRR and increase the hardness.

Machining Parameters are listed below in **Table 4**:

Table 4: Machine Parameter

Current	7 to 9 Ampere
Pulse on Time (Ton)	30 to 210
Pulse Off Time (Toff)	3 to 9
Polarity	Positive

5. EXPERIMENTAL VALUES

Following are the tables which represents the MRR values in different machining conditions. Based on the MRR &, Hardness (KgF) values a comparison chart has been made to check which machining environment is showing significant results in this regards.

Table 5: MRR results for different types of Dielectric

Exp No.	Current (I)	Ton	Toff	MRR (powder mixed)	MRR (EDM)	MRR (Kerosene)
1	7	60	5	0.083	0.043	0.074
2	7	80	5	0.045	0.042	0.071
3	7	100	5	0.048	0.058	0.079
4	7	100	6	0.053	0.056	0.070
5	7	120	6	0.058	0.036	0.079
6	8	130	6	0.064	0.057	0.079
7	8	130	7	0.056	0.080	0.083
8	8	150	7	0.059	0.046	0.080
9	8	170	7	0.070	0.039	0.081
10	8	170	8	0.054	0.054	0.072
11	9	190	8	0.064	0.034	0.084
12	9	200	8	0.055	0.047	0.111
13	9	200	9	0.060	0.029	0.083
14	9	210	9	0.062	0.049	0.074

Abbreviations:-
I = Current
Ton = Pulse on time
Toff = Pulse off time
MRR= Material Removal Rate

Fig 3: EDMed Work piece

6. RESULT & DISCUSSIONS

The comparative study of present work, addition of chromium powder mixed with EDM oil led to a good surface finish when compared to pure dielectric. Though Kerosene has shown a good result over the other two, but because of the hazardous effect of kerosene on the health of the operator using kerosene as dielectric fluid has never been acknowledged. The table shown below shows the comparison,

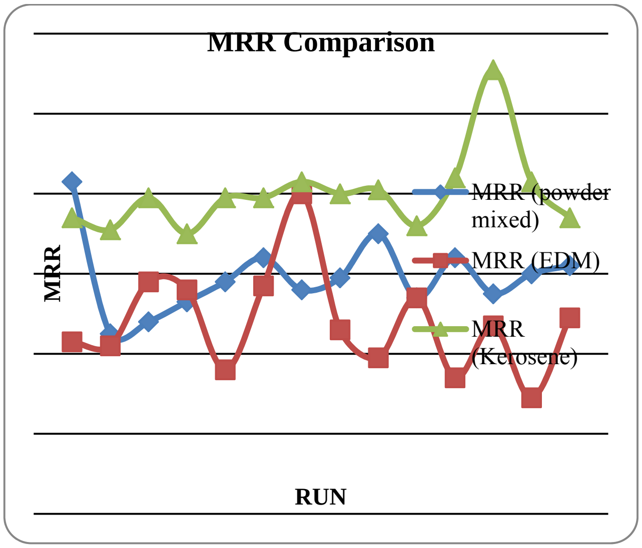

Fig 4: MRR comparison for different machining Environment

As the experimental design used is orthogonal array the effect of each process at different level can be found. The effect of four parameter i.e. current, pulse on time, pulse off time and powder concentration on MRR as been shown in **Fig 4.** The hardness value for different machining condition has also been calculated and shown in **Table 6** and the comparison has been shown through **Fig 5.** It shows that hardness value of chromium powder mixed EDM oil is higher than the other dielectric fluids.

Run	Hardness of Powder mixed (kgf)	Hardness of EDM oil(kgf)	Hardness of kerosene(kgf)	Hardness vaue before experim ent
1	74	69	72	49
2	75	70	73	50
3	76	75	70	48
4	74	71	73	49
5	75	69	72	48
6	74	72	73	51
7	75	69	74	51
8	75	72	76	52
9	70	71	73	49
10	76	75	75	47
11	72	71	72	52
12	75	65	73	48
13	75	76	69	52
14	76	71	74	52

Table 6: Effect on Hardness value

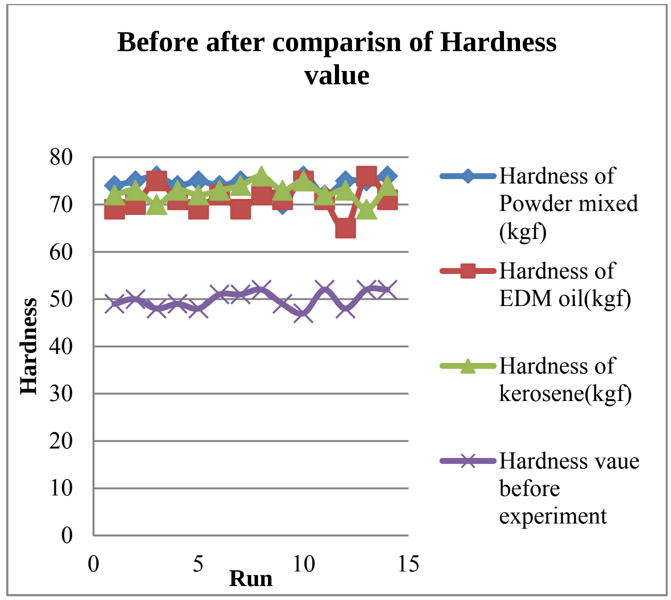

Fig 5: Comparison of Hardness

Based on the above study microstructure of the Die steel W304 has been studied after the machining process. The first figure (**Fig 6** (a)) shows the presence of Kerosene as white layer whereas the grey layer stands for steel. Because of the high presence of kerosene layer on the surface it shows a moderate enhancement of hardness factor. The next figure i.e. **Fig 6**(b) is of pure EDM oil which has fewer amounts of disposed dielectric media on it as a result it has shown less harder surface in the hardness check. The third figure **Fig 6** (c) has shown a significant amount of presence of chromium on the EDMed surface which might be the influential factor for the high hardness value of chromium based EDM oil machined product.

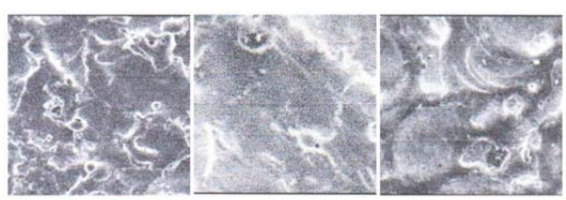

Fig 6: SEM micrographs of (a) Kerosene (b) EDM oil (c) Chromium powder mixed EDM oil

7. CONCLUSION

Based on the experiments performed on the experimental setup for the PMEDM process, following conclusions can be drawn,

1. MRR is mainly affected by current, pulse-on time and powder concentration. With the increase in current and pulse-on time, MRR increases. But it is also observed that with the increased concentration of chromium powder, MRR tends to decrease.
2. Current is the most dominant factor affecting both MRR. Both the performance data show an increasing pattern with increase in current for any other parameter.
3. Chromium powder mixed EDM oil has shown an impressive enhancement of hardness over the other two dielectric media.

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