Material migration and surface improvement of OHNS die steel material by EDM method using tungsten powder-mixed dielectric

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Abstract: - Material migration and surface improvement using electrical discharge machining has become a key research area in the last two decades. Material may migrate to the machined surface of workpiece either from the tool electrode or from powder mixed in dielectric. This paper reports the results of experimental study carried out to evaluate the improvement in machined surface properties of OHNS die steel machined by electrical discharge machining using tungsten powder mixed in the dielectric medium. Gap current, pulse on time and pulse off time were taken as process parameters and micro-hardness of the machined surface was taken as the response parameter. Scanning electronic microscopy showed the topography of the machined surface, there are discrete craters along with some volcanic features, and many spherical droplets left on the EDmed surface, which indicate that the material removal mechanism is melting and evaporation. Spectroscopic and EDS analysis show substantial transfer of tungsten and carbon to the workpiece surface and an improvement of more than 100% in micro-hardness for all the trial conditions. Presence of tungsten was observed on all machined surfaces in the form of intermetallic compounds with iron, as carbides and in the form of alloyed cementite. Presence of carbon was observed on all machined surfaces in the form of solid solutions in ferrite and cementite phases or their independent hard carbides. These formations caused significant increase in microhardness. This was confirmed by the XRD analysis. Tribological analysis showed that coefficient of friction is higher for PMEDM work materials which shows significant rise in the microhardness than the parent material.

Key-Words: - Material migration, Surface improvement, Tungsten powder, Micro-hardness, Powder-mixed EDM, Scanning Electronic Microscopy, Energy Dispersive Spectroscopy.

1 Introduction

Electrical discharge machining (EDM) is a well-established method for manufacturing of geometrically complex and hard material parts that are extremely difficult-to-machine by the conventional machining processes. There have been various attempts to improve the surface finish after electrical discharge machining by polishing and other means. But improvement in surface during machining itself would result in short machining time. From this viewpoint powder mixed EDM is assuming a great importance. Suspended powder mixed EDM not only imparts fine surface finish but also modifies the surface. Surface improvement during machining has added a new dimension to electrical discharge machining process. Most of the research work using powder-mixed dielectric focus on improving the process parameters such as material removal rate, tool wear rate and surface roughness. The study of the impact of such machining on surface improvement began about two decade ago. Wong et al. (1998) concluded that whilst graphite and silicon powders gave mirror-finish on SKH-54 work material, aluminium powder failed to give the same. The use of negative electrode polarity was found to be essential for achieving mirror-finish condition [1]. Furutani et al. (2001) used titanium powder in kerosene dielectric and obtained titanium carbide layer of hardness 1600HV on carbon steel with a negatively polarized copper electrode, 3A peak current and 2µs pulse duration [2]. Simao et al. (2003) conducted surface modification of H13 hot work tool steel by WC/cobalt electrodes and identified the effect of key operating factors using L_8 fractional factorial Taguchi design. The alloyed/modified layer had relatively few micro-cracks, an average thickness of 30µm and surface hardness of 1319 HK, up from 640 HK [3]. Yan et al. (2005) added urea to distilled water as the dielectric medium for machining titanium and obtained TiN on the work surface which exhibited improved friction and wear characteristics [4]. Kansal et al. (2006) adopted Taguchi design for optimization of process parameters to get optimal surface roughness along with material removal rate. They found that concentration of silicon powder in dielectric, peak current and pulse duration significantly affect the surface roughness and material removal rate in PMEDM [5]. Kumar et al. (2009) presented a review on the phenomenon of surface modification by electric discharge machining and discussed its future trends [6]. Ali et al. (2011) have studied the effect of two PMEDM milling process parameters i.e. electrical discharge energy and concentration of SiC powder in the dielectric fluid for machining titanium alloy Ti-6Al-4V. Addition of SiC powder at 10 g/l in dielectric fluid significantly reduced Ra surface roughness. However, higher concentration of SiC powder (above 20 g/l) increased the surface roughness [7]. Mai et al. (2012) studied the effect of adding CNT powders to the dielectric on the surface integrity and the machining efficiency of the workpiece. They found that the surface roughness of the workpiece and the machining efficiency of EDM with CNT powder mixed into the dielectric were improved by 70% and 66%, respectively, compared with conventional EDM [8]. Kumar and Batra (2012) have investigated the response of three die steel materials to surface modification by EDM method with tungsten powder mixed in the dielectric medium. They concluded that under appropriate machining conditions, significant amount of material transfer take place from the powder suspended in the dielectric medium to the work material [9]. Kumar et al. (2012) presented a review on the fundamental principles of EDM and work done with regard to effect of operating parameters on material removal rate, tool wear rate, surface roughness and surface improvements on titanium alloys work piece [10]. Bhattacharya et al. (2013) investigated the improvement of surface properties measured in terms of improved finish and increased microhardness of die steel materials with Si, W and graphite powders mixed in dielectric in PMEDM process using Taguchi design [11]. The present work investigates the surface improvement of OHNS dies steel material by EDM with tungsten powder suspended in the dielectric medium. Increase in micro-hardness of the machined surface was taken as indicator of surface alloying.

2 Experimentation

The study was undertaken to investigate the migration of tungsten powder to the OHNS die steel material surface by suspending tungsten powder in the dielectric medium. The chemical composition of the workpiece materials obtained by spectroscopy analysis is shown in Table 1. The workpiece was machined with electrolytic copper (99.9%) as electrode material. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94 °C, kinematic viscosity-23 cSt at 40 °C) was used as dielectric fluid. The dielectric was mixed with tungsten powder of size 325 mesh. The maximum and minimum level of current, pulse on time and pulse off time were chosen in a way so that a reasonable cut or MRR is obtained on the surface without arcing. For the present study powder concentration of 3 gm/l was kept constant throughout the experimental trials. Above 3 gm/l of powder concentration a black spot was observed on the machined surface due to limited flushing of dielectric at machining zone. Also powder concentration above 10 gm/l caused arcing of the workpiece surface due to narrowing of effective inter-electrode gap due to increased powder concentration. Other process parameters such as gap voltage (50 V), flushing pressure (0.5 kg/cm^2), and machining time 10 mins were kept constant throughout the experimental trials. Experiments were carried out on an Electrical Discharge Machine (Die-Sink type Model- C 400x250) of Electronica Machine Tools Limited with NC control in Z-axis and negative polarity for electrode. For using tungsten powder-mixed dielectric, a small tank of acrylic sheet was placed in the main machining tank to isolate it from the filtering system of the machine. This tank was provided with a stirrer and small pump to keep the powder suspended uniformly in the dielectric throughout the machining cycle. A schematic diagram of machining set-up is shown in figure 1. After machining, the surfaces were washed with oil to remove any accumulated debris at the corners followed by acetone cleaning. Figure 2 shows the OHNS materials before and after EDM process. All the machined surfaces thus obtained were subjected to micro-hardness testing using a load of 1000 g for duration of 20 seconds. Before and after machining the micro-hardness was measured at five different places and average values were noted. Scanning electron microscopy was used to analyze the structural features of the machined surfaces. Composition testing was done by using optical emission spectrophotometer to confirm material migration and for quantitative analysis of the changes in the constituents of the machined surfaces.

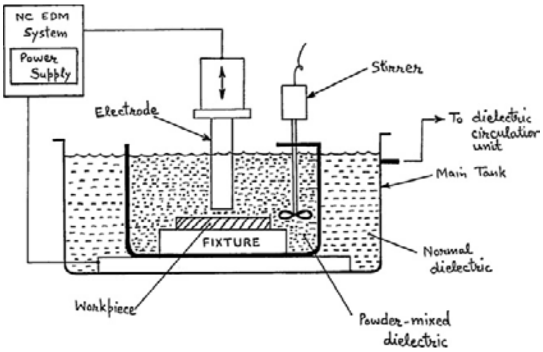

Fig. 1 Schematic diagram of machining set-up [9]

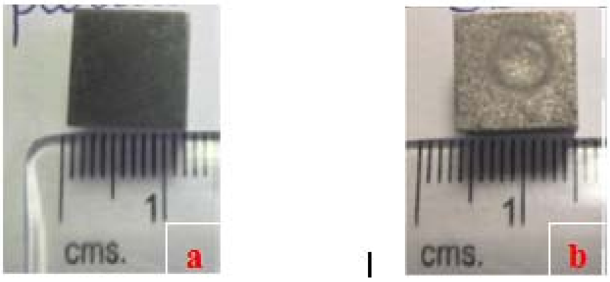

Fig. 2 a) OHNS Parent material
b) OHNS EDMed surface

3 Results and Discussions

All the machined surfaces thus obtained were subjected to micro-hardness testing using a load of 1000 g for a duration time of 20 secs. Before and after machining micro-hardness for each sample are given in table 1. More than 100% increase in micro-hardness is observed for all the samples. Samples showing best value of micro-hardness were further subject to surface analysis by SEM and spectroscopy analysis.

Table 1 Micro hardness of work material before and after machining

Sr. No	**Gap Current (A)**	**Pulse on time (µs)**	**Pulse off time (µs)**	**Average Hardness (HV)**
1	Parent Material			506
2	5	12	7	1043
3	3	8	7	1024
4	1	4	7	989
5	1	4	9	1076
6	3	8	9	1115
7	5	12	9	1090
8	5	12	8	1077
9	3	8	8	1087
10	1	4	8	1041

3.1 Spectroscopic analysis

Spectroscopic analysis of the surface before and after machining (table 2) shows a substantial pick-up of carbon and tungsten. The presence of tungsten and carbon pick-up indicates that the reaction is taking place in the plasma channel and it settles down on the machined surface during pulse off - time. Results showed significant material transfer from the suspended powder in dielectric. The carbon percentage increased in all work materials can be attributed to breakdown of the hydrocarbon dielectric. Presence of tungsten was observed in all workpiece surfaces machined with tungsten powder in the form of intermetallic compounds with iron; as carbides; or in the form of alloyed cementite. Fine dispersion of hard particles can be seen in the microstructures. These formations caused significant increase in microhardness. The increase in microhardness can be attributed to increase in carbon leading to cementite and transfer of alloying elements to the machined surface. These elements results in formation of their solid solutions in ferrite and cementite phases or their independent hard carbides.

Table 2 Chemical composition of work material before and after machining

Elements	Before Composition (wt. %)	After Composition (wt.%)
C	**0.94**	**8.87**
Si	0.29	1.79
Mn	1.55	1.51
Cr	0.35	0.46
W	**0.25**	**2.89**
V	0.013	0.015
Mo	0.17	0.16
S	0.021	0.021
P	0.029	0.026
Fe	96.387	84.258

3.2 Microstructural and surface topography analysis

The microstructures were observed using a Scanning Electron Microscope. The microstructure of OHNS die steel is shown in figure 2 which consists of spheroidal cementite phase in the matrix of tempered martensite. Figure 3 shows the SEM structure on the surface of OHNS die steel machined by EDM using tungsten powder suspended in dielectric. As can be seen from the topography, there are discrete craters along with some volcanic features, and many spherical droplets left on the EDmed surface, which indicates that the material removal mechanism is melting and evaporation. The upper material in extremely high temperature region will vaporize, while the lower material will melt. Two regions are clearly visible - one is the original material and another is the recast layer which has a brighter white colour. A smaller thermal gradient occurs at the lower pulse current, thus forming a thinner recast layer. The recast layer appears thicker as the pulse current increases because at a higher pulse current, a steeper thermal gradient builds up possibly causing a thermal effect beneath the melting zone. This phenomena leads to a greater removal of molten layer that is not flushed out by the dielectric fluid but it re-solidifies and remains attached to the machined surface. The thickness of recast layer depends on electrode material, type of dielectric and also the flushing conditions. EDM erodes the surface randomly and the surface finish is poor because of more frequent cracking of dielectric fluid as well as metal expulsion. The microcracks present on the re-solidified features observed in figure 3 are attributed to the differential thermal gradient on the surface.

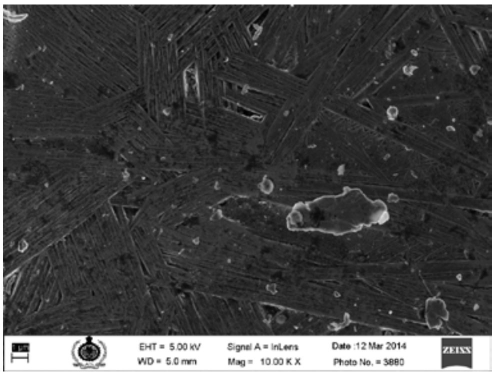

Figure 2 SEM micrograph of OHNS die steel

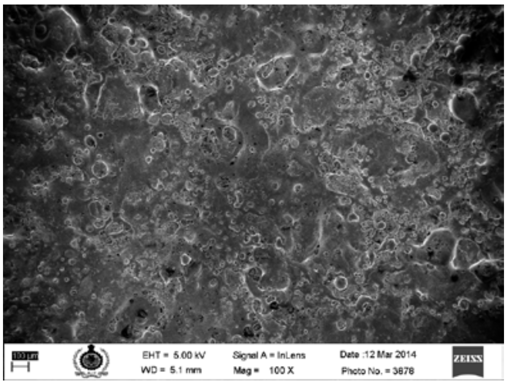

Figure 3 SEM of OHNS die steel after machining

3.3 Wear and Friction Analysis

Wear test was performed on the parent OHNS work material along with PMEDM processed samples. The coefficient of friction of OHNS die steel was found to be 0.212. Table 3 shows the wear test results, it can be seen from the table that coefficient of friction (COF) for OHNS parent material is low in comparison to EDMed surface. The surface EDMed by using copper electrode showed higher COF as seen from table 3. It can be been seen from table 1 that the trial no. 5,6,7 has higher hardness which increases the surface roughness thereby raise in coefficient of friction of the specimen.

Table 3 Coefficient of friction results

Trial No.	Gap Current	Pulse On	Pulse Off	Coefficient of Friction
1	5	12	7	0.229
2	3	8	7	0.221
3	1	4	7	0.22
4	1	4	9	0.209
5	3	8	9	0.353
6	5	12	9	0.287
7	5	12	8	0.247
8	3	8	8	0.281
9	1	4	8	0.237

3.4 XRD analysis

XRD pattern obtained from the machined surface given in figure 4 shows the presence of WC, Fe_3C and elemental W. This confirms the transfer of tungsten from the tungsten powder suspended in dielectric and migration of carbon from the dielectric onto the die material surface. The corresponding spectroscopic analysis of the machined surface confirm carbon pick up by the machined surface from the initial 0.94% to 8.87% and tungsten from 0.25% to 2.89% (Table 2).

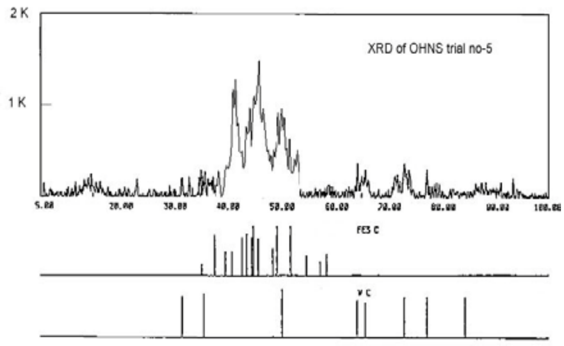

Figure 4 XRD pattern of OHNS

4 Conclusions

Experiments were conducted on OHNS die steel material by electrical discharge machining using machining conditions favoring material transfer from tungsten powder suspended in the dielectric medium. Surface alloying with tungsten and carbon has a significant effect on its properties as observed from the increase in microhardness by more than 100% for all work materials. SEM, spectroscopic analysis and XRD analysis revealed significant amount of material migration from the suspended powder and dielectric being deposited on the PMEDM machined surfaces. Favorable machining conditions for material transfer by EDM are found to be low discharge current (less than 3 A), shorter pulse on-time (less than 8 µs), longer pulse off-time (more than 7 µs) and negative polarity of the tool electrode. Peak current is the most significant factor for the phenomenon of surface modification. Tribological results reveals that the coefficient of friction is high for modified surface due to increase in the surface roughness of the specimen because of migration of particles from powder and dielectric. Under appropriate machining conditions, significant amount of material transfer can take place from the powder suspended in the dielectric medium to the work material.

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References:

[1] Y.S. Wong, L.C. Lim, I. Rahuman, W.M. Tee, Near mirror-finish phenomenon in EDM using powder-mixed dielectric. Journal of Materials Processing Technology, Vol. 79, 1998, pp. 30-40.

[2] K. Furutani, A. Saneto, H. Takezawa, N. Mohri, H. Miyake, Accretion of titaniumcarbide by electrical discharge machining with powder

suspended in working fluid. Precision Engineering, Vol. 25, 2001, pp.138–144.

[3] J. Simao, H.G. Lee, D.K. Aspinwall, R.C. Dewes, E.M. Aspinwall, Workpiecesurface modification using electrical discharge machining. International Journalof Machine Tools & Manufacture, Vol. 43, 2003, pp. 121–128.

[4] B.H. Yan, H.C. Tsai, F.Y. Huang, The effect in EDM of a dielectric of a ureasolution in water on modifying the surface of titanium. International Journal of Machine Tools & Manufacture, Vol. 45, 2005, pp. 194–200.

[5] H.K. Kansal, S. Singh, P. Kumar, Performance parameters optimization of powder mixed electric discharge machining (PMEDM) by Taguchi method, West Indian Journal of Engineering, Vol.29, No.1, 2006, pp.81-94.

[6] S. Kumar, R. Singh, T.P. Singh, B.L. Sethi, Surface modification by electrical discharge machining: A review, Journal of Materials Processing Technology, Vol. 209, 2009, pp.3675–3687.

[7] M.Y. Ali, N. Atiqah, Erniyati, Tungsten powder mixed micro electro discharge milling of Titanium alloy, International Journal of Mechanical and Materials Engineering, Vol.6 No.3, 2011, pp.338-342.

[8] C. Mai, H. Hocheng, S. Huang, Advantages of carbon nanotubes in electrical discharge Machining", International Journal of Advanced Manufacturing Technology, Vol.59, Issue 1-4, 2012, pp.111-117.

[9] S. Kumar, U. Batra, Surface modification of die steel materials by EDM method using tungsten powder-mixed dielectric, Journal of Manufacturing Processes, Vol. 14, 2012, pp.35- 40.

[10] S. Kumar, R. Singh, A. Batish, T.P. Singh, Electric discharge machining of titanium and its alloys: a review, International Journal of Machining and Machinability of Materials, Vol. 11, No. 1, 2012, pp. 84-110.

[11] A. Bhattacharya, A. Batish, N. Kumar, Surface characterization and material migration during surface modification of die steels with silicon, graphite and tungsten powder in EDM process, Journal of Mechanical Science and Technology, Vol. 27, No.1, 2013, pp.133-140.