EMPLOYING SiC NANO-POWDER DIELECTRIC TO ENHANCE MACHINABILITY OF AISI D3 STEEL IN ELECTRICAL SPARK MACHINING

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Abstract: Augmenting the machining capability of Electric Spark Machining (ESM) has continually been a foremost concern in the manufacturing sector. Although, ESM with powder blended dielectric has revealed the substantial potential in enhancing material removal rate and improving surface finish, usage of proper powder material is still not very specific. The current work utilized SiC nano powder blended dielectric and examined its role along with other governing factors viz., peak current, pulse-on time and gap voltage on material extraction rate (MER) during powder-blended ESM (PBESM) of AISI D3 steel (a high carbon high chromium steel), that is now-a-days widely used in header dies, punches and other applications in Tool and Die industries. Results showed that all the considered governing factors have substantial impact on material extraction. A significant enhancement of 24.7% on material extraction is observed with blending of nano powder into dielectric.
Key words: AISI D3 Steel, SiC nano powder, Powder-Blended ESM (PBESM), Material Extraction Rate (MER)

1. INTRODUCTION

In recent times, among all available Die Steels, AISI D3 steel is widely used in header dies, punches and other applications in Tool and Die industry (Singh, N.K. and Poras, A., 2018; Jamadar, M.M. and Kavade, M. V, 2014; Abrol, A. and Sharma, S., 2015). It is a specially alloyed (high carbon and high chromium), cold worked steel designed for high impact toughness, strength and wear resistance at room and higher temperatures. Its' low machinability and high hardness [HRC: 54-61] made this material difficult-to-cut using conventional machining process (Serope, K. and Steven R., S., 2002). Among all modern non-traditional machining procedures conceived in the recent past, Powder Blended Electric Spark Machining (PBESM) turned out to be very well known for machining these steels (Tan, P.C. and Yeo, S.H., 2011). Suspending 37, 44 and 74μm sized aluminium powder of quantities 0-12g/L in EDM oil supplied by the manufacturer (Kumar, A. et al., 2011) fabricated circular holes on Inconel 718 using copper electrode. It is stated that powder concentration and size influenced EDM efficiency. It was also mentioned that highest Material Removal Rate (MRR) is obtained for 44μm powder at 6g/L concentration. H K Kansal et al., (2006) mixed (20-30)μm aluminium powder into kerosene with quantities up to 6 g/L to machine Al-10%SiCp material for 40minutes time. It was reported that added aluminium powder enhanced MRR up to certain (3g/L) concentration. Also it was stated that most influential parameters on performance of EDM are concentration of added powder and peak current. Kumar, S. and Singh, R., (2010) investigated the effect of pulse on-time, peak current, and pulse off-time when machining OHNS die steel dipped in commercial grade kerosene blended with 15g/l manganese powder. It was witnessed that all input factors show noteworthy effect on micro hardness with peak current being the most significant factor by contributing 83.41%. An enhancement in micro hardness from 607 to 1049.33 HV was also observed. This improvement was due to migration of added powder upon to the machined surface submerged in dielectric. Long, B.T. et al., (2014) examined the influence of various titanium powder volumes, pulse off time, discharge current, peak current and pulse-on time on MRR, Tool Wear Rate (TWR) and Surface Roughness (SR) when machining SKD61 hot work steel using copper electrode. It was conveyed that the addition of Ti powder resulted in 45.45% enhancement in MRR, 33.6% reduction in TWR and 21.5% reduction in (SR. Singh, S. and Kalra, C.S., 2014) suspended tungsten powder into EDM oil dielectric to observe the machining performance on EN24 alloy steel in terms of MRR. The other input factors considered were duty cycle, peak current, and pulse-on time. An enhancement of 90.78% of MRR was observed by increasing powder concentration. In another attempt by (H K Kansal et al., 2007) to optimize process parameters utilizing Taguchi design, 25mm diameter blind holes were drilled on AISI

D2 Die steel when it is dipped in Kerosene doped with 0-4g/L 30µm silicon powder. It was mentioned that optimum machining rate is obtained at 4g/L powder concentration. Unses, E. and Cogun, C., (2015) investigated the influence of 37µm graphite powder blended kerosene when machining Ti-6Al-4V Alloy. It was reported that the added powder enhanced the material removed by 25%.

It is apparent from the preceding studies, that substantial work has been recorded on the role of PBESM in enhancing material removal rate. Further, it is evident that earlier studies reported the findings reckoned after blending micron-size metal (Al, Mn, Ti, W), non-metal (Gr) and metalloid (Si) powders into ESM dielectric. Moreover, a few studies are available on PBESM of AISI D3 steel. Despite possessing the favourable characteristics like low density and high thermal conductivity (Talla, G., et al., 2017; Ali, M.Y. and Atiqah, N., 2011), the effect of SiC nano powder has not been studied enough in the PBESM of AISI D3 steel. Hence, this research work concentrates on utilizing SiC nano powder and evaluates its role along with other governing factors, on material extraction rate (MER) during powder-blended ESM of AISI D3 steel.

2. MATERIALS AND METHODS

2.1 Materials

AISI D3 STEEL (30×30×5) as portrayed in Figure 1 is chosen as the workpiece. The presence of chromium resists oxidisation and this steel is conductive, it is suitable for electric spark machining.

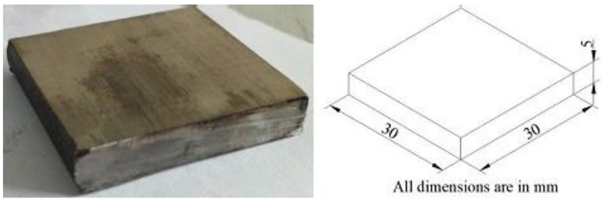

Fig. 1. AISI D3 steel workpiece

Copper electrode of 9.5mm diameter and 150mm length, as presented in Figure 2, is selected as tool due to its inherent properties viz., high thermal conductivity, melting point and density. SiC Nano-powder procured from SISCO Research Laboratories Ltd is utilized in the current work. The average crystallite size of SiC nanopowder is 50nm as claimed by the manufacturer.

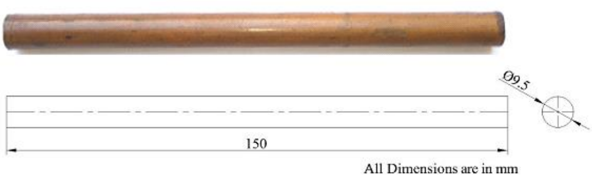

Fig. 2. Copper Tool

2.2 Experiment Set-up

Smart ZNC (S-ZNC) ESM machine manufactured by ELECTRONICA INDIA LIMITED available in GMR Institute of Technology which is acquired as a part of DST funded project is utilized to conduct all sets of experiments. The main operating tank has the dimensions of 80×50×35 and requires 140lts dielectric oil. If the main operating tank supplied with the machine is used directly, a significant amount of nanopowder is needed for mixing in such large tank to obtain desired powder concentration in dielectric fluid for operation. Further, employing the existing filtering system provided with the machine may damage the filtering system due to the clogging problems that may arise due to re-circulation of the nanopowder blended dielectric. So, to overcome these difficulties, there is a need to design, fabricate and install a new experimental setup on the existing EDM machine. With the modified working tank placed inside the main tank, only a small amount of nanopowder per litre as detailed in Table 1 is blended into the dielectric.

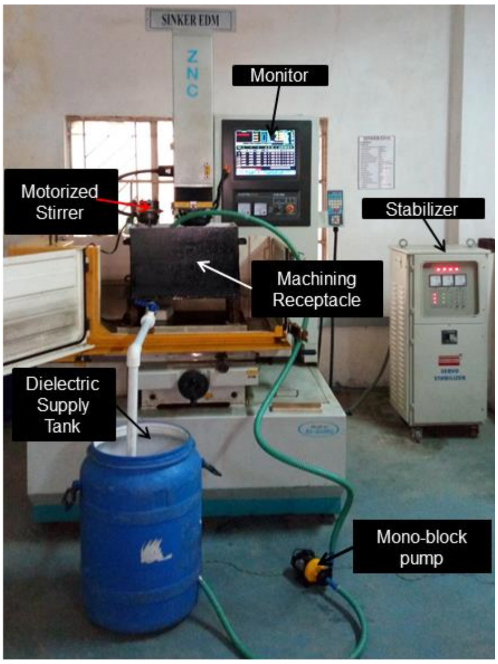

Fig. 3. PBESM Experiment Set up

The newly fabricated set-up is as in Figure 3. It consists of mild-steel machining receptacle that can accommodate 10lts of powder-blended dielectric. It also consists of a motorized stirrer fitted to the side wall of machining receptacle at the top, workpiece holding magnet, and dielectric recirculation pump. Motorized stirrer prevents agglomeration and powder particles settling at the lowest point in the tank. The magnetic field created by permanent magnets will help to segregate the scrap/debris from the dielectric fluid. Dielectric recirculation pump helps in continuous circulation of the powder blended dielectric fluid in the spark gap (the tool-workpiece interface).

2.3 Governing factors and Performance Assessment Parameter

Four Governing factors, i.e. Concentration of powder blended (*COPB*), Gap Voltage (*GV*), Pulse-ON Time (*PoT*) and Peak Current (*PC*), are selected for the present research work. Selection of governing factors is judged by the point that they have a noteworthy influence on PBESM characteristics. Table 1 depicts their levels and values used during experimentation.

Table 1. Governing factors and their levels

Parameter	Units	Level				
		-2	-1	0	1	2
COPB	g/l	0	0.2	0.4	0.6	0.8
GV	V	40	50	60	70	80
PoT	µs	100	200	300	400	500
PC	A	2	4	6	8	10

Material Extraction Rate (MER) in mm^3/min is considered as Performance Assessment Parameter. It is calculated by weight loss method (Kansal, H.K., et al., 2006) employing the equation (1).

$$\text{MER } (mm^3/min) = \Delta T_w/(\rho \times t) \qquad (1)$$

where ΔT_w = weight difference of the workpiece before and after machining (g); ρ = density of the work material in (g/mm^3); t = machining time in minutes.

A digital weighing balance capable of weighing a minimum of 0.02g and a maximum of 320g is used in current work to measure the workpiece weight before and after machining.

2.4 Experimentation

Both workpiece and tool surfaces are adequately cleaned before machining. Workpiece is connected with positive polarity for all the experiments. Based on the operational manual of the ESM machine, servo sensitivity (SEN) which controls the speed of quill is set to 7 during idle tool travel and 3 during machining and pulse duty cycle is set to 10 (Santarao, K., et al., 2018). The experiment time is set to 20min in accordance to the literature (Yih-Fong, T. and Fu-Chen, C., 2005; Singh, P. et al., 2010, Tzeng, Y.F. and Lee, C.Y., 2001). Thirty experiment tests i.e., combinations of governing factors' values, were contemplated agreeing to Central Composite Design (CCD) of Response Surface Methodology (RSM).

3. RESULTS AND DISCUSSION

The various combinations of governing factors for conducting the experiments and the measured MER values are listed in Table 2. Main effect plots that graphically describe the variation of Material Extraction Rate upon changing the governing factors levels are drawn by grouping the MER values by factor levels of each governing factor and then averaging them (Rajeswari, B. and Amirthagadeswaran, K.S., 2017).

Table 2. MER values for all combinations

Exp. No	COPB (g/l)	GV (V)	PC (A)	PoT (µs)	MER (mm^3/min)
1	0.0	60	6	300	2.117
2	0.2	50	4	200	2.055
3	0.2	50	4	400	1.126
4	0.2	70	4	200	1.501
5	0.2	70	4	400	0.511
6	0.2	50	8	200	4.597
7	0.2	50	8	400	3.211
8	0.2	70	8	200	4.507
9	0.2	70	8	400	3.188
10	0.4	60	2	300	0.977
11	0.4	40	6	300	2.102
12	0.4	60	6	100	3.422
13	0.4	60	6	500	1.859
14	0.4	60	6	300	2.145
15	0.4	60	6	300	2.196
16	0.4	60	6	300	2.196
17	0.4	60	6	300	2.145
18	0.4	60	6	300	2.196
19	0.4	60	6	300	2.145
20	0.4	80	6	300	2.525
21	0.4	60	10	300	5.676
22	0.6	50	4	200	1.695
23	0.6	50	4	400	1.796
24	0.6	70	4	200	2.173
25	0.6	70	4	400	2.137
26	0.6	50	8	200	3.037
27	0.6	50	8	400	3.056
28	0.6	70	8	200	4.648
29	0.6	70	8	400	3.958
30	0.8	60	6	300	2.787

3.1 Effect of COPB on MER

Impact of COPB on Material Extraction Rate is depicted as in Figure 4. On observing, it can be inferred that as powder concentration increases from zero level to 0.6 level an increasing trend is prevailing. The probable reason for this enhancement in MER is that the semi-conductive or conductive fine particles present in the spark gap can significantly lessen the breakdown strength of the dielectric. This low breakdown strength dielectric eases the ignition process which in due course results in a superior spark gap. The larger spark gap can facilitate the flushing process, thus providing higher MER in PBESM (Yih-Fong, T. and Fu-Chen, C., 2005; Jahan, M.P., et al., 2010). But from 0.6 level to 0.8 level a decrease in MER is observed. The decrease of MER after 0.6g/l might be attributed to short circuit formed at more powder density. This situation enables the machining process to become an irregular condition to the net decline in MER (Jahan, M.P., et al., 2010; Kansal, H.K., 2005).

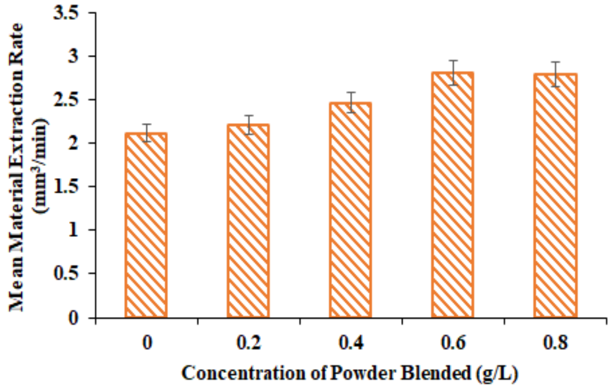

Fig. 4. Variation of MER with Concentration of Powder Blended

3.2 Gap Voltage effect on MER

The variation of the MER with the variation of Gap Voltage from 40V to 80V is depicted in Figure 5.

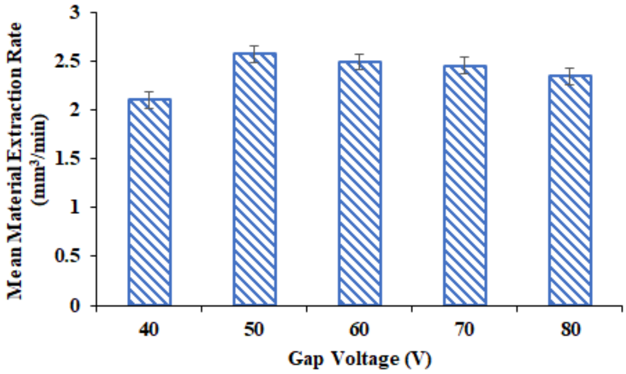

Fig. 5. Variation of MER with Gap Voltage

It is evident that till 50V of Gap Voltage MER is found to increase. For further increase in Gap Voltage a down trend is observed in the MER. Initially as the Gap Voltage increases the increase in MER is observed due to high spark energy. Later, at high Gap Voltage, the spark gap increases, resulting in increased time to fill the discharge gap with ions and electrons. For this reason, the energy density and energy dissipation efficiency decreases in the discharge gap. Hence, decrease in MER is figured out (Kumar, A. et al., 2011; Wu, K.L. et al., 2009; Talla, G., et al., 2016).

3.3 MER variation with respect to Pulse-ON time

The dependence of Material Extraction Rate when changing PoT from 100µs to 500µs is presented in Figure 6.
An observation into this graph reveals a downtrend in this response within the range considered. The energy in the form of heat between the surfaces of two electrodes, first transforms the surface layers of the work material into liquid and then into vapour stage.

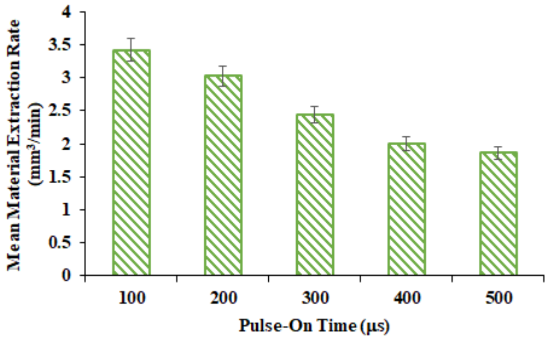

Fig. 6. Deviation in MER with pulse ON time

Later, work material in vapor phase comes out of the spark gap which is further cooled by the surrounding dielectric resulting in the formation of debris. With increase in Pulse-ON time, the plasma channel will get widened in the spark gap leading to the reduction of the heat energy density on the workpiece. As a result, the vaporization of the material in the spark gap will be reduced and hence the material extraction. (Yih-Fong, T. and Fu-Chen, C., 2005; Tzeng, Y.F. and Lee, C.Y., 2001).

3.4 MER change with Peak Current

The varying nature of rate at which material is extracted with change in peak current is depicted in Figure 7. As peak current increases from a low level of 2A to a high level of 10A a continues increment in response is observed. This observation is due to the fact that as peak current increases an expansion in the spark energy prompts impetuous force on the stock surface. This force expels more volume of material in molten form and intensifies the material removed from stock (Bai, X. et al., 2013).

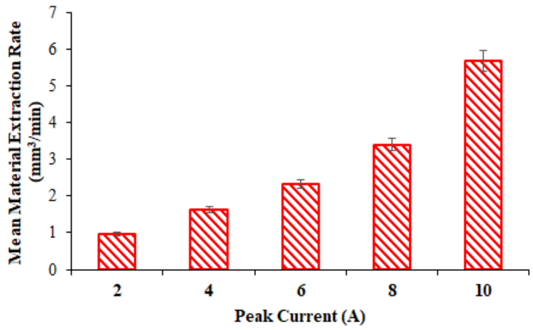

Fig. 7. MER change with Peak Current

4. CONCLUSIONS

In the current research work, experimental investigation to evaluate the effect of SiC nano powder-blended dielectric and ESM governing factors was carried out according to RSM-based design of experiment. Results clearly demonstrated remarkable improvement in Material Extraction Rate for PBESM compared to ESM without powder additive. All the considered governing factors have substantial impact on MER. It is observed that mean MER enhanced from 2.117mm^3/min to

$2.812 mm^3/min$ (24.7%); with addition of nano powder into dielectric. It is also observed that mean MER enhanced from $0.978 mm^3/min$ to $5.677 mm^3/min$ (82.7%) with increase in peak current. However, pulse-on time and gap voltage had inverse effect on MER.

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