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Influence of dominant variables and their optimization for nano powder blended EDM process

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Electric discharge machining (EDM) is a non-contact type manufacturing process used to machine hard materials. Obtaining surfaces with the desired surface finish is the primary challenge when employing this process in any industry. Powder blended EDM, a process in which properties of dielectric are varied by blending it with an appropriate weight of powder, is one among many methods coined to overcome this challenge. Also, previous researchers concentrated on blending dielectrics with semi-metal, metal and non-metallic powders to understand the variations in material removal rate and surface finish. Results inferred employing ceramic powders as a blend in EDM dielectric medium have been still limited. Hence, to bridge this gap, the current work attempts to investigate the influence of ceramic powder concentration, pulse-on time, peak current, gap voltage on the surface roughness of AISI D3 Die steel. Several experiments have been conducted with different combinations of process parameters using Taguchi method. Results indicated that powder concentration plays a significant role in enhancing surface finish, i.e., the quality of the machined surface. Further, among the other parameters considered peak current has the highest impact followed by pulse-on time and voltage on the performance response. Also, the optimum levels of process parameters have been obtained as peak current – 6 Amp, pulse-ON-time – 100µs, gap voltage – 70V and SiC nano powder concentration – 0.5g/L.

Keywords: SiC nanopowder, Surface roughness, Taguchi technique, Micro-cracks

1 Introduction

In recent years, electric discharge machining (EDM) gained prominence due to its effective machining of high precision micro-size products with complex geometries irrespective of the hardness of the material used[1,2]. In order to improve EDM efficiency researchers followed three different approaches. In the first approach, fine powder is suspended into dielectric fluid which improves homogeneous disbursement of sparking among the powder particles creating shallow craters on the workpiece exterior surface causing enrichment in surface finish[3].The second approach is tool rotation that creates flushing effect and reduces debris accumulation within the discharge gap thereby enhancing material subtraction rate[4]. The third approach is vibrating the workpiece which enhances the machining time[5]. Out of three methods first approach offers better machined surface quality to the workpiece[4]. Tzeng Yih-fong *et al.*[6] proclaimed that 70–80nm powder blended Hercules ED 320H resulted in better surface finish on SKD-11. Jahan *et al.*[1] experimented with 55 nm Gr blended Total FINA ELF EDM3 oil when machining cemented tungsten carbide. GS Prihandana *et al.*[7] experimented with ultrasonicated 55nm Gr blended kerosene on silver-tungsten and reported that surface quality of machined surface improved. Tan *et al.*[8] reported that 40-47 nm SiC and 45-55 nm Al_2O_3 blended Idemistu Daphene cut HL25-S oil on stainless mold steel reduced the average surface roughness by 14-24%. Marashi *et al.*[9] concluded that 40-60 nm Ti powder blended hydrocarbon oil on D2 steel resulted in an enhancement of Material Removal Rate and reduction in average surface roughness. A glimpse of literature reviewed is tabulated in Table 1.

It is obvious from Table 1 that researchers tested cemented tungsten carbide, silver-tungsten, stainless mold steel, D2 die steel materials. It is also evident that earlier researchers blended dielectrics with semi-metal (Gr), metal (Al, Cr, Cu, Ti) and non-metallic (Al_2O_3) powders to interpret the variations in Material Removal Rate and Surface Finish. Results inferred employing ceramic powders as a blend in EDM

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Table 1 — Glimpse of literature reviewed.

Reference	Authors	Workpiece Material	Powder & Size (μm)	Dielectric used	Findings
[1]	M P Jahan, M Rahman, Y S Wong	WC–10 wt.% Co	Graphite 0.055	Total FINA ELF EDM 3	High MRR achieved at 0.8 g/L concentration
[2] [5] [7]	G S Prihandana, M Mahardika, M Hamdi, Y S Wong, K Mitsui	Silver–Tungsten	Graphite 0.055	Kerosene	Surface quality of machined surface improved
[4] [8]	P C Tan, S H Yeo, Y V Tan	Stainless Mold Steel	Aluminium Oxide (0.040-0.047), Silicon Carbide (0.045-0.055)	Idemistu Daphene cut HL25-S oil	Average surface roughness reduced by 14-24%
[6]	TzengYih-fong, Chen Fu-chen	SKD-11	Al, Cr, Cu, SiC 0.07–0.08, 10–15, 100	HERCULES ED 320H	Finest particles resulted in better surface finish
[9]	H Marashia, A A D Sarhana, H Mohd	D2 Die steel	Titanium 0.04-0.06	Hydrocarbon Oil	Enhancement was observed in both MRR and average surface roughness

dielectric medium are still limited. Hence, to bridge this gap, the current research focused on ceramic powder (SiC) as blend in EDM dielectric to machine AISI D3 steel, a most commonly used material for die & tool making, and to interpret the variation in surface roughness. Further, optimum combination of parameter levels to achieve a better surface finish is also reported after conducting a validation experiment.

2 Experiment Set-up and Materials

Smart ZNC (S-ZNC) EDM 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 control system of the machine has an option to alter the levels of all the input variables like discharge voltage, pulse on time, pulse duty cycle, polarity, peak current and flushing type that are available on this machine. This machine accommodates tool travel of maximum 25cm along the Z-axis. The main operating tank of the machine allows tool movement of 30cm and 20cm along X and Y directions respectively, which can be operated manually along each axis at a time. The main operating tank has the dimensions of 80cm × 50cm × 35cm and requires 140 L 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 2 is blended into the dielectric.

Three parts of the newly fabricated small operating tank set-up as in Fig. 1 are (i) machining receptacle (ii) internal powder-blended dielectric circulation system that is operated during machining and (iii) external powder-blended dielectric system that is operated after machining. Machining receptacle is an open-top, rectangular shaped mild-steel tank which can accommodate 10lts of powder-blended dielectric. The volume of this machining receptacle is fixed so that it fits into the main operating tank such that the tool-workpiece contact area, work holding magnet, dielectric recirculation pump are entirely submerged in the dielectric. Internal powder-blended dielectric circulation system consists of a motorised stirrer fitted either to the side wall of machining receptacle at the top or fitted on a tripod stand, workpiece holding magnet, and dielectric recirculation pump. Stirring system is employed in this tank to achieve a homogeneous dispersion of nanopowder in the dielectric fluid. Motorized stirrer prevents agglomeration and settling of powder particles at the bottom of 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 the proper blending of powder with dielectric fluid and circulating the same in the spark gap (the tool-

Table 2 — Experimental trials incorporating L9 OA.

Experiment Trail	Levels				Surface Roughness values (μm)				S/N Ratio
	A (Amperes)	B (μsec)	C (Volts)	D (g/l)	Along A	Along B	Along C	Mean	
1	5	50	50	0	6.91	6.24	6.58	6.575	-16.3579
2	5	100	60	0.5	4.55	4.55	4.56	4.550	-13.1602
3	5	150	70	1	5.03	5.18	5.10	5.105	-14.1599
4	6	50	60	1	4.57	4.69	4.67	4.630	-13.3116
5	6	100	70	0	4.69	4.42	4.57	4.555	-13.1698
6	6	150	50	0.5	4.85	4.59	4.73	4.720	-13.4788
7	7	50	70	0.5	5.00	4.95	4.96	4.975	-13.9359
8	7	100	50	1	5.04	4.90	4.97	4.970	-13.9271
9	7	150	60	0	6.57	6.61	6.80	6.590	-16.3777

Fig. 1 — Experimental set-up.

workpiece interface) continuously. External powder-blended dielectric system comprises dielectric storage tank fitted with filters and a mono block pump. Permanent magnets are used in this tank to separate the debris from the dielectric fluid. The actual picture and close view of experimental setup are as in Fig. 1. AISI D3 die-Steel of size 45mm×32.5mm×12mm and copper rod of dimensions 150mm×9.5mm are considered as work piece and tool, respectively in this experimentation. Tzeng Yih-fong *et al.*[6] reported that fine particles result in better surface finish, as such 50nm sized SiC powder is opted for present investigation.

2.1 Experiment plan

Four, three level quantitative type process variables viz., peak current (A), pulse-on time (B), gap voltage (C), and powder concentration(D) are chosen for present investigation. Surface roughness (SR) is considered as response. It could require a whole of eighty one (3^4) experiments to find the optimized combination of variables if full factorial design is carried out[10].In order to address this, the Taguchi method utilizes orthogonal arrays designed to contemplate the whole parameter space and its influence on response with minimum number of examinations[11,12]. As suggested by Datta *et al.*[13] L9 orthogonal array is selected to conduct experiments.

2.2 Surface roughness measurement

The roughness of a surface is purely dependent on its texture. It is counted by the vertical nonconformities of the real surface under inspection from the perfect surface. It is defined as the average value of roughness profile from the centre line. If this deviation is significant, the surface is said to be rough, else smooth. The expression of R_a is as in Eq. (1).

$$R_a = \frac{1}{l}\int |y(x)|.dx \quad \text{... (1)}$$

where,l is the sampling length, y is the height of peaks and valleys of roughness profile, and$x$ is the profile direction. It is schematically illustrated as in Fig. 2.

A surface roughness tester, Mitutoyo make (Model No. SJ-201), depicted in Fig.3 is used to measure surface roughness of the machined workpieces. It employs the centre line average method to display the required response. This roughness tester works in the range of -200 µm to +150 µm and has a diamond tip stylus. The stand supplied with the instrument is placed on the surface place on which the workpiece is placed so the test surface is facing top and parallel to the surface plate. Later the instrument SJ-201 is placed on the surface plate so that the stylus tip comes in contact with the machined surface at the boundary. Now by clicking the start button of the instrument, the stylus moves back and forth diametrically on the machined surface to assess the profile. Once the stylus reaches back to the starting point, it calculates the average value and displays the same on the screen. The surface roughness is measured along three directions on the machined surface which are equally spaced as shown in the schematic Fig.4, i.e., along three diameters on the machined surface confirmed by

Fig. 3 — Roughness measurement.

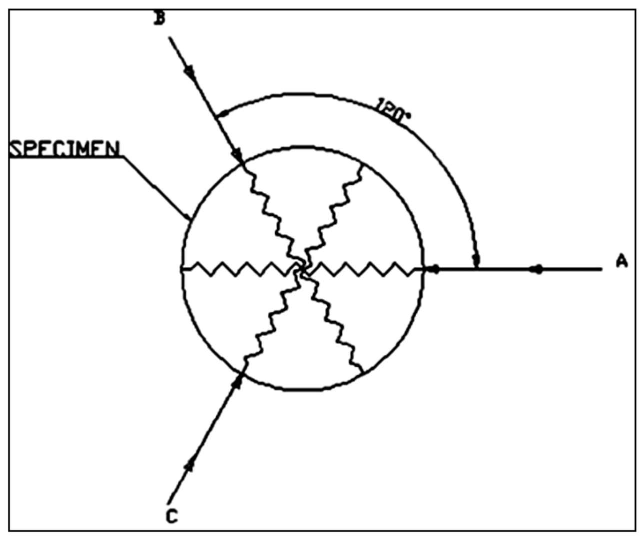

Fig. 4 — Roughness measuring schema[15].

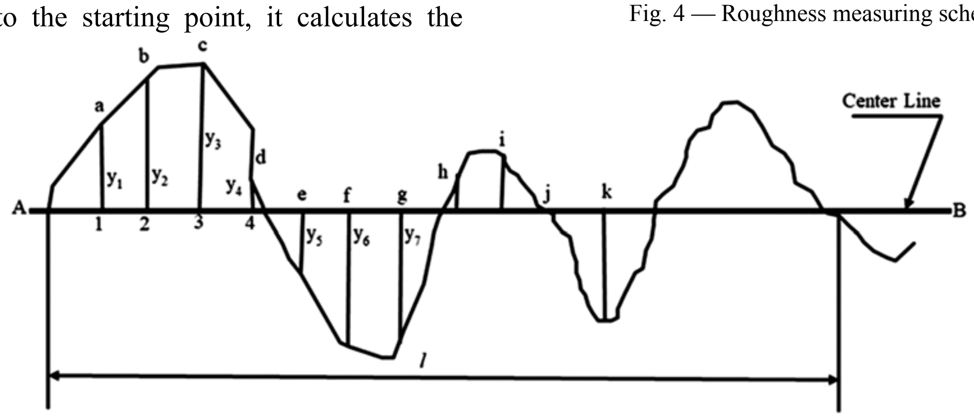

Fig. 2 — Surface roughness schematic[14].

visual inspection. Later the average of these values is calculated as the surface roughness of a specific specimen for further analysis.

3 Results, Analysis and Discussion

Data collected for all experiments are presented in Fig. 5. They are then transformed into their respective S/N ratio(signal to noise ratio) using MINITAB software and tabulated in Table 2 as Taguchi design utilizes S/N to compute variation in data[16]. In the present work, formula for S/N ratio depicted in equation (2) is used. Table 3 represents the average values of raw data of SR, S/N ratios, Δ (Delta) and rankings for each variable. Machined workpieces are depicted in Fig. 6.

$$S/N\ ratio = -10\ log_{10}\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \quad \ldots (2)$$

A careful observation of Rank column in Table 3 reveals that Powder Concentration and Peak Current are the most dominant variables affecting the SR and this observation is similar to as observed by

Table 3 — Average values of raw data and S/N ratio at different levels.

Process variable	Raw data Average values					S/N data Average values				
	L1	L2	L3	Δ	Rank	L1	L2	L3	Δ	Rank
A	5.410	4.635	5.512	0.88	2	-14.56	-13.32	-14.75	1.43	2
B	5.393	4.692	5.472	0.78	3	-14.54	-13.42	-14.67	1.25	3
C	5.422	5.257	4.878	0.54	4	-14.59	-14.28	-13.76	0.83	4
D	5.907	4.748	4.902	1.16	1	-15.30	-13.52	-13.80	1.78	1

Note: L1, L2, L3 correspond to Level1, Level2 and Level3, respectively.

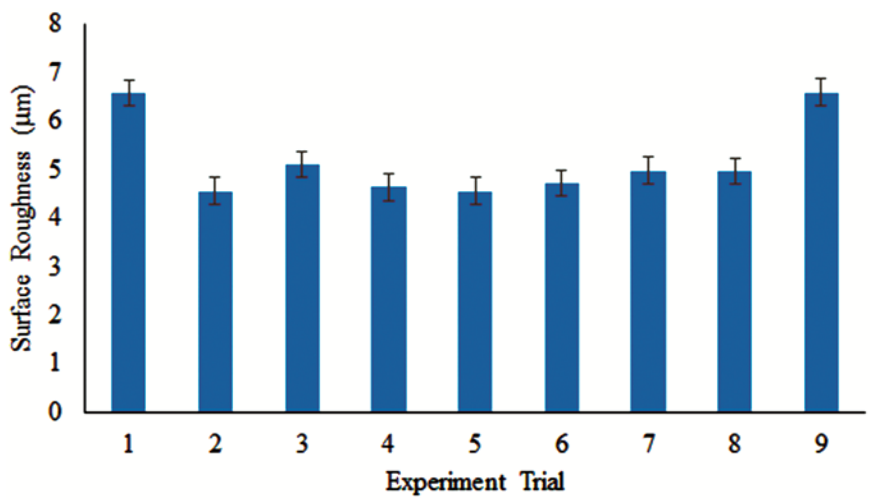

Fig. 5 — Surface roughness data.

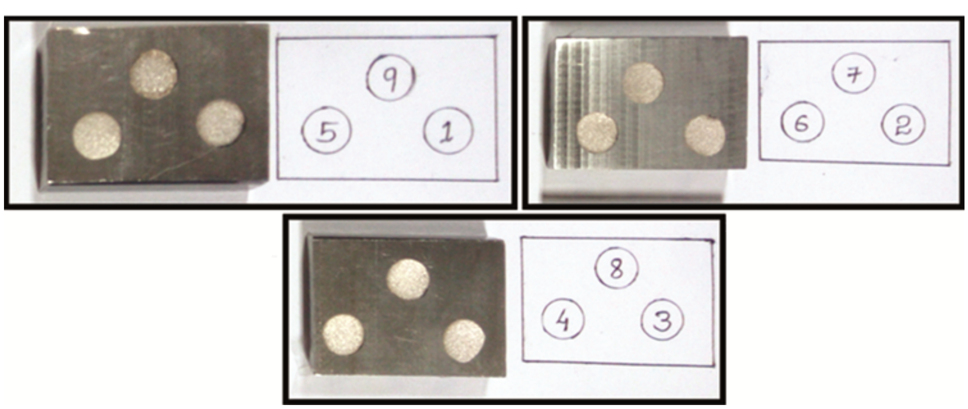

Fig. 6 — Blind holes fabricated for all combinations.

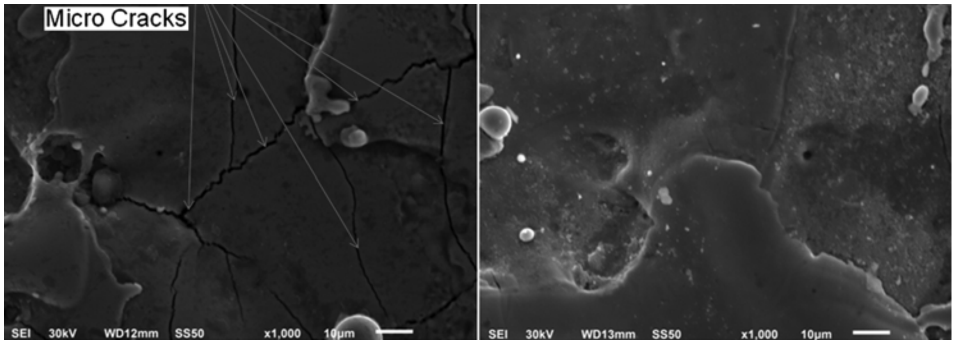

Fig. 7 — Micro-crack appearances on un-blended and blended dielectric machined surface.

Gangadharudu Talla *et al.*[17] and Harmesh Kumar *et al.*[18] Procedure adopted from a research article by H.K. Kansal *et al.*[16] is used to determine the optimal settings of input variables for best SR. Five steps involved in the procedure are as follows:

- Choose the variable level for lowest average SR value from "raw data average values" (Table 3).
- Select the variable level at highest S/N ratio value either from "S/N data average values of" (Table 3).
- Compare the levels obtained in step 1 and step 2.
- If they are equal, then optimal variable settings for best response are the ones obtained.
- If they are not equal compare the relative contribution of the process variable for mean and S/N ratio, then select the level consequent to a higher value.

Following the procedure, the corresponding variable levels of lowest SR and highest S/N ratio for SR are underlined in Table3. It is evident that the variable levels A2, B2, C3 and D2 are optimal settings for better SR. A better surface finish is noticed at low peak current and addition of powder into dielectric. The basis for the abatement in SR is the fact the added powder amends the plasma channel. The plasma channel becomes enlarged and widened. The sparking is uniformly strewn among the powder particles; accordingly, electric density of the spark alleviates. Subsequently, homogeneous attrition (shallow craters) occur on the workpiece surface. This gives rise to enhancement in the surface finish. Further, a confirmatory experiment conducted at the optimum machining conditions obtained i.e., Peak current – 6Amp, pulse-on-time – 100µs, Gap voltage – 70V and SiC nano powder concentration – 0.5g/L, revealed a ~20% reduction in surface roughness.

3.1 Effect of added powder on surface texture

The horizontal portion of the blind hole's surface was captured for both blended and unblended conditionemploying a scanning electron microscope, JEOL make – JSM6510LV, at WD 12 mm, 1000X magnification and SEI 30kV and presented in Fig. 7. As SiC nano powder added into dielectric, micro-cracks appeared less on the surface (Fig. 7(b)) as a result of the over-all impact of the breaking up as well as syndication of the electric energy path over the surface. In addition, the suspension of powder in nano size provided a superior sparking space, which introduced abatement in electric discharge power denseness, consequently minimal explosion force considering that micro-cracks are interlinked with the progression of thermal stresses exceeding the materials ultimate tensile strength[7].

4 Conclusions

In the present work SiC of 50nm size is blended into EDM Dielectric and its effect along with three other process variables on surface roughness of blind holes fabricated on AISID3 steel is investigated. Further, to the application of Taguchi technique for optimization, the following conclusions can be drawn:

(i) Powder concentration is most dominant influencing variable on Surface Roughness of fabricated blind holes. Peak Current and Pulse-ON time are the other dominant variables on Surface Roughness in a chronological order. The effect of Gap Voltage is least on Surface Roughness.

(ii) The optimal variable settings for best Surface Roughness are Peak current – 6Amp, pulse-on-time – 100µs, Gap voltage – 70V and SiC nano powder concentration – 0.5g/L. A confirmatory experiment conducted with the obtained optimal setting revealed a ~20% reduction in surface roughness when SiC nano powder is blended into EDM dielectric.

(iii) As SiC nano powder is added into dielectric, micro-cracks appeared less on the surface as a result of the over-all impact of the breaking up as well as syndication of the electric energy path over the surface.

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