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Comparison on machining characteristics of AISI 304 steel during micro and nano powder mixed electrical discharge machining process

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Abstract: The experimental analysis on the influence of duty factor and powder particle size on discharge energy, material removal rate and surface integrity is made during powder mixed electrical discharge machining process. Molybdenum-di-sulfide (MoS_2) powder particles of two different size viz. 40µm (micro) and 90 nm (nano) are used. During experimentation duty factor is varied as 2, 4, 6, 8, 10 and 12. A comparative evaluation on the effect of using two size of molybdenum-di-sulfide powder particle in dielectric medium is studied. For all duty factors, micro powder offered high discharge energy and better surface finish compared to that of nano powder. Nano powder offered high material removal rate compared to that of micro powder. The occurrence of series discharge during powder mixed electrical discharge machining is observed using pulse train generated in gap and using scanning electron microscope image of machined surface. The e energy dispersive X-ray spectroscopy analysis of machined surface reveals the deposition of molybdenum-di-sulphide from dielectric medium for both micro and nano powder mixed electrical discharge machining process.

1. Introduction

Electrical discharge machining (EDM) is a spark erosion process used to create complex profiles on hard to machine electrically conductive materials. Material removal in EDM happens by repetitive spark that occur at random location in between the tool and work piece, separated by a small gap immersed inside a dielectric medium. Recent research work involve in studying the effect on suspension of conductive powder particles into dielectric mediumknown as powder mixed EDM (PMEDM),to improve EDMs machining characteristics. Conductive solid powder particles of varying dimension and lipophilic surface agents were added to kerosene dielectric of EDM process and published some improvement in surface integrity of machined surface [1]. Zhao et al. attempted to make a comparison on surface generated using conventional EDM and powder mixed EDM processes. Aluminium powder of 10µm diameter is mixed in liquid dielectric of PMEDM process and the experimental result shown that, PMEDM produce better surface compared to that machined with conventional EDM process [2]. Cogun et al. made an effort to generate hard wear resistant surface by mixing boric acid into liquid dielectric of EDM process [3]. Pure Silicon of 10µm and SiC (mesh size 500) particles with varying concentration 0-25 g/l were used to machine AISI H13 steel and IF steelrespectively during PMEDM process. The surface roughness value of 2~3 µm is achieved by using 5 g/l of silicon powder concentration and surface roughness of machined surface increase at higher concentration [4-5].Authors made an attempt to explore the effect of mixing Cr, graphite, SiC, Al, Fe, CNT powder in dielectric medium on machining characteristics during EDM process and stated that among all powders, Al and CNT powder offered better surface morphology [6-7]. Chen et al. [8] studied the amount of re-solidified layer formed on pure titanium work piece during titanium powder (35-45 µm size) mixed EDM process and stated the re-solidified layer thickness and surface cracks increase while using deionized water as dielectric medium.Authors proposed a hypothesis on deposition of titanium nitride on machined SKD 11 steel surface using TiN powder of ~2 µm size mixed in kerosene dielectric medium during EDM process [9]. Prakash et al. [10] explored the possibility of generating bio-compatible layer on β-titanium material using pure silicon powder <35µm size mixed in dielectric medium during EDM process. Wang et al. [11] proposed a hypothesis by conducting mono pulse experiments to understand the plasma channel properties by suspending aluminium powder of 100 nm size into kerosene dielectric of EDM process. Razak et al. [12] studied the corrosion behaviour AZ31 magnesium alloy machined using 90 nm size zinc powder mixed in dielectric medium of EDM process. Rajeswari and Shunmugam made an extensive study to understand EDM gap phenomena by suspending graphite powders (10µm size) into dielectric medium [13-14]. Authors have studied the impact of graphite powder suspended into dielectric medium during EDM machining of Nimonic263 super alloy [15].

Literature disclosestheattempt made by researchers to explore the influence of various conductive powder particles such as Al, Cr, Si, SiC, Ti, TiN, MoS_2 and graphite of size range 90 nm-45 µm mixed in dielectric medium during EDM process. However, the influence on using molybdenum-di-sulfide powder into hydrocarbon based dielectric medium in EDM process is not much explored. The objective of this work is to explore the impact of different sizes of MoS_2 powder suspended into dielectric medium and studying the machining characteristics of AISI 304 steel machined during MoS_2 powder mixed EDM process.

2. Experimental details

Electronica die-sinking EDM machine (model smart ZNC) with iso-pulse generator is used for conduct of experiments. The experimental setup and test condition used for conduct of experiment is given in figure 1 and table 1 respectively. Experiments are conducted by varying duty factor at 2, 4, 6,

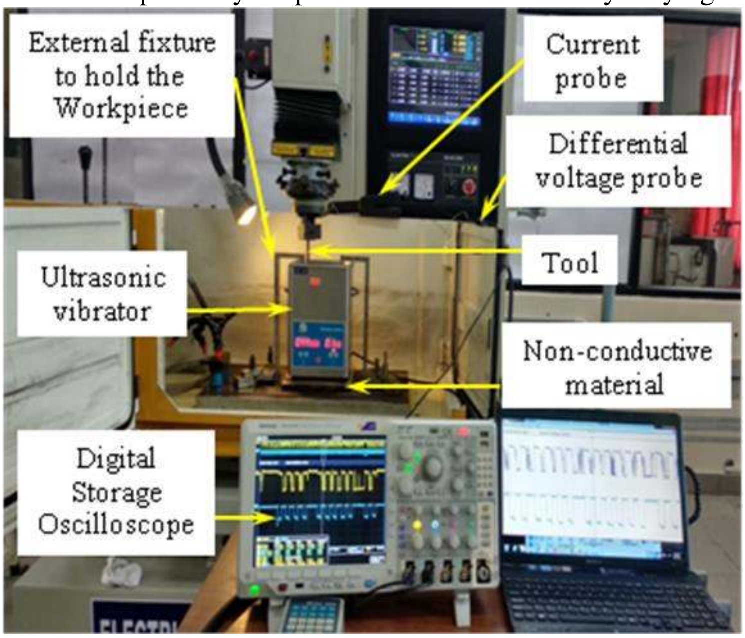


Figure 1. Experimental setup used for conduct of experiments.

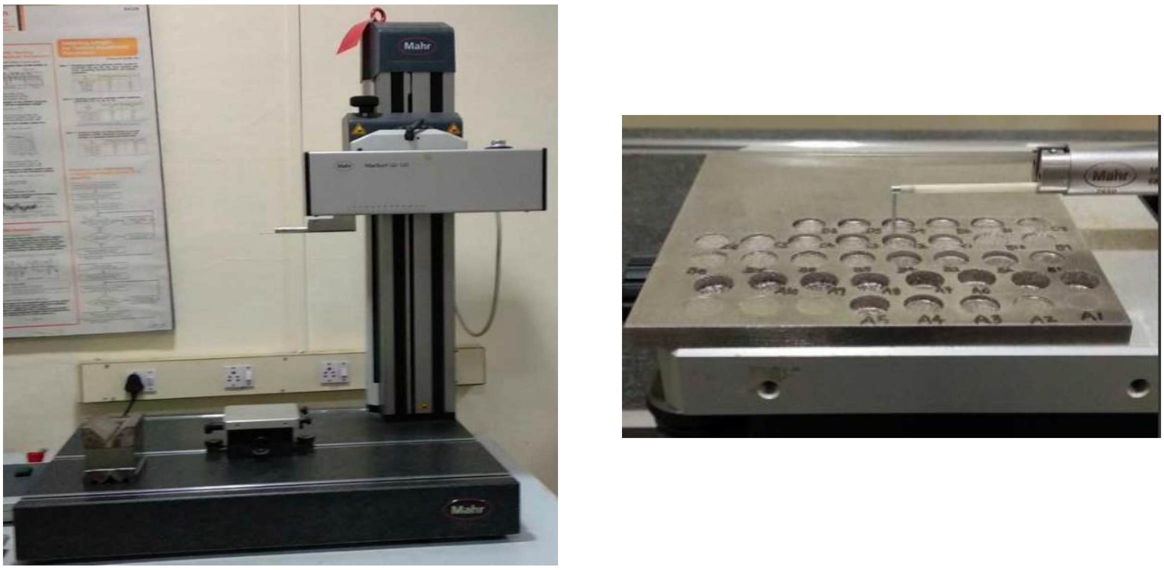
8, 10, and 12; by maintaining pulse duration 300μs, peak current 6A, and gap voltage 80V constant. Molybdenum-di-sulphide (MoS_2) powders of size 40 μm (micro powder) and 90 nm (nano powder) are mixed in dielectric medium. Additionally, a constant ultrasonic vibration is given to dielectric medium to improve flushing of debris from spark gap. The effect of duty factor and powder particle size on discharge energy, material removal rate (MRR) and surface roughness are analysed. The voltage and current pulse train generated in spark gap is captured using a digital storage oscilloscope for time duration of 40ms. The discharge energy (J) is calculated from these pulse train data using the equation (1)

$$Discharge\ energy\ (E) = \int_0^{t_e} u(t)i(t)dt \qquad (1)$$

wheret_e is effective machining time, in second; u(t) is instantaneous voltage, in volt; i(t) is instantaneous current, in ampere. Material removal rate (mg/min) is calculated from the difference in mass of the component before and after machining divided by machining time (10 minutes). The surface finish of machined component is measured using MarSurf GD 120 roughness measuring instrument as shown in figure 2.

Table 1. Experimental conditions.

Parameters	Values
Pulse duration (μs)	300
Peak current (A)	6
Gap voltage (V)	80
Duty factor	2, 4, 6, 8, 10, 12
Workpiece material	AISI 304 steel; dimension 100 x 100 x 10 mm
Tool material	Copper; ϕ8mm
Dielectric medium	Elektra (Electronica India Ltd)
MoS_2 powder size	40μm (micro), 90nm (nano)
Powder concentration	1 g/l



(a) (b)

Figure 2 Surface roughness measurement (a) 2D roughness measuring instrument (MarSurf GD 120), (b) Close up view of stylus measuring surface roughness on PMEDM machined surface.

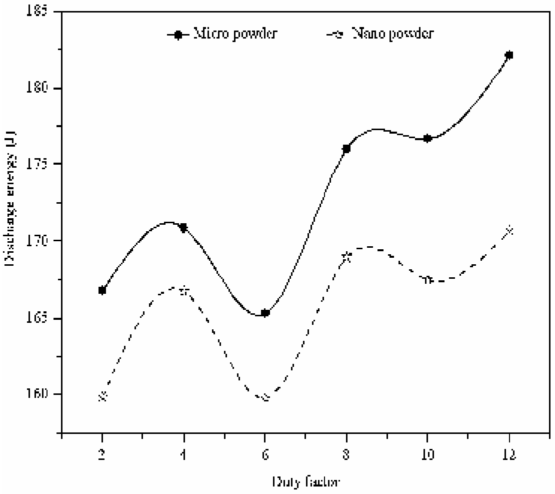
3. Results and discussion

The influence of duty factor on discharge energy, MRR and surface roughness is presented in table 2 and figure 3.It is observed experimentally, for both micro powder and nano powder increasing duty

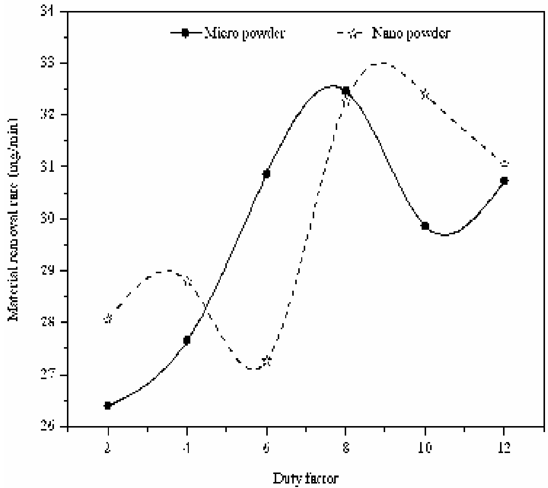
Table 2. Influence of duty factor on discharge energy, MRR and surface roughness.

Exp. No	Duty factor	Discharge energy (J)		Material removal rate (mg/min)		Surface roughness (μm)	
		Micro	Nano	Micro	Nano	Micro	Nano
1	2	167	160	26.40	28.07	7.841	8.076
2	4	171	167	27.67	28.80	6.587	7.065
3	6	165	160	30.87	27.27	6.367	6.214
4	8	176	169	32.47	32.27	6.812	6.859
5	10	177	168	29.87	32.40	5.919	6.409
6	12	182	171	30.73	31.07	5.966	6.706

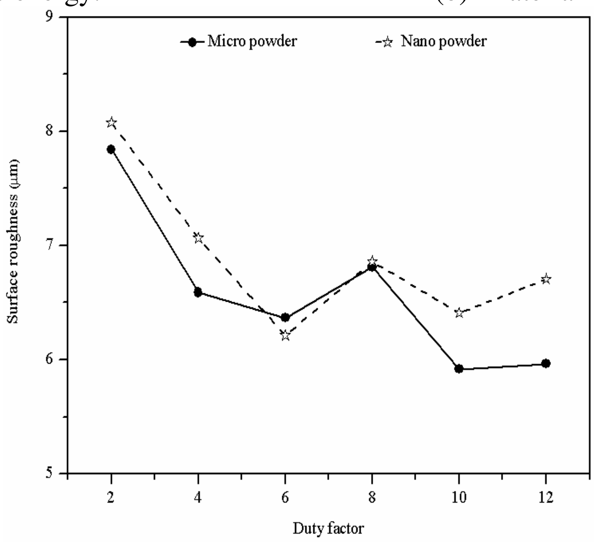
Constant parameters: Pulse duration 300μs, Peak current 6A, gap voltage 80V



(a) Discharge energy.



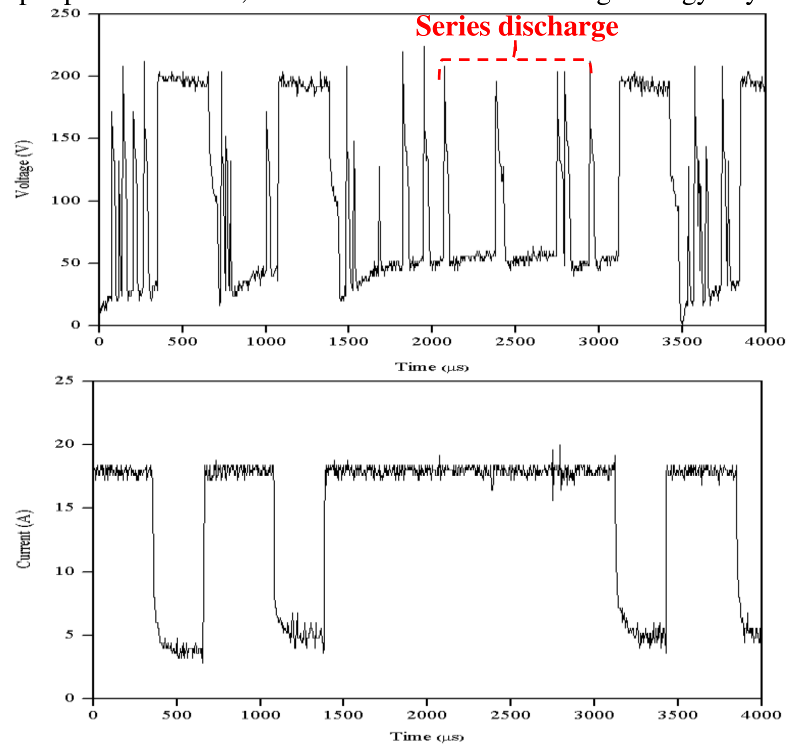
(b) Material removal rate.



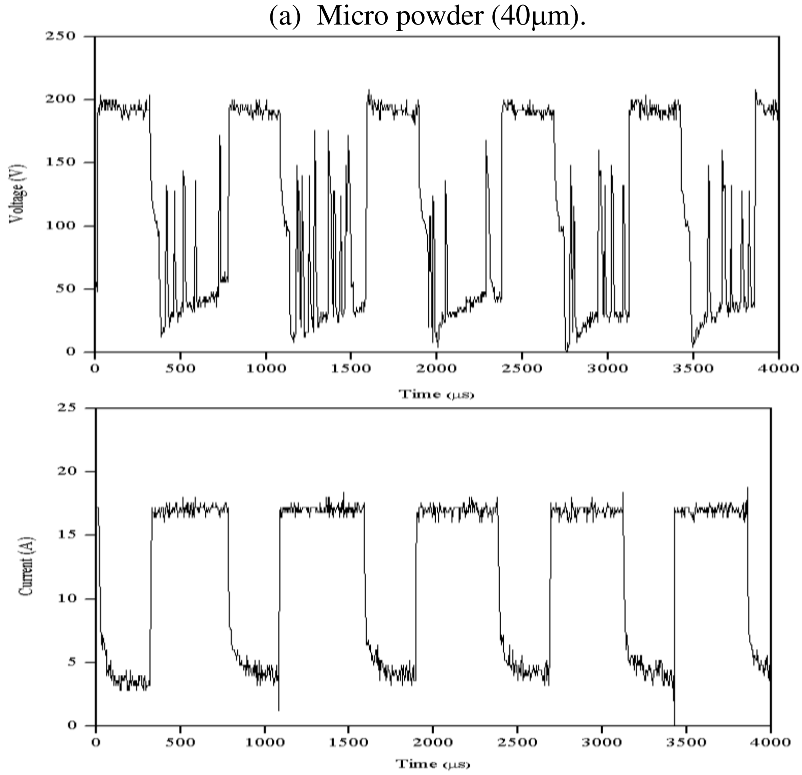
(c) Surface roughness.

Figure 3. Effect of duty factor and powder size on discharge energy, MRR and surface roughness.

factor, discharge energy increases as shown in figure 3 (a). Increasing the magnitude of duty factor, discharge duration per pulse increases, which leads to rise in discharge energy. By varying duty from 2



(a) Micro powder (40µm).



(b) Nano powder (90 nm).

Figure 4. Voltage and current pulse train acquired for pulse duration 300µs, peak current 6A, gap voltage 80V and duty factor 4.

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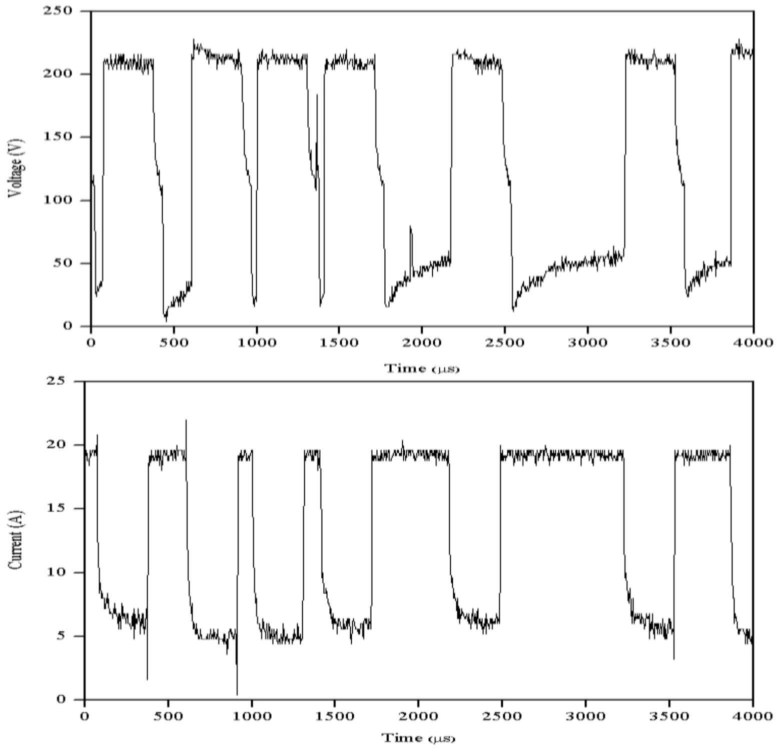
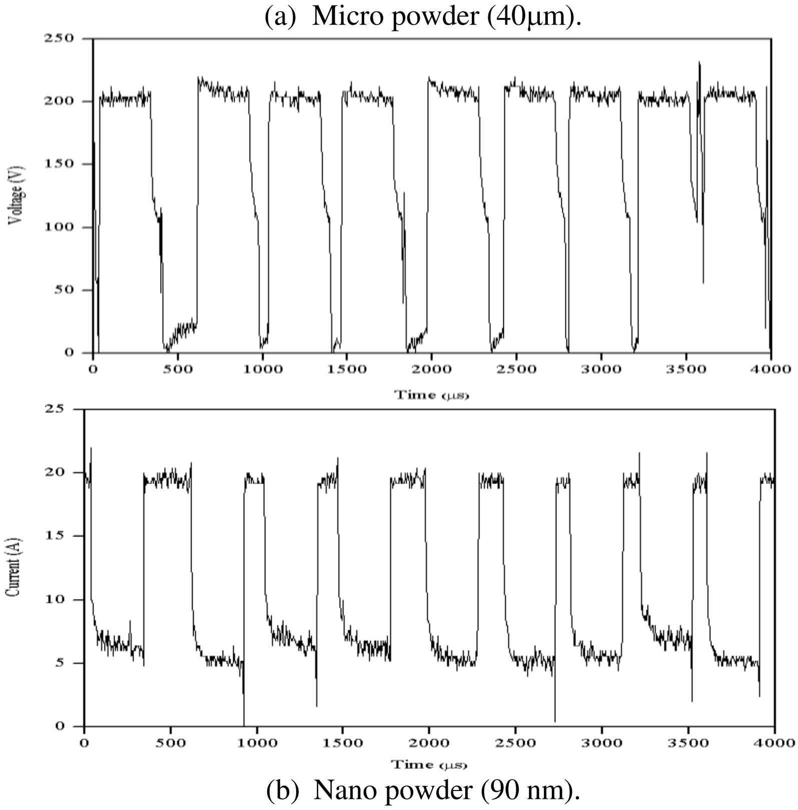


(a) Micro powder (40μm).



(b) Nano powder (90 nm).

Figure 5. Voltage and current pulse train acquired for pulse duration 300μs, peak current 6A, gap voltage 80V and duty factor 10.

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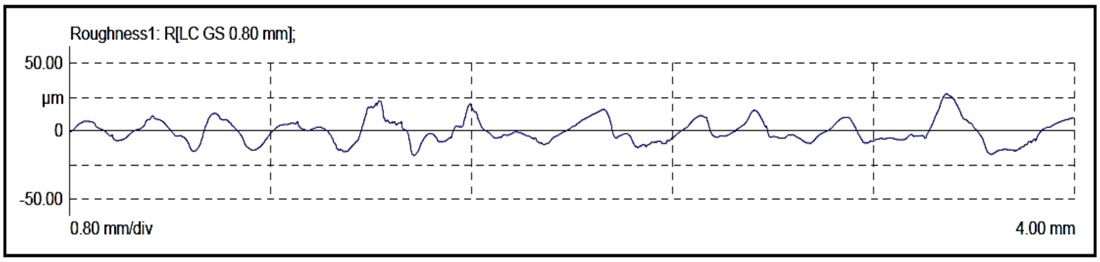
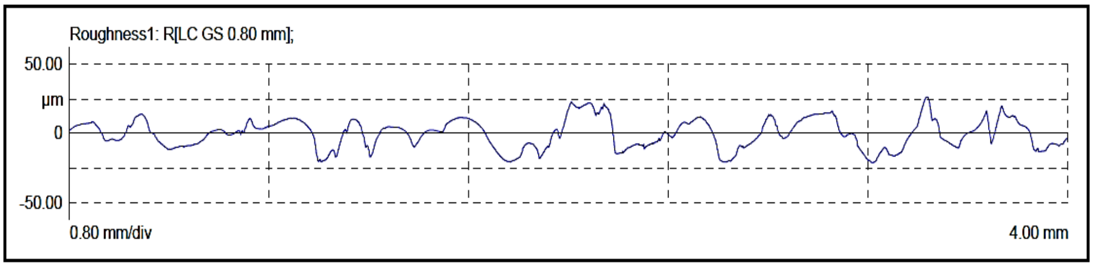
to 12, the discharge energy obtained for micro powder is high compared to that obtained using nano powder. The suspension of powder particle leads to formation of series discharge [2, 7] that reduces discharge energy. For a fixed concentration (1 *g/l)* of powder suspended into dielectric medium, micro powder produce more series discharge compared to that of nano powder. Figure 4 shows the voltage and current pulse train of micro and nano size powder acquired for duty factor 4. The pulse train reveals that, the magnitude of current pulse is high in micro powder compared to that of nano powder, which resulted in reduced discharge energy.

The effect of duty factor on MRR for two different size of molybdenum-di-sulfide powder is given in figure 3(b). It is noted that, at low duty factor (2 & 4) and high duty factor (10 & 12); MRR obtained using micro powder is less compared to that of nano powder. At high duty factor 6 and 8, micro powder produce high MRR compared to that of nano powder. The powder particles suspended in dielectric medium, try to bridge the gap between the tool and workpiece, which result in increased spark frequency and series discharge. At low duty factors (2 & 4), micro powder produce more series discharge compared to that of nano powder. The energy produced by series discharge pulse is not sufficient to melt and vaporize work material; and does not aid for material removal. This resulted in reduced MRR for micro powder. At high duty factor, the increase in spark frequency and reduction in series discharge as shown in figure 5, leads to rise in MRR for nano powder.

The significance of varying duty factor and powder size on surface roughness is presented in figure 3(c). For both micro and nano powder machined components; the surface roughness is measured at three different location and its average value is given in table 2. As the duty factor increase from 2 to 12, surface roughness decrease for both micro and nano powder. It is found experimentally that for all duty factors, component machined using micro powder generate less roughness compared to that machined using nano powder. the occurrences of more series discharge in micro powder, removes less amount of material from machined surface; that resulted in better surface finish compared to that of nano powder. Figure 6 shows 2D roughness profile of component machined using micro and nano powder. Figure 7 shows the scanning electron microscope image and energy dispersive X-raay spectroscopy analysis (EDAX) of surface machined using micro and nano powders. The series discharge can be observed from SEM micrograph of micro powder. Also, the EDAX analysis of both micro and nano powder machined surface reveal the deposition of MoS_2 from dielectric medium on to the machined surface.

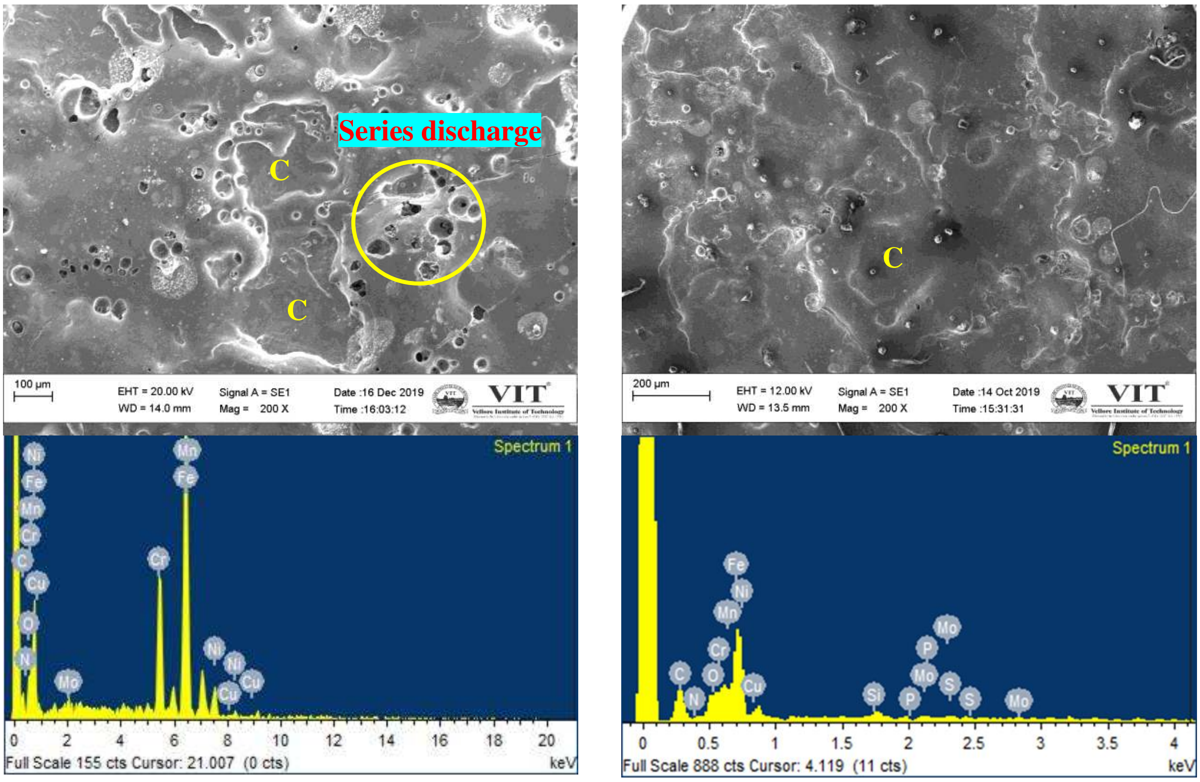


(a) Micro powder (R_a – 6.9788 µm).



(a) Nano powder (R_a – 8.6456 µm).

Figure 6. Surface roughness of components machined using pulse duration 300µs, peak current 6A, gap voltage 80V and duty factor 10.



(a) Micro powder. (b) Nano powder.

Figure 7. SEM and EDAX analysis of component machined using pulse duration 300µs, peak current 6A, gap voltage 80V and duty factor 4 (C-Crater).

4. Conclusion

Experimental analysis on impact of duty factor and powder particle size on discharge energy, material removal rate and surface roughness during powder mixed EDM are analysed. The discharge energy increases with rise in duty factor for both micro and nano powder. As duty factor increases, the discharge duration and spark frequency increase which resulted in increased discharge energy. At low duty factor (2 & 4) and high duty factor (10 & 12), nano powder mixed dielectric offered increased MRR compared to that of micro powder mixed dielectric. For all duty factor values, the occurrence of series discharge in micro powder offered better surface finish compared to that machined using nano powder.

Acknowledgement

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5. References

[1] Ming Q Y and He L Y 1995 *J. Mater. Process. Technol.* **52** 44-53
[2] Zhao W S, Meng Q G and Wang Z L 2002 *J. Mater. Process.Technol* **129** 30-33
[3] Cogun C, Ozerkan B and Karacay T *Proc. Inst. Mech. Eng. B* **220** 1035-1050
[4] Pecas P and Henriques E 2008 *Int. J. Adv.Manuf. Tech.* **37** 1120-1132
[5] Ekmekci B and Ersoz Y 2012 *Metall. Mater. Trans. B* **43B** 1138-1148
[6] Jabbaripour B, Sadeghi M H, Shabgard M R and Faraji H 2013 *J. Manuf.* Process **15** 56-68

IOP Conf. Series: Materials Science and Engineering **912** (2020) 032057 doi:10.1088/1757-899X/912/3/032057

[7] Kumar H 2014 *Int. J. AdvManuf. Tech.***76**105-113
[8] Chen S L, Lin M H, Huang G X and Wang C 2014 *Appl. Surf. Sci*.**311** 47-53
[9] Muttamara A and Messes J 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **157** 012021
[10] Prakash C, Kansal H K, Pable B S and Puri S 2016 *J. Mech.Sci.Technol.* **30** 4195-4204
[11] Wang X, Liu Y, Zhang Y, Sun Q, Li Z and Shen Y 2016 *Int. J. Adv.Manuf. Tech.* **82** 1063-1069
[12] Razak M A, Rani A M A, Saad N M, Littlefair G and Aliyu AA 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **344** 012010
[13] Rajeswari R and Shunmugam M S 2019 *Int. J. Adv.Manuf. Tech.* **100** 1945-1964
[14] Rajeswari R and Shunmugam M S 2019 *Proc. Inst. Mech. Eng. B* **233** 2515-2530
[15] Sahu D R and Mandal A 2020 *Mater. Manuf. Process* 10.1080/10426914.2020.1718695