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Research article

The effect of Al2O3 Micro Powder added in Dielectric on Electro Discharge Machining Performance of Ti6Al4V

Mojtaba Esmailian*

Faculty of Mechanical, Malek Ashtar University of Technology, Iran

*mojtaba@mut-es.ac.ir

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Abstract

Titanium Alloys due to appropriate physical and mechanical properties, have broad industrial applications. Electro discharge machining (EDM) is a widely accepted non-traditional material removal process used to manufacture titanium alloys components with intricate shapes and profiles. Using powder as additive for increasing performance of EDM process has been recently investigated. This process is called powder mixed EDM (PMEDM), which is a complex machining process and is governed by a number of machining parameters. The objective of present research is to realize the potential of Al2O3 powder as additive in enhancing performance of PMEDM on Ti6Al4V. Full factorial technique has been adopted to plan and analyze the experimental results. Pulse on time, pulse off time, current and powder are taken as machining parameters. Material removal rates (MRR), tool wear rate (TWR) and surface roughness (SR) are taken as response parameters. The results of variance analysis of the results show that the current, pulse on time, pulse off time, and powder have, respectively, the greatest effects on the results and the surfaces of samples is better with powder than without powder.

Keywords: EDM, Al2O3 Powder, Ti6Al4V, DoE, SEM.

1- Introduction

Among the non-traditional methods of material removal processes EDM has drawn a great deal of researchers' attentions because of its broad industrial applications. This technique has been widely used in modern metal working industries for machining of casting and forging dies, dies powder metallurgy, aerospace and surgical components.

Most of optimization researches in the field of EDM have been studied the performance of process by investigating on MRR, TWR, and SR. One strategy that has been used recently in order to achieving better performance of EDM process is adding powder to dielectric fluid. It has been introduced that the use of Gray Relational Analysis (GRA) in selecting optimum PMEDM condition on multiple performance characteristics. MRR, TWR, and SR were adopted to evaluate the machinability performance characteristics [1]. Jeswari [2] carried out some studies on the effect of addition of graphite powders to kerosene dielectric fluid in EDM of mild steel. An increase in MRR and reduction in TWR were reported. Furutani k., et al. [3] described the influence of the discharge current and pulse duration on the titanium carbide (TiC) deposition process by EDM with titanium powder suspended in working oil. It has been investigated the influence of electrical parameters during PMEDM of hastelloy. The study indicated that all input machining parameters including peak current, gap voltage, and pulse on time and duty cycle strongly affect the machining performance of hastelloy [4]. EDM characteristics studied with aluminum, graphite, and silicon powder additives indicated that machining characteristics such as MRR and SR improved and better mirror-like machined surface were obtained [5]. It has been indicated that the improvement of the machined surface of EDM by adding aluminum powder and surfactant into dielectric. According to this study the surface roughness of workpiece in EDM process improved [6]. Lin et al. [7] researched on EDM of Al–ZN–MG alloy with mixed of silicon carbide powder and dielectric fluid. This experiments have shown a reduction in Ra and also enhanced wear-resistance. The results of Jabbarpour [8] experimentally on EDM of Ti6Al4V alloy state that pulse of time and input current has more influence on produced Ra. Kolli and Kumar [9] experimented with PMEDM using boron carbide nanoparticles for EDM of titanium. Moreover, it has been suggested that addition of various powders in dielectric fluid during EDM results in improvement of performance measures in comparison to that achieved by conventional EDM [10]. The influence of main process parameters, including the peak current (Ip), the pulse on time (Ton), and the powder concentration (Cp) on surface properties, i.e., surface roughness (Ra), microhardness of surfaces (HV), and surface morphology of SKD61 steel machined by PMEDM with tungsten carbide powder, has been studied by Van Tao Le [11]. The surface properties of the electromagnetic powder discharge machining process (PMEDM) using alumina and silicon carbide abrasive powder, an electrical fluid for Ti6Al4V titanium alloy had reviewed by Joshi et al. [12]. In a research, Shahbazi et al. investigated the effective parameters in the electrical discharge machining process of aluminum 413 composite using the Taguchi method [13]. Also, HajHosseini et al. investigated the effect of electrical discharge machining (EDM) input parameters on A356 nanocomposite reinforced with 3.5% alumina (Al2O3) using Taguchi technique. [14].

Main problem in EDM of titanium alloys is low MRR. Furthermore, surface finishing would be reduced when MRR increases. Since many factors would be effective in this process, design of experiments (DoE) plays a vital role in optimization of the process. In this work, the influence of pulse on time, pulse off time, current and powder on the MRR, TWR and SR of Ti6Al4V have been discussed and optimal machining parameters were also proposed. Also, with the help of the SEM device, the surface of the parts has been examined in different situations.

2- Experimental Details and Procedures

2-1 Instruments, Materials and Their Specifications.

The experiments were run on an EDM machine type Anarak 20 amp which is shown in Fig. 1. (The EDM machine has the ability of voltage overshooting). The electrodes adopted in this paper are made of copper. The length of electrodes is 2 cm and cross section area is 12.7*12 mm which is illustrated in Fig. 2. According to the number of experiments and to reduce costs, the length of the copper electrodes is considered to be 2cm, and a holder is used to close the electrodes in the EDM machine, which is shown in Fig. 3. The electrode is placed inside the holder and connected to the holder by a screw, and the holder is connected from the other side inside the EDM machine. The workpiece adopted in this work was Ti6Al4V alloy that is the most titanium alloys for aerial parts. Powder investigated in this research is aluminum oxide (Al2O3). Concentration and grain size of powder have great effect on the results. Concentration of the powder in this study is 20 gr/l and the powder's grain size is considered 9 µm which is a completely fine powder. The dielectric fluid used in the experiments is kerosene oil form Behran Oil Co. Surface roughness was measured by surface roughness tester SURFTEST.500 and in order to study the SEM of workpiece surface the Philips XL30 SEM was used. The workpieces and electrodes were weighed before and after each experiment using an electric balance with a resolution of 0.0001 gr to determine the value of MRR and TWR.

2-2 Design of Experiments

In order to determine the effects of process parameters on the performance measures, all the experiments were planed based on DOE.

2-2-1 Selection of Machining Parameters

Pulse on time, pulse off time, current and powder have been taken as input machining parameters. The reason why these factors have been chosen is that they are the most general and frequently used among EDM researchers. These essential factors and their levels were listed in Table 1. In this process, DC current with a voltage of 80 volts is passed through the electrode.

Fig. 1 EDM machine Anarak 20A

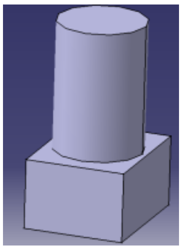


Fig. 2 Electrode

Fig. 3 Holder

Table 1: Factors and Levels

Factor	Level 1	Level 2	Level 3
Current (A)	3	6	9
Pulse on time (µS)	300	650	850
Pulse off time (µS)	70	110	
powder	+	-	

The experimental design is based on the effective parameters, and their variations are shown in Table 2. The results of measuring the TWR, Ra and MRR are also shown.

2-2-2 Selection of Response Variables.

The response variables selected in this study were MRR, TWR and the Surface Roughness (SR). For efficient evaluation of the PMEDM process, the larger MRR and the smaller TWR are regarded as the best machining performance. Therefore, the MRR is considered as the larger the better characteristic and the TWR is considered as the smaller-the-better characteristic in this experimentation.

2-2-3 Experimental Design

A proper design of experiments is conducted to perform more accurate, less costly and more efficient experiments. Full factorial technique is used widely in DOE recently and is employed to perform the experimental design. In this case a mixed full factorial design, 3*3*3*2 design, has been selected due to the number of factors and factor’s levels considered in the study (Table 1). Each run is replicated two times so that the total number of runs is 72. The resolution of this full factorial design allows us to estimate all main effects and factor interactions in this study. Note that run orders were used randomly during the experiments. The machining time for each experimental specimen is 45 min.

3- Results and Data Analysis

3-1 Analysis of MRR.

According to the analysis of variance (ANOVA), all factors and their interactions significantly affect the MRR. Fig. 4 depicts the plot of factors on MRR. This plot can be used to graphically assess the effects of factors on response. Fig. 4 indicates that the MRR tends to increase, with increase in current. It is seen from this plot that pulse off time has reverse effect on MRR and powder has direct effect on MRR. Also, Fig. 4 presents that at first pulse on time has direct effect on MRR but with increasing pulse on time during the experiments MRR is almost constant.

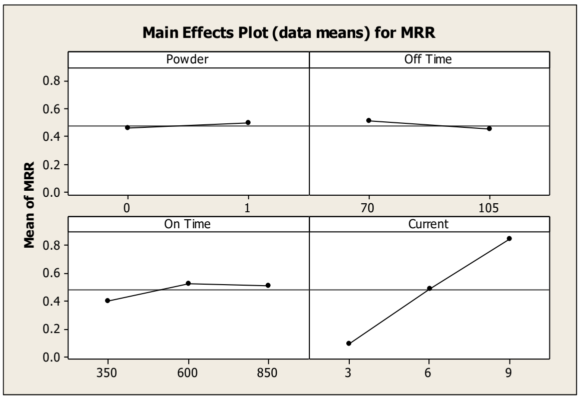


Fig. 4 Effects of factors on MRR

3-2 Analysis of TWR

According to the analysis of variance (ANOVA), all factors and their interactions significantly except powder*pulse on time and powder*current affect the TWR. Fig. 5 illustrates the plot of factors on TWR. As shown in Fig. 5, the TWR tends to decrease by adding powder to the dielectric fluid. The TWR increases with increase in pulse off time.

Also, Fig. 5 shows that increase in pulse on time results in lower TWR but after certain level pulse on time has not so dominant effect on TWR. Moreover, the TWR decreases with increase in current. After certain level of range of 6A the TWR tends to increase. Hence, minimum TWR is obtained at 6A current. It can be understood through Fig. 6 that current and pulse on time has interaction effect with each other.

As can be seen in Fig. 6, when the pulse on time parameter is equal to 350 µS, by increasing current from 3A to 6A the TWR value decreases.

Table 2: Experimental design and the results electro discharge machining

StdOrder	Powder	Off Time	On Time	Current	TWR	Ra	MRR
1	1	70	350	3	2.1429	2.98	0.14
2	1	70	350	6	6.1728	4.53	0.405
3	1	70	350	9	8.7209	5.38	0.86
4	1	70	600	3	1.6129	4.45	0.186
5	1	70	600	6	0.3497	3.35	0.715
6	1	70	600	9	0.8108	4.44	0.925
7	1	70	850	3	1.9126	3.37	0.183
8	1	70	850	6	0.6374	5.53	0.706
9	1	70	850	9	0.5952	3.76	0.924
10	1	105	350	3	31.6667	2.58	0.03
11	1	105	350	6	6.3014	3.57	0.365
12	1	105	350	9	15.4272	4.48	0.632
13	1	105	600	3	3.0864	2.74	0.081
14	1	105	600	6	0.6446	2.9	0.543
15	1	105	600	9	0.5435	3.69	0.828
16	1	105	850	3	4.1667	2.79	0.072
17	1	105	850	6	0.5736	4.09	0.523
18	1	105	850	9	0.4242	4.78	0.825
19	0	70	350	3	6.4706	3.71	0.085
20	0	70	350	6	10.7463	5.23	0.335
21	0	70	350	9	18.4211	6.52	0.76
22	0	70	600	3	3.0303	2.46	0.099
23	0	70	600	6	0.7447	3.63	0.47
24	0	70	600	9	0.7692	6.54	0.91
25	0	70	850	3	2.1739	1.6	0.092
26	0	70	850	6	0.7692	3.95	0.455
27	0	70	850	9	0.7955	4.28	0.88
28	0	105	350	3	16.6667	2.71	0.045
29	0	105	350	6	14.4444	4.8	0.27
30	0	105	350	9	12.2485	6.08	0.845
31	0	105	600	3	4.0541	2.74	0.074
32	0	105	600	6	0.6731	3.09	0.52
33	0	105	600	9	0.8197	4.45	0.915
34	0	105	850	3	5.6338	1.96	0.071
35	0	105	850	6	0.9259	3.88	0.54
36	0	105	850	9	0.7303	5.52	0.89
37	1	70	350	3	2.7586	3.06	0.145

38	1	70	350	6	6.6265	4.67	0.415
39	1	70	350	9	8.8166	5.33	0.845
40	1	70	600	3	1.3298	4.53	0.188
41	1	70	600	6	0.5517	3.22	0.725
42	1	70	600	9	0.915	4.62	0.929
43	1	70	850	3	1.3514	3.33	0.185
44	1	70	850	6	0.4909	5.35	0.713
45	1	70	850	9	0.6011	3.85	0.915
46	1	105	350	3	21.25	2.63	0.04
47	1	105	350	6	6.8571	3.43	0.35
48	1	105	350	9	17.4326	4.68	0.631
49	1	105	600	3	3.5294	2.87	0.085
50	1	105	600	6	0.5405	2.88	0.555
51	1	105	600	9	0.4819	3.75	0.83
52	1	105	850	3	4.6667	2.84	0.075
53	1	105	850	6	0.6542	3.98	0.535
54	1	105	850	9	0.4734	4.81	0.845
55	0	70	350	3	7.2222	3.31	0.09
56	0	70	350	6	10.8696	5.36	0.345
57	0	70	350	9	19.1601	6.47	0.762
58	0	70	600	3	3.1915	2.45	0.094
59	0	70	600	6	0.9677	3.56	0.465
60	0	70	600	9	0.929	6.43	0.915
61	0	70	850	3	2.8736	1.48	0.087
62	0	70	850	6	0.6742	3.82	0.445
63	0	70	850	9	0.9827	4.06	0.865
64	0	105	350	3	15.5556	2.84	0.045
65	0	105	350	6	14.3657	4.85	0.268
66	0	105	350	9	18.8242	6.35	0.842
67	0	105	600	3	3.3784	2.76	0.074
68	0	105	600	6	0.7547	3.31	0.53
69	0	105	600	9	0.9413	4.7	0.903
70	0	105	850	3	5.1471	1.88	0.068
71	0	105	850	6	0.8411	3.71	0.535
72	0	105	850	9	0.7856	5.76	0.891

But with increasing current from 6A to 9A, the TWR value increases, while in pulse on time 600 µS and 850 µS with the increase of the current, the TWR values first decrease and then it is proven that this state is the most favorable condition in the changes of the effective parameters.

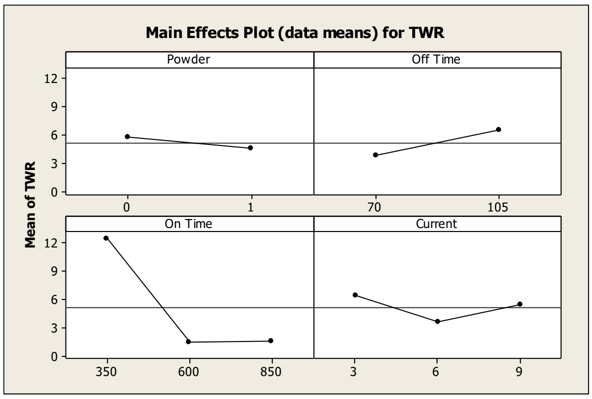


Fig. 5. Effects of factors on TWR

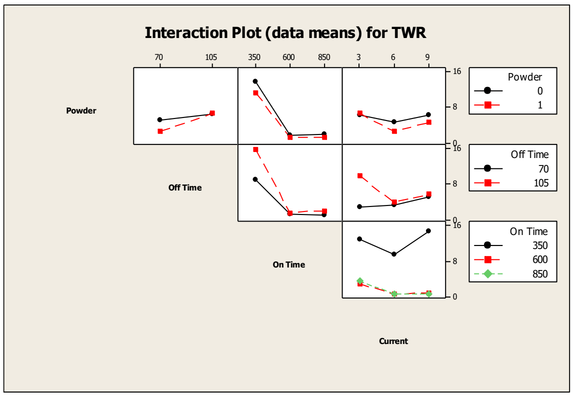


Fig. 6. Effects of factor’s interactions on TWR

3-3 Analysis of SR.

Fig. 7 shows that powder, pulse off time, pulse on time and current have the significant effect on Ra. In addition, powder and pulse off time have reverse effects on Ra. In addition, it is indicated from this figure that pulse on time at first has a significant reverse effect on Ra but during the process Ra is constant. As indicated in Fig.7 current has direct proportion to the Ra; that is, by increasing current, Ra increases significantly.

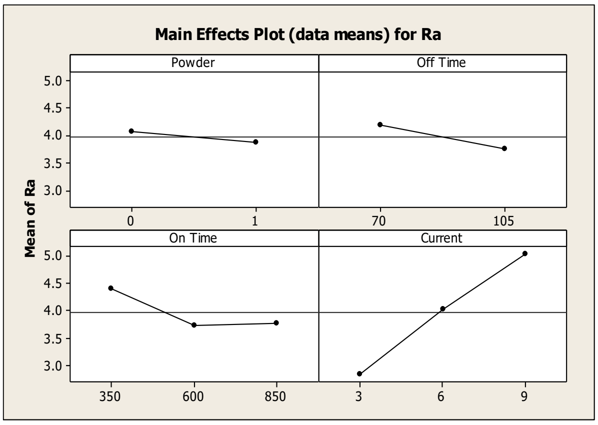


Fig. 7. Effects of factors on SR

3-4 SEM Results

3-4-1 SEM Results in Accordance with Adding Powder

SEM is used to examine the surface quality of EDM of Ti6Al4V workpieces. Figs. 8 and 9 show the surfaces of workpieces with and without powder with magnifications of 50X and 400X. As indicated in Figs. 8 and 9, surface finishing is better with powder than without powder.

3-4-2 SEM Results in Accordance with Pulse off Time.

The surface of samples in two levels of pulse off time with and without powder are shown in Figs. 10 and 11, resp[ectively. As you can see, in any case, the surface has completely random pits and protrusions that do not have a specific order, and the size of the pits on the surface resulting from the lower and upper off Time in the case where we use powder is not much different. While the size of the pits in the surface resulting from the low off Time in the case that we do not use powder is larger than the surface resulting from the high off Time. Therefore, the surface roughness is more in this case.

3-4-3 SEM Results in Accordance with Pulse on Time.

Figs. 12 and 13 presents the surface of samples in three levels of pulse on time with and without powder. As can be seen, in both cases, the surface has completely random pits and protrusions that do not have a specific order, and the size of the pits in the resulting surface decreases with increasing pulse on time in both cases with and without powder. The pulse on time improves the smoothness of the surface.

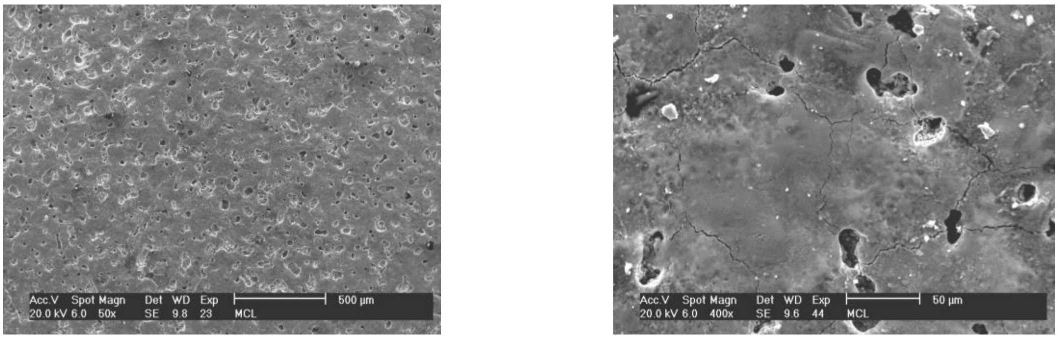
3-4-4 SEM Results in Accordance with Current.

The surfaces of samples in three levels of current are shown from Figs. 14 and 15. It can be seen from Figs. 8 to 15 that surface finishing is better with powder than without powder.

4- Conclusion

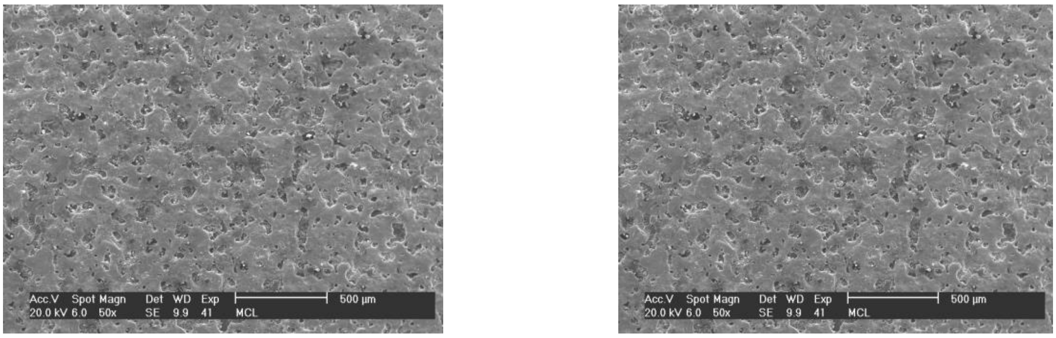
Micro Al2O3 powder particles are mixed in EDM dielectric fluid. Empirical modeling with the help of DOE led to following conclusions:

- Adding Al2O3 powder has a suitable effect on performance of machining, consequently the MRR increase, TWR decrease and SR is improved.
- Increasing the pulse off time an undesirable influence on performance of machining because the MRR tends to decrease and the TWR tends to increase.
- By increasing pulse on time to 600 has positive effect on increasing the MRR and decreasing the TWR.
- By increasing pulse on time to 600 has positive effect on SR but by increasing pulse on time Ra is almost constant.



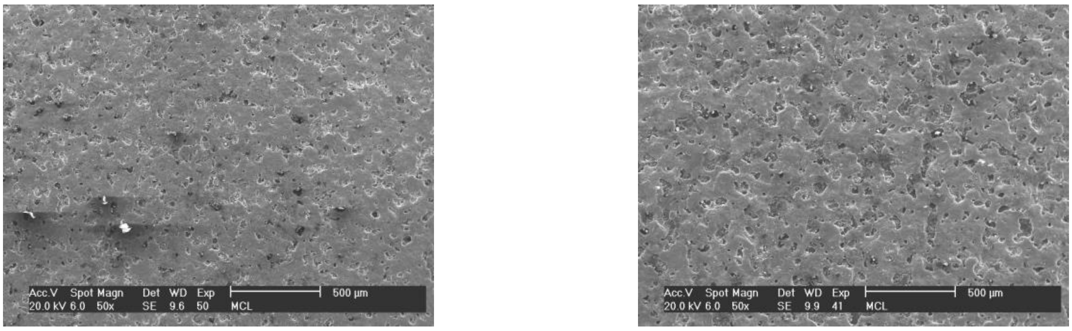
(a) (b)

Fig. 8. SEM micrographs of sample's surface without powder (a- 50X, b-400X)



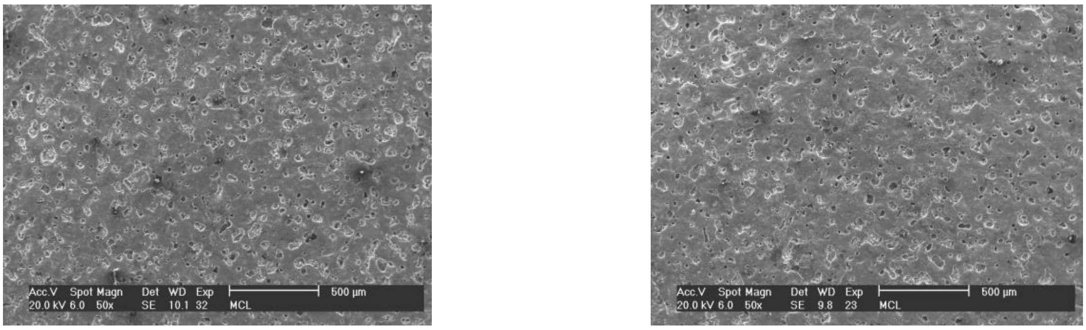
(a) (b)

Fig. 9. SEM micrographs of sample's surface with powder (a- 50X, b-400X)



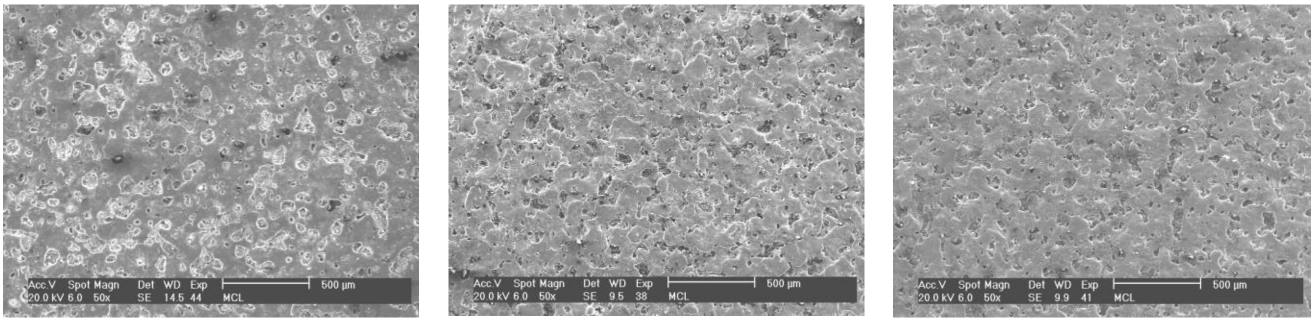
(a) (b)

Fig. 10. SEM micrographs of sample's surface without powder (a- Off Time=105 μs , b- 70 μs)



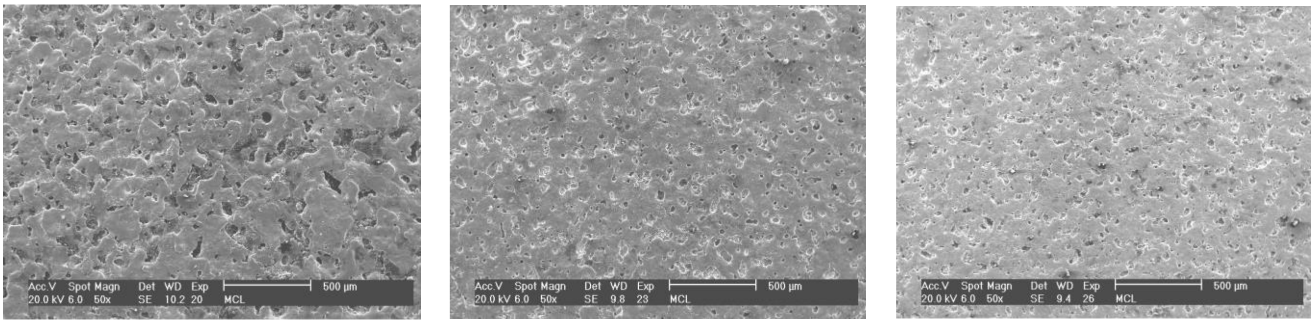
(a) (b)

Fig. 11. SEM micrographs of sample's surface with powder (a- Off Time=105 μs , b- 70 μs)



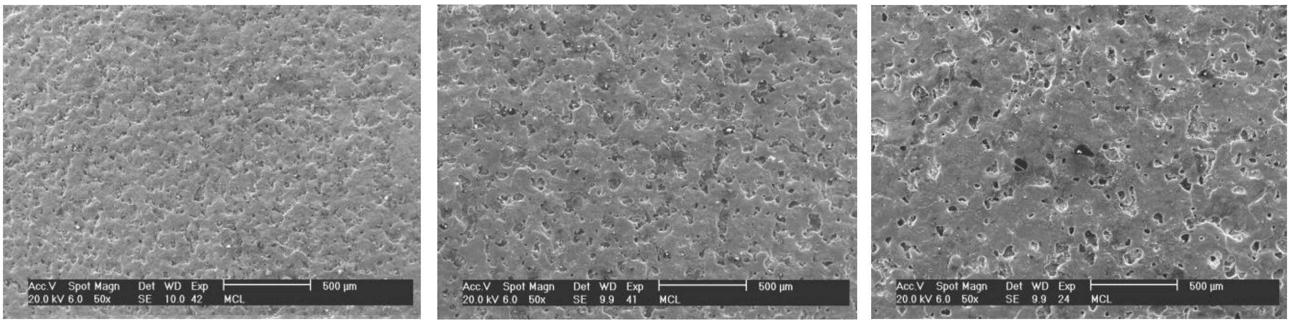
(a) (b) (c)

Fig. 12. SEM micrographs of sample’s surface without powder (a- On Time=350 μs , b- 600 μs , c- 850 μs)



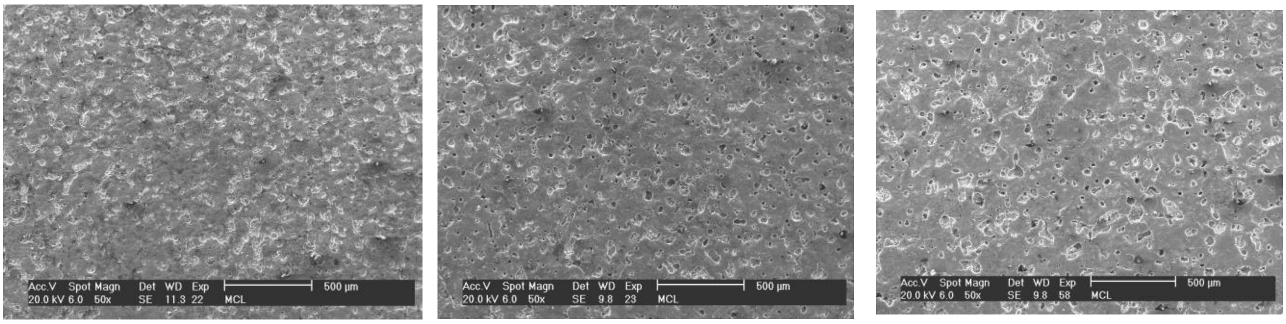
(a) (b) (c)

Fig. 13. SEM micrographs of sample’s surface with powder (a- On Time=350 μs , b- 600 μs , c- 850 μs)



(a) (b) (c)

Fig. 14. SEM micrographs of sample’s surface without powder (a- I=3A, b- I=6A, c- I=9A)



(a) (b) (c)

Fig. 15. SEM micrographs of sample’s surface with powder (a- I=3A, b- I=6A, c- I=9A)

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