

# Surface alloying using tungsten disulphide powder mixed in dielectric in micro-EDM on Ti6Al4V

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**Abstract.** Surface alloying has been popular in recent days for the surface modification of machining components. The present involves the practical application of micro electrical discharge machining ( $\mu$ -EDM) process with powders mixed in the dielectric fluid for surface alloying applications. The experiments were carried out on Ti6Al4V sheets using tungsten tool with the use of tungsten disulphide ( $WS_2$ ) powders suspended in the de-ionised water as the dielectric medium. Sparks occur in between the tool electrode and the work piece gap on the local region, such that melting takes place. It results in the disassociating the dielectric fluid and the powders mixed within it and hence undergo the process of alloying. Design of experiments was used for carrying out the experiments using Taguchi method where the process parameters were taken in L9 array. The desired parametrical settings adopted was voltage, duty factor and concentration of the powder particles. The EDM alloyed samples undergo field emission scanning electron microscope (FESEM) self-equipped with EDS analysis. In addition to that the surface roughness, material removal rate and micro-hardness was measured. The work relates to the use of lubricating powders in the dielectric fluid such that the alloy formed can give some self-lubricating properties. Results showed formation of recast layer (RL) containing traces of  $WS_2$  substrate over the Ti6Al4V work piece surface hence improving the lubrication characteristics of the alloyed material.

## 1. Introduction

The development of different alloys has been a cost-effective way to use the materials for obtaining way better performance characteristics, when used at detrimental operating environment such as corrosion, wear, temperature, friction, etc. Thus in order to achieve desirable properties for such dramatically changing environmental conditions during various applications, it is required to alloy the materials carefully. Some properties that can be achieved by means of alloying can be high resistance to corrosion. Wear resistant, high hardness, lubricating surfaces, etc. Local alloying is much cheaper than alloying the entire component as such only the desired contact area can be alloyed as per requirement [1]. Surface modification of materials can be done by means of removing or depositing the material over a conductive surface with electrical discharge machining process (EDM) [2]. Controlled electrical sparks are generated in between the tool and the electrode, for the result of which melting and evaporation takes place, and hence, material is either deposited or removed from the surface. The EDMed surface shows the formation of a layer, which is a result of the crystallisation of the molten material [3]. The interaction of the tool material, work piece material and the decomposed



dielectric by-product results in alloying, wherein the tool material upon re-solidification deposits on base of the craters [4]. In surface modification process, polarity plays a major role, where positive polarity of the tool results in increased surface roughness [5]. Surface beneficial features can be obtained by the use of variants in EDM such as rotary tool EDM, powder mixed dielectric electrical discharge machining (PMEDM), or by using powder metallurgy compact tool electrode [6-10]. These surface improvement techniques using EDM is widely implemented for moulding, tooling, for increasing the life span of the components, and for reducing the time and manufacturing cost [11]. The need of miniaturised components has led to the emergence of micro-manufacturing. Most of the micro-components are made of Titanium and its alloys, which are in high practice in industries such as nuclear, aerospace, bio-medical, energy, and underwater applications. This is due to the fact that titanium and its alloys possess high strength-to-weight ratios, fatigue strength, fracture toughness, better corrosion resistance behaviour as compared to other metals, and can be operated at high temperatures. Owing to these striking properties of titanium and their alloys, machining them by means of conventional techniques is quite difficult, as such non-traditional machining processes has taken up for surface alloying [12]. EDM being able to cut material of any hardness is used for deposition or alloying processes. Thus, due to miniaturization of components, and their increasing demand in manufacturing industries,  $\mu$ -EDM is used to develop desirous layer on the work material to study the performance and features of the same.

To this aspect, powder mixed dielectric in EDM/ $\mu$ -EDM is one such method to develop surface alloys or coating surfaces and thus the surface integrity can be enhanced. Various research has been carried out with respect to surface alloying or coating using PMEDM/PM  $\mu$ -EDM process. The use of suspended powders in micro/nano form in EDM is the most recent progress for reformation of the potential of the conventional type of EDM process. The powders are suspended in the dielectric, with a small gap in between the electrodes and voltage is applied in between them. The particles gets energised as such the dielectric breakdown takes place and the electrode gap distance is increased. A chain like structure is developed between the electrodes, thus creating a bridging effect and hence decreasing the insulating strength of the dielectric. This results in the formation of shallow craters due to effective distribution of discharge energy within the dielectric medium, which in turn reduces the surface roughness [13]. The powder particles on account of high temperature generation between the electrodes, melts and gets re-solidified over the work piece along with the electrode material. The modified layer developed over the work piece surface affect the performance of the components. With various combination of parameters and other conditions, a lot of work has been done in EDM [13-15]. In a study, Chow et al. [16] used SiC and aluminium powders suspended in kerosene and found substantial improvement in flushing efficiency and increase in electrode gap. Yeo et al. [17] showed the effect of powder particles mixed in dielectric and the crater properties using  $\mu$ -EDM. It was found that the crater size was smaller and the error in circularity was comparatively less when machined without powders. The effect of micro powdered MoS<sub>2</sub> mixed in dielectric with ultrasonic vibration assisted EDM set-up and found significant improvement of machined surface along with material removal rate [18]. Jahan et al. [19] used graphite, alumina and aluminium nano powders in dielectric to obtain better surface finish by using  $\mu$ -EDM of tungsten carbide, when the most influencing parameters were particle concentration, size, and density, electrical and thermal conductivity of the powders. Chen et al. [20] analysed the modified machined surface using titanium powder mixed in dielectric  $\mu$ -EDM which showed reduced surface cracks at a concentration level of 3g/L, whereas no micro-cracks were found with increasing concentration of 6g/L and shorter pulse duration of current 0.1A. They also concluded that the addition of powders with suitable concentration reduces the micro-cracks and increase the wettability of machined surfaces.

Most of the research has been carried out using many powders but the use of tungsten disulphide powder in  $\mu$ -EDM is not clear. Hence, the present study shows the effectiveness of EDM alloying which is carried out locally to improve the surface characteristics. The material removal rate (MRR), surface roughness (SR) and hardness values (HV) are calculated and Taguchi method is employed for

optimization of the process parameters. In addition to that, the FESEM and EDS results are shown for the authenticity of the experiments.

## 2. Experimental Methodology

### 2.1. Materials and experimental set-up

The work piece was selected as Ti6Al4V sheets of 185 $\mu$ m thickness and tungsten tool of 0.5mm diameter was used for the tool material. Tungsten disulphide powders was used with de-ionised water as the dielectric medium. The work piece had a hardness value of 349 HV according to Vickers hardness specification. A small sized 3-axes CNC system equipped with the micro-EDM was use for conducting the experiments as shown in Figure 1. The longitudinal and the transverse linear motion is given to the work piece by the XY-stage. The work piece is submerged in the dielectric with proper clamping whereas the tool is given rotational motion by a motor driven chuck. The vertical motion is also given to the tool with the help of another motor attached to the system. Lab-View software enables the axes movement and the pulse power supply is transistor-based one. Figure 2 indicate the work piece and tool materials.

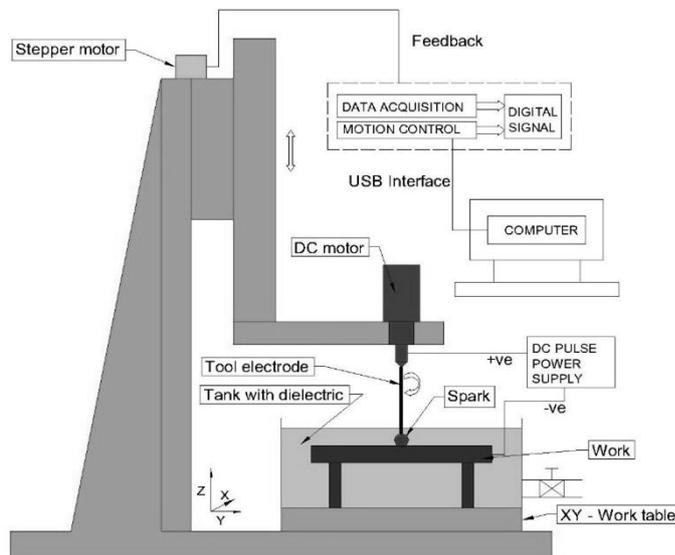


Figure 1. Schematic of micro-EDM set-up

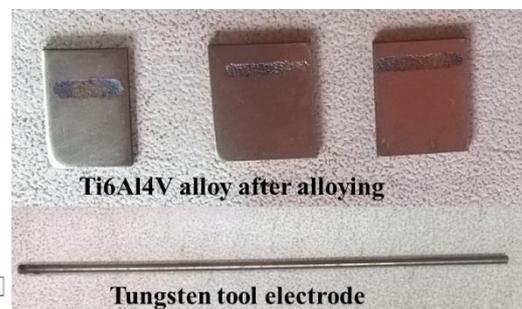


Figure 2. Work piece and tool electrode

### 2.2. Machining procedure

The experiments were carried out by selecting Taguchi design of experiments, which involves use of orthogonal arrays for organising the process parameters at various levels where they should be varied. The variable input parameters include the concentration of the tungsten disulphide powder particles (g/L), voltage (V) and duty factor (%). The experiments are conducted for a time duration of 20 minutes on Ti6Al4V work piece using tungsten tool electrode with tungsten disulphide powders mixed in the dielectric (de-ionised water). The tool is set to be positive whereas the work piece is given negative polarity since alloying of the former is done on the later. The response includes material removal rate (MRR) calculated by weight loss method, surface roughness measured by Mitutoyo surface roughness tester, and the micro-hardness was measured by Vickers hardness test at a load of 0.5kg with dwell time of 10 seconds. The various level of parameters is shown in Table 1 below.

The material removal rate (MRR) is calculated by the following formula:

$$MRR = \frac{W_f - W_i}{t} \text{ g/min}$$

Where  $W_f$  is the weight of work piece before machining (g),  $W_i$  is the weight of work piece after machining (g) and  $t$  is the machining time (min)

Table 1. Machining process parameters with their respective levels.

Parameters	Unit	Level 1	Level 2	Level 3
Voltage (V)	V	20	40	60
Powder Concentration (P Conc.)	g/L	6	8	10
Duty Factor (DF)	%	40	50	60

### 3. Results and Discussions

A total of nine experiments were conducted using Taguchi design of experiments. For calculation of MRR, the weight of the work piece were taken before and after conducting the experiments using electronic balance of resolution 0.0001g. The weight difference gives the amount of material dispersed off from the work piece, and hence this difference is divided by the machining time i.e. 20 minutes. The experimental data is then recorded in MINITAB statistical software where the responses are shown in Table 2, and the mean values of MRR, SR and HV and respective signal to noise ratios are calculated and shown in Table 3, Table 4, and Table 5 respectively. The observed MRR and micro-hardness values are set to ‘higher the best’ and the surface roughness values are set to ‘lower the best’ [21]. The variation of MRR with the variation of input parameters is shown in Figure 3. It is evident that the increasing powder concentration is directly proportional to the MRR which means it increases. It is due to the fact that increased content of powder particles lower the breakdown characteristic strength of the dielectric, and hence bridging effect of the particles is seen enabling the increment of frequency of sparks [7]. This helps in increased material removal. The discharge energy per pulse increases with the increase in voltage, as such MRR increases. The maximum MRR is obtained for 50% duty cycle as seen from graph.

Table 2. Experimental runs with responses.

Expt. No.	Voltage	Duty factor	Concentration	MRR	SR	HV
1	20	40	6	0.0100000	0.88031	498.365
2	20	50	8	0.0104500	0.79861	510.576
3	20	60	10	0.0105250	0.67856	501.500
4	40	40	8	0.0112925	1.07010	534.713
5	40	50	10	0.0114875	1.02837	544.345
6	40	60	6	0.0112000	1.06748	523.623
7	60	40	10	0.0125000	1.13140	564.198
8	60	50	6	0.0124750	1.26234	552.234
9	60	60	8	0.0123530	1.15840	566.473

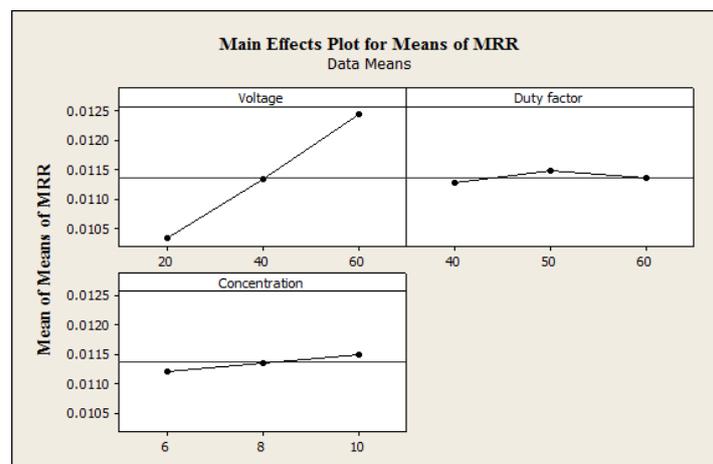


Figure 3. Mean of means of MRR

Similarly the surface roughness variation is seen in Figure 4. It is clear that it varies uniformly with concentration as such it decreases with the increase in concentration level. Moreover, it is directly proportional to the voltage since more erosion takes place and more material is removed, thus, crater

size is more and surface roughness is more. Irregular deposition of powders on the material surface leads to higher values of surface roughness. Minimum surface roughness is obtained at lower voltage and duty factor.

Again from Figure 5, the micro-hardness variation with respect to different parameters is shown. It reflects the increasing hardness with higher concentration of powder. It is seen that the micro-hardness values are increased as compared to that of the parent material. It means the hardness value of Ti6Al4V work piece was found to be 351HV whereas substantial increment of alloyed surface hardness values are seen. Moreover, higher hardness value is obtained at 50% duty cycle and 10g/L concentration.

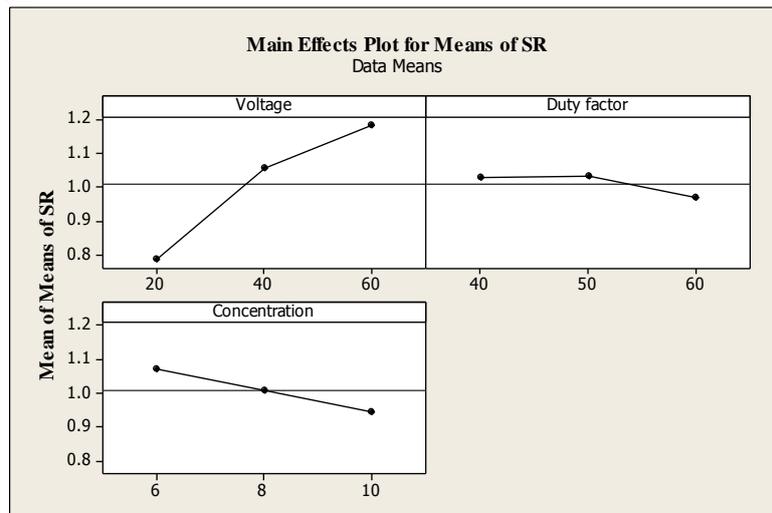


Figure 4. Mean of means of surface roughness

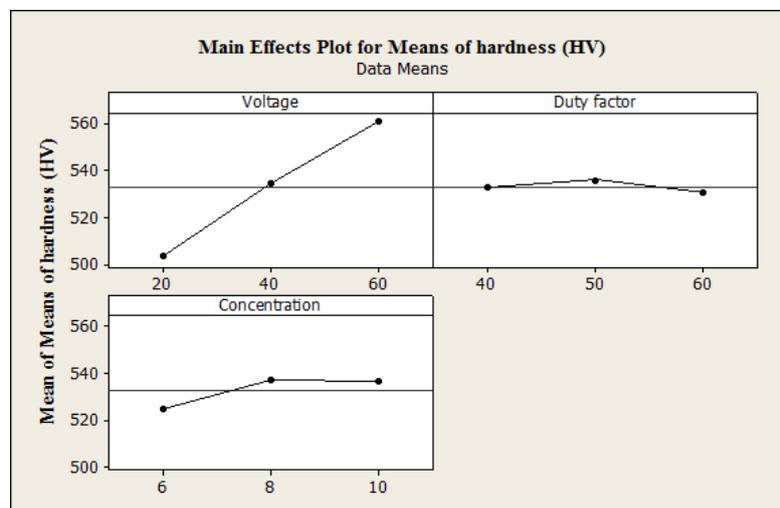


Figure 5. Mean of means of micro-hardness

Table 3. Response table showing mean and S/N ratios for MRR (Larger is better).

Level	Voltage	Duty Factor	Concentration
1	-39.72	-39.00	-39.03
2	-38.92	-38.83	-38.91
3	-38.10	-38.91	-38.80
Delta	1.62	0.17	0.23
Rank	1	3	2

Table 4. Mean and S/N ratios of surface roughness response parameter (Smaller the better).

Level	Voltage	Duty Factor	Concentration
1	2.14294	-0.18451	-0.49448
2	-0.46622	-0.10440	0.02922
3	-1.45767	0.50796	0.68431
Delta	3.60062	0.69246	1.17879
Rank	1	3	2

Table 5. Mean and S/N ratios of micro-hardness response parameter (Larger the better)

Level	Voltage	Duty Factor	Concentration
1	54.04	54.51	54.39
2	54.55	54.57	54.60
3	54.98	54.48	54.58
Delta	0.94	0.09	0.20
Rank	1	3	2

The morphological characteristics can be observed from the FESEM images captured shown in Figure 6 and Figure 7. The surface micrographs of the layer deposited on the work piece surface shows the particle are present in agglomerated form. The images indicate the deposition of tungsten tool material and WS<sub>2</sub> particles from the dielectric on the Ti6Al4V alloy work piece. Figure 6 shows the SEM image of low parametric setting with low voltage (20 V), 50% duty factor and at 6g/L concentration. It is seen that low deposition takes place. Less or no micro-cracks were seen on the surface of the alloyed samples. Figure 7 denotes the high voltage (60 V), 50% duty factor and concentration of 10g/L parametric setting. It is observed that more material deposition takes place on the surface.

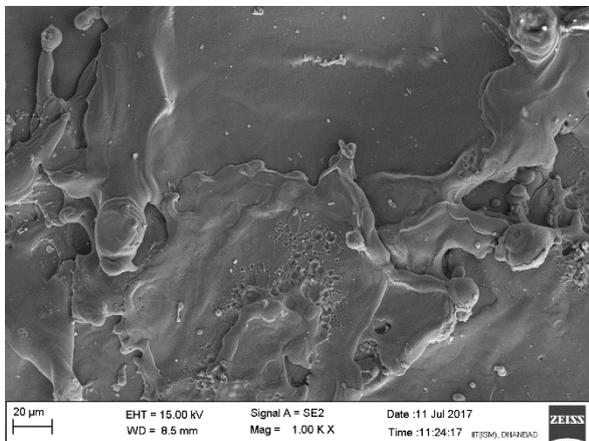


Figure 6. SEM of sample at 6g/L concentration

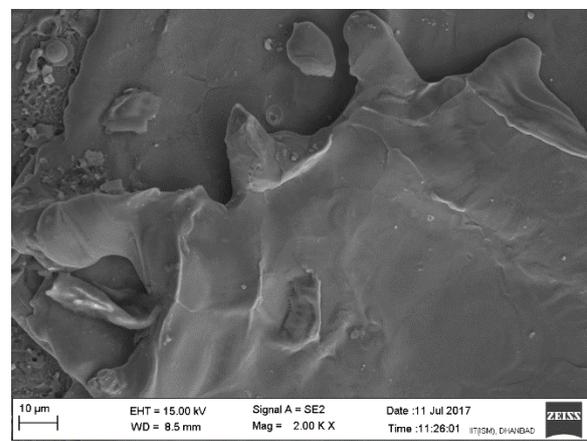


Figure 7. SEM of sample at 10g/L concentration

#### 4. Conclusion

In this paper, surface alloying is done by means of electrical discharge process by the use of tungsten tool electrode with tungsten disulphide powders mixed in the dielectric upon Ti6Al4V alloy work electrode. A reverse polarity is maintained between the two electrodes. Taguchi design of experiments for total 9 experiments have been conducted as such higher material removal rate is achieved while increasing the powder concentration and voltage. Low surface values are obtained at lower voltages, higher concentration and duty factor of 50%. The micro-hardness values are increased with the increase in concentration of powder particles and high voltage values. The SEM micrographs reveal the formation of recast layer on the work material, which means surface alloying is done by the use of powder mixed micro-electrical discharge machining process. Local alloying can be done by this technique as such for further applications.

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