International Journal of Modern Physics B
2040164 (7 pages)

DOI: 10.1142/S0217979220401645

Studying the microhardness on the surface of SKD61 in PMEDM using tungsten carbide powder

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Received 1 February 2020
Revised 20 April 2020
Accepted 1 May 2020
Published 28 August 2020

Electrical discharge machining (EDM) process is widely used to process hard materials in the industry. The process of electrical discharge is changed and called PMEDM when alloy powder is added in the oil dielectric. In this study, the effect of tungsten carbide alloy powder added in the dielectric on the microhardness of surface (HV) status of the workpiece SKD61 after machining is investigated. Studies show that the microhardness of surface obtained by PMEDM is generally better than that by normal EDM. The experiment shows that at the selected process window, adding the powder has resulted in an improvement of the microhardness up to 129.17%.

Keywords: EDM; PMEDM; surface modification; tungsten carbide powder; microhardness.

PACS numbers: 52.80.-s, 81.20.-n, 81.70.-q, 89.20.Bb

1. Introduction

The electrical discharge machining (EDM) technology in mechanical manufacturing has been limited due to low productivity and low surface quality. Many studies in recent years have focused on improving surface quality. One of the methods to

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improve surface quality is to add powder into the dielectric fluid. In powder-mixed EDM (PMEDM) process, the conductive particles mixed in the dielectric fluid reduce the insulation possibility of dielectric fluid and increase the electrical discharges between the electrode and the workpiece.[1] Besides, the spark discharges are more even and extended,[2] leading to the reduced charge density which makes the craters become shallower. Consequently, the process becomes more stable and results in a better surface quality.

Many authors have reported the different aspects of PMEDM. The result showed the effect of the impurity particles in the dielectric fluid of EDM process and reported that adding alloy powder into the solvent did improve the surface finish[3]: Wang[4] researched the impact of mixed alloy powder from Al and Cr in the dielectric fluid, where the metal coat and the surface roughness were changed. Mohri *et al.*[5–7] studied the effect of the silicon powders (Si) on the quality surface of workpiece after machining. The results showed surface resistance to corrosion and a surface roughness (R_a) of less than 2 μm. Uno *et al.*[8] showed that nickel powders mixed in the dielectric liquid of EDM process transformed the surface of workpiece in bronze and aluminum. The nickel powders (Ni) were used to coat a surface layer on the workpiece to increase abrasion resistance of surface. Bhattacharya *et al.*[9] reported the effects of tungsten powder on the surface roughness and the microhardness of surface. The results showed good surface finish and higher microhardness. Chen and Lin[10] found that an alloyed layer that can improve the hardness and wear resistance of the machined surface can be obtained by adding titan carbide (TiC) particles into the dielectric. Ming and He[11] investigated the effect of additives in the dielectric fluid for EDM process, and the experimental results showed that the additives could improve the surface quality of workpiece. Zain *et al.*[12] utilized tantalum carbide (TaC) powder during EDM of stainless steel (SUS 304) to achieve excellent surface microhardness.

Various researchers employed different powders mixed with the dielectric fluid to achieve a desired quality of the machined surface for specific applications. However, the above-mentioned studies did not focus on the influence of tungsten carbide powder on the surface properties of workpiece, especially in a finishing and semi-finishing process. Thus, this study aims to analyze the impact of tungsten carbide powder on the surface properties (microhardness) of the steel SKD61 part at finishing and semi-finishing processes.

2. Experiment

2.1. *Materials and equipment*

The experiment used Daido Steel SKD61-Amistar (JIS - Japan). The dielectric fluid used was Shell Oil EDM Fluid 2. The powder used as an additive in this study was the WC-727-6 of Praxair Surface Technologies, with a particle size of less than 31 μm.

Table 1. Experimental conditions.

Deposition condition	Current (A) (I_p)	Pulse on (μs) (T_{on})	Pulse off (μs) (T_{off})	Current voltage (V)	Powder concentration (g/l)	Dimension of workpiece
Detail	1A; 2A	16 μs; 32 μs; 50 μs	50 μs	80–120 V	20; 40; 60	$D = 19$ mm; $L = 50$ mm

2.2. *Experimental method*

An electrical discharge machine from the Aristech Company, model CNC-460 EDM, was used to remove the upper part of the SKD61 workpiece to obtain dimensions as in Table 1. The copper electrode polarity was negative. The chemical composition was measured by EDX on a scanning electron microscope JSM6610LA - JEOL. Layer coating in surface of workpiece was taken by a microscope AXIO-A2M. Microhardness of surface was determined by microhardness tester DURAMIN-STRUERS. The wear test was measured by the Universal Micro Materials Tester platform.

3. Results and Discussion

3.1. *Microhardness*

The microhardness of the surface is an average value of three points on the surface of workpiece. According to Figs. 1 and 2, the microhardness on the surface of workpiece in PMEDM is higher than the microhardness on the surface of workpiece in EDM due to the appearance of the tungsten content into the surface of workpiece after machining by PMEDM. Tungsten mixed in the dielectric under the heat of EDM is combined with carbon cracking in the dielectric or carbon of material to

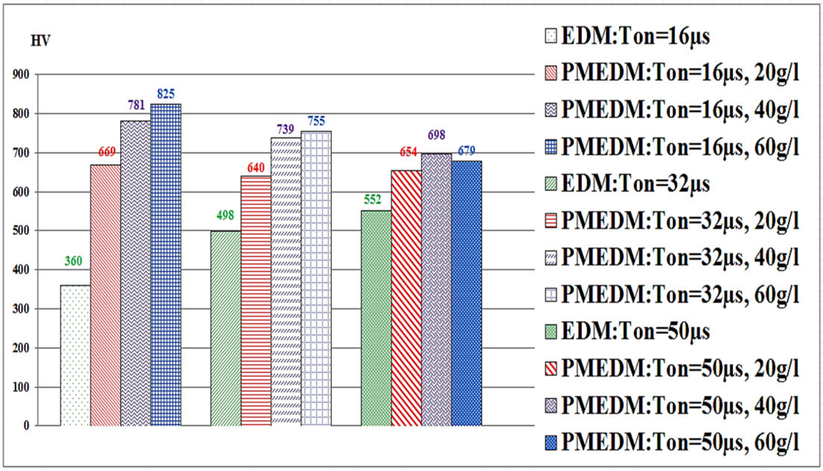

Fig. 1. (Color online) Microhardness on the surface of workpiece (HV) at $I_p = 1$ A.

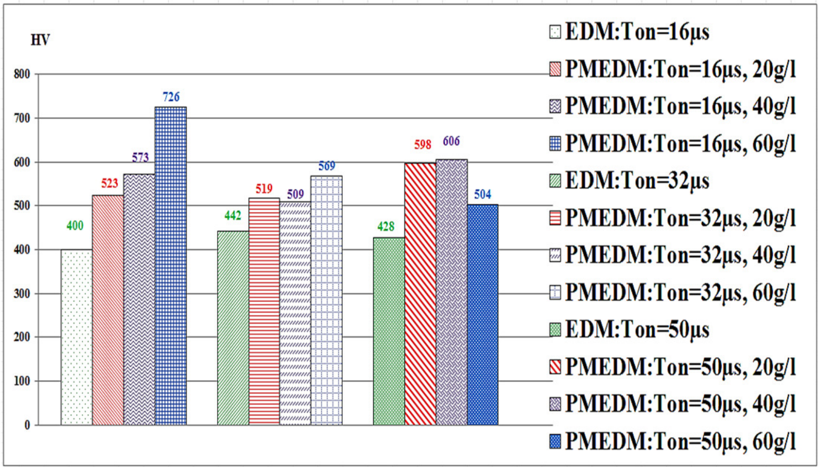

Fig. 2. (Color online) Microhardness on the surface of workpiece (HV) at $I_p = 2$ A.

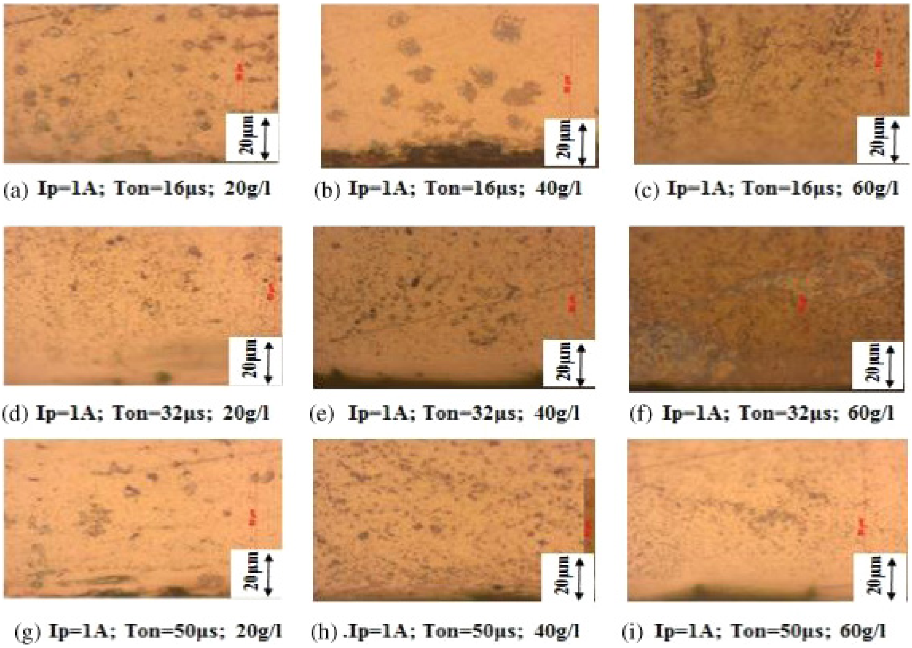

Fig. 3. (Color online) The tungsten carbide phase of longitudinal section at $I_p = 1$ A, 500 times.

form Tungsten carbide, as shown in Figs. 3 and 4 and Table 2. This explains the phenomenon: the microhardness on the surface of workpiece in PMEDM is higher than the microhardness on the surface of workpiece in EDM, the change highest of microhardness on the surface of workpiece between PMEDM and EDM is 129.17% at the mode $T_{\text{on}} = 16$ μs; $I_p = 1$ A and concentration 60 g/l in Fig. 1.

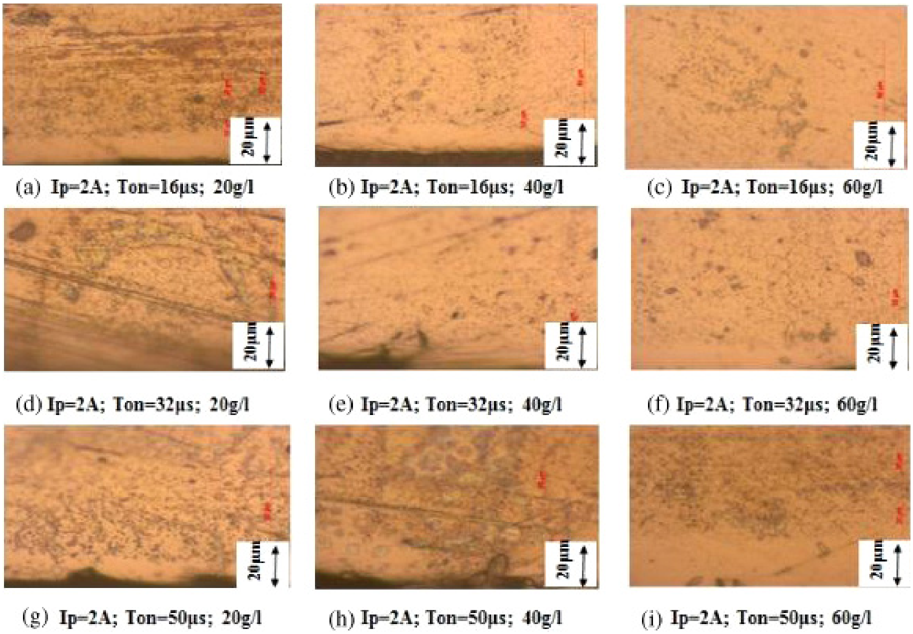

Fig. 4. (Color online) The tungsten carbide phase of longitudinal section at $I_p = 2$ A, 500 times.

Table 2. The tungsten content penetration into the surface of workpiece.

Pulse on	$T_{\text{on}} = 16$ μs			$T_{\text{on}} = 32$ μs			$T_{\text{on}} = 50$ μs		
Powder concentration	20 g/l	40 g/l	60 g/l	20 g/l	40 g/l	60 g/l	20 g/l	40 g/l	60 g/l
W(%) at $I_p = 1$A	10.2	40.474	62.407	0.237	11.82	14.723	3.563	10.6	10.493
W(%) at $I_p = 2$A	9.687	39.27	47.81	4.783	0.867	5.403	6.85	7.693	4.467

The short time of electrical discharges (T_{on}) having the microhardness on the surface of workpiece is more than that at the long time of electrical discharges (T_{on}). The cause of this phenomenon is as follows: The short time of electrical discharges leads to the low bubble pressure first time and reports a concentration of tungsten powder more the next time, therefore, during the next time of electrical discharges in the discharge channel, the region has more tungsten penetration into the surface of workpiece. Also, the time of electrical discharge and the current of electrical discharges is reasonable to generate the enough heat channel to melt the tungsten powder and the generate imbalances of energy in the surface of workpiece, thus majorly enabling tungsten penetration into the surface of workpiece. Also, due to the concentration of the metal powder, particles appear more in the process of forming the discharge channel leading to the unstable incident during spark discharges.[3,13] This is also the main cause of reducing chemical process of carbide due to the formation of heat channels.

3.2. *Tests of the surface wear resistance*

In the wear test section, this paper selected a sample with the highest microhardness on the surface of workpiece and a sample with the lowest microhardness on the surface of workpiece to test wear. According to Fig. 5, the sample with the minimum wear rate processed by PMEDM is 0.0000154. In Fig. 6, the sample with the maximum wear rate processed by EDM is 0.0000344, so the result of improved wear resistance is 123.38%.

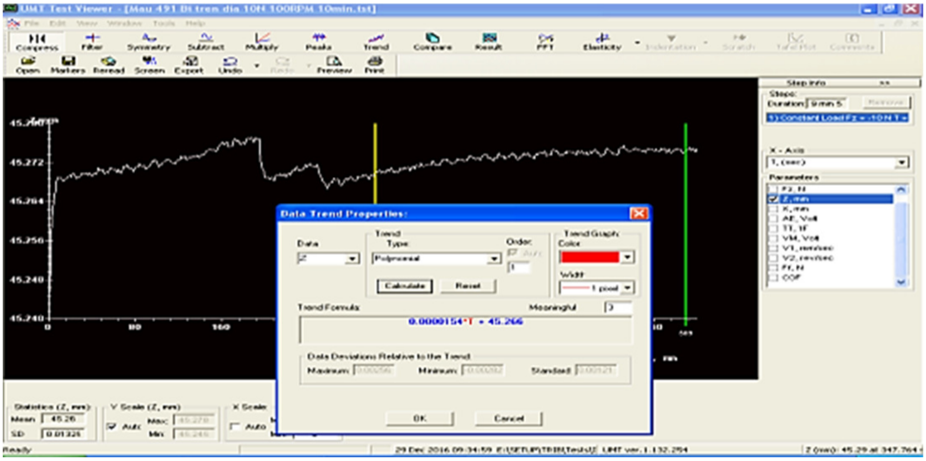

Fig. 5. (Color online) The surface wear rate of sample at $I_p = 1$ A; $T\mathrm{on} = 16$ μs; 60 g/l.

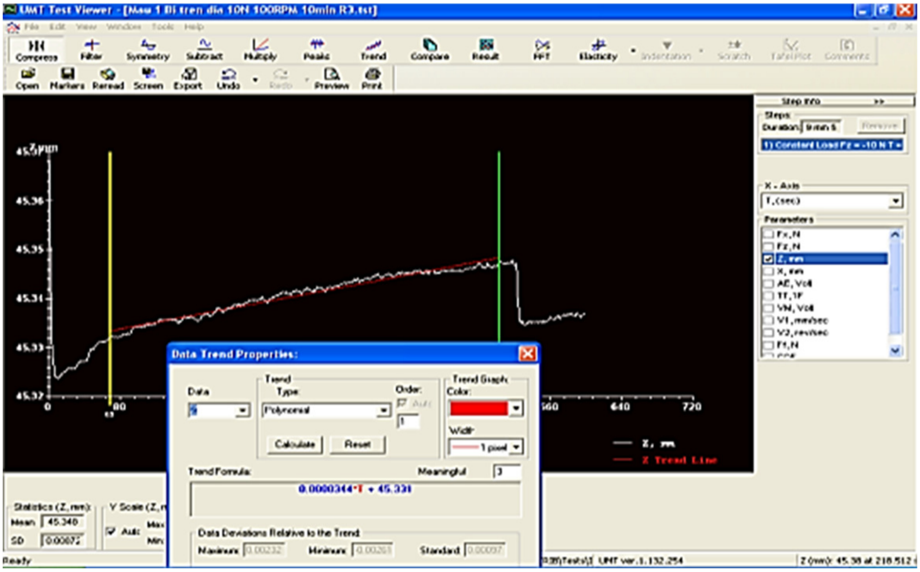

Fig. 6. (Color online) The surface wear rate of sample at $I_p = 1$ A; $T_{\mathrm{on}} = 16$ μs; 0 g/l.

4. Conclusion

In this research, all powder concentrations produced improvements of the microhardness for all combinations of I_p, T_{on}. Moreover, the change highest of microhardness on the surface of the workpiece between PMEDM and EDM is 129.17% at the mode $T_{\text{on}} = 16$ μs; $I_p = 1$ A and concentration 60 g/l. The wear test of the surface of workpiece by PMEDM at $I_p = 1$ A, $T_{\text{on}} = 16$ μs, 60 g/l as compared to that of the surface of workpiece by EDM with the same electrical technology regime resulted in improved wear resistance by 123.38%.

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