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The Influence of Electrical Parameters on the Penetration of Tungsten into the SKD61 Workpiece Surface in PMEDM using Tungsten Carbide Powder

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Abstract

In the study, the authors studied the effect of the electrical current (I_p); the time-on discharge (T_{on}) on the penetration of tungsten into the surface of SKD61 steel at different concentrations of tungsten carbide powder used in powder mixed electrical discharge machining. The research has shown that the electrical current and the time-on discharge can impact greatly on the penetration of tungsten and the carbidation of the steel surface. In the mode of low electrical discharge, the penetration of tungsten into the surface and the carbidation of the surface is better than that of the mode of high electrical discharge.

Keywords: EDM, PMEDM, Surface modification, Tungsten carbide powder.

1. Introduction

The material SKD61 is a material with the mechanical properties suitable for molds and machine parts. Especially when heat-treated or chemically treated, SKD61 can achieve good mechanical properties. Tungsten is a metallic element with the low thermal expansion and high strength, a high melting temperature of about 3422°C. In addition, the resistance to oxidation, acid and alkali corrosion of tungsten is very good. These characteristics are also shown when tungsten is penetrated into SKD61 surfaces. The valuable surface characteristics created by the penetration of tungsten is being useful in tools and molds in the practice, particularly in the mechanical engineering industry.

In the method of processing, the electrical discharge machining (EDM) is widely used in mechanical engineering. EDM is used for machining high-strength material that are difficult with other methods. In recent years, there have been some studies to improve the quality of surface workpiece by EDM. One of the methods to improve the machining quality is to add powder into the dielectric fluid. In the process of powder mixed EDM (PMEDM), the conductive particles mixed in the dielectric fluid reduces the insulation possibility of the dielectric fluid and therefore increases the electrical discharges between the electrode and the workpiece [1]. Besides, the spark discharges are more even and extended [2]. In addition, during spark discharges, a thermal channel is formed which allows the melting of the metal particles and the chemical separation of carbon element in the dielectric fluid that enables the carbidation process on the surface of workpiece in PMEDM. Therefore, the surface quality is improved considerably, especifically the micro hardness and the abrasion resistance. These are the main reasons for many researchers to focus on PMEDM.

In 1980, Erden and Bilgin [3] detected the effect of impurities in the dielectric liquid of EDM method, the authors have verified the experiments and theory to determine the influence of impurities, which found that adding the alloy powders impurities in the dielectric liquid that has improved the quality surface of workpiece after machining. Following the ensuing years many authors have studied the effect of impurities are mixed in the dielectric liquid of EDM, specifically with some typical authors:

Wang et al [4] studied the impact of mixed the alloy powders (Al and Cr) in the oil dielectric of EDM process. Wang proved the electric parameters, the nature and concentration of the alloy powders in the dielectric liquid are influential in technology properties and quality surface. Thus the coated metal and the surface roughness are changed.

Mohri et al [5,6,7] studied the effect of the silicon powders on the quality surface of workpiece after machining. The results are surface resistant to corrosion and the surface roughness (Ra) of less than 2 μm.

Uno et al [8] showed that the nickel powders mixed in the dielectric liquid of EDM process, that has transformed the surface of workpiece in bronze, aluminum. The nickel powders was used to coat a surface layer on the workpiece to make high abrasion

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resistance. Also authors pointed that coating thickness increased with increasing concentrations of nickel powders.

In the world, very few authors studied tungsten carbide powders mixed in the dielectric liquid of EDM process to alter surface properties of workpiece. Within the framework of the paper, the authors investigate the impact of electrical parameters on the surface properties such as micro hardness of the steel SKD61 as well as the study of carbidation process of the surface after PMEDM.

2. Experiment

The total experiment plan is shown in Figure 1. The following sessions describe in details the materials and methods of the experiments.

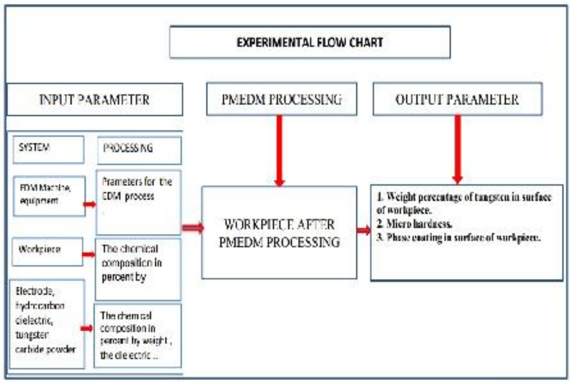

Fig. 1. Experimental flow

Table 1. The Chemical Composition in Weight Percentage of SKD61

C%	Si%	Cr%	Mo%	V%
≤0.38	≤1.0	≤5.0	≤1.25	≤1.0

Table 2. The Technical Properties of Shell Oil EDM Fluid 2

Properties	Unit	Value
Velocity at 40^0C	cSt	2.25
Density at 15^0C	kg/l	0.773
Freezing temperatures (max)	^{0}C	-27
Thermal conductivity	W/m ^{0}C	0.01

Table 3. The Chemical Composition of Tungsten Carbide Metal Powder

C%	Co%	Fe%	W%	Other components
≤5.56	≤11.9	≤0.02	≤82.5	<0.01

Table 4. The Particle Size in Weight Percentage of Tungsten Carbide Metal Powder

5.5µm	11µm	16µm	22µm	31µm
≤5.23%	≤25.98%	≤59.74%	≤89.35%	≤98.93%

2.1. Materials and Equipment

The experiment used Daido Steel SKD61-Amistar (JIS- Japan) with the chemical composition as shown in Table 1. The dielectric fluid is Shell Oil EDM Fluid 2. The technical properties are shown in Table 2. The particle size and the chemical composition in percent by weight of tungsten carbide metal powder is shown in Table 3 and Table 4.

2.2. Experiment 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 5. The copper electrode polarity was negative. In this experiment, tungsten carbide metal powder was mixed into the dielectric fluid with the concentrations as in Table 5.

Table 5. Experimental Conditions

Deposition Condition	Detail
Current (A) (I_p)	1A, 2A
Pulse on (µs) (T_{on})	16 µs, 32 µs, 50 µs, 200 µs
Pulse off (µs) (T_{off})	50µs
The dielectric fluid	Shell EDM Fluid 2
Polarity of Cu-electrode	Negative (−)
Current voltage (V)	80-120 V
Powder concentration (g/l)	20; 40; 60

The parameters of the process are given in Table 5. The chemical composition was measured by Energy-dispersive X-ray spectroscopy (EDX) on a scanning electron microscope JSM6610LA- JEOL (JAPAN). Layer coating in surface of workpiece was taken by a microscope AXIO-A2M. Micro hardness of surface was determined by micro hardness tester DURAMIN- STRUERS

3. Results and discussion

3.1. Analyzing the content of the element tungsten penetration into the surface of workpiece

Using the EDX method to determine the chemical composition of surface by region. As shown in Figure 2

As shown in Figure 3a;3b;3c, the chemical composition of surface is determined at the mode I_p = 1 A, T_{on} = 16 µs, 60g/l. The tungsten content of the surface is averaged among the three surface region on the workpiece.

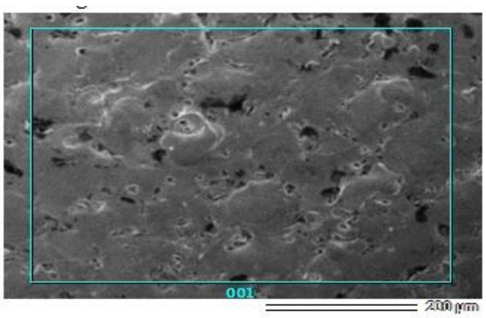

Fig.2. The region determine the chemical composition of surface by EDX

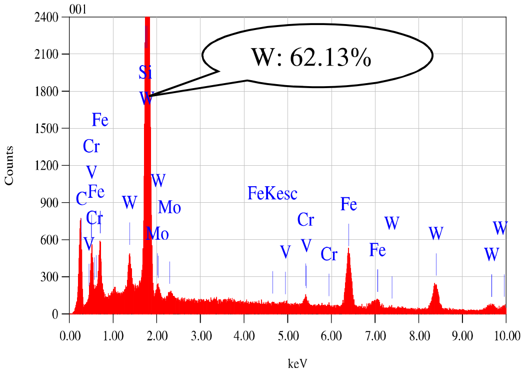

Fig. 3a. The region I

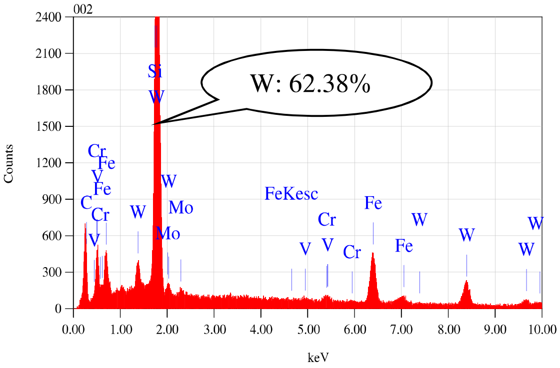

Fig. 3b. The region II

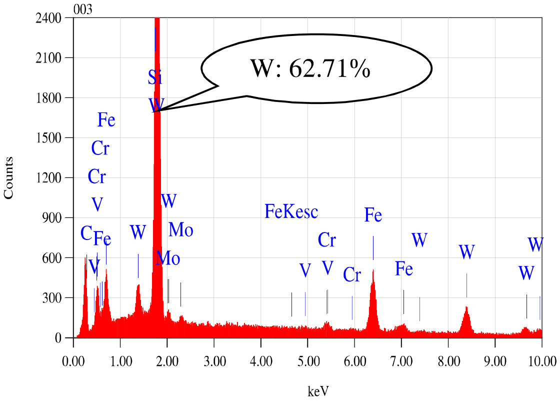

Fig. 3c. The region III

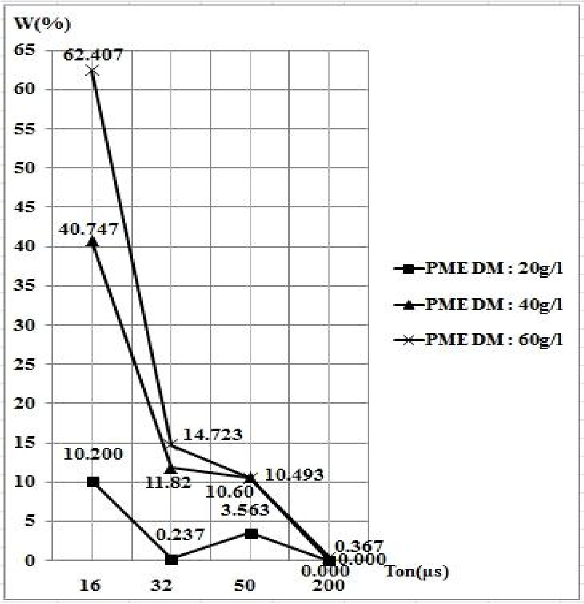

Fig. 4. The tungsten content penetration into the surface of workpiece at I_p = 1A

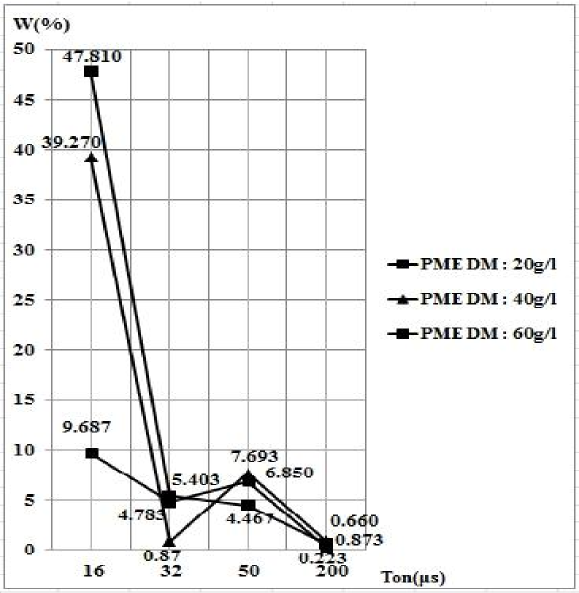

Fig. 5. The tungsten content penetration into the surface of workpiece at I_p = 2A

The tungsten content penetrate into the surface layer of workpiece at I_p = 1A; I_p = 2A from figures 4 and 5:

According to the graph in Figure 4, 5:

Considering at the pulse on time, or time-on (T_{on}), the element tungsten always penetrated into the surface of SKD61 steel. The only at two modes of T_{on} = 200 μs, I_p = 1A, the concentration of 20 g/l and 40 g/l (Figure 2), the tungsten does not penetrate into the surface of workpiece.

The cause of this phenomenon can be explained as follows: The heat of the electrical discharges has molten the tungsten carbide powder which later on penetrate into the surface of workpiece. The element tungsten does not penetrate into the surface of workpiece at T_{on} = 200 µs mode, I_p = 1A, the concentration of 20 g/l and 40 g/l, is due to the prolonged sparks time, the high bubble pressure of the previous period reduced the concentration of tungsten powder in the next period, leading to little or no penetration of tungsten carbide into the workpiece surface.

At the short time of eletrical discharges (T_{on}), the tungsten content in the surface of workpiece are more than that at the long time of eletrical discharges (T_{on}). At the mode T_{on} = 16 µs, the tungsten content in the surface of workpiece is more than at the T_{on} = 32 µs; 50 µs; 200 µs at Ip = 1 A and I_p = 2 A. Also, according to the diagram in Figure 4, T_{on} = 16 µs; I_p = 1 A and concentration of 60 g/l having the highest tungsten content into the surface of workpiece, which is 62.407%.

This phenomenon is due to the short time of electrical discharges, which leads to the low bubble pressure of the previous period, leading to a higher concentration of tungsten powder in the next period. Therefore, during the next electrical discharge period, the tungsten penetration into the surface of workpiece in the discharge channel forming region is much higher. Also, the time of electrical discharge and the current of electrical discharges are at reasonable levels to generate a heat channel to melt the tungsten powder and then generates the energy imbalances in the surface of workpiece, enabling of tungsten penetration into the surface of workpiece.

3.2. Micro hardness on the surface of workpiece.

Using the micro hardness tester DURAMIN-STRUERS to determine the micro hardness of surface. The micro hardness of the surface is an average value of three point on the surface of workpiece.

According to the graph in Figure 6, 7, the micro hardness on the surface of workpieces in PMEDM method are higher than the micro hardness of the surface of workpieces in the EDM method.

This phenomenon can be explained by the appearance of the tungsten content in the surface of workpiece after machining, according to Figure 8, 9. The tungsten content are changed in to carbide on the surface of workpiece under the thermal effect of the EDM process. The carbon may come from the dielectric or the based material. This explains the fact that the micro hardness on the surface of workpiece in PMEDM is higher than the micro hardness on the surface of workpiece in EDM. The improvement comparing between the micro hardness on the surface of workpiece in PMEDM and the micro hardness on the surface of workpiece in EDM is lowest by 2.76% at the mode T_{on} = 200 µs; I_p = 1 A and concentration 20g/l. The highest improvement of micro hardness on the surface of workpiece between PMEDM and EDM is 129.17% at the mode T_{on} = 16 µs; I_p = 1 A and concentration 60g/l.

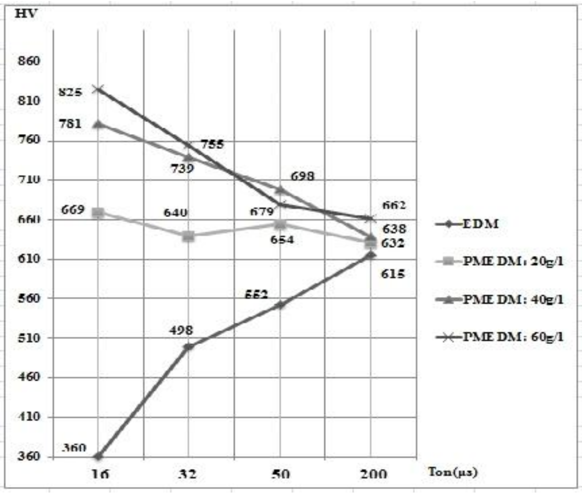

Fig. 6. Micro hardness on the surface of workpiece (HV) at I_p = 1 A

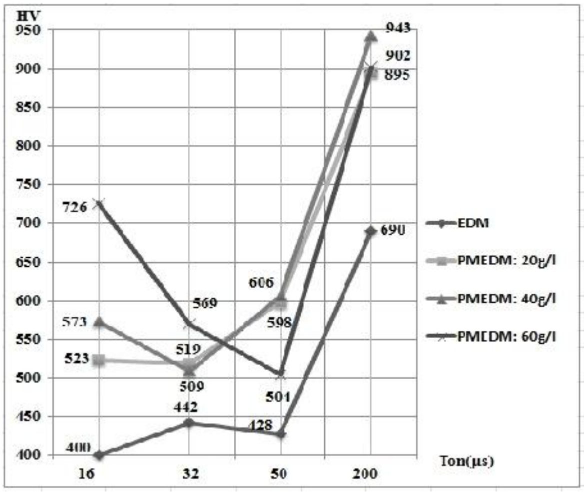

Fig. 7. Micro hardness on the surface of workpiece (HV) at I_p = 2 A

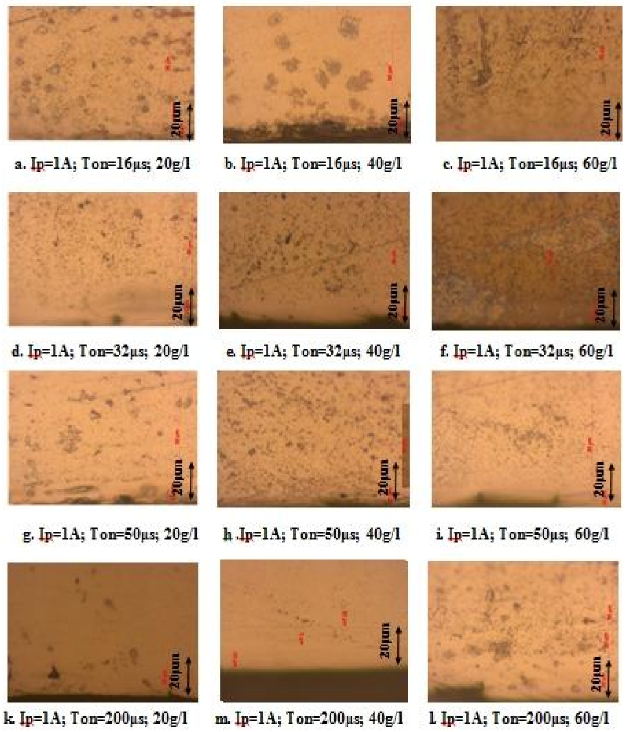
a. Ip=1A; Ton=16µs; 20g/l
b. Ip=1A; Ton=16µs; 40g/l
c. Ip=1A; Ton=16µs; 60g/l
d. Ip=1A; Ton=32µs; 20g/l
e. Ip=1A; Ton=32µs; 40g/l
f. Ip=1A; Ton=32µs; 60g/l
g. Ip=1A; Ton=50µs; 20g/l
h. Ip=1A; Ton=50µs; 40g/l
i. Ip=1A; Ton=50µs; 60g/l
k. Ip=1A; Ton=200µs; 20g/l
m. Ip=1A; Ton=200µs; 40g/l
l. Ip=1A; Ton=200µs; 60g/l

Fig. 8. The tungsten carbide phase of longitudinal section at I_p = 1 A, 500 times magnification

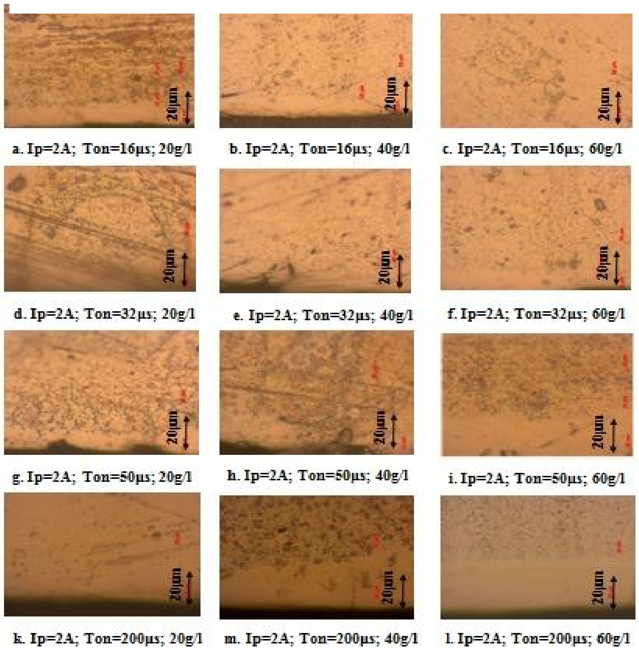
a. Ip=2A; Ton=16µs; 20g/l
b. Ip=2A; Ton=16µs; 40g/l
c. Ip=2A; Ton=16µs; 60g/l
d. Ip=2A; Ton=32µs; 20g/l
e. Ip=2A; Ton=32µs; 40g/l
f. Ip=2A; Ton=32µs; 60g/l
g. Ip=2A; Ton=50µs; 20g/l
h. Ip=2A; Ton=50µs; 40g/l
i. Ip=2A; Ton=50µs; 60g/l
k. Ip=2A; Ton=200µs; 20g/l
m. Ip=2A; Ton=200µs; 40g/l
l. Ip=2A; Ton=200µs; 60g/l

Fig. 9. The tungsten carbide phase of longitudinal section at I_p = 2 A, 500 times magnification

This was partly due to the lower tungsten content of the surface. Also, the high concentration of the metal powder particles during forming the discharge channel has resulted in an unstable spark discharges condition [3]. This is also the main cause of reduction in chemical carbidation process due to the formation of heat channels.

Considering the micro hardness using the tungsten powder, where I_p = 1 A; I_p = 2 A, the micro hardness increases with the increasing concentration. However, the micro hardness at I_p = 1 A; T_{on} = 50 µs; 60g/l is lower than the micro hardness at 40 g/l. Similarly, the micro hardness at I_p = 2 A; T_{on} = 32 µs; 40 g/l is lower than the micro hardness at I_p = 2 A; T_{on} = 32 µs; 20 g/l, the micro hardness at I_p = 2 A; T_{on} = 50 µs; 60 g/l is lower than the micro hardness at I_p = 2 A; T_{on} = 50 µs; 20 g/l and 40 g/l.

4. Conclusions

The research investigating the tungsten penetration into the surface of workpiece under the influence of the electrical discharges curent (I_p), the time electrical discharges (T_{on}) and the powder concentration in PMEDM using tungsten carbide alloy powder mixed into the oil dielectric has achieved the following new results:

1. The micro hardness on the workpiece surface in PMEDM is improved as compared to that of EDM.

2. The highest tungsten content at I_p = 1 A; T_{on} = 16 µs and concentration 60 g/l, where the penetration into the surface of workpiece is 62.407%.

3. The improvement of the micro hardness of the workpiece surface of PMEDM as compared to that of EDM is lowest by 2.76% at the mode T_{on} = 200 µs; I_p = 1 A and concentration 20 g/l. The highest change of micro hardness of the workpiece surface between PMEDM and EDM of 129.17% was obtained at the mode T_{on} = 16 µs; I_p = 1 A and concentration 60 g/l.

4. At I_p = 1 A; T_{on} = 16 µs with all the different concentrations, the tungsten penetration into the surface of workpiece is highest and there is a significant improvement the micro hardness of PMEDM in comparison with EDM.

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