

Influence of the Electrical Conductivity of Dielectric Fluid on WEDM Machinability

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ABSTRACT: In wire-electrical discharge machining (WEDM), The dielectric plays an important role as the working fluid. During machining, the melted material by heat is dispersed into dielectric. The presence of minute metal particles (gap debris) contaminates dielectric fluid. It affects the material removal rate and properties of the machined surface because it exists in the spark gap between work and electrode. This work deals with the effect of the electrical conductivity of a dielectric fluid on the metal removal rate and surface quality by WEDM. The specimens are three types of sintered carbides and a low-carbon steel. Experimental results show that increasing the fraction of cobalt in carbides improves the metal removal rate, but the surface quality is degraded as a greater quantity of solidified metal deposits on the eroded surface. Lower electrical conductivity of the dielectric results in a higher metal removal rate as spark gap reduced. The debris, the surface characteristics of material and wire electrode were also analyzed through scanning electron microscopy (SEM) and surface roughness tester.

Key words: electrical conductivity of dielectric, cobalt fraction of sintered carbide, wire electrical discharge machining, offset

1 INTRODUCTION

Wire EDM(WEDM) has been an important nontraditional machining process, and regarded as a reliable and flexible machining method, due to its capability of machining any material with electrical conductivity more than $0.01\mu\text{S}/\text{cm}$.

WEDM is a numerically controlled, modified EDM technique where the work geometry is generated by a NC-controlled traveling wire. A CNC WEDM machine can generate almost any 3-D intricate parts at a considerable cutting speed with a new wire electrode and generator. Further, the method is applicable to an extensive variety of work materials including hard alloys, PCD, CBN and silicon wafers.

In WEDM, the erosion mechanism has been described as melting and/or evaporation of the surface material by the heat generated in the plasma channel.

S. Banerjee et al proposed three dimensional transient temperature distribution and crater formation of the wire during a single discharge period in the electrical discharge machining process by an explicit finite-difference model.

Usually some extra repetitive finish cuts along the contour of a previous rough cut are necessary, done by offsetting the wire by a small amount, to obtain the specified accuracy and a good surface quality. The finish cut is a side-cutting process, which uses a smaller offset value and lower electrical energy.

The surface eroded by EDM is of random nature.

Therefore, the study of the surface is to be done not only from metallurgical aspects but also from the point of view of its topography. In EDM process, the thermal expansion is generated intensively in the vicinity of discharge point.

2 DIELECTRIC

The dielectric has several functions including insulation, ionization, cooling, and removal of waste metal particles. As the voltage builds up, the water ionizes and becomes a conductor. After the spark, which develops tremendous heat, the water becomes coolant, and flushes away the eroded material. Wire EDM uses high-pressure flow of the water dielectric to wash away the debris. The water exits a nozzle at pressure up to 300 psi to surround the cutting wire and flush away the eroded material.

When dielectric oil breaks down, electrons move towards the anode under the electric fields from the no-load potential. These electrons collide with neutral atoms producing many positive ions and electrons that move across the channel toward the cathode and anode respectively. The plasma channel is short about $10\mu\text{m}$. If kerosene is used, the number of sparks is initially small, but is increased as the metal debris diffuses into the channel. Since deionized water does not have free electrons, this phenomenon does not occur in the same manner as above.

The electrical conductivity of water is expressed to measure its current value and is related with specific

resistance of its own ($\Omega \text{ cm}$). The water used is collected into dirty tank and metal particles of it are filtered out through filter cartridge unit. The conductivity of the filtered water is controlled automatically through ionic exchanger unit according to the conductivity designated by operator.

The electric field is now given by the quotient of the applied voltage divided by the electrical gap. The electrical gap is defined, by opposition to the mechanical one, by the part-electrode distance (μm) minus the local mean debris diameter [3]. These debris are due to the contamination.

$$E(x,y) = \frac{U}{\text{Gap}(1 - \text{contamination}(x,y))}$$

where, U is the applied voltage.

This paper deals with the results of a series of WEDM tests carried out on various cemented carbides having different percentage of cobalt present in tungsten carbides (GT10, GT20, GT30), and a low-carbon steel (S25C). The aim of these tests is to evaluate the machinability and other characteristics of those materials due to the variation of the electrical conductivity of dielectric.

3 EXPERIMENT

3.1 Machine

The experiments were conducted using a Robofil 220 CNC wire cutting machine from the Charmilles Co. (Swiss). As listed in table 1, the wire electrode used was zinc-coated brass (Cu: 65, Zn: 35%) wire, 0.25mm diameter.

Table 1 Chemical composition of sintered carbides

Items Carbide	Chemical composition (%)		
	Co	TiC + TaC	WC
GT 10	6	-	94
GT 20	12	3	85
GT 30	15	3	82

Table 2 Chemical composition of low-carbon steel (S25C)

Chemical composition (%)								
C	Si	Mn	P	S	Ni	Cr	Mo	Fe
0.28	0.26	0.66	0.05	0.06	0.10	0.12	0.04	remants

3.2 Experimental procedure

The WEDM process consists of one rough cut and four successive finish cut operations, varying machining

conditions according to machine-manufacturer's operating manual. Cutting conditions for the experimental procedures are shown in table 3.

Table 3 Cutting conditions

Items	Kinds	
Workpiece (thickness = 5mm)	3 sintered carbides (Co 6, 12, 15%)	
	Low-carbon steel (S25C)	
Wire	material	Zn coated CuZn35 brass
	feedrate	60 mm/sec
	diameter	0.25 mm
Cutting regime	A) Rough cut B) As A + fine shaping C) As A + surface semi-finishing D) As A + surface finishing E) As A + surface micro finishing	
WEDM machine	Robofil 220 (Charmilles Co., Swiss)	
Dielectric	Deionized water, Electrical conductivity : 5, 10, 15, 20 $\mu\text{S/cm}$	

4 EXPERIMENTAL RESULTS AND DISCUSSION

We analyzed the machinability and surface characteristics of workpieces used in the WEDM test. Data were gathered on each material relative to the electrical conductivity, removal rate and surface roughness parameters. To analyze the machined surface characteristics of workpieces, they were molded into epoxy, ground with diamond wheels and polished with diamond paste.

Roughness and topography were measured by the aid of surface roughness tester (Tallysurf-120L, Tallyhobson Co.) on a measuring length of 4.0mm and a cutoff length of 0.8mm.

4.1 Material removal rate and surface roughness

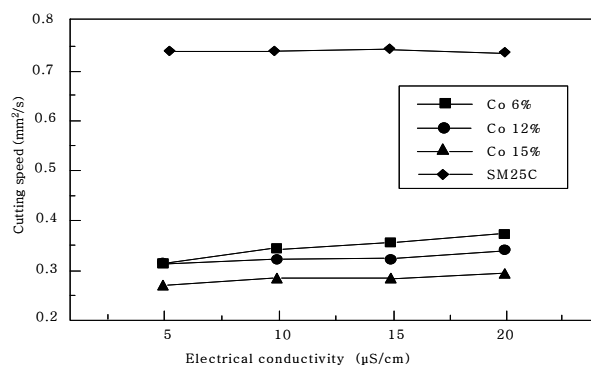
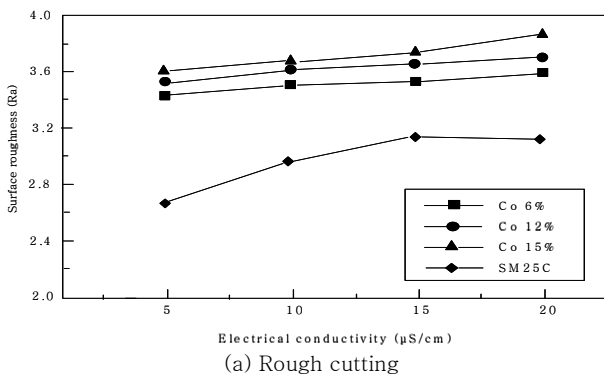


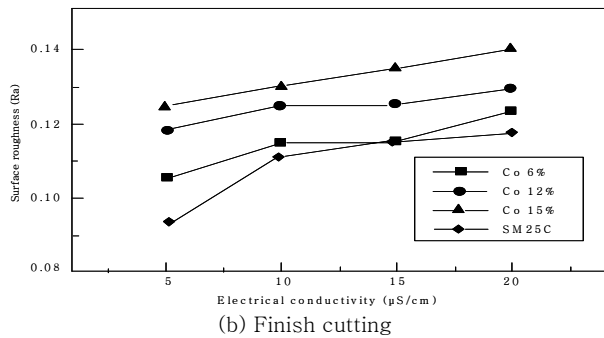
Fig. 1 Electrical conductivity and cutting speed

Fig. 1 shows the average cutting speed for rough

cutting as a function of electrical conductivity of dielectric. Higher electrical conductivity of dielectric yields a higher removal rate. The reason for this is that finely dispersed waste particles make it possible for ionization channels to build up more rapidly. When the spark progresses through the water towards the workpiece, it may encounter pieces of ejected material. This debris can improve process stability, probably by the reduction of arcing frequency, but too much debris in a spark gap is generally believed to be the cause of arcing.



(a) Rough cutting



(b) Finish cutting

Fig. 2 Relationship between electrical conductivity and surface roughness

Fig.2 shows the surface roughness for rough cutting and four finish cuts for workpieces. In case of sintered carbides, these graphs show that lower cobalt content decreases the surface roughness. They also show that the surface roughness after roughing and three or four finish cuts is independent of cobalt content. With a high Co-content, the final surface quality is worse because a greater quantity of solidified metal deposits on the eroded surface.

4.2 Surface Characteristics

The rough-cut surface of a workpiece, GT-10 (WC 90%, Co 10%) was analyzed with EDS as shown Fig.3. This figure suggests that a certain amount of wire material gets deposited on the workpiece surface. There 2.18 % of copper can be seen, coming from the wire material. This means that the transfer of wire material (Cu, Zn) to the workpiece occurs during normal sparking.

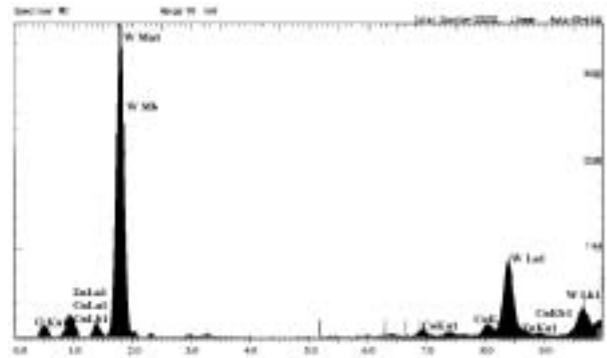
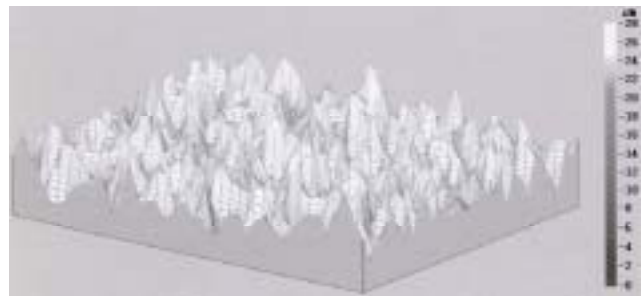


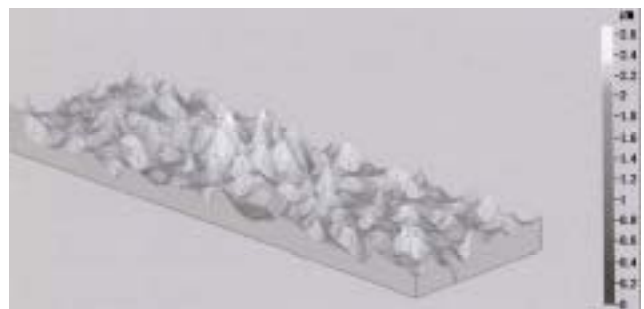
Fig. 3 X-ray diffraction pattern from rough-cut surface of sintered carbide(WC 90%, Co 10%, electrical conductivity of dielectric 20µS/cm)

And it is considered that the cutting surface consists of cleavage planes sometimes contaminated with Cu and Zn.

The surface eroded by EDM is of random nature. Therefore, the study of surface is to be done not only from metallurgical aspects but also from the point of view of its topography. The surface of material generated using WEDM is composed of many microscopic craters associated with the random spark discharge.



(a) by rough cutting



(b) by finish cutting (6th cutting)

Fig. 4 Surface topography of WEDMed sintered carbide (Co 16%, electrical conductivity of dielectric 20µS/cm)

WEDM topographies are presented in Fig 4 by surface roughness tester (measuring length of 4.0 mm, interval of 0.05 mm and a cutoff length of 0.8 mm), the crater structure with their high peaks adjacent to valleys of removed material is clearly evident. Fig 4(a) shows that the rough

cutting leaves a large crater having large diameter and depth in random location. The size of the craters produced on the workpiece surface depends mainly upon the energy of the discharge. When successive fine cutting of five times are imposed over the rough surface, many high peaks on rough-cut surface were removed. The height of peak, $4 \sim 6 \mu\text{m}$ was lowered to $0.8 \sim 2.4 \mu\text{m}$ as shown Fig 4(b).

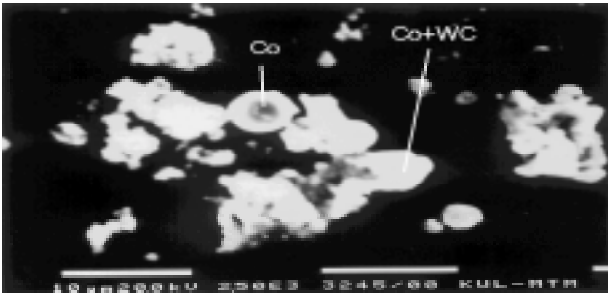


Fig. 5 SEM photograph for debris during rough cutting (WC 88%, Co 12%)

Fig. 5 shows the analyzed debris from the polluted dielectric with EDS. Molten mixture of WC-Co and Co of Sintered Carbide are detected. Cu and Zn can be found, which means some part of wire electrode material with workpiece are also melted and dispersed into the dielectric during machining.

The presence of minute particles in insulating liquids drastically lowers the breakdown strength of dielectric. Evidently, gap debris facilitates ignition process and increase gap size. According to these observations and knowledge, debris can improve process stability probably by the reduction of arcing frequency. Small gap size (approximately $5\text{--}30 \mu\text{m}$) is often considered a cause for the instability since debris evacuation could be blocked. In accordance with a traditional strategy to avoid arcing, the main cause for an unstable process, gap size should always be increased to evacuate more debris.

5 Conclusions

The following conclusions were drawn from the experimental results of WEDM performed on a low-carbon steel and 3 different sintered carbides under variation of electrical conductivity of dielectric fluid.

- 1) The grade of the cemented carbide has an influence on the machining results. Low cobalt concentration yields a higher removal rate, however the microcracks will be somewhat longer.
- 2) It is important to have good quality water in the work tank. Higher electrical conductivity of water yields a higher removal rate but poorer surface smoothness. It is recommended that the ideal conductivity vary from 5 to $10 \mu\text{S}/\text{cm}$ to prevent from corrosion and electrolytic

wash for fine surface and precision machining.

3) The presence of mixed carbides (TiC, TaC) has no influence on the erosive process. Cobalt wash along edge is present in all alloys.

4) EDS reveals that some of the wire electrode material from the WEDM gets deposited onto the workpiece surface. Some elements of workpiece material can also be seen on the wire electrode surface during EDM.

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