Influence of the Electrical Conductivity of Dielectric on WEDM of Sintered Carbide

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This work deals with the electrical conductivity of dielectric and cobalt percentage on output parameters such as metal removal rate and surface roughness value of sintered carbides cut by wire-electrical discharge machining (WEDM). To obtain a precise workpiece with good quality, some extra repetitive finish cuts along the rough cutting contour are necessary. Experimental results show that increases of cobalt amount in carbides affects the metal removal rate and worsens the surface quality 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 the gap between wire electrode and workpiece reduced. Especially, the surface characteristics of rough-cut workpiece and wire electrode were analyzed too. To obtain a good surface equality without crack, 4 finish-cuts were necessary by reducing the electrical energy and the offset value.

Key Words : Electrical Conductivity of Dielectric, Cobalt Amount of Sintered Carbide, Wire Electrical Discharge Machining, Offset

1. Introduction

During the last decade, WEDM has become an important nontraditional machining process, widely used in the aerospace, automotive and tool and die industries. WEDM has nearly obtained a monopoly position in some important areas, due to its capability of machining any material with electrical conductivity more than 0.01S/cm with high cutting speed, high precision and satisfying surface finish. 5-axis CNC WEDM machine has been routinely employed in the machining of complex 3-dimensional shape and the surface roughness has improved to better than 0.2mRa. The range of materials that are machined by WEDM has increased considerably, including now sintered carbides, PCD, PCBN and specific ceramics.

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. A spark is produced between the wire electrode (usually smaller than 0.3mm) and workpiece through deionized water, (used as dielectric medium surrounding the workpiece) and erodes the workpiece to produce complex two and three-dimensional shapes.

Usually some extra repetitive finish cuttings along the contour of a previous cut are necessary, by offsetting the wire by a value, so that the specified accuracy and a good surface quality can be obtained.

2. WEDM of Sintered Carbide

Carbide is sintered material made up of carbide granules (such as tungsten carbide or silicon

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carbide) that are held together by a cobalt binder. Especially, for WEDM grades exist Ni binder and also a lot of additional elements are possible to prevent depletion of the binder as good as possible.

Actually the binders glue and pull the carbide granules together under great tension. The problem to EDM machining is that the binder is highly conductive while the carbide granules resist the flow of current. Thus the current from the EDM spark flows through the binder and around the carbide granules. The spark vaporizes the cobalt and disintegrates the carbide grains on a tiny spot on the surface. The water vapour bubble caused by the spark collapses violently and the deionized water flushes away the melted cobalt and pieces of WC grains. Then the whole process is repeated.

Lower cobalt concentration yields a higher removal rate and lower relative wear in the study of machinability of cemented carbides by spark erosion, however, the microcracks are somewhat longer. At the lowest of pulse duration, the surface roughness and microcracks yields minimum.

To obtain a precise workpiece with good surface quality, some extra repetitive finish cuts along the previous rough cut are necessary by changing the offset value between wire electrode and workpiece. The finish cutting is a type of side cutting process, which needs a smaller offset value and electrical energy.

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 WC (GT10, GT20, GT30). The aim of these tests consists in evaluating the machinability and characteristics of those materials due to variation of the electrical conductivity of dielectric in WEDM.

Deionized water was used as dielectric. Dielectric has several functions like insulation, ionization, cooling, removal of waste metal particles. As the voltage builds up, the water deionizes and becomes a conductor. After the spark, which develops tremendous heat, the water becomes coolant, then it must flush away the eroded material.

The better electrical conductivity of water-dielectric with respect to oil-dielectric means the discharge channel is less constricted. The wider discharge channel provides a better energy discharge channel distribution and therefore more material is melted and delivered out. A contaminated spark-gap causes process disturbances. The greater the discharge gap to the workpiece, the larger and shallower the discernable discharge craters and therefore identical spark energy will provide a superior surface finish with water-dielectric.

These investigations were carried out for several dielectric conductivities, keeping the remaining machining parameters constant.

3. Experiment

3.1 Machine

The experiments were conducted on a Robofil 220 CNC wire cutting machine of Charmilles Co. (Swiss). The used electrode is zinc-coated brass (Cu: 65, Zn: 35%) wire, 0. 25mm diameter. Wire feed rate is 60 mm /sec with tension 900 gf as listed in Table 1.

Table 1 Chemical composition and mechanical properties of sintered carbides

Items / Carbide	Chemical composition			Mechanical properties			
	Cobalt (%)	TiC+TaC (%)	WC (%)	Compressive strength (N/mm^2)	Modulus of elasticity (kN/mm^2)	Thermal expansion (mm/m℃)	Hardness (Hv 30)
GT 10	6	-	94	5,400	630	5.5	1,550
GT 20	12	3	85	4,500	580	5.9	1,300
GT 30	15	3	82	4,100	540	6.5	1,200

Table 2 Cutting conditions

Items		Kinds
Workpiece	Kinds	WC: 3 types (Co 6, 12, 15% respectively)
	Dimension	10×5×50(W×T×L, mm)
Electrical conductivity		4 kinds (5, 10, 15, 20μS/cm)
Wire	Base material	CuZn37 brass
	Coating	4 μm Zn
	Tension	900gf
Cutting regime		5 types : main cut, main+finish cut (1), main+finish cut (2), main+finish cut (3), main+finish cut (4)
WEDM machine		Robofil 2000 Charmilles Co., Swiss)

3.2 Experimental procedure

The WEDM process consists of one rough cutting and four finish cutting operations varying machining conditions according to machine-manufacturer's operating manual.

Workpiece materials are 3 types of cemented carbides having different percentage of cobalt present in WC (Cobalt percent: 6, 12, 15%, respectively) that covers a wide range of chemical compositions and properties as listed in Table 1. Among them, GT20 and GT30 have 3% of Titanium carbide and Tantalium carbide in WC. Cutting conditions for the experimental procedures are listed as shown in Table 2.

4. Experimental Results and Discussion

We analyze the machinability and surface characteristics of 3 types of WC used in a WEDM test. Data were gathered on each material relative to the parameters of electrical conductivity, removal rate, and surface roughness.

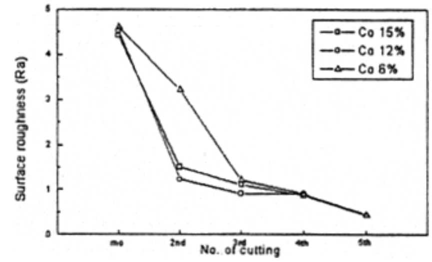


Fig. 1 Surface roughness (Ra) for the different machining operations

To analyze layer and characteristics of the machined surface, workpieces were molded into epoxy, ground with diamond wheels and polishing with diamond paste.

The variation in the quality of surface generated by various machining parameters were studied by comparing scanning electron microscope(SEM) photographs (model JSM-6300, JEOL Ltd. , Japan), operated at 20kV with energy dispersive spectrometers (EDS) after etching. Dielectric fluid was deionized water varying electrical conductivity to 5, 10, 15, 20 μS/cm as controlled by a deionized filtering system.

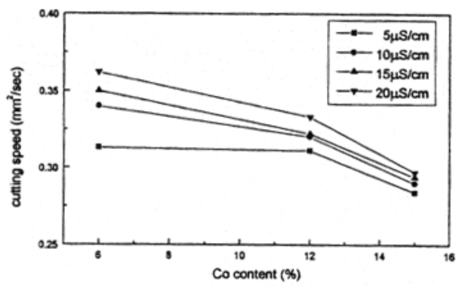
Roughness was measured by the aid of Talysurf-120L on a measuring length of 4.0mm and a cutoff length of 0.8mm. Scanning electron microscope(SEM) was also used to analyze the debris collected from the EDM process.

4.1 Material removal rate and surface roughness

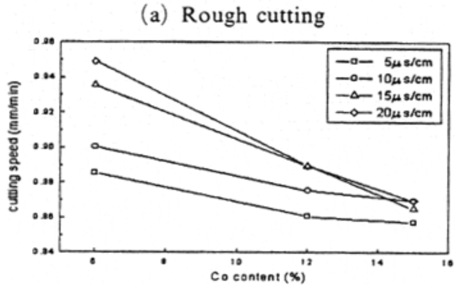
Figure 1 shows the surface quality after rough cutting and four finish cuttings for three carbides with respectively 6, 12, 15 % cobalt. The percentage of cobalt has an influence on the speed of erosion. However it shows that the surface roughness after roughing or after 3 or 4 times of finish cuts is independent of cobalt content.

A high Co-content worsens the final surface quality as a greater quantity of solidified metal deposits on the eroded surface.

The graphs in Fig. 2 show the average cutting speed depending on the percentage of cobalt after rough cutting (a) and 4 times of finish-cuttings (b) for three types of carbides varying electrical

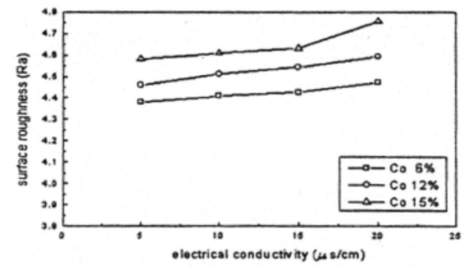


(a) Rough cutting

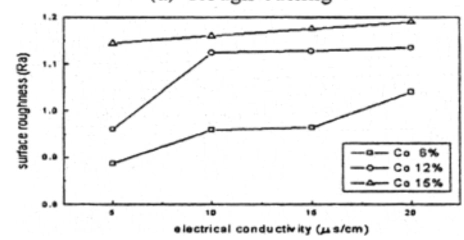


(b) Finish cutting

Fig. 2 Relationship between electrical conductivity and cutting speed



(a) Rough cutting



(b) Finish cutting

Fig. 3 Relationship between cobalt content and surface roughness

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 hit a piece of ejected material. debris can improve process stability probably by the reduction of arcing frequency. Too much debris in a spark gap is generally believed to be the cause of arcing.

The graphs in Fig. 3 show that lower cobalt content decreases the surface roughness under same condition of Fig. 2. WC having a higher cobalt content that yields has been melted into the dielectric yields a greater quantity of solidified cobalt that deposits on the eroded surface and worsens the final surface quality compared to WC with a smaller cobalt content.

Lower electrical conductivity of the dielectric yields a better surface roughness. Combined top and bottom flushing of dirty water can produce a line of holes right down the middle of the cut. However it cannot be effective because low electrical conductivity requires to change quite often with new ionic resin in ionic exchange filter system.

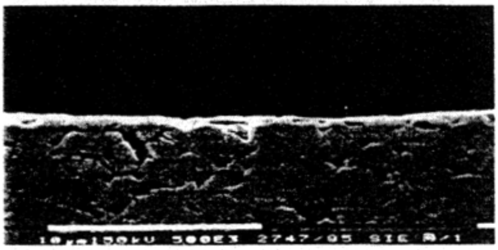
4.2 Surface characteristics

The machined specimen have been cut, ground and polished with various kinds of diamond powders (5, 3, 1 μm respectively) to able to investigate the surface characteristics of EDM machined surfaces by rough cutting. After polishing with diamond wheels and cotton wheels, the EDMed surfaces were etched in Murakami reagent. The metallographic section of an electro-eroded surface observed through a scanning electron microscope shows how corrosion appears as shown in Fig. 4(a). It can be seen that the edge and transformation zones were subjected to very high temperatures and partially melted.

This surface can be divided into three zones. The outermost surface is a "recast" area, resulting from a molten mixture of carbide grains loosely held together by an insufficient amount of cobalt binder. It can be clearly seen that cracks are distributed over the entire eroded surface and that the cracks extend far beyond the thermally influenced area into the basic material.

However, the ideal sparks collapse completely

(a) By rough cutting



(b) By finish cutting

Fig. 4 Surface characteristics of workpiece after WEDM (WC 90%, Co 10%, electrical conductivity of dielectric: 10μS/cm)

as the voltage immediately goes back to zero, so that the molten cobalt is resolidified and washed away with carbide grains leaving an almost recast-free surface.

There is no way that a cut can be made without at least some recast layer, but with the latest technology, the layer can be reduced down to around 2 μm. The new pulse-type machine sends one pulse at a time with current flow control. Kerosene is often used instead of deionised water as it is used in die-sinking EDM for the protection against electrolytic effects especially by the Japanese manufacturers.

During the corrosive process, a rather intense electric field is formed in the cutting area between WC and wire along the edge at the inlet and outlet of the wire. This phenomenon activates an electrochemical reaction that induces a fast and significant loss of cobalt of WC. The cobalt is leached in a cationic form into the water.

Tools with surfaces as shown in Fig. 4(a) would have low resistance to fracture and thus very short endurance compared to the same tools produced with conventional methods. The recast layer must be removed by grinding or lapping, to restore the carbide to a crack-free surface. If it is not removed, premature wear with probable chipping or flaking will result.

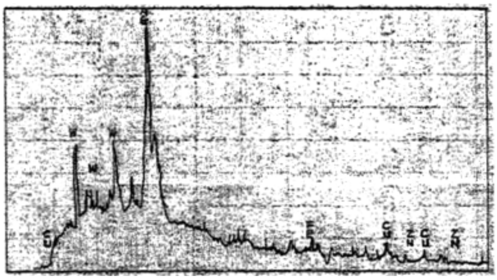


Fig. 5 X-ray diffraction pattern from WEDMed surface

Below the recast layer, an "eroded" area and an "intact" area exist. In the eroded area, binder cobalt is depleted, making the tungsten particles look like loose pebbles. And small spots of pits, cracks and only carbides are left.

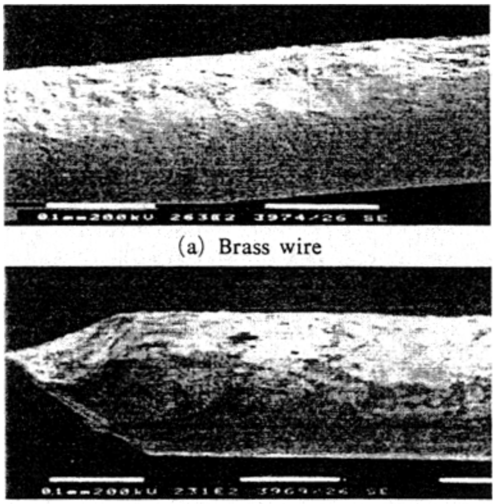
From Fig. 4(b), it is also found that the 4 final finish cuttings result in a thin recast area (1~2μm deep) without cracks using the standard technology given in the operating manual. By resorting to successive finishing cuts having less energy, the zone influenced by rough cutting can be almost removed. But usually lapping or grinding might be added to this fine-cut surface for the better surface and longer life of tool like die components.

The rough-cut surface of a workpiece, GT-10 (WC 90%, Co 10%), was analyzed with EDS (energy dispersive spectrometer) as shown Fig. 5.

This figure suggests that some amount of wire material get deposited on the workpiece surface. 2.18% of copper coming from the wire material can be seen. This means that the transfer of wire material (Cu) to the workpiece occurs during normal sparking. The cutting surface consists of cleavage planes sometimes contaminated with Cu and Zn.

4.3 Wire electrode

Figure 6(a) and (b) are the surfaces of brass wire and Zn-coated brass wire electrode after EDM. Due to the heat generated by the electrical spark between electrode and workpiece, some



(a) Brass wire

(b) Zn-coated brass wire

Fig. 6 Wire electrode after WEDM

part of electrode surface is melted and flushed into the dielectric. Another part is recast on the electrode surface. Cobalt and tungsten elements of the workpiece can also be seen on the surface. This means that these elements are melted and deposited onto the wire electrode surface as shown Fig. 5. Wire rupture can occur when the mechanical stress exceeds the tensile strength of wire. This phenomenon is facilitated due to the thermal load on the wire.

5. Conclusions

(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 worse surface roughness. It is advised that the ideal conductivity varies from 5 to 10 μS/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 amount of wire electrode material from the WEDM get 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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References

ASM, *Cemented Carbides,* Metals Handbook, Vol. 2, 10th Edition, pp. 950~977.

Brooks, K. J. A., 1992, "World Directory and Handbook of Hardmetals and Hard Materials," 5th edition, pp. 85~89, International Carbide Data.

Charmilles Technologies Co., 1998, Operaring manual.

Cornelissen, H., Snoeys, R. and Kruth, J. P., 1977, "Investigation on the Optimal Machining Conditions for Electro-Discharge Machining of Cemented Carbides," *5th North American Metalworking Research Conference* (NAMRC-5), pp. 258~263.

Dauw, D. F. and Albert, L., 1992, "Two Decades of Wire-EDM Evolution: A Significant Improvement of Overall Performance," *Proc. of the 10th Inter. Symp. Electromachining* (ISEM-10), pp. 300~319.

Dunnebacke, George, 1992, "High Performance Electrical Discharge Machining Using Water-Based Dielectic," *Proc. of the 10th Inter. Symp. For Electromachining (ISEM-X)*, pp. 161~169.

Gadalla, A. M. and Tsai, W., 1989, "Electrical Discharge Machining of Tungsten Carbide-Cobalt Composites," *J. American Ceramic Society*, Vol. 72, No. 8, pp. 1396~1401.

Huang, J. T., Liao, Y. S. and Hsue, W. J., 1991, "Determination of Finish-Cutting Operation Number and Machining-Parameters Setting in WEDM," *J. of Mat. Proc. Tech.*, Vol. 87, pp. 69~81.

Kobayashi, K., 1995, "The Present and Future Developments of EDM and ECM," *Proc. of the 10th Inter. Symp. Electromachining (ISEM-XI)*, pp. 29~48.

Konig, W., Dauw, D. F., Levy, G. and Panten, U. 1988, "EDM, A Future Step Towards the Machining Ceramics," *Annals of the CIRP*, Vol. 37, No. 2, pp. 625~631.

Lenz, E., Katz, E., Konig, W. and Wertheim, R., 1975, "Cracking Behaviour of Sintered Carbides during E. D. M.," Annals of the CIRP, Vol. 24, pp. 109~114.

Levy, G. N. and Wertheim, R., 1988, "EDM Machining of Sintered Carbide Compacting Dies," *Annals of the CIRP*, Vol. 37, No. 1, pp. 59~62.

Luo, Y. F., 1997, "The Dependence of Interface Discharge Transitivity Upon the Gap Debris in Precision Electrodischarge Machining," *J. of Material Processing Tech.*, Vol. 68, pp. 121~131.

Magara, T., Kobayashi, K., Yatomi, T. and Hon, K. K. B., 1989, "Micro-Finishing by High Frequency AC Source in Wire EDM," *ISEM-9*, pp. 76~79.

Maggi, F., 1991, "Wire Cut Electro-Erosion of Hard Metals," Agie Erosion Technology, April.

McCleary, Gail P. 1984, "Cutting Tungsten Carbide with Wire EDM -from the Carbide Manufac-turer's Point of View," *The carbide and Tool Journal*, Nov. -Dec. , pp. 3~8.

Storr, M., 1992, "New dielectric medium IONOPLUS IME-MM," *Proc. of the 10th Inter. Symp. For Electromachining (ISEM-X)*, pp. 161~169.

Williams, R. E. and Rajurkar, K. P., 1991, "Study of Wire Electrical Discharge Machined Surface Characteristics," *J. of Mat. Proc. Tech.* Vol. 28, pp. 127~138.