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Surface Quality of Carbide Metal After Electrical Discharge Machining

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Abstract. Recently, the requirements for machining shape-complex products made of hard-to-machine materials, including carbide, have been increasing significantly. However, their machining is rather problematic. Additionally, a high-quality standard of the machined surface is generally required, not only in terms of roughness but also in terms of the geometric accuracy of the machined surface. All this while maintaining a high level of economy in the machining process. However, meeting these demanding requirements in real technical practice is not always an easy task. Moreover, in combination with modern machining processes, only a limited number of production technologies can meet this requirement. Therefore, due to the high demands placed on today's modern production and the required high standard of the machined surface, progressive EDM technology is increasingly finding its application. And it is through this progressive technology that it is possible to achieve relatively good success in carbide machining. The aim of this paper was therefore to describe in detail the results of an experimental investigation aimed at identifying the quality of the machined surface achieved in terms of the roughness parameters of the machined surface in the electrical discharge machining of selected types of carbides using a wire tool electrode.

Keywords: Electrical discharge machining, surface quality, productivity, carbide

Introduction

An essential part of achieving high qualitative as well as quantitative standards is a thorough knowledge of all aspects and real possibilities of the applied production technology. Detailed examination of all sub-elements and their interrelationships must not escape attention, which will allow the provision of comprehensive information for continuous improvement of the achieved process results [1]. An even more challenging task is the achievement of favourable work results in the machining of carbides. A large number of problems are associated with their machining [2,3]. But their main common feature is the low productivity of production in their machining. Therefore, the primary objective in the machining of carbides is to achieve the required quality level of the machined area while maintaining high manufacturing productivity [4,5]. All this, of course, takes into account the economy of the EDM process itself [6,7]. Therefore, the experimental research aimed at comparing the qualitative indicators of the machined area in terms of roughness parameters when machining selected types of carbides using WEDM technology.

1. Basic characteristics of carbides

Hardmetals belong to the group of composite materials that are made of particles of hard metallic or non-metallic materials. These are interconnected most often through a metallic element [8]. Hard metals are also known as sintered carbides or sometimes just carbides. Carbides are produced from powder by the process of powder metallurgy, through which materials capable of achieving high strength and withstanding harsh operating conditions can be obtained [9,10]. Powder metallurgy can combine powders of different types and characteristics that are otherwise difficult to compact, thus producing a final material with hybrid or novel properties, which is considered one of its main advantages. It is classified as a tool material and partly as a structural material, characterized by high hardness, high compressive strength, high modulus of elasticity, sufficient toughness, low thermal expansion, good machinability, good cold weldability, and corrosion resistance. In terms of materials, it is a group of materials made up of fine particles of hard carbides of certain wear-resistant metals such as tungsten, titanium, and tantalum, which are bonded together by a relatively small amount of a ductile metallic binder with a lower melting temperature. The most typical binder metal is mainly cobalt. The basic constituent of almost all hard metals is hexagonal tungsten carbide. Machining them by any of the classical or progressive methods based on force cutting of the material is in some cases very problematic. In this respect, the electrical discharge machining technology is a clear alternative for their machining [11,12].

2. Carbide machining using electrical discharge machining technology

Electrical discharge machining can generally be characterized as a machining process that is based on the electrical discharge principle [13]. It is carried out between the tool electrode and the work material using precisely controlled, cyclically repeating electrical discharges in the presence of a dielectric [14,15]. Since the whole machining process is carried out in a force-free manner, it finds its suitable application also in the machining of hard metals [16,17]. This advanced technology produces machining tools characterized by high hardness, strength, and wear resistance from the material. Since carbides are the third hardest material after diamond and cubic boron nitride, they are very difficult to machine. It is an almost impossible task to machine the material into products with complex shapes and precise dimensions using conventional machining methods [18]. In addition to diamond cutting tools and diamond-impregnated grinding wheels, electrical discharge machining technology represents one of the suitable machining methods for this high-hardness material.

A certain problem in machining carbides by electrical discharge machining technology is the electrical conductivity of cobalt, which exceeds that of tungsten. So the cobalt binder in tungsten carbide erodes earlier, with the carbide granules falling out of the base material during electrical discharge machining n even without melting. Hence, the amount of cobalt binder predetermines the rate of electrical discharge machining and, at the same time, the magnitude of the energy applied during machining determines the magnitude of the base material removal rate. In addition, the dropout of the cobalt binder causes microcracks on the machined surface. These can be eliminated by applying multiple finishing cuts. In the past, when EDM machines used capacitor generators that applied higher discharge energy at the EDM point, extensive micro-cracks occurred during the machining of the workpieces. With the gradual introduction of DC generators, the extent of the micro-cracks on the machined surface has been substantially reduced. Today, many modern EDM machines are equipped with AC pulse generators. These generators are particularly suitable for machining hard metals because they produce smaller heat-affected zones and cause less cobalt loss than machines with DC electrical discharge generators. Despite the relatively good results achieved in machining hard metals with modern EDM machines, it is advisable to apply multiple finishing cuts to achieve the best possible quality of the machined surface.

3. Material and methods applied in the experiment

Three types of carbides, namely K10F, K06F, and Ti6Al4V, were used in the experiment. K10F carbide is used in practice for machining unhardened steels, especially at a lower hardness of 40 HRC. It is suitable for machining aluminum alloys, magnesium, cast iron as well as other non-ferrous materials. In practice, K06F is used to produce tools for drilling and milling cast iron, ceramic and plastic composites, wood, steel, etc. Ti6Al4V hardmetal is characterized by excellent strength, low modulus of elasticity, high corrosion resistance, and good weldability and is suitable for heat treatment. It is used for a variety of applications in the aerospace, marine, automotive, and energy industries. The following Table 1 lists the selected physical properties of the carbides used in the experimental research.

Carbide metal	**Physical properties of carbide metals K10F, K06F a Ti6Al4V**					
	Density (g.cm^{-3})	Hardness	Melting point (°C)	Electrical resistance (Ω.cm)	Thermal conductivity (W.m^{-1}.K^{-1})	Tensile strength (MPa)
K10F	14.3	92.5 HRA	2870	200	67	1560
K06F	14.8	93.1 HRA	3410	220	68	1720
Ti6Al4V	4.42	36 HRC	1649	170	7.2	1000

Table 1. Selected physical properties of the carbides used in the experimental research.

In addition to the physical properties of the material being machined, of which thermal conductivity and electrical conductivity in particular have a significant influence on the quality of the machined surface and the productivity of the EDM process, the chemical composition of the material also has a significant influence. The following Table 2 shows the chemical composition of the carbides used in the experimental research.

Carbide metal	**Chemical composition of carbide metals K10F, K06F a Ti6Al4V**									
	WC (%)	Co (%)	Ti (%)	Al (%)	V (%)	N (%)	C (%)	H (%)	Fe (%)	O (%)
K10F	90.0	10.0	—	—	—	—	—	—	—	—
K06F	94.0 %	6.0 %	—	—	—	—	—	—	—	—
Ti6Al4V	—	—	—	6.0 %	4.0 %	0.05	0.1	0.0125	0.3	0.2

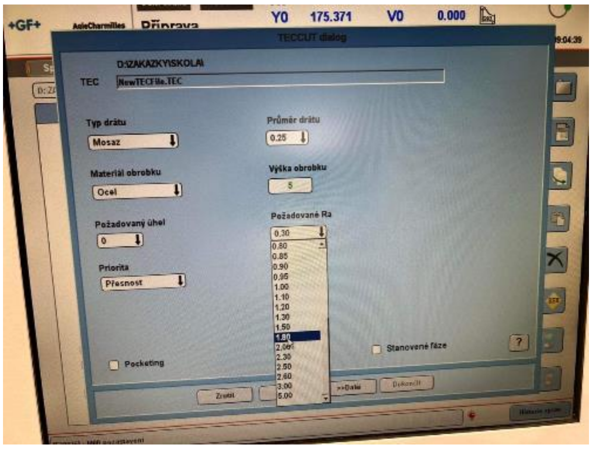
Table 2. Selected chemical properties of the carbides used in the experiment.

The experimental samples were made on an AgieCharmilles CUT 20P EDM machine, the basic technical parameters of which are listed in Table 3.

Machine and workpiece parameter	Size
Machine dimensions	2500 mm/2500 mm/2200 mm
Max. Axis Travel X/Y/Z	350 mm/250 mm/250 mm
Max. workpiece size	820 mm/680 mm/250 mm
Max. workpiece weight	400 kg
Wire tension	3 ~ 30 N
Wire speed	30 ~ 330 mm/s
Air pressure	0.6 ~ 0.9 MPa
Best roughness Ra	< 0.25 µm
Full load current	13.5 A
Max. taper angle	± 10°/ 25 mm
Measurement resolution	0.10 µm

Table 3. Basic technical parameters of the AgieCharmilles CUT 20P EDM machine.

It is an EDM machine that uses wire with a diameter ranging from 0.10 to 0.30 mm as a tool with automatic winding. A brass-coated wire with a diameter of 0.25 mm and a tensile strength of 900 N/mm^2 was used as a tool for the fabrication of the experimental specimens. As a working medium, the electrical discharge machine uses a dielectric fluid based on deionized water, which is fed into the 200 l working area by a pump from a 600 l reservoir. Figure 1 below shows a screenshot of the AgieCharmilles CUT 20P electrical discharge machine, showing the main technological and process parameters that were applied to the experimental samples in the experiment.



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Průměr drátu
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Materiál obrobku
Ocel
Výška obrobku
5
Požadovaný úhel
0
Požadované Ra
0.30
Priorita
Přesnost

Figure 1. The setting of the technological parameters applied in the experiment.

Using an AgieCharmilles CUT 20P EDM,15 mm long cuts with different roughness of the machined surface were made on K10F, K06F, and Ti6Al4V carbide samples with dimension 20 mm × 7 mm × 150 mm. In total, three variations of the settings of the main technological and process parameters were applied to each type of carbide, thus achieving three quality levels of the machined surface in terms of roughness parameters. For the first cut, a machined surface roughness of approximately Ra = 3.0 µm was to be achieved, for the second cut at a level of approximately Ra = 1.5 µm and for the third cut at a level of approximately Ra = 0.5 µm.

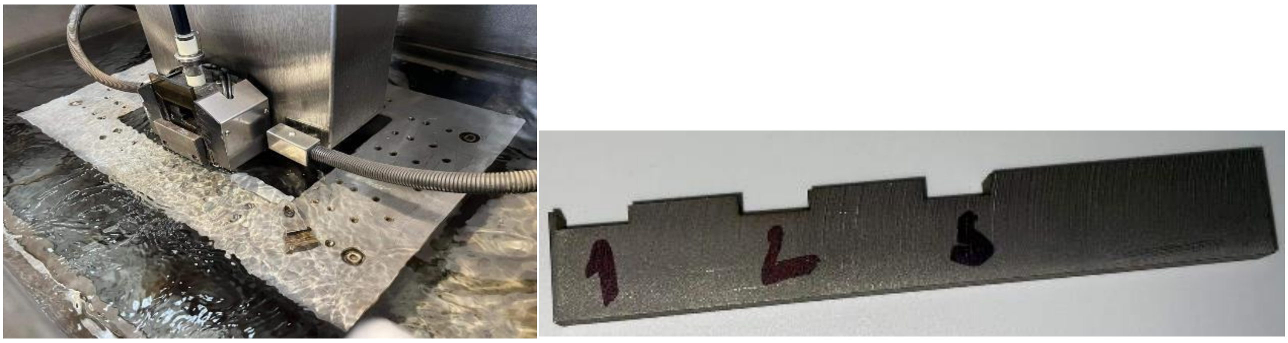

Figure 2. Fabrication of 1st, 2nd, and 3rd qualitative sections on the experimental Ti6Al4V carbide sample.

Measurement of the quality parameters of the machined surface in terms of the roughness parameters of the machined surface of the experimental samples was carried out using a Mitutoyo SJ 400 contact measuring device with measurement accuracy 0.01 µm. The measured data of surface roughness parameters *Ra* and *Rz* of the made cuts on the experimental samples are recorded in the following Table 4.

Carbide metal	**Measured values of surface roughness (*Ra* and *Rz*) of the 1st, 2nd and 3rd cuts**			
	Surface roughness parameter	***1st cut***	***2nd cut***	***3rd cut***
K06F	*Ra* (µm)	1.87	1.06	0.30
	Rz (µm)	11.47	6.92	1.97
K10F	*Ra* (µm)	2.05	1.39	0.32
	Rz (µm)	13.47	8.17	2.09
Ti6Al4V	*Ra* (µm)	2.73	1.96	0.75
	Rz (µm)	16.48	12.73	5.14

Table 4. Measured values of surface roughness of sections on experimental samples made of K10F, K06F and Ti6Al4V carbide.

Based on the measured values of the surface roughness parameters *Ra* and *Rz* of the 1st, 2nd, and 3rd sections made on the experimental K10F, K06F, and Ti6Al4V carbide samples, the graphical dependencies in Fig. 3 were constructed.

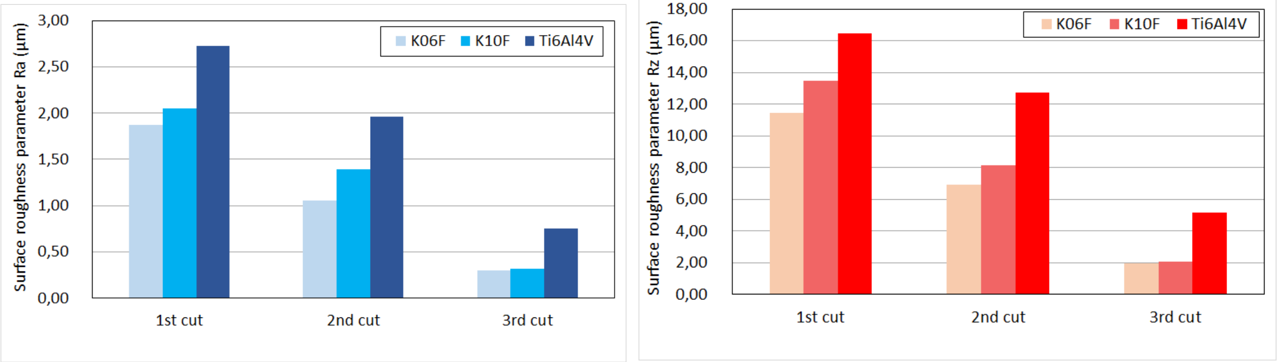

Figure 3. Dependence of the roughness parameters Ra and Rz on the number of cuts of the samples made from K10F, K06F and Ti6Al4V carbide.

From the graphical dependence in Fig. 3 it can be observed that with identical settings of the main technological and process parameters, the best qualitative results in terms of the roughness parameters Ra and Rz were achieved in the machining of carbide K06F for all three quality cuts. The lowest values of the roughness parameters Ra = 0.30 μm and Rz = 1.97 μm were obtained on the 3rd cut. On the other hand, with identical settings of the main technological and process parameters, the worst quality results in terms of roughness parameters Ra and Rz were obtained when machining Ti6Al4V carbide at all three quality cuts. The highest value of the roughness parameters Ra = 2.73 μm and Rz = 16.48 μm was obtained at the 1st cut. Based on the experimentally obtained data, it can be concluded that even with the identical setting of the main technological and process parameters in wire EDM, the quality of the machined surface in terms of the surface roughness parameters Ra and Rz differs when the type of material being machined is changed. In the case of K10F and K06F carbides, these differences were relatively small. On the contrary, in the case of comparison of the measured results of surface roughness Ra and Rz between K10F, K06F and Ti6Al4V these differences were already significant. Based on the data obtained, it can be concluded that the change in the quality of the machined surface achieved in terms of surface roughness parameters is due to the different physical properties and different chemical compositions of the machined material. Therefore, further experimental research should be oriented towards the identification of those properties and chemical composition of the machined material that have a significant influence on the different quality of the machined surface after wire EDM, even with identical settings of the main technological and process parameters.

Conclusion

A huge advantage of wire tool electrode EDM technology compared to other conventional and progressive machining technologies is the ability to machine carbides. These can be machined quite efficiently, especially thanks to the force-free machining method, which places almost no limits on the machinability of the material. In the case of EDM, the mechanical properties of the material to be machined have only a minimal effect on its machinability. However, its physical properties and chemical composition do have an influence. Therefore, the experimental research was focused on the identification of the quality parameters of the machined surface after electrical discharge machining with wire tool electrodes of selected types of carbides with the identical setting of the main technological and process parameters. It was found that the best quality of the machined surface in terms of roughness parameters was achieved with the carbide with the K06F designation. On the other hand, the worst quality of the machined surface in terms of roughness parameters was achieved when machining carbide with the designation Ti6Al4V. Therefore, future experimental research will be oriented towards identifying the physical properties and chemical composition of the carbides that have a significant effect on the quality of the machined surface after wire EDM in terms of the roughness parameters of the eroded surface.

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