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Study on Electrical Discharge Machining Characteristics of Coated Electrodes

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Low electrode wear EDM is attained by the adhesion of heat resolved carbon made from kerosine type machining fluid to the electrode end surface. This phenomenon, however, occurs only under long pulse duration. Therefore, the low electrode wear EDM under finishing condition is impossible so far. In the previous paper, the authors developed a turbostratic carbon electrode whose structure is very similar to the heat resolved carbon generated in EDM process and made it clear that the low electrode wear EDM was possible by using the electrode even under finishing condition. In this study, a carbon coated electrode and a SiC coated one which can be made rapidly at low cost were developed and their EDM characteristics were investigated. Experimental analysis pointed it out that both electrodes were effective in reducing electrode wear under finishing condition.

1. INTRODUCTION

In electrical discharge machining(EDM) process, the reduction of electrode wear is very important for high accuracy machining. Electrode materials with high heat resistance, large thermal conductivity and high resistance to discharge impact are particularly effective for low electrode wear EDM (which means that the electrode wear rate is less than 1vol.%). Therefore, copper and graphite have widely been used so far. It has been clarified that the electrode wear can be reduced by using a long pulse condition with anode electrode, since heat resolved carbon made from kerosine type machining fluid adheres to the electrode end surface and it protects the electrode from the heat and the impact of electrical discharge[1-2]. The authors[3] reported that turbostratic carbon electrode with the same structure as the heat resolved carbon was developed by chemical vapor deposition(CVD) method and the low electrode wear EDM was possible by using the carbon electrode even under short pulse duration such as finishing condition. However, in respect of cost, there are some problems for practical use.

In this study, a turbostratic carbon coated graphite electrode, which can be rapidly made at low cost, is newly developed and the EDM characteristics of this electrode are experimentally investigated. Moreover, a silicon carbide(SiC) coated graphite electrode is also developed and evaluated.

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2. EDM CHARACTERISTICS OF CARBON COATED ELECTRODE

2.1 Turbostratic Carbon

Low electrode wear EDM is attained by the adhesion of heat resolved carbon made from kerosine type machining fluid to the electrode end surface. Mohri et. al.[4] reported that the heat resolved carbon was composed of turbostratic carbon. Fig.1 shows turbostratic structure and graphite one. As shown in the figure, carbon atoms are arranged regularly in the case of graphite structure. On the other hand, hexagonal lattice plane laminates irregularly in the case of turbostratic structure.

Based on the report, the authors developed a new carbon electrode with turbostratic structure by CVD method and made it clear that low electrode wear EDM was possible even under finishing condition by using this carbon electrode(CVD-carbon electrode). However, there still remain the problems of high cost and long time required for making it.

2.2 Carbon Coated Electrode

In this study, a new electrode, in which graphite electrode was coated with carbon, was developed by CVD method. Fig.2 shows the schematic illustration of CVD method for making the electrode. While 1,2-dichloroethylene as vapor source and argon as carrier gas are mixed and send to a graphite rod heated up to about 1500℃ in the plating room, heat resolved carbon is generated on the graphite rod surface.

Fig.3 shows the structure of heat resolved carbon[5]. Black parts are graphite base material. In laminar(a), hexagonal lattice plane laminates parallel to the surface of graphite but irregularly, different from graphite structure. That is, the structure is turbostratic in this case. In columnar(b), arcuate lattice plane laminates round the carbon which was previously resolved in vapor and adhered to the graphite surface. The carbon structure of the electrode used in this experiment is a mixture of laminar and columnar. Then, it is very similar to the heat resolved carbon adhering to the electrode end surface in EDM process. And this

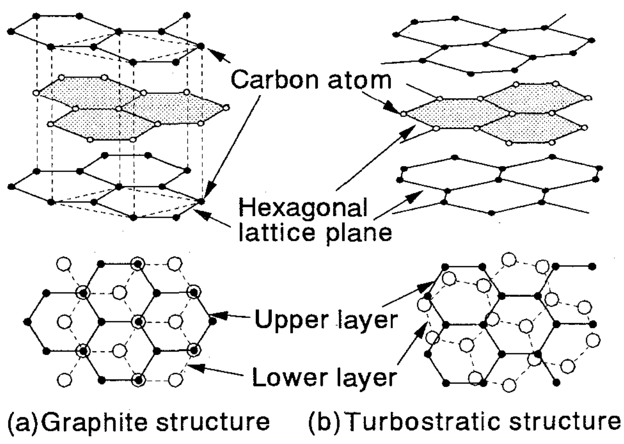

Fig.1 Difference in structure

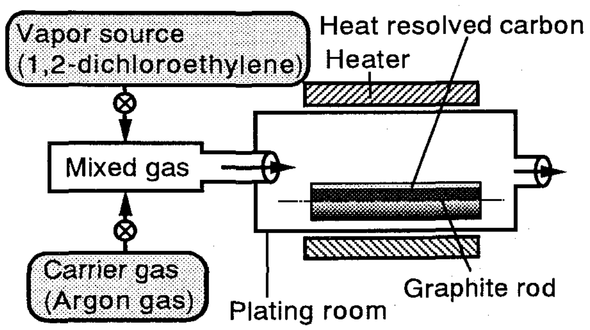

Fig.2 Schematic illustration of CVD method

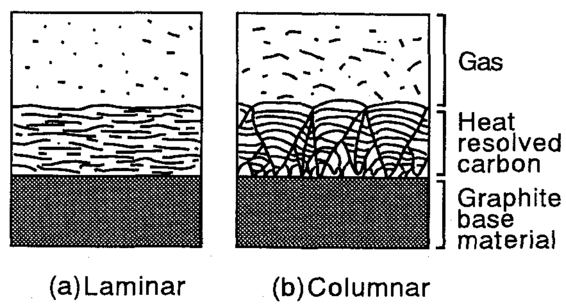

Fig.3 Structure of heat resolved carbon

electrode can rapidly be made at low cost, compared with CVD-carbon electrode reported before.

Table 1 shows physical properties of coated carbon and graphite. As shown in the table, resistivity and heat conductivity in the layer direction of coated carbon greatly differ from those in the thickness direction since the structure is almost piled up in layer. That is, in the layer direction, an electric current flows easily and heat also conducts quickly. In other words, the structure is highly anisotropic. It is also shown that the specific gravity of coated carbon is larger than that of graphite. It means that the structure of coated carbon is denser than that of graphite.

2.3 Experimental Procedures

Experiments are performed using the NC electrical discharge machine with transistor switching circuit. Machining conditions are set as Table 2. Graphite electrode and CVD-carbon electrode reported in the previous paper are also used for comparison. Fig.4 shows shape and structure of carbon coated graphite electrode. The thickness of coated carbon layer is about 50 μm and the diameter of the electrode is 6mm. Since the coated carbon layer laminates perpendicular to the machining surface of the electrode as shown in the figure, resistivity is large and thermal conductivity is small in machining direction.

2.4 Electrode Wear Characteristic

Fig.5 shows relationships between electrode wear and pulse duration for three kinds of electrode. The electrode wear was calculated by the change of its length. As can be seen in the figure, the

Table 1 Physical properties of coated carbon and graphite

	Specific gravity (g/cm^3)	Resistivity ($\mu\Omega\cdot$cm)	Heat conductivity (W/(m$\cdot$K))
Coated carbon	2.0	($\perp$)50000 (//) 700	2 300
Graphite	1.8	1400	75.4

($\perp$) Thickness direction
(//) Layer direction

Table 2 Machining conditions

Electrode	Carbon coated electrode, Graphite electrode
Workpiece	Carbon tool steel SK3
Polarity	Electrode : (+)
Non-loaded voltage	Eo=120V
Discharge current	Ip=6A
Pulse duration	τp = 4 -100 μs
Duty factor	D.F.=50%
Machining fluid	Kerosine type fluid

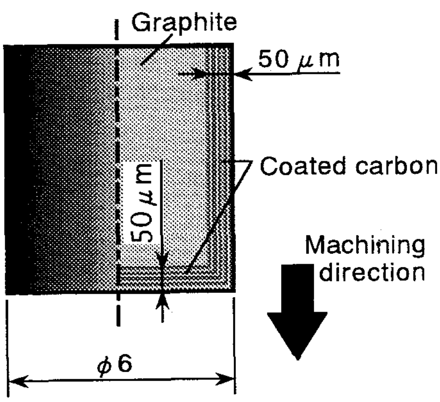

Fig.4 Shape and structure of carbon coated electrode

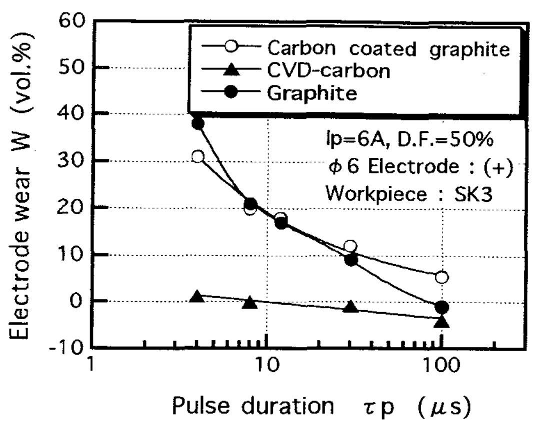

Fig.5 Relationships between electrode wear and pulse duration

electrode wear decreases with an increase of pulse duration in all cases. Under short pulse duration, the value in the case of carbon coated electrode is about 30 vol.% and smaller than that in the case of graphite one. The electrode wear under finishing condition can be reduced by using the carbon coated electrode. On the other hand, the former is a little larger than the latter under long pulse duration. It is considered that the week bond of the coated carbon in deposition direction, as well as large resistivity and small heat conductivity at machining area in machining direction lead to large electrode wear in the case of this electrode(3). That is, under the condition with large single pulse discharge energy such as long pulse duration, the coated carbon layer comes off easily because of large impact force.

In order to confirm when the coated carbon layer wears under long pulse duration, the electrode end surface is observed, making the electrode discharge occur at a part of electrode end surface as shown in Fig.6. The coated carbon wears as the machining proceeds. The thickness becomes approximately half of 50μm after 60sec and all of the coated carbon wears after 120sec under this condition. However, the part of exposed graphite hardly wears after 300sec. It is obvious that the wearing speed of the coated carbon under long pulse duration is much larger than that of graphite. It is expected that the electrode wear might become smaller by strengthening the bonding force in deposition direction.

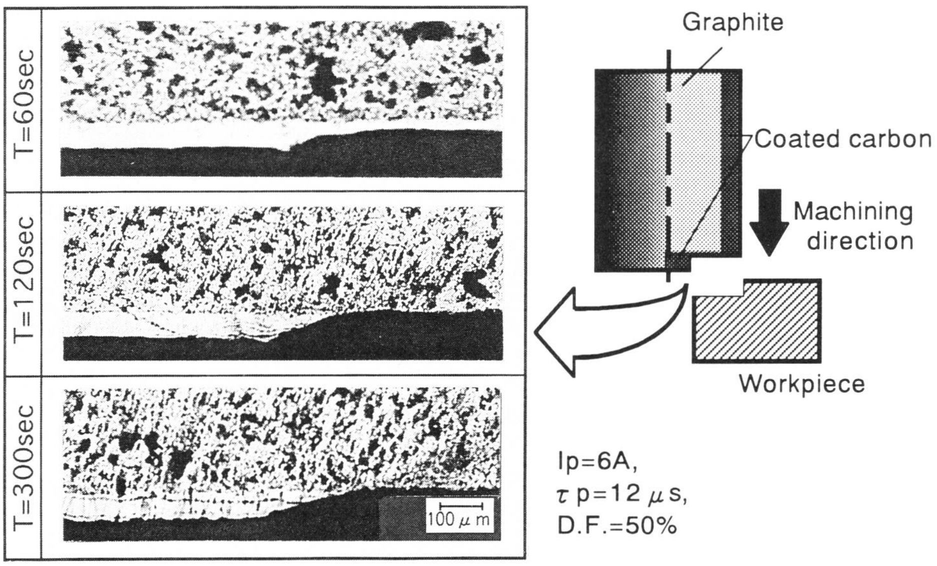

Fig.6 Wear process of coated carbon

Fig.7 shows the relationships between the surface roughness of machined surface and the pulse duration. The surface roughness in the case of carbon coated electrode is as large as that in the case of graphite one under short pulse duration. Considering this result together with electrode wear characteristics mentioned before, carbon coated electrode is effective only under finishing condition.

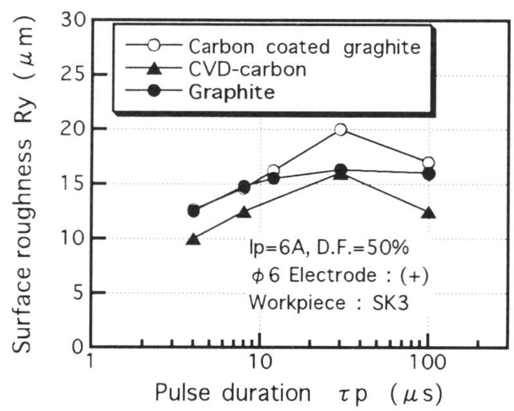

Fig.7 Relationships between surface roughness and pulse duration

3. EDM CHARACTERISTICS OF SILICON CARBIDE COATED ELECTRODE

Next, silicon carbide(SiC), which has high heat resistance and high hardness, was coated on the surface of graphite electrode by CVD method and the characteristics of this electrode were evaluated. Fig.8 shows schematic diagram of the SiC coated electrode. The thickness of SiC layer is approximately 750 μm, and the diameter of this electrode is 10 mm.

Fig.9 shows variations of the electrode wear with pulse duration for SiC coated graphite electrode and ordinary graphite. The electrode wear decreases with an increase of pulse duration in cases of both electrodes. Under short pulse duration, the electrode wear in the case of SiC coated electrode is smaller than that in the case of graphite one. It was made clear that SiC coated electrode had effect for reducing electrode wear under finishing condition.

Fig.10 shows variations of the removal rate with pulse duration. As can be seen from the figure, the removal rate in EDM with SiC coated electrode is twice as large as graphite under short pulse duration. Fig.11 shows variations of the surface roughness of the machined surface. The surface roughness with SiC coated electrode is larger than that with graphite one under short pulse duration, while the former is almost the same as the latter under long pulse duration.

Fig.12 shows SEM image of the machined surfaces. Under short pulse duration, the size of a crater in the case of SiC coated electrode is larger than that in the case of graphite electrode. Judging

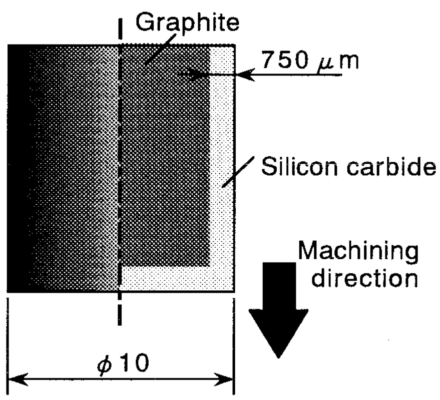

Fig.8 SiC coated electrode

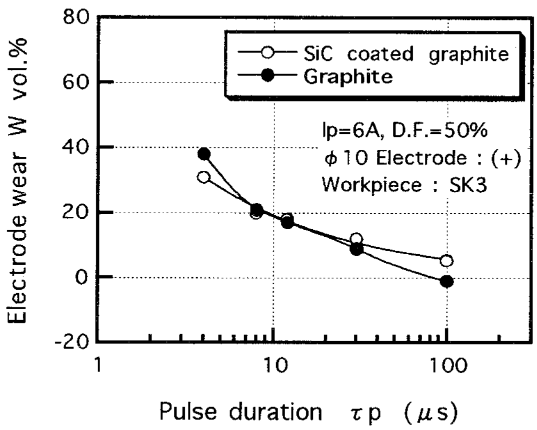

Fig.9 Variations of electrode wear with pulse duration

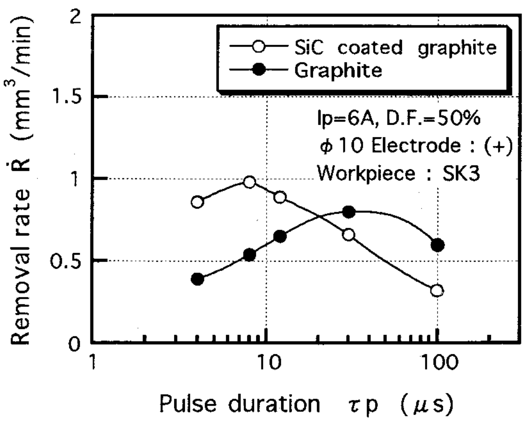

Fig.10 Variations of removal rate with pulse duration

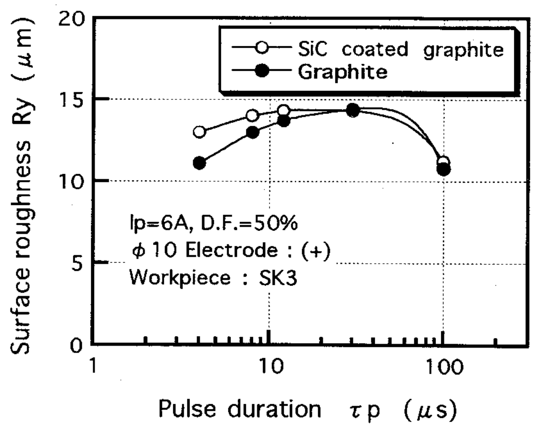

Fig.11 Variations of surface roughness of machined surface with pulse duration

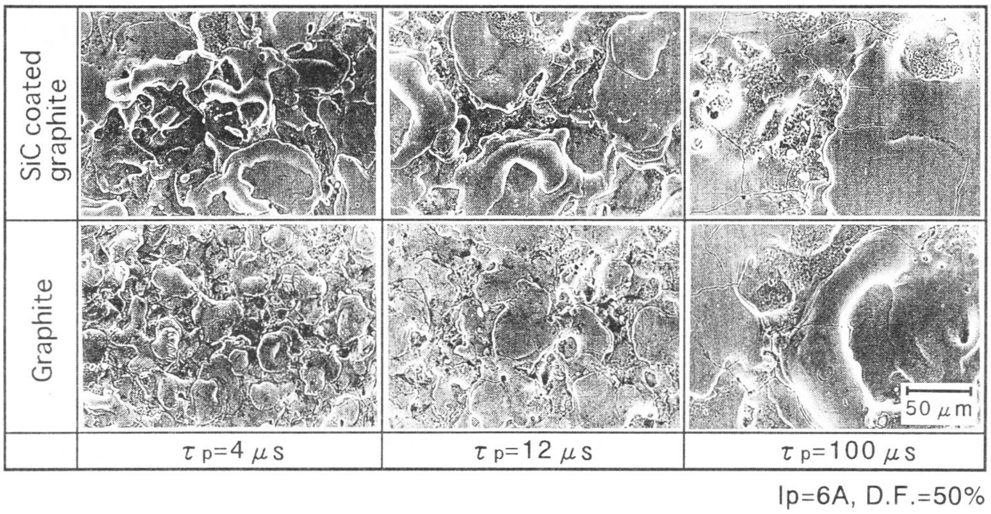

Fig.12 SEM images of EDMed surface

from these images, it is expected that the discharge energy distributed to workpiece in the case of SiC coated electrode is larger than that in the case of graphite one because of the different of electrode material(6). As a result, the removal rate and the surface roughness using SiC coated electrode are larger than those using graphite electrode under short pulse duration, as mentioned above. As shown in the micrographs, cracks are observed on the machined surface under all pulse durations in the case of graphite electrode. On the other hand, it cannot be observed under short pulse duration in the case of SiC coated electrode.

4. CONCLUSIONS

In this study, carbon coated electrode and SiC coated electrode were newly developed and these EDM characteristics were experimentally investigated. Main conclusions obtained are as follows:

(1) Carbon coated electrode with turbostratic structure and SiC coated one are effective in reducing electrode wear under finishing condition.

(2) Removal rate in EDM with SiC coated electrode under finishing condition is much larger than that with graphite electrode.

(3) There is no crack on the machined surface when EDMed with SiC coated electrode under finishing condition.

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