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# Surface Analysis of Bimetal After EDM Machining Using Electrodes with Different Physical and Mechanical Properties.

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**ABSTRACT**

In the electrical discharge machining (EDM) of bimetallic materials, the physical processes occurring at the interface of adhesion of the two materials are different from the processes inherent in the machining of a homogeneous material. This is primarily due to the fact that the bimetal components possess different mechanical and physical properties and have different electroerosion resistance. Due to the fact that the electro resistance of bimetal components is different, the tool electrode is subjected to uneven wear during EDM. Uneven wear of the tool electrode in the machining of bimetals tends to reduce the quality of the machined surface. The scope is to study the process of copying-piercing EDM of bimetals using the tool electrodes with different physical and mechanical properties. It was found that the machining of bimetal with copper tool electrode provides the greatest machining uniformity. It was shown that in the min mode the copper tool electrode provides for the most accurate depth of the burn, according to a predetermined control program. It was shown that duralumin tool electrode does not allow machining steel-copper bimetal. It was shown that on the surface of the machined steel layer the number of micro-cracks at the grain boundaries increases regardless of the electrode tool material. The number of micro-cracks increases together with the increase of the pulse strength. The increase of the number of micro-cracks on the machined surface can lead to the emergence of micro-defects and reduce the operational properties of the entire part. It is shown that in the machining of bimetal copper layer polyhedral holes are formed on the machined surface. The increase of the pulse strength leads to the enlargement of polyhedral holes to the size of about 30-80 microns, regardless of the tool electrode material. Enlargement of holes to the macro elements is capable to reduce operating properties throughout the part.
**Keywords:** electrical discharge machining (EDM), tool electrode, bimetal, wear, precision, structure.

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## INTRODUCTION

The development of technology calls for the creation of materials with the complex of properties which provide for high strength, corrosion resistance, thermal conductivity, heat resistance, wear resistance, etc. Often some metals and alloys can not provide the range of properties required. Therefore, the layered metal compositions were widely adopted. Such materials can be made by joining dissimilar metals in a monolithic composition preserving a reliable connection of components in further machining and in operation (Shabgard *et al.*, 2014; Ojha *et al.*, 2010; Neulybin *et al.*, 2014). Such materials include bimetals.

During mechanical treatment of bimetals using blade tool (lathe tools, milling cutters) the presence of shock in the cutting zone in inevitable. This reduces the quality of the machined surface and increases wear of the cutting part of the tool. The hardness of some bimetallic compositions (e.g. surfaced coatings) may exceed the limit of their workability by the cutting tool, respectively, the machining of such materials on the blade metal processing machines is often impossible (Kovalenko, 1986).

The use of electro-dimensional methods of materials machining is the adequate solution to this problem. The electrical discharge machining (EDM) is one of such methods (Foteev, 1997; Zolotykh, 1959; S"yanov, 2002). Currently, the EDM method is one of the most common methods of machining of advanced materials, including bimetals, and it is taken as the basis for most of the processes both in batch and mass production.

The EDM is based on the effect of melting and evaporation of the material microportions under the thermal influence of electrical energy pulses. This energy is released in the discharge channel between the surface of the workpiece and the electrode tool immersed in the liquid dielectric medium (Ploshkin, 2006; Dey, 2013; Janmanee, & Muttamara, 2010). In the electrical discharge machining (EDM) of bimetallic materials, the physical processes occurring at the interface of adhesion of the two materials are different from the processes inherent in the machining of a homogeneous material. This is primarily due to the fact that the bimetal components possess different mechanical and physical properties and have different electroerosion resistance. Also, chemical compounds with modified physico-mechanical properties – the intermetallics are formed in the coating in the transition zone between bimetal layers. Intermetallics have a higher melting temperature than the parent metals. Almost all intermetallics are brittle, since the bond between the atoms in the lattice becomes covalent or ionic, and not a metal one. Some of them have semiconducting properties, and, the closer to stoichiometrics is the elements ratio, the higher is the electric resistance. In this connection, during the EDM of bimetals the cracks occur on the machined surface at grain boundaries (Figure 1) (Shabgard *et al.*, 2014; Ojha *et al.*, 2010).

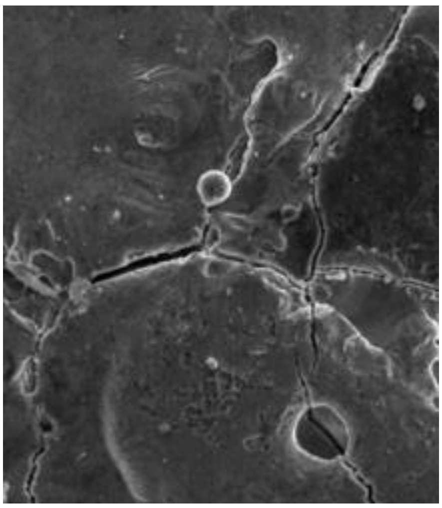

**Figure 1. Cracks on the machined bimetal surface (x1000)**

Due to the fact that electroerosion resistance of the bimetal components is different, the tool electrode is subjected to uneven wear during EDM (Tsai *et al.*, 2003; Liu *et al.*, 2012). Uneven wear of the tool electrode in the processing of bimetals leads to reduction of the quality of the machined surface (Lee, & Tai, 2003; Pellicer *et al.*, 2009).

The scope is to study the process of copying piercing EDM of bimetals using the electrode tools with different physical and mechanical properties.

## MATERIALS AND METHODS OF STUDY

A steel substrate with a copper weld coating is used as the machined sample. Base material is 09G2S steel (GOST 19281-89, Table 1).

**Table 1. Chemical composition of 09G2S steel**

| C | Si | Mn | Ni | S | P | Cr | N | Cu | As |
|---|---|---|---|---|---|---|---|---|---|
| 0.11 | 0.6 | 1.4 | 0.2 | 0.03 | 0.03 | 0.2 | 0.007 | 0.2 | 0.07 |

Weld pad material is M1 copper (GOST 859-2001, Table 2).

**Table 2. Chemical composition of M1 copper**

| Fe | Ni | S | As | Pb | Zn | O | Sb | Bi | Sn | Cu+Agmin |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.004 | 0.001 | 0.003 | 0.002 | 0.004 | 0.003 | 0.04 | 0.002 | 0.0005 | 0.07 | 99.9 |

Bimetal processing was performed on the copy-piercing EDM machine Smart CNC (Arakelyan *et al.*, 2014).

The following were used as the tool electrode tools: steel 20 GOST 1050-88; duralumin D16 GOST 4784-74; copper M2 GOST 859-2001. The diameter of the electrodes for all the machining modes was 8 mm. EDM Oil – IPOL SEO 450 was selected as the working fluid. The machining modes are presented in Table 3.

**Table 3. Machining modes**

| Mode | Ton, mcs | Ip, A | U, B | Machining target depth, mm | Pulse strength N, W |
|---|---|---|---|---|---|
| Min | 1 | 0.5 | 50 | 5 | 25 |
| Med | 100 | 3 | 50 | 5 | 150 |
| Max | 750 | 20 | 50 | 5 | 1000 |

The study of machined surface of the samples was performed on a scanning electron microscope (SEM) Phenom World G2 ProX at x500-4000 increases and an accelerating voltage of 15kV. Prior to the study, the samples were cleaned of deposits resulting from the machining (Simonov *et al.*, 2016).

The electrodes wear measurement was performed on the Carl Zeiss Contura G2 coordinate-measuring machine.

## RESULTS AND DISCUSSION

Table 4 shows the values of non-uniformity of the bimetal machining by electrodes with different physical and mechanical properties in the minimum, medium, and maximum modes.

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**Table 4. Non-uniformity of the metal machining**

<table>
<tr><th colspan="3">Bimetal processing using duralumin tool electrode</th></tr>
<tr><td>Min mode</td><td>Med mode</td><td>Max mode</td></tr>
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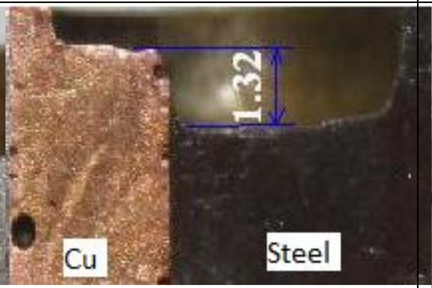
<td>
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<tr><th colspan="3">Bimetal processing using steel tool electrode</th></tr>
<tr><td>Min mode</td><td>Med mode</td><td>Max mode</td></tr>
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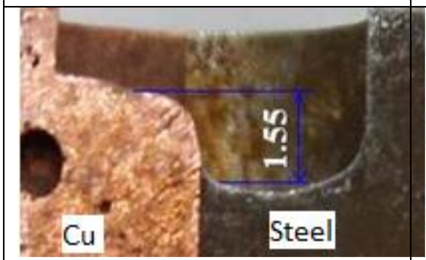
<td>
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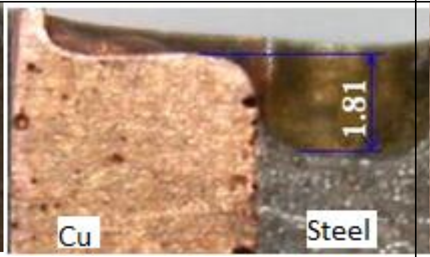
<td>
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<tr><th colspan="3">Bimetal processing using copper tool electrode</th></tr>
<tr><td>Min mode</td><td>Med mode</td><td>Max mode</td></tr>
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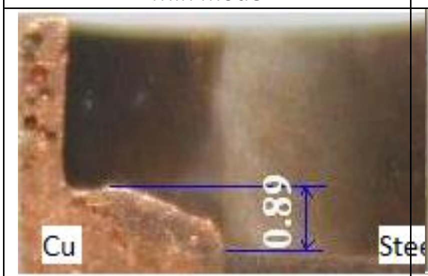
<td>
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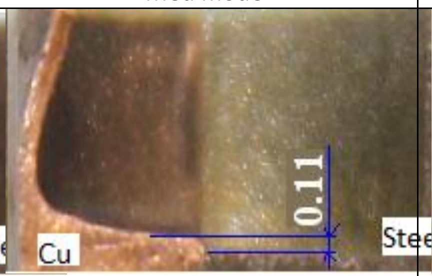
<td>
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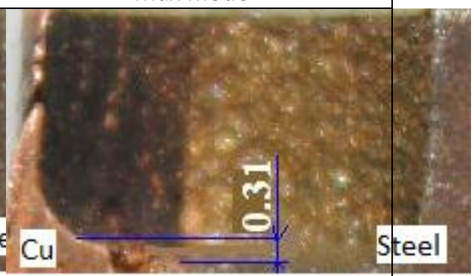
<td>
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The study showed the occurrence of the bimetal processing non-uniformity (on steel and copper layers) during EDM by electrodes with different physical and mechanical properties.

In bimetal EDM using duralium tool electrode, the machining target depth was not achieved. The machining of bimetal copper layer in the min and max modes was accompanied by an increased wear of the tool electrode, the allowance removal from the copper layer was not observed. The greatest burning depth by duralumin electrode was achieved in min mode, and was 2.5 mm. It was shown that the greatest burning depth of the copper layer using duralumin tool electrode is provided in med mode and is 0.7 mm.

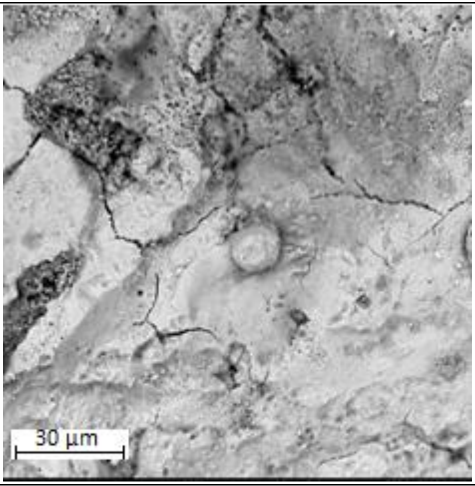
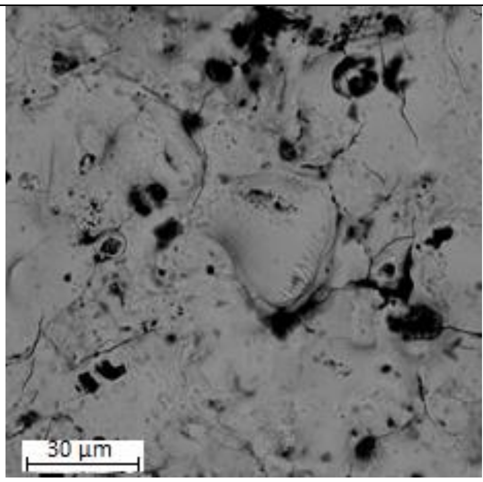
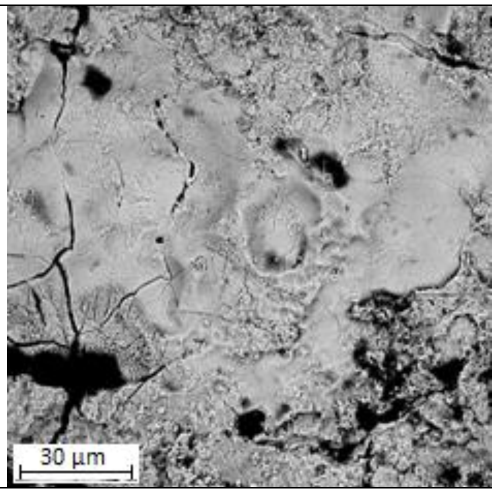
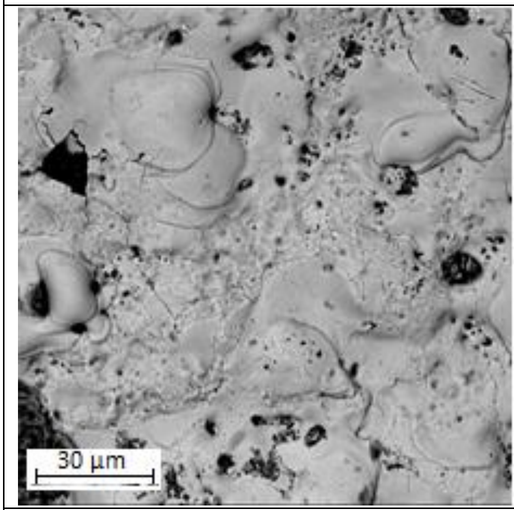
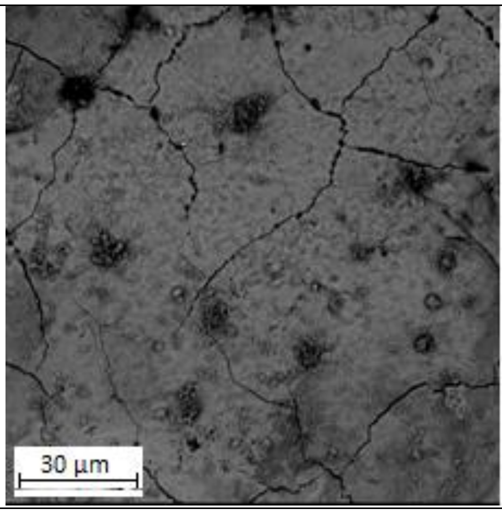
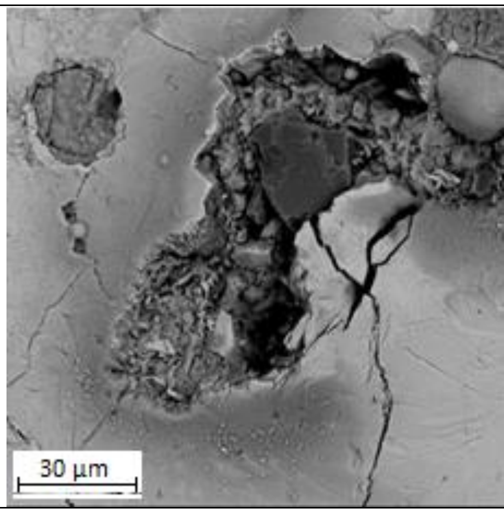
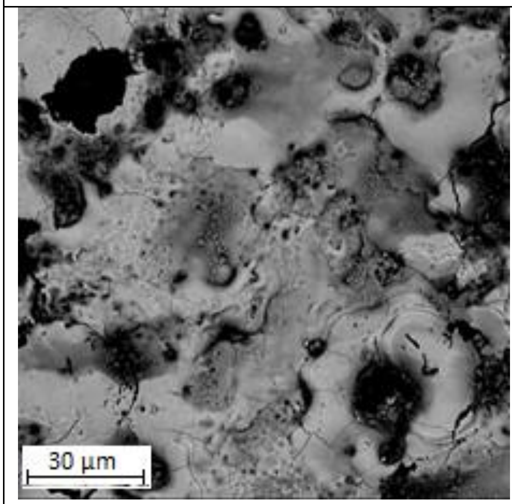
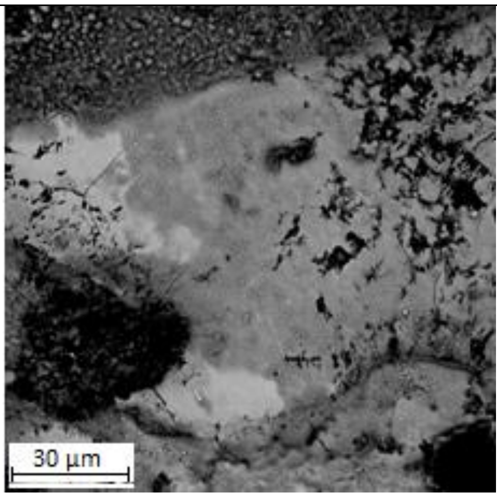
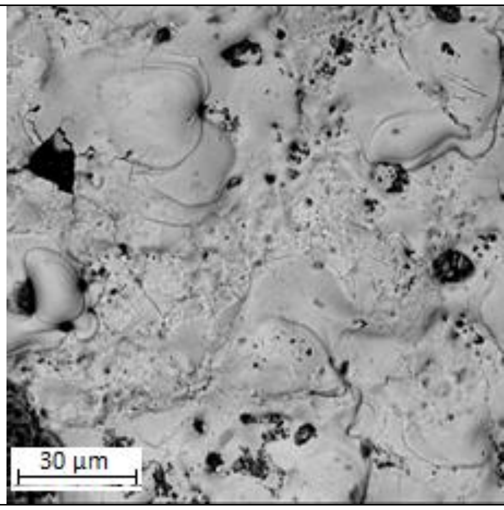
In bimetal processing using steel electrode (unlike dural) the removal of material from both layers of bimetal was shown. The greatest burning depth was reached in min mode, and was 2.7 mm. It was shown that in bimetal processing using steel tool electrode the increase of the pulse strength leads to increased wear of the tool electrode in place of machining of the bimetal copper layer.

The bimetal machining using copper tool electrode provides the greatest uniformity of machining in comparison with steel and duralumin electrodes. It was shown that the min mode provides for the greatest burning depth (3.7 mm). The largest electrode wear was observed in the max mode.

The analysis of the machined steel layer bimetal surface is shown in Table 5.

ISSN: 0975-8585

**Table 5. Machined surface of the bimetal steel layer (x 2000)**

| **Steel layer machining using duralium tool electrode** | | |
|---|---|---|
| Min mode | Med mode | Max mode |
|  |  |  |
| **Steel layer machining using steel tool electrode** | | |
| Min mode | Med mode | Max mode |
|  |  |  |
| **Steel layer machining using copper tool electrode** | | |
| Min mode | Med mode | Max mode |
|  |  |  |

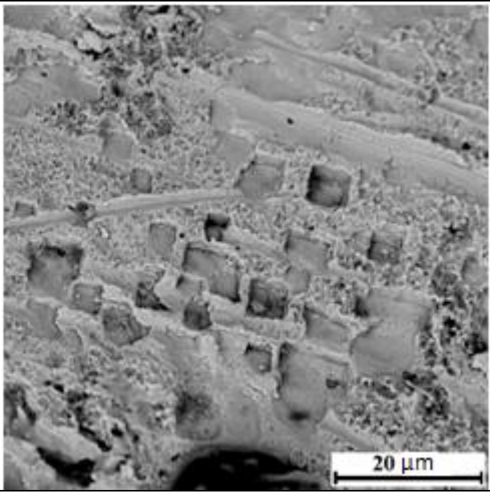
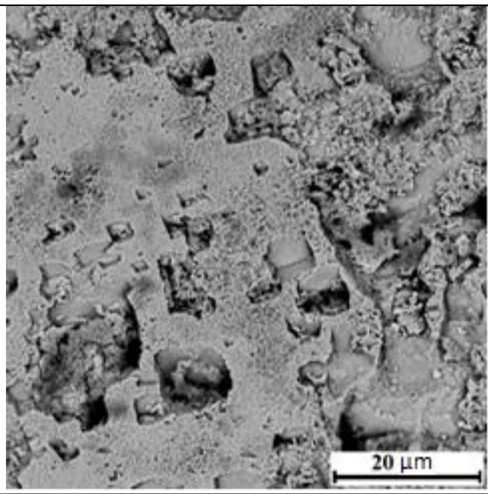
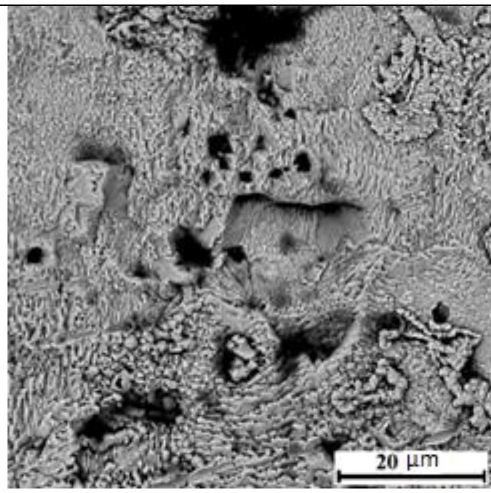
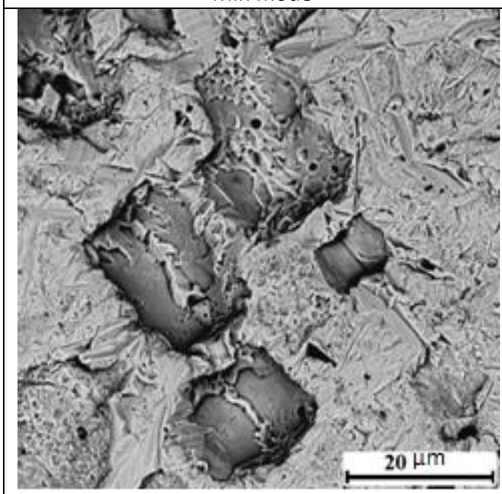
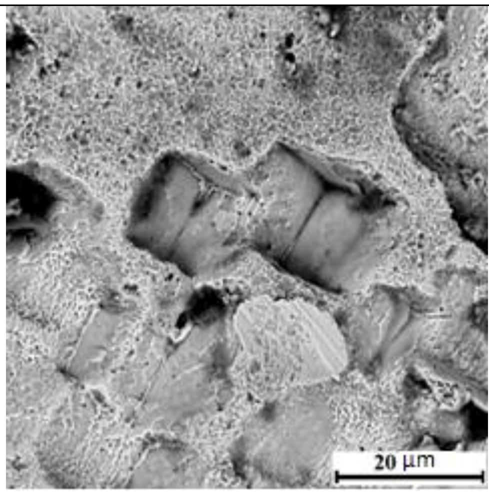
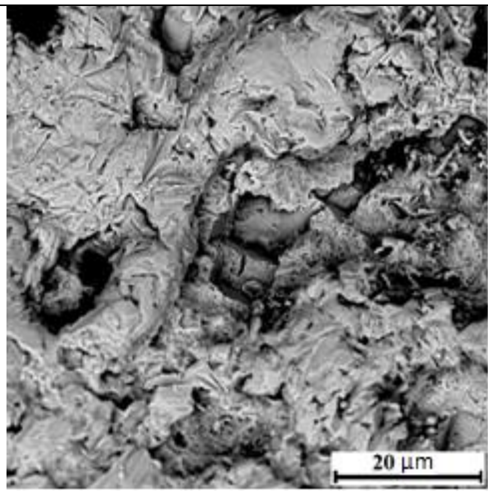
The micro-cracks were observed on the steel layer of the bimetal surface before EDM. After EDM, the number of micro-cracks increased at the grain boundaries. It was shown that during the increase of pulse strength the number of micro-cracks also increases. When machining the steel layer in max mode, the traces of the surface layer brittle rupture are visible. The greatest number of micro-cracks is observed in the processing of steel bimetal layer by the tool electrode in med mode. The pulse strength increase (when working with steel duralumin tool electrode) leads to enlargement of micro-cracks and chipping of the machined surface.

After treatment of the bimetal steel layer using copper tool electrode, the traces of congealed material of the tool electrode are visible on the machined surface. Molten particles of the copper tool electrode unevenly cover the surface of the bimetal steel layer. It was noted the formation of micro-cracks on the congealed tool electrode material.

The presence of micro-cracks on the machined bimetal steel layer surface may cause macro defects of the surface layer and reduce the operating properties of the part.

The analysis of the machined surface of the bimetal copper layer is presented in Table 6.

**Table 6. Copper machined surface (x 4000)**

| **Bimetal copper layer machining using duralumin tool electrode** | | |
|---|---|---|
| Min mode | Med mode | Max mode |
|  |  |  |
| **Bimetal copper layer machining using steel tool electrode** | | |
| Min mode | Med mode | Max mode |
|  |  |  |

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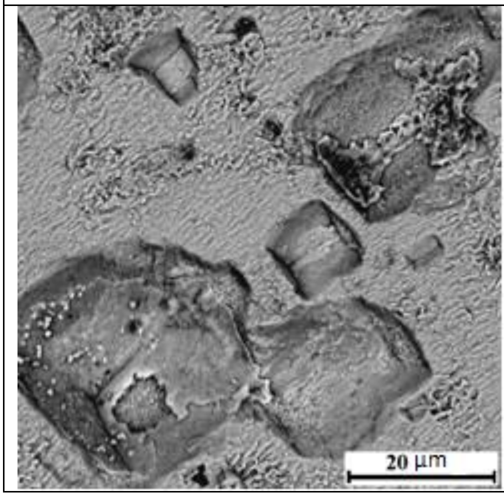
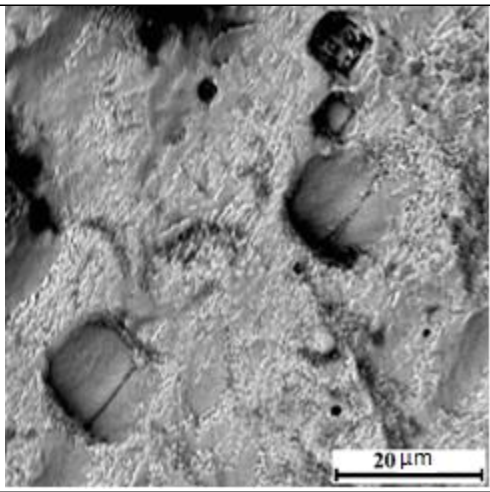
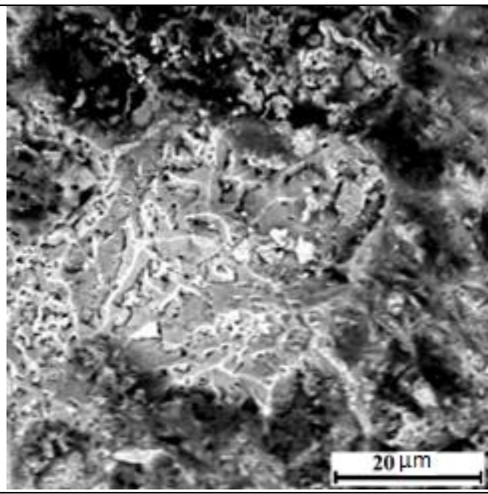
| Bimetal copper layer machining using copper tool electrode | | |
|---|---|---|
| Min mode | Med mode | Max mode |
|  |  |  |

The characteristic feature of the machined surface of the bimetal copper layer is the presence of bimetal microholes, forming a common weblike structure of the fracture surface, and the polyhedral holes having cubic morphology. The model of formation of these elements on the surface after the EDM is complex. According to the group of authors of this paper, the local elemental composition of the structural volumes plays an important role in this process, because of the disequilibrium of the process the effects of the local potential difference, electrical conductivity and resistivity were implemented, leading to the formation of polyhedral holes.

It was shown that machining of the copper layer in min and med modes using duralumin tool electrode leads to the formation of the weblike structure of the machined surface and formation of the polyhedral holes of small dimensions having a cubic morphology. The similar machining using steel electrode increases the size of the polyhedral hole. The maximum dimensions of the polyhedral holes on the treated surface are observed after treatment using copper tool electrode in min mode. It was found that the processing in max mode using any of the electrodes in the experiment results in an overall surface melting.

## CONCLUSIONS

1. Bimetal machining using copper tool electrode provides for the greatest machining uniformity. It was shown that the min mode and the use of the copper tool electrode provide for the most accurate burning depth, according to a predetermined control program. It was shown that duralumin tool electrode does not allow machining steel-copper bimetal.
2. It was shown that on the surface of the layer machined, regardless of the tool electrode material, the number of micro-cracks at the grain boundaries increases. The number of micro-cracks increases together with the increase of the pulse strength. The increase of the number of micro-cracks on the machined surface can lead to the emergence of micro-defects and reduce the operational properties of the entire part.

It was shown that in the machining of the bimetal copper layer polyhedral holes are formed on the machined surface. Increased pulse strength leads to the enlargement of polyhedral holes to about 30-80 microns, regardless of the tool electrode material. Enlargement of holes to the macro elements is capable to reduce operating properties throughout the part.

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