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Studying the Technology of Creating Cortical Electrode Instruments using the Rapid Prototyping Technology

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Abstract

This paper shows the results of studying the technology of manufacturing cortical electrode-instruments (EI) with the use of indirect methods of the Rapid Prototyping technology. Functional EI prototypes were made by layered synthesis of the photopolymer material with the use of the stereolithography technology (SLA - Stereo Lithography Apparatus). The article is focused on two methods of indirect EI manufacturing. One of the EI prototypes was used for making a molded wax model for hot investment casting, followed by applying copper coating. The second prototype was used for applying copper plating to a prepared current-conductive layer. As a result of EDMing a steel workpiece, both EIs reached the desired depth, which is 1 mm. The copper plating applied to the EI preserves its integrity. Through the use of the casting technology, there is a possibility to cut the economic costs by 35%. Using a prototype with preliminarily applied conductive coating makes it possible to make geometrically-complex EIs.

Keywords: Hot investment casting, Rapid prototyping electrode-instrument, Galvanic treatment, Stereolithography, Photopolymer

1. Introduction

The main limiting factor in the use of copy-piercing EDM machines is the limited technological capabilities of manufacturing geometrically-complex electrode instruments (EIs) [1]. Making EIs takes about 50% of the total cycle time in electrical discharge machining of the workpieces [2]. Various matrices and molds that consist of many complex cavities and concavities require an individual electrode, which are sequentially manufactured and used in the process of electrical discharge machining. This technique is used because of the complexity of obtaining the profile of the EI mold by traditional technologies with the help of mechanical processing on CNC machines.

One of the promising solutions for reducing the complexity, time and costs at the stage of obtaining geometrically-complex EIs is the use of the rapid prototyping technology. The technology is designed for creating physical and functional prototypes by computer models (CAD) designed in various computer-aided design (CAD) suites.

Currently, there are direct and indirect production of EIs with the use of rapid prototyping technologies [3,4].

In case of direct production of EI, functional prototype obtained by the layer-by-layer synthesis without subsequent technological operations is used in electrical discharge machining (EDM) of the workpieces. One of the examples of direct production is creating an EI with the use of the technology of selective laser sintering (SLS) of powder metal materials. Significant disadvantages of the SLS technology is significant roughness of the surface of the obtained EIs, which requires subsequent machining, and increased EIs wear [5].

In case of indirect EI production with the use of the rapid prototyping technology, EI models made by layer-by-layer building are the intermediate step in the process of making EI for EDM workpieces.

In course of analyzing works [6], the authors performed studies aimed at developing applications and methods of indirect EI production with the use of rapid prototyping technology. Functional EI prototypes made of wax materials with the use of rapid prototyping technology were used as molding wax prototypes for subsequent casting of metal EIs. The quality of manufactured tooling with the use of molding EIs was assessed with the use of the method of reverse engineering (RE), which allowed to optimize the technological process at all EI production stages. In using indirect methods of EI production, a promising direction is the EI production followed by electroplating treatment for applying copper plating. This technique has not been fully studies, and is relevant.

This study is aimed at assessing the possibility of producing EIs with the use of indirect methods followed by galvanic treatment.

2. Methods and development of the technology for creating cortical EIs

For making cortical EIs by indirect methods with the use of rapid prototyping, several implementations of the technology are used:

1. Making a cortical EI with the use of the hot casting technology from AI alloy with subsequent galvanic treatment;
2. Making a cortical EI with the use of a stereolithographic functional prototype, followed by galvanic treatment.

The scheme of making EIs by indirect methods is shown in Fig. 1.

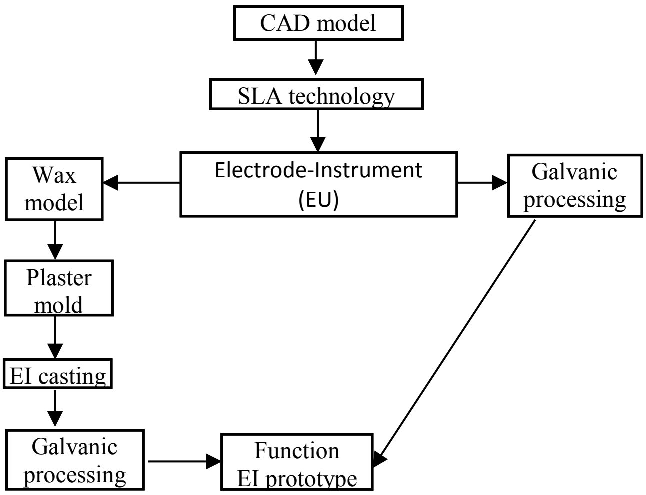


Fig. 1. The scheme of making a cortical EI by indirect methods with the use of rapid prototyping technology

Fig. 1 shows two methods of making cortical EIs. For the purpose of making a functional EI prototype, a 3D computer model is made in the KOMPAS – 3D CAD system (Fig. 2).

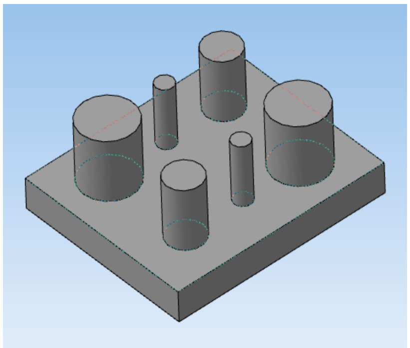


Fig. 2. A three-dimensional model of EI

Stereolithography (SLA) from the Envisiontec company is used as the rapid prototyping technology. The essence of SLA technology is changing the phase state of the photosensitive acrylic material SI500 used for building, namely, transfer from the liquid to the solid state under the influence of ultra-violet radiation. On a working platform of the installation, a mask of the image of EI model section is created, and is exposed to UV radiation layer after layer. Digital Light Processing (DLP) is used in this kind of exposure.

Before building a prototype, the CAD model of the EI is processed in the Materialise Magics application for orientation on the platform of the installation and building the supporting devices (Fig. 3).

The CAD model of the EI is cut into 0.100 mm layers and each layer is exposed for 10 seconds.

The built functional EI prototype is used as the master model for making the wax molding model and electroplating.

The wax molding model is made by creating a silicone mold from the EI prototype, and pouring molten wax into the mold cavity. The hardened wax model is extracted from the silicone mold, and set in a metal box for pouring plaster mixture [7]. The plaster mold is heat-treated in a furnace for removing the wax, and for pouring molten aluminum. The hardened casting of the EI is extracted from the plaster mold, and cut off from the molding channels.

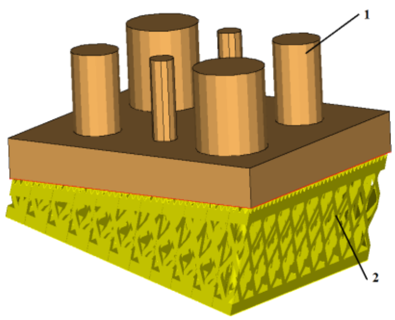


Fig. 3. Processing a CAD model of the EI for layer-by-layer building at the SLA – Envisiontec Perfactory XEDE installation: 1 - EI model, 2 - supporting devices

The ready casting the EI from the aluminum alloy is galvanically treated for applying copper plating (cortex).

The other functional plastic EI prototype was subjected to direct process of electroplating after layer-by layer building. The copper coating is applied to the polymer surface.

3. Studying the technology of making cortical EIs

In the production process of cortical EIs with the use of hot investment casting, an EI prototype made by layer-by-layer building according to SLA technology at the Envisiontec Perfactory XEDE installation is used as the master model.

The CAD model shown in Fig. 3 is oriented at the angle of 15° to the working surface of the installation for reducing warping of the mold of the EI prototype due to significant shrinkage of the material being used, which is 5-8%.

3.1. Studying the process of galvanic treatment of EI castings

Copper coating is applied to the obtained EI casting with the help of electroplating according to the scheme shown in Fig. 6.

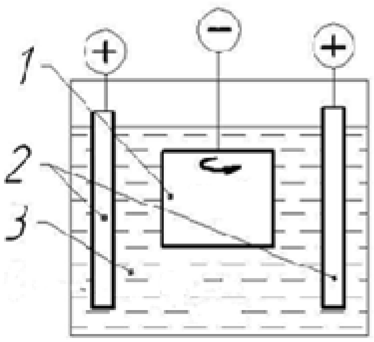


Fig. 6. Schemes of galvanic metallization with full immersion of the EI casting: 1 – EI Casting; 2 – electrodes; 3 – electrolyte bath

Parameters and materials used in the process of galvanic treatment of the EI casting are shown in Table 2.

Table 2.
Parameters of the process and materials

Electrolyte composition	Density of current	Electrolyte temperature	Time of copper plating
$CuSO_4 \cdot 5H_2O$ – 180 g/l; H_2SO_4 – 40 g/l; H_3BO_3 – 40 g/l.	1 A/dm²	20 ºC	24 hours

The EI casting is completely immersed in the electrolyte solution. For the purpose of increasing the speed of copper plating, the solution is stirred after 2 hours, following extraction of the EI casting.

A smooth layer of copper coating is formed on the EI casting (Fig. 7 – 1). Areas without copper coating are found in the center of the EI castings (Fig. 7 – 2). Copper build-ups are found of the ribs. Fig. 7 – 3.

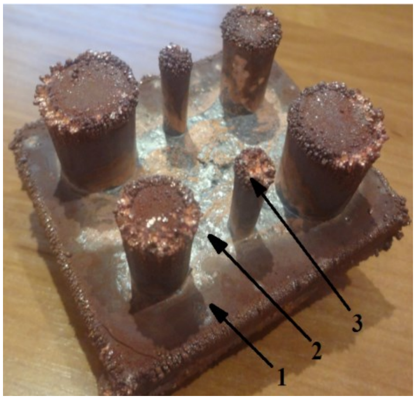


Fig. 7. A cortical EI obtained by casting after galvanic treatment: 1 – copper coating layer; 2 – uncovered areas; 3 – copper build-ups

Copper build-ups are found of the ribs (Fig. 7 – 3). This effect is due to insufficient temperature of copper sulfate and high density of current during electroplating.

4. Studying the methods of making cortical EIs with the use of the RP technology

The functional prototype of EI made with the use of the RP technology from photopolymer material does not have conductive properties, which prevents its direct use in galvanic treatment.

The intermediate step in making EIs with copper coating is application of the conductive layer through chemical plating.

4.1. Studying the process of chemical metallization of the EI prototype

The following solutions were prepared for chemical metallization:

1. Degreasing solution of sodium hydroxide (NaOH) with the mass fraction of 10%, 500 ml. The prepared quantity of sodium hydroxide weighed with a technical weigher in the amount of 50 g is dissolved in 450 ml of distilled water with vigorous stirring of the components.
2. Surface activator: tin dichloride ($SnCI_2$), an aqueous solution with the mass fraction of 10%, 500 ml. The prepared quantity of tin dichloride weighed with a technical

weighed in the amount of 50 g is dissolved in 450 ml of water with vigorous stirring of the components.

3. Tub for rinsing with distilled water, 500 ml.
4. Bath for silver-plating:
   Composition A:
   - Silver nitrite ($AgNO_3$) - 20 g;
   - Ammonium nitrite (NH_4NO) - 8.0 g;
   - Distilled water - 172 ml.

   Composition B:
   - Sodium hydroxide (NaOH) - 7.6 g;
   - Distilled water - 192.4 ml.
   - Glucose, aqueous solution with the mass fraction of 5% - 100 ml;

   Composition C:
   - Tartaric acid ($C_4H_6O_6$) - 1.5 g.

Before silver plating, composition B is boiled on a heater for 3 to 5 minutes in a 100 ml heat-resistant glass.

After preparing all necessary solutions and equipment for chemical plating, it is necessary to degrease the EI prototype. Degreasing is done by immersing it in an aqueous solution of sodium hydroxide with the mass fraction of 10 for 5 minutes.

Then the degreased prototype of the EI should be washed in a tub with distilled water. After rinsing, the surface of the EI prototype should be activated. It is done by dipping in an aqueous solution of tin dichloride with the mass fraction of 10% for 5 minutes.

Silvering is performed in 500 ml polyethylene containers, where three prepared solutions A, B and C are mixed. The time of EI prototype exposure in the tank with the solution is 10 minutes.

After the process of chemical metallization is complete, EI should be rinsed in water. Silver plated workpieces are dried suspended at 50°C for 1 h.

4.2. Studying the process of EI prototype copper coating

Copper coating is applied to the preliminary conductive layer. The modes of galvanic treatment are shown in Table 2.

On the base of the EI, the primary dielectric layer is formed (Fig. 8 – 1). The main working surfaces of the EI, i.e. six cylinders, are covered with copper layer.

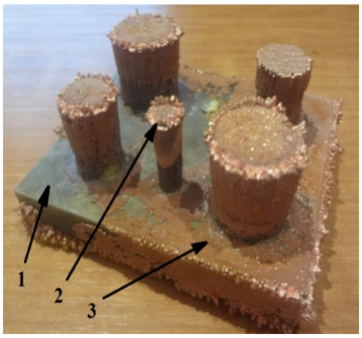


Fig. 8. Cortical EI: 1 – the primary conductive layer; 2 – copper build-ups; 3 – copper layer

There are copper buildups on the ribs (Fig. 8 – 2), same as on the EIs obtained by casting. This effect is associated with the modes of galvanic treatment. The copper layer (Fig. 8 – 3) formed at the ends of the cylinders is 1.44 mm thick.

5. Studying the process of EDMing a cortical EI workpiece

The cortical EI obtained with the use of the rapid prototyping technology is fixed in a copy-piercing EDM machine Smart CNC (Fig. 9) for the process of electroerosion EDM.

Fig. 9. EI fixed in the EDM machine.
Processed material is grade 65C steel, GOST 14959 -79

The parameters of the EDM process are shown in Table 3. Industrial oil I-20A is used as the working fluid.

Table 3.
Parameters of the EDM process

E code	Ip, A	U, B	Machine polarity
43	2	50	Direct

E code is the Software code of the operating tables of the machine, Ip is current, U is voltage.

EI processing depth is 1 mm. Processing is done by one cylinder (Fig. 10 A) to reduce the processing time.

Fig. 10. Cortical EIs after processing in the EDM machine. A is the processing area

As a result of the experiment, the desired depth in processing with both electrodes has been reached. The time of electrodes processing was 90 minutes.

Fig. 11 shows the results of processing a steel workpiece with cortical EIs and the RP technology.

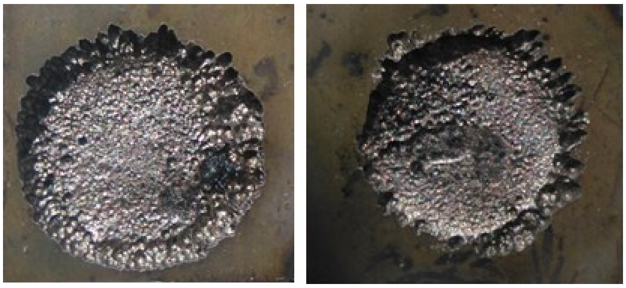
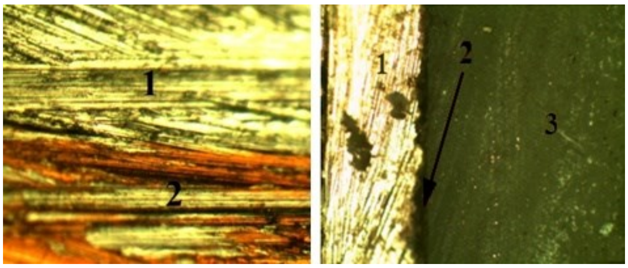


Fig. 11. The surface of the steel workpiece after EDMing with cortical EIs: a – imprint after treatment with cast EIs; b – imprint after treatment with EIs obtained through the RP technology

The EDM process was accompanied by abundant sparking, without short circuiting.

Fig. 12 shows that after electric discharge machining of cortical EIs made with the use of the rapid prototyping technology, the applied copper layer does not have damage, chips, or cracks.



a b

Fig. 12. Cortical EIs at X50 magnification: a - a cortical EI obtained by casting; 1 – metal base; 2 – copper layer; b – a cortical EI obtained by the rapid prototyping technology; 1 – copper layer; 2 – preliminary conductive layer; 3 – polymer base.

The obtained cortical EI is suitable for multiple processing, the galvanic plating does not lose integrity. The coating does not have defects, there is no copper layer delamination.

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5. Conclusions

1. As a result of analyzing the existing methods of obtaining EIs with the use of rapid prototyping technology, it has been found that using SLA technology makes it possible to obtain cortical EIs. The process of hot investment casting cuts economic costs for making geometrically-complex electrode-instruments by 35%.
2. The performed study of making cortical EIs using the RP technology has shown that the EI built can be galvanically treated for forming the working outline. The thickness of applied copper coating is 1.44 mm. This thickness removes surface defects of the coating and preserves integrity with the EDM. The study of EDMing a steel workpiece with cortical EIs obtained by rapid prototyping has shown that the copper layer is not destroyed after treatment, the EI retains its dimensions, and is suitable for repeated use.

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