A REVIEW OF UNCONVENTIONAL PROCEDURES FOR MANUFACTURING TOOL ELECTRODES USED IN EDM

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Abstract. Electrical discharge machining (EDM) is an unconventional process for machining electrically conductive materials that are difficult to process by other known means. EDM requires that the tool, at least in the die sinking technology, to be the negative of the cavity to be processed. Therefore, processing of tool electrodes is a necessary step but also is the cause for substantial costs associated with machining and the time needed to complete it. Technologies based on the principle of additive manufacturing could be a viable alternative to produce these electrodes. This paper intends to provide a review of possibilities of additive manufacturing - AM to be used as a process to produce tool electrodes to be used in die-sinking EDM.

Keywords: EDM, EDM electrodes, additive manufacturing

1. Introduction

One of the motivations because electrical discharge machining has grown is the fact that it is not influenced by the mechanical properties of processed materials (more precisely the hardness). Typical examples where EDM is applied successfully are those related to the processing of tool steels, hardened steels, and special design electrical conductive ceramics. In general, through EDM can be processed all the material having an electrical conductivity value above 0.01 S/cm [1, 2].

Because, during processing, tool electrode shape is transferred to the work-piece its geometry is essential to be accurate. Traditionally, tool electrodes, with 3D geometry, are made through milling. As a rule of thumb, as the geometry is more complicated both time processing and costs are higher. Consequently, reducing processing time and associated costs generate reduced time and costs of obtaining the various components made through EDM.

In contrast to traditional production techniques, which involves the injection of material into an existent form or removal of material from a blank (to name just two of the technologies), additive manufacturing processes are based on a 3D virtual model. A specialized machine transforms this model, layer by layer, into a solid object by depositing successive layers of material. Perhaps the most important advantage of such technology is that the final product does not require further processing.

The equipment (3D printers) used to generate 3D objects can achieve this by one of these popular methods:

- using a polymer-based material in a liquid state that is transformed into solid by a light beam;
- by bonding microscopic granules of materials by means of a binder or by means of a laser beam;
- by extruding melted materials;
- by melting the material (Fused deposition) [3].

Although the processes for obtaining final part are named in various ways the synthesis presented could be applied the entire range of nowadays available 3D printing machines. At the same time, regardless of the technology used, a common denominator is the fact that objects are resulting by depositing successive layers of material.

The benefits of AD to manufacturing tool electrodes to be used in EDM are related to the fact that about 50% of process costs are generated by using conventional processes in order to obtain these tools. More, due to the costs involved, traditional production is destined to products, which satisfy the requirements of a large number of consumers. This causes a limitation of production flexibility. Obviously, this cannot be said about the production tool electrodes. In the same time, this process consumes remarkable time and financial resources in relation to the final product. Because of the waste generated in the production of tool electrodes, it is also a process that is not friendly to the resources used.

Through AM can be produced (as practice demonstrated) complex objects, including assemblies with moving parts. Because it requires fewer operations in achieving effective end product, incorporating all the features required and desired, it means that the production cycle (for AM) is a short one and are only used strictly necessary quantities of materials for product realization.

To materialize this, is presented the common method of obtaining plastic components. Using a plastic injection machine, the final form of the product is generated by the mould used. Generally, the shape of the mould is produced by using an appropriate tool electrode through EDM. Unfortunately, even at a minor change in the product geometry is necessary to change the mould generating, this way, additional costs. Not considered as necessary to be presented costs and complexity associated with a production system for the moulds manufacturing. Using AM is possible to generate tool electrodes that could be immediately used in production of moulds reducing the costs and time connected to traditional way of manufacturing.

Because of the benefits, industry is more and more attracted to the AM. "Wohlers Report 2014" attests this fact [4, 5]: *"…the market for 3D printing, consisting of all products and services worldwide, grew to $3.07 billion last year (2013 A/N). Compared with an averaged 27% growth rate over the past 26 years, the compound annual growth rate (CAGR) of 34.9% is the highest in 17 years. The CAGR for the past three years (2011–2013) was 32.3%*".

2. Application of additive manufacturing to production of EDM tool electrodes

There are and can be performed several classifications about additive fabrication processes and machines that makes this. As this paper investigates the extent to which they can apply to the realization of tool electrodes will be evaluated only those of them who have this potential.

As mentioned, processing by EDM implies that both tool and part to present a sufficient electrical conductivity. From this point of view, a possible delimitation AM processes can be done in relation to the material used. This criterion divides the methods for the realization of tool electrodes in two categories: made from non-conductive and from electrically conductive materials.

2.1. Tool electrodes made of electrical nonconductive materials

Tool electrodes made of nonconductive materials cannot be used immediately for EDM, requiring several subsequent metallization operations such as platting, spraying, painting etc. [6]. Most often, this first operation does not provide an enough thickness of electrical conductive layer and therefore requires other additional operations: electroplating, electroforming, metal spraying etc. According to [7] the first stage can assure only a 10 to 50 µm thickness of metallic coating and the second operation can provide a thickness up to 180 µm. Of course, the operations can be repeated, the final coating being a sequence of successive layers.

Attraction of indirect manufacturing processes is not difficult to clarify. First, the large availability of 3D printers explains this phenomenon. Secondly, the costs involved in making products are much lower compared to other 3D printing processes. In [8] are presented the following values in order to obtain one cubic centimetre of a 3D printed part: 1.10 € for nylon, 2.26 € for acrylic, 6.31 € for steel and 9.82 € for silver. However, because by using this process cannot be obtained electrodes ready-to-use (it is a multi-stage process), the domain does not present a major attraction for the industry.

2.2. Tool electrodes made of electrical conductive materials

Selective Laser Sintering (SLS) uses a laser beam to sinter powdered material. The parts are obtained from thin layers of solidified powdered material, which is spread over a building platform by a roller. Then a laser beam, according to CAD drawing, is deflected in such a way to sinter only the material of the layer that is printed. After a layer is printed, the building platform is lowered, by the thickness of a single layer, and process is repeated. Therefore, successive layers are connected between them. A graphic explanation of this process is presented in [9]. SLS sinters the material, (heat the material) below the melting point until the particles combine one to each other (particles in current and previous deposited layer).

Selective Laser Melting (SLM) is a similar process to SLS and sometimes the terms are used as interchangeable terms. In case of SLM, the part is produced in a close chamber in an inert atmosphere. For example, in case of SLM 280 machine [10], the chamber dimensions are 280 x 280 x 350 and is used o mixture of Ar/N_2 as inert gases. Another element that differentiates is the fact that SLM melts the material, creating a melt pool in which material is consolidated before cooling to form a solid structure. Because SLM melts the powder, some pure materials can be used.

Dürr et al. [11] present one of the first attempts to use AM technique in order to obtain tool electrodes, given, in fact, the name sintering of EDM-electrodes. In the first instance, a bronze-nickel powder mix was used achieving a 20% porosity. The authors found that the wear of such electrodes is comparable to massive copper electrodes but the wear behaviour is not favourable leading to an improper change of the shape of the electrodes and of the machined part (X210Cr12 and C45 steel). Because the unsatisfactory behaviour was attributed to electrode porosity, a new set of experiments were performed with electrodes impregnated with silver. These electrodes led to a decrease in relative wear by 30-50% in contrast to an infiltration with tin-containing solder and a material removal rate (MRR) near to 12.5 mm^3/min. The study is ended with the suggestion that further research should focus on the optimization of the process parameters of the EDM. The research is mentioned because it is one of the first to prove the viability of this approach.

One of the recent researches [12] shows the development of electrodes through SLS method and technological aspects regarding EDM machining. The materials used were powders of pure copper, bronze-nickel alloy, copper/bronze-nickel alloy, and steel alloy. Electrodes were used for EDM in the case of three processing regimes, roughing, semi-finishing, and finish, on Charmilles Roboform 30CNC die sinking machine. Electrodes were sintered using an EOS M250 machine, in a nitrogen inert atmosphere. EDM experiments were carried out over samples of tool steel (AISI H13).

Electrical parameters were as follows: rough (32 A over 8 min.), semi-finish (12 A over 25 min.), and finish (4 A over 40 min.). At roughing, the maximum MRR reported was near 18 mm^3/min (for bronze-nickel and copper/bronze-nickel materials). The steel alloy SLS made electrode has the worst performance ("*removing almost no material from the workpiece*"). At finishing, the maximum MRR was 0.05 mm^3/min at 120% volumetric wear. As a conclusion, study reports that SLS tool electrodes performance was lower compared to the solid copper electrodes. From all SLS electrodes, the bronze-nickel presents the best performance and the SLS copper electrodes showed the poorest performance. The general conclusion is that other materials must be identified (or developed new mixes) in order to simultaneously satisfy both the requirements of SLS and EDM.

In quite similar conditions to those presented in [12], Amorim [13] repeated the experiments, this time using a TiB_2-CuNi powder mix for SLS electrodes. The most important finding is the fact that TiB_2-CuNi SLS electrodes showed a much better behaviour than SLS copper electrodes in terms of MRR and relative wear. Around this behaviour should be noted that the poorer performance of the copper SLS is due to the sintering mechanism. The acknowledged results for MRR were at roughing 14.0 mm^3/min., for semi-finishing 10.3 mm^3/min, and at finishing 2.39 mm^3/min. The conclusions states that TiB_2-CuNi SLS electrodes perform better than SLS copper electrodes whatever the nature of EDM regime used, but performance was lower compared to electrodes made out of solid copper. Nevertheless, the material analysed, presented good performances to recommend it in terms of both SLS and EDM.

Despite last minute search through Google Scholar, ISI Web of Knowledge, and Emerald Insight, no relevant scientific literature regarding manufacturing tool electrodes through SLM method was founded. In the author's opinion, this is due mainly because of so-called patents war. Many of the methods of making products by AM and machines used for this purpose have been or are protected by copyright. A different approach was in relation to 3D printers released under Open Source license. This last case is the one that progressed quickly through the community contribution. This is the reason why is now possible to own a personal 3D printer like the one used to print on paper. To show that the field is one in which new solutions are still developed, a patent filed in 2014 is presented, related to obtaining interwoven layers deposited by the additive manufacturing technique [14].

3. Evolution and future developments

Attractiveness and possibilities of AM have attracted not only enthusiasts or scientists. The main research bodies and governments are offering substantial funds for developing the additive manufacturing domain, sometimes as a part of future digital manufacturing industry. In USA, which is the biggest market for AM, White House announced, in 2012, the launch of public-private institute for manufacturing innovation in Youngstown, Ohio, namely National Additive Manufacturing Innovation Institute [15, 16]. The institute will receive an initial $30 million in federal funding, matched by $40 million from the winning consortium.

In Europe, the European Commission (EC) launches the EU Framework Programme for Research and Innovation, Horizon 2020 [17]. The funds allocated are EUR 1.2 billion for developing Factories of the Future (FoF). Moreover, in June 2014, EC hosts even a workshop on Additive Manufacturing [18].

4. Conclusions

Generally, in order to obtain tool electrodes, through unconventional technologies, empiric method are used (trial and error type). In consequence, is necessary an investigation over the methods regarding elementary forms (rectangular and/or circular in section) design and obviously the ones with complex 3D shape.

The results in terms of material removal rate are, mostly, in inconsistency. Theoretical aspects do not come in the support of a single theory that can be applied successfully to industrial level.

Most experimental researches into the area that includes the realization electrodes tool focused on getting them from non-electrically conductive materials that were then covered with various layers of varying thicknesses electro conductive materials.

Far fewer are works that deal with the subject of EDM processing using tool electrodes of 3D complex shape. Under these conditions, subjects like MRR, tool wear, and surface roughness are open for further research. For non-circular shaped electrodes, remain to investigate their behaviour in terms of wear and shape deformation (especially for those with triangular section). There are little experimental researches regarding the processing, with electrodes made by various unconventional techniques, of parts from the same material.

Finally, although there are attempts on the realization of electrodes through unconventional methods, there is little relevant literature regarding the behaviour of these electrodes in conditions of industrial practice. However, the future of additive manufacturing equipment and technologies used for exist because mass production tends to give way to custom products, individualized and environmentally friendly. To these can be added the tendency of production systems to on-demand manufacturing, evident in the desire to reduce manufacturing costs.

In the end, this paper could assists researchers to sightsee further application of AM in designing tool electrodes to be used in EDM.

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Received in October 2014