Performance of sinking EDM electrodes made by selective laser sintering technique

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Abstract Electrical discharge machining (EDM) is a nonconventional machining process widely applied for the manufacture of intricate shapes in hard materials which are not easily machined by conventional machining processes. The production of geometrically complex EDM electrodes is difficult, time consuming, and it can account for about 50% of the total process costs. Selective laser sintering (SLS) can be an alternative technique to produce EDM electrodes in a faster way. This work conducted an experimental study on the performance of EDM electrodes made by SLS using pure copper, bronze–nickel alloy, copper/bronze–nickel alloy, and steel alloy powders. Important EDM performance measures such as material removal rate and volumetric relative wear were investigated and discussed for finishing, semifinish, and roughing regimes. This work contributes with an insight into the production of EDM electrodes via selective laser sintering, as an alternative technique to conventional machining processes, as well as to evaluate the performance of the electrodes, and also provide directions for future research on this field.

Keywords SLS technique · EDM electrodes · Process performance

Nomenclature

- $i_c$ Discharge current (A)
- $u_i$ Open circuit voltage (V)
- $u_e$ Discharge voltage (V)
- $t_e$ Discharge duration (μs)
- $t_i$ Pulse duration (μs)
- $t_0$ Pulse interval time (μs)
- $t_p$ Pulse cycle time ($t_i+t_0$; μs)
- $V_e$ Electrode wear rate (mm³/min)
- $V_w$ Material removal rate (mm³/min)
- $\vartheta$ Volumetric relative wear ($V_e/V_w$; %)
- $\tau$ Duty factor ($t_i/t_p$; %)

1 Introduction

The unique feature of machining any electrical conductive material regardless its hardness makes the electrodischarge machining process (EDM) one of the most extensively used nonconventional material removal process. Examples of applications include the precision machining of hardened steels, carbides, ceramics, and any material that offers an electrical conductivity higher than 0.01 S/cm [1]. Geometrically complex shapes that would be extremely difficult to be produced...
using conventional machining processes can be easier manufactured with EDM [2], therefore ranking EDM as one of the major processes applied in precision mechanical industry to generate complex three-dimensional components [3].

In the EDM process, the electrode shape is transferred into the workpiece material. Therefore, it is essential that the electrode shape replicates the desired workpiece geometry. EDM electrodes are commonly manufactured by conventional machining, e.g., milling. The more complicated the geometry of the desired component, the more difficult, time consuming, and expensive it is produce the corresponding electrode by conventional machining. Consequently, reducing the electrode manufacturing time and costs will also reduce the component machining time and costs.

Once the role of EDM has been constantly redefined, due to new machining technologies such as high-speed milling, the development and application of new technologies to maintain and improve the use of EDM in precision mechanical industry is an important demand. One aspect related to this is the production of electrodes in a faster way. An efficient technology for producing EDM electrodes can be the selective laser sintering (SLS), which can be classified as a rapid tooling technique [4], where tools and parts can be made directly, without any intermediate process. The SLS process builds intricate shaped parts directly from a computer-aided design (CAD) design without any intervention of specialized tools [5]. In this process, a thin layer of powdered material is spread over the surface of a building platform and leveled by a blade. A laser beam is used to selectively sinter or melt the powder particles. This beam is deflected and guided by mirrors according to the cross-section of the part’s mathematically sliced CAD model and transmits the energy input to the current layer. As a consequence, the powder is sintered or melted, connecting the particles and linking the current layer to the previous already solidified layer. Shortly after, the construction platform is lowered by one layer thickness and the blade mechanism applies new material to the building platform. At this point, the construction process is repeated layer by layer until the component is built, e.g., sinking EDM electrode.

Figure 1 exemplifies variables that influence the SLS process behavior, which are divided as the laser, the materials, the environment, the exposure, and the machine [6]. One of the most important variable in the SLS process is the energy density, which can be expressed by Eq. 1.

\[ E_V = \frac{P_L \cdot t_{ww}}{V} = \frac{P_L}{h_s \cdot D_S \cdot v_s} \]  (1)

Here, the energy density \( E_V \) [J/mm³] is a function of the laser power \( P_L \) [W], the exposure time \( t_{ww} \), the scan speed \( v_s \) [mm/s], the degree of overlap by hatch distance \( h_s \) [mm] and the layer thickness \( D_S \) [mm]. If the energy density is too low, the SLS made electrode will be porous presenting poor quality [7]. On the other hand, if the energy density is too high the electrode can present defects such as residual stresses and a poor surface quality, which will promote bad EDM performance.

This work contributes with an attempt to produce EDM electrodes via SLS, as an alternative technique to conventional machining processes, as well as to evaluate the performance of the electrodes produced by this technique. For that reason, experimental investigations on the electrodes made by SLS using pure copper, bronze–nickel alloy, copper/bronze–nickel alloy, and steel alloy powders were carried out under finish, semifinish, and roughing regimes. The EDM performance was measured in terms of the material removal rate \( (V_w) \), which represents the volume of material removed from the workpiece per unit of time (cubic meter per second), and volumetric relative wear \( (\vartheta) \), which represents the ratio between the electrode wear rate to material removal rate.

2 Experimental method and procedures

2.1 Electrodes manufacturing

The electrodes were manufactured at the Institut für Maschinenwesen of the Technische Universität Clausthal,