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Preliminary communication

Application of a Cold Spray Based 3D Printing Process in the Production of EDM Electrodes

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Abstract: Cold spray process principles allow the production of near-net-shape metal parts with a fast layer deposition by using 3D printing techniques via supersonic 3D deposition (SP3D). This innovative additive manufacturing process allows an easy and quick production of copper and aluminium parts with future possibilities to expand materials and alloys. The speed and materials enable the application of this cold spray based 3D printing process for the production of tools. In this paper, Electrical Discharge Machining (EDM) electrodes were fabricated by using SP3D to investigate its application in tool production. Requirements for the materials of electrodes and some existing solutions for the production of EDM electrodes with additive manufacturing methods are described first. The fabrication and experimental results are then presented for 3D printed copper EDM electrodes that were tested by using St 37-2 (DIN 17100) steel as the workpiece.

Keywords: additive manufacturing; cold spray; EDM; heat treatment; metal printing

1 INTRODUCTION

Electrical Discharge Machining (EDM) is a process based on the thermoelectric phenomenon and controlled erosion of material due to repetitive short duration sparks generated in the gap separating the tool and workpiece submerged in liquid dielectric [1-3].

The EDM process is compiled of several phases that are performed continuously until the desired workpiece geometry is achieved [2, 3]:

- ignition phase,
- formation of the plasma channel and vapour bubble,
- discharge phase and
- ejection phase.

A major advantage of this process is the possibility of application where machining with more conventional processes would be difficult: workpiece materials with higher hardness (i.e. heat treated steels), micro machining requirements, machining of composites or batch production of parts [1, 4]. Regarding the suitability for EDM processing, Amorim and Weingaertner [3] name electrical conductivity as one of the major properties required from the workpiece. The main parameters of EDM are the type of the EDM machine, workpiece and electrode material, electrode shape and rotation, type of dielectric and method of flushing [3, 5].

Electrical input parameters that must be taken into consideration for EDM are [5, 6]: discharge current (I_p), gap voltage (V_g), pulse ON time (T_{on}) and pulse OFF time (T_{off}), polarity, electrode gap, pulse frequency and duty factor.

The effectiveness of the process is measured by the material removal rate, electrode wear, wear ration (ratio of the electrode and material removal rate), surface finish and the difference between the electrode and cavity size (over cut) [5- 9].

Apart from the above mentioned parameters, Amorim and Weingaertner [2, 3] name the workpiece material removal rate, electrode resistance to wear, workpiece surface roughness, tool electrode material machinability and tool electrode material cost as important factors for the electrode material selection.

1.1 EDM Process and Materials for Electrodes

The main considerations for the EDM electrode are the erosion of the workpiece and transmission of electric current [7, 8]. Therefore, in the selection of electrode material, apart from the above mentioned parameters, electrical and thermal conductivity, the melting point, chemical composition and mechanical properties must be taken into consideration [9-14].

Due to the mentioned requirements, the first obvious choice for an electrode are metallic materials. Typical metals used for EDM electrodes are copper, brass, silver, tungsten, zinc, copper tungsten, silver tungsten, tungsten carbide and tellurium copper [10, 11]. Another very important material in EDM tool production is Graphite (Graphite has lower density and can hence be used for larger electrodes [3], it has a high melting point, but lower mechanical properties than metallic materials [11]). In order to mitigate the fragility of pure graphite, copper graphite electrodes can be used [11].

According to [3], the use of a different electrode material can produce the same results (Copper vs. Graphite). However, the cost difference must be taken into consideration.

Copper as an electrode material has some advantages over graphite. Copper is used for applications that require a highly polished surface or coined shape (for engraving), and it is a good choice for a wire EDM [3, 9].

In this paper, EDM electrodes from cold sprayed copper powder were produced by using the additive manufacturing technology SP3D.

1.2 Additive Manufacturing for EDM Electrode Production

Tool production is often connected to the manufacturing of products with (often) complex geometry, limited number of pieces [15] and requirements for specific material properties (i.e. high wear resistance or conductivity). Additive manufacturing introduces some benefits in tool production, such as the decrease of fabrication time or costs, possible elimination or reduction of manufacturing steps and improvement of tool design/functionality [15, 16]. These benefits allow a valid case to be made to investigate the possibilities of an additive manufacturing application for the production of EDM electrodes.

In the 1990's, attempts were made to apply stereolithography (STL) models for EDM tool production [17, 18]. Further development of rapid tooling processes resulted in several possible variations of the additive manufacturing of EDM electrodes that could be produced from non-conductive materials (i.e. stereolithography forwarded by metallisation), conductive materials (selective laser sintering (SLS) process) or cast made materials [19-21].

The area of Metal Additive Manufacturing (Metal AM) has been rapidly growing in last five years as it is used for the production of parts in the automotive, aircraft, medical technology industry and in the defence domain [22]. The development of new processes such as SP3D printing (based on the cold spraying of metal) opened the possibility of an investigation of another EDM electrode production method directly from conductive materials (copper).

2 SPEE3D PRINTING OF COPPER

The copper electrodes used in this experiment were 3D printed on a LightSPEE3D printer (SPEE3D, Australia). LightSPEE3D printers utilize a patented Supersonic 3D Deposition (SP3D) process to deposit material into near-net-shape bulk components. The process is derived from the existing cold spray (CS) technology. CS has been and still is used in repair and coating operations around the world, but is primarily limited to 2-dimensional applications. SPEE3D's technology utilizes its software, TwinSPEE3D, to slice a specified geometry and generate toolpaths by using sophisticated algorithms. The software generates a pre-programed path that a 6 axis robot arm performs over a stationary cold-spray gun to build a part in 3 dimensions.

Unlike the existing 3D printing technologies which require heat to melt material [23-25], SP3D is a kinetic process. Metal particles are accelerated up to Mach 3 [26]. The kinetic energy at this speed causes particles to highly plastically deform when they splat (technical term) onto the surface of the substrate, or part. This creates a high-density metal part as more material is continuously added. Since the SP3D process is not thermal, it is capable of producing parts significantly faster than other technologies by achieving high deposition rates. A limiting factor on thermal based technologies is the time required to melt and then solidify the material before the next layer is laid down.

Currently, LightSPEE3D is capable of printing aluminium, copper, and various copper and aluminium alloys. Research is being conducted to increase the number of materials that can be printed with useful metallurgical properties for numerous applications using the SP3D technology. Examples of material possibilities include bronzes, stainless steel and titanium, which are all able to be cold sprayed with the existing technologies [27].

The LightSPEE3D printer can produce copper parts at up to 100 g/min [26]. However, for the purpose of EDM tools, the machine deposited material at 20 g/min in order to increase deposition efficiency and dimensional accuracy as a higher production speed was not necessary. The deposition efficiency (DE) at 20 g/min is approximately 90%, with 10% of the powder being removed with a dust extraction system to be recycled.

3 EXPERIMENTAL SETUP

3.1 EDM Electrode Production

EDM electrodes (samples 1 – 9, Tab. 1, Fig. 1) were produced with the following parameters:

- Printing parameters:
  - Carrier gas: air,
  - Carrier gas stagnation temperature: 400 °C,
  - Carrier gas stagnation pressure: 30 bar,
  - Substrate: deoxidized 5052 aluminium at room temperature
  - Printing layer thickness: 1.68 mm
  - Printing time for 4 samples: 90 min
- Powder material: AMPS 99.9% Copper, D50 = 30 µm, D10-D90 = 10 to 45 µm
- Electrode geometry is shown in Fig. 1
- Post-printing heat treatment parameters are shown in Tab.1. After the treatment, electrodes were machined on a lathe to final dimensions.

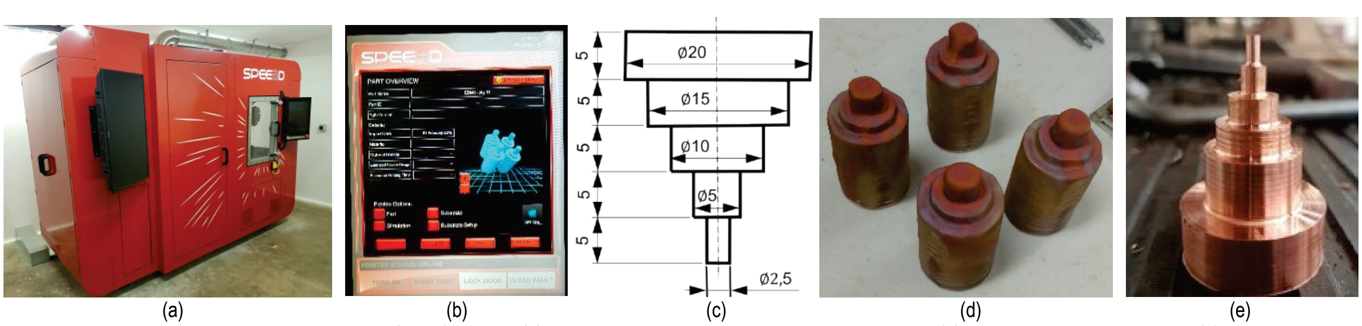

Figure 1 Electrodes were produced on the LightSPEE3D printer (a) using a pre-set geometry as displayed on the HMI (b), with dimensions given in mm (c). The as-printed samples (e) were then heat-treated according to Tab. 1, then machined on a lathe to produce the SP3D printed electrode (f).

The printed parts underwent different heat treatment regimes: 1) no heat treatment, 2) 330 °C, 3 hours, water quench 3) 400 °C 3 hours, water quench (Tab. 1). A control sample that was produced from the copper bar stock (sample 10, Tab. 1) was included. Heat treatment was performed to reduce the cold working of the material. Oxidation levels and conductivity of the 3D printed material are planned to be tested between groups in future research.

Table 1 Post printing heat treatment parameters

Sample no.	Heat treatment temperature, °C	Heat treatment time / quenching media
1	400	3 hours / water
2	330	3 hours / water
3	Not treated	
4	330	3 hours / water
5	Not treated	
6	330	3 hours / water
7	400	3 hours / water
8	Not treated	
9	400	3 hours / water
10	Produced from copper bar by machining	

Machining the as printed components to the required geometry on a lathe was difficult due to the brittle nature of the cold sprayed parts. The material does not deflect, but instead, areas with small cross sections would break in the lathe. The feed rate and depth of the cut were lowered to compensate. A 4-jaw chuck rather than a 3-jaw chuck was needed to adjust for the larger variation in the as printed geometry compared to a typical bar stock.

3.2 EDM Machining

EDM testing was performed on an AG80L Die sinker EDM machine (Sodic Europe Ltd.) in industrial conditions in the Gumiimpex-GRP company in Varaždin, with the following parameters:

- Workpiece: St 37-2 steel plate (123 × 70 × 30 mm) milled and grinded, without thermal processing. Tab. 2 shows the mechanical properties and Tab. 3 shows the thermo-physical data from the Iordachescu M et al. study (as cited in [28])
- Dielectric: EDMFLUID 108 MP/S.

Table 2 Mechanical properties of the St 37-2 material (thickness: 16.1 < 40 mm) [29]

Property	Value
Tensile strength, MPa	360-510
Yield strength, MPa	225
Elongation, %	26
Impact energy KV 20°C, J	> 27

Table 3 Thermo-physical data of the St 37-2 material [28]

Temperature, °C	20	200	400	600	800	1000	1600
Specific heat, J/kg °C	465	527	606	761	685	618	840
Density, kg/m^3	7850	7770	7700	7630	7590	7510	7100
Conductivity, W/m °C	48.07	43.89	38.04	31.77	25.50	28.01	34.28

Table 4 Chemical composition of the St 37-2 material

Element	%	Element	%	Element	%
Al	0.0265	Mn	1.2726	S	0.0108
C	0.1511	Nb	0.0325	Si	0.2433
Co	0.0318	Ni	0.0468	V	0.0390
Cr	0.0174	P	0.0156	Fe	98.110
				Other	0.0026

The chemical composition of the St 37-2 material was measured by using the optical emission spectrometer ARL 3460, which has a database for steel, copper and aluminium. The spectrometer analysis results are shown in Tab. 4.

The used EDM parameters are shown in Tab. 5.

Table 5 EDM parameters

Tool electrode	Copper	Workpiece material	St 37-2 steel
Polarity	+	Peak Current, A	5
Pulse on time, μs	110	Voltage, V	55
Pulse off time, μs	45	Dielectric fluid	EDMFLUID 108 MP/S
Surface Roughness, μm	4,1-4,4	Overcut, μm/Side	80

Based on the expected roughness of the treated surface, the machine automatically selected the processing parameters, such as the metal removal rate, pulse ON time, pulse OFF time and electricity power.

4 RESULTS

The obtained test results of the application of the cold spray based printing method, SP3D, for the production of EDM electrodes have shown that material is usable and comparable with the traditionally produced copper electrodes. The test results for all electrodes described in Tab. 1 are shown in Figs. 2-6. Note that no distinct differences are seen at a macro level of the control (sample 10) from the 3D printed samples (Figs. 2-6).

Figure 2 Workpiece after machining

Figure 3 Workpiece surface for the printed and not heat treated EDM electrode (samples 3, 5, 8)

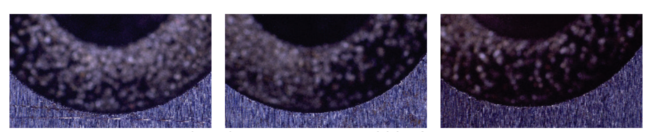

Figure 4 Workpiece surface for the printed and 330 °C heat treated EDM electrode (samples 2, 4, 6)

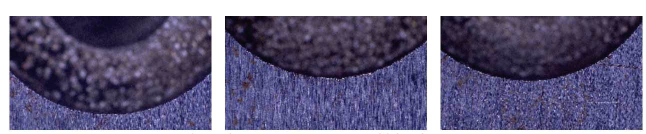

Figure 5 Workpiece surface for the printed and 400 °C heat treated EDM electrode (samples 1, 7, 9)

The St 37-2 workpiece surface condition after machining with printed electrodes that were not heat treated after printing is shown in Fig. 3. Fig. 4 shows the workpiece surfaces machined with electrodes that were heat treated to 330 °C, and the surfaces machined with electrodes that were heated to 400 °C are shown in Fig. 5.

The surface produced by an electrode that was made by a solid copper bar is shown in Fig. 6.

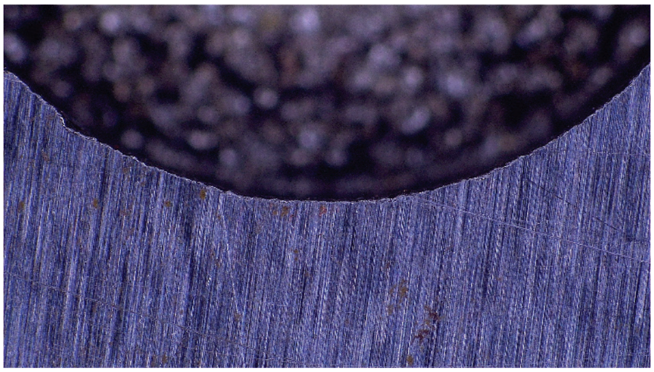

Figure 6 Workpiece surface for a bar stock produced EDM electrode (control, sample 10)

The presented results show a possible application of the SP3D printing of metals for the production of EDM electrodes. As this process is cheap and fast in comparison to other metal printing processes [26], it could provide a unique solution in situations where a specific shape of the tool is required.

Research in EDM has produced investigations of processes with electrode cooling in order to reduce electrode wearing [30, 31]. This fact combined with the fact that the SP3D technology can produce solid objects with enclosed channels leads to the possibility that the SP3D printing technology could be a solution for the production of electrodes (and tools in general) with built-in liquid cooling systems.

5 CONCLUSION

The development of a new additive manufacturing process based on cold spray opened a range of possibilities in tool production. In this preliminary research, the SP3D technology was tested for the production of copper EDM electrodes. Three different groups of printed EDM electrodes that varied by heat treatment were compared with a conventionally produced copper electrode (Tab. 1). All electrodes were tested on a mild steel workpiece. Preliminary results have shown that a cold spray based 3D printing technology can be used for EDM with a satisfactory production output.

In the future, research will be conducted in order to increase the efficiency of electrode production and application regarding the following: the influence of heat treatment temperature on conductivity, SP3D produced electrode wear rates and possibly, introduction of the alloying of copper powder in order to improve mechanical properties of electrode materials.

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