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SURFACE AND SUBSURFACE FEATURES OF MICRO ELECTRO DRILLED PARTS PRODUCED BY SLS

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Abstract: *An innovative concept in industrial manufacturing is to produce parts, as near as possible, close to their final shape and contour, implementing non-chipping techniques. In this way the additive manufacturing gives the possibility of a finished product with minimal cutting and the opportunity to reduce the productive steps. Sometimes innovative component of high temperature and corrosion resistance material need micro drilling has final process. This need has developed an attraction to EDM as a micro-machining method to obtain negligible machining forces, which minimizes tool deformation and enables delicate micro features to be produced. This paper investigates micro electro-discharge drilling of Cr-Co-Mo specimen built by selective laser sintering.*
Key words: *EDM, CrCoMo alloy, Near-net shape, Material Removal Rate, Electrode Wear*

1. INTRODUCTION

Additive manufacturing processes are time-compression-technologies that create near-net shaped components from CAD models to product deposition. The main focus of this technology is to produce parts, as near as possible close to their final shape and contour, implementing non-chipping techniques. In this way the manufacturing gives the possibility of a finished product with minimal cutting. Near-net shape technology also generates the opportunity to reduce the productive steps for a given process chain. Both the above-mentioned characteristics have the same main goal: achieving cost reduction. This fundamental target incorporates several other advantages, such as: reduction of process variability, quality improvement in the finished product and the possibility to focus the design of mechanical devices on functional features, eliminating technical constraints imposed by the process. Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining. Recent progress made in the field of aviation, space, automobile, electronics and computer, medical, optics, miniature manufacturing and others (Kumar, 2008; Emmelmann C. et al., 2009; Vandenbroucke B. et al., 2007) has created the need for small and micro-size holes with high aspect ratio in extremely hard and brittle materials. The increasing use of these alloys led to analyze, in this research, the effects of micro electro-discharge drilling on surface e subsurface features of Cr-Co-Mo specimen built by selective laser sintering. The ability to create near-net shape componenst in CrCo with additive manufacturing and the micro-drilling of the components are very recent. For this reason, are not present critical overview on the subject in the literature.

To verify the optimal micro-EDM process parameters settings, the Material Removal Rate (MRR), the Electrode Wear Rate (EWR) are considered. The surface and subsurface features of the machine material are investigated by SEM.

2. EXPERIMENTAL PROCEDURE

Tensile test specimen, performed in accordance *ASTM E8M* specifications, has been produced by *selective laser sintering* using Co-Cr-Mo alloy. Table 1 shows the tested alloy composition and mechanical performances of bulk material. Standard parameters were used on *Eosint-M270* to fabricate the laser-sintered specimens (Table 2). Every layer is constructed by dividing the slice area into squares of 4 mm side, built one next to the other. After every square's building the laser spot is realigned. On each layer the laser acts with parallel wipes directed according to a definite scan vector. For the next layer the scan vector is rotated by 25° with respect to the previous one. The alloy is used to produce specimens built with 3 different orientations (4 for each orientation) in regard to powder deposition plane and laser path (Figure 1).

<table>
<tr><td rowspan="2">Co-Cr-Mo</td><td>Co</td><td>Cr</td><td>Mo</td><td>Si</td><td>Mn</td><td>Ti</td><td>Co</td></tr>
<tr><td>59.5</td><td>31.5</td><td>5.0</td><td>2.0</td><td>1.0</td><td>-</td><td>59.5</td></tr>
<tr><td>Density [g/cm^3]</td><td colspan="2">Melting Range [°C±15°C]</td><td colspan="2">Thermal Expansion Coefficient [25-300°C, x10^{-6}]</td><td colspan="2">Wrought Tensile Strength [MPa]</td><td>Cast Tensile Strength [MPa]</td></tr>
<tr><td>8.8</td><td colspan="2">1634 - 1664</td><td colspan="2">9.2</td><td colspan="2">960
1151-1179</td><td>689</td></tr>
</table>

Tab. 1. Composition and physical properties of Co-Cr-Mo alloy (Arcam Data sheet, Del Corso, Metals Handbook)

Table 2 summarizes the EDM parameter settings adopted in the present study. It can be seen that the pulse current ranges from 13 to 53A, and that the pulse-on durations (τ_{ON}) and the pulse-off durations (τ_{OFF}) are 20, 30 and 10,20 μs respectively. Each experiment specified an open voltage value of U = 200V and a duty factor ($\tau_{ON}/(\tau_{ON} + \tau_{OFF})$) equal to 0.5 and 0.75.
The dielectric and electrode characteristics are: dielectric= deionized water; copper electrodes Φ=0.6 mm, 300 mm length; hole depth= 8.74 mm. Each test was repeated 3 time. The hole profiles on the workpiece were inspected by cross-sectioning the specimens across the holes.

Parameters	*Value*
Laser power	200W
Laser spot diameter	0.200 mm
Scan speed	up to 7.0 m/s
Building speed	2-20 mm^3/s
Layer thickness	0.020 mm
Protective atmosphere	max 1.5% oxigen

Tab. 2. Parameters used for building the DMLS specimens

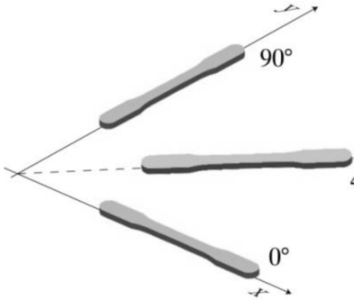

Fig. 1. Specimen: built in three orientations with respect to the machine distinctive directions

EDM parameters	*Setting condition*
Discharge current I [A]	13, 19, 33, 49, 53
Pulse-on duration τ_{ON} [μs]	20, 30
Pulse-off duration τ_{OFF} [μs]	10, 20
Duty factor τ	0.5, 0.75
Electrode material	Copper
Diameter of electrode [mm]	0.6
Electrode length [mm]	300

Tab. 3. Experimental machining setting

3. RESULTS AND DISCUSSION

The rupture surfaces were observed by scanning electron microscopy SEM, with integrated energy-dispersive X-ray microanalysis (EDX). The results have showed that the directional effect is negligible in terms of density and UTS. In fact the greatest difference density between bulk material and sintered one is about 2.3% and the average value of UTS is in the range 1080-1110 MPa, with elongations of about 12.5%. Structure is presented as a series of droplets formed by fine grains. Some fractures, such as quasi-cleavage and flutes, exhibit a unique appearance but cannot be readily placed within any of the principal fracture modes. The fractography of Co-Cr-Mo shows a quasi–cleavage fracture (Figure 2). During EDM, the main output parameters are the Material Removal Rate (MRR), removed volume of workpiece material divided by time, and Electrode Wear Rate (EWR), ratio between volume of material removed from the electrode and the volume of material removed from the workpiece (Table 4). It is desirable to obtain the maximum MRR with minimal EWR. The volumes were determined by measuring the profiles of the tool electrode and machined hole with an optical microscope.

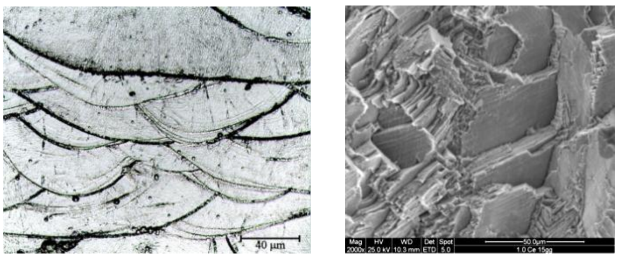

Fig. 2. Co-Cr-Mo structure and quasi-cleavage rupture surface

The SEM observation of the section attacked has showed for all the tests that a transition zone is absent between the electro-eroded surface and the unchanged part, defined *white area* for the steels, and the sub-surface cracks are absent. The irregularities of the holes are due to material re-deposited on the surface (Figure 3).

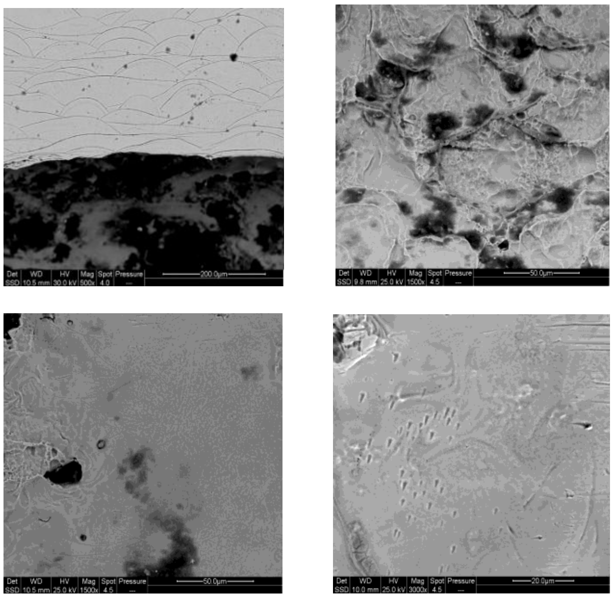

Fig. 3. Example of a hole

U [V]	*I* [A]	*Drilling speed v* [mm/min]	*Machining time T* [min]	*EWR* [mm/min]	*MRR* [mm^3/min]
50	19	37.1	0.236	72.2	57.1
60	33	43.5	0.201	149.4	58.2
40	33	41.1	0.213	117.5	50.6
45	49	37.6	0.233	150.4	61.5
32	13	16.5	0.529	32.1	17.0
45	53	55.4	0.158	237.6	69.6
68	53	62.1	0.141	334.0	89.4
45	53	33.2	0.263	64.7	35.4

Tab. 4. MRR and EWR as function of process parameters used

4. CONCLUSIONS

The mEDM drilling of Cr-Co-Mo alloy is an tool expensive process but it allows to obtain a deep hole without transition zone and without sub-surface cracks. The next step of the research focuses on the completion of fatigue tests on component benchmark as manufactured and on a microdrilled.

5. REFERENCES

Arcam Data sheet, electron beam melting ASTM Co-Cr-Mo F75 after heat treatment

Del Corso G.J. (1995*). Co-Cr-Mo powder metallurgy articles and process for their manufacture*, Patent:5462575

Emmelmann C., Petersen M., Goeke A. (2009). *Laser Freeform Fabrication for Aircraft Applications*, Proceedings of the Fifth International WLT-Conference on Lasers in Manufacturing, pp 171–174

Kumar S. (2008). *Iron-based powders and SLS/SLM for rapid tooling*, PhD thesis, Katholieke Universiteit Leuven. Leuven, Belgium

Metals Handbook (1990), *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*, Tenth Edition, Volume 2, ASM International, p 451

Vandenbroucke B., Kruth J.P. (2007). *Selective laser melting of biocompatible metals for rapid manufacturing of medical parts*, Rapid Prototyp J 13 4:196–203