

Finishing of laser-machined coronary stents by plasma electrolytic polishing

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Abstract

Cardiovascular stents are biomedical devices for the treatment of stenosis problem in the vascular system. Stenosis can be considered as the narrowing of the vessel in a way that creates a block or contraction to blood flow. In order to overcome such blockings, stents are placed and expanded in the narrowing location. Stent manufacturing is vastly done by laser beam machining and requires a good accuracy and control of the process to be successful.

Recent studies have assessed nanosecond-pulsed lasers for efficient production in terms of productivity and quality. To achieve the required properties with regard to burr and dross removal, edge rounding and surface finishing, currently chemical etching followed by electrochemical polishing is applied after laser machining. Both from the perspective of process control, speed and repeatability as well as biocompatibility, these chemical finishing processes, using concentrated acids, are far from optimal.

Plasma electrolytic polishing (PeP) can provide an alternative, using biocompatible, aqueous solutions and high DC voltages of $u > 200$ V to establish a vapour skin around the workpiece which leads to the generation of an atmospheric plasma. Here, electrochemical and electrothermal reactions take place which remove burr and dross and smoothen the workpieces' surface. Roughness values of $R_a \geq 0.02$ μm have been achieved.

This work presents the study of a novel stent manufacturing route for producing permanent stents in AISI 316L stainless steel. The stent mesh was microcut employing a ns-pulsed fiber laser. The stents were post-processed via traditional chemical etching and PeP. The results were compared in terms of geometrical integrity and surface roughness.

Medical devices; stent; laser machining; plasma electrolytic polishing; finish machining; deburring

1. Introduction

An ageing society is generating an increasing demand for medical treatments of the blood circulation system, among them a large number of interventions to prevent blockage of arteries. Cardiovascular stents are metallic biomedical devices for the treatment of incidents such as stenosis in the vascular system. Stenosis can be considered as the narrowing of the vessel in a way that creates a block or contraction to blood flow. In order to overcome such blockings, stents are placed and expanded in the narrowing location.

2. Stent manufacturing route

Stent manufacturing is vastly done by laser beam machining, starting from a tubular stainless steel material. The cutting of the filigree structures requires a good accuracy and control of the process to be successful [1]. After laser cutting, the excess material has to be removed and the surface smoothened.

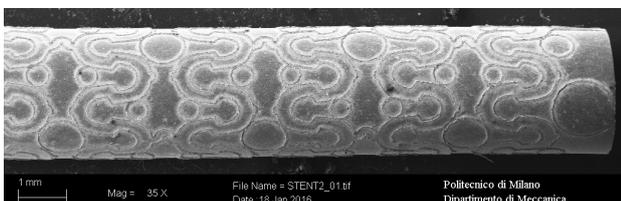


Figure 1. Cardiovascular stent (AISI 316L), after laser machining

2.1. Conventional processing

Recent studies have assessed nanosecond-pulsed lasers for efficient production in terms of productivity and quality. To achieve the required properties with regard to burr and dross removal, edge rounding and surface finishing, currently chemical etching followed by electrochemical polishing is applied after laser machining. Both from the perspective of process control, speed and repeatability as well as biocompatibility, these chemical finishing processes, using concentrated acids, are far from optimal.

2.2. Plasma electrolytic polishing

Plasma electrolytic polishing (PeP) can provide an alternative, using biocompatible, aqueous solutions [2]. PeP is an ablating process based on combination of current-induced chemical and physical removal. Its setup is an electrolytic cell where the part is immersed in an electrolyte and contacted as anode. The used aqueous electrolyte is low concentrated and material-specific, with typical conductivity values of $80 \leq \sigma \leq 140$ mS/cm.

The substantial phenomenon of this plasma electrochemical process is the induced formation of a plasma skin around the anodically contacted part in the liquid electrolyte. The plasma skin is formed under atmospheric pressure and at a high applied DC voltage of $200 \text{ V} \leq u_{PeP} \leq 400 \text{ V}$.

The characteristics of the PeP process are a comparatively low current density of $J_{PeP} \approx 0.2 \text{ A/cm}^2$ and a calm process. Although there is a high temperature plasma skin encasing the part, temperatures on the workpiece surface are limited by the boiling point of the electrolyte and do not exceed $\vartheta_{el} < 120$ °C.

Within the process, electrochemical reactions such as (anodic) metal dissolution, (anodic) oxide formation, hydrogen formation and alkalization, plasma reactions such as an ionization of the steam hull and hydrothermal reactions such as metal dissolution by metal-water reaction can take place [3] which remove burr and dross and smoothen the workpieces' surface. The development of the vapour skin which is coating the part and results in a plasma zone and the connection with electrochemical processes are the background for the surface effects that are responsible for the exceptional surface quality. Roughness values of $R_a \geq 0.02 \mu\text{m}$ have already been achieved.

3. Experiment

To assess the feasibility of PeP for the finish machining of stents, parts were produced applying nanosecond laser machining with optimised parameter sets. The tubes were intentionally not fully cut, but only a kerf was produced.

Then, three groups were created: a) no further treatment; b) chemical etching; c) chemical etching and electro polishing. Group b) and c) were chemically etched in a solution of 3 mL HF, 9 mL HNO_3 , 88 mL H_2O for 30 minutes.



Figure 2. laser cut parts before PeP (from left to right: group a), b), c))

In SEM imaging, the remaining dross after laser machining and the sharp edges after etching are visible (Fig. 3).

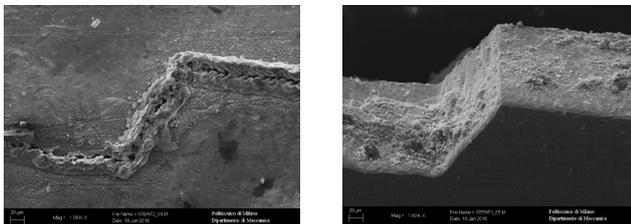


Figure 3. laser cut parts before (left) and after etching (right)

The parts were plasma electrolytically polished at $u_{PeP} = 200 \text{ V}$ in an aqueous electrolyte for a duration of $t_{PeP1} = 30 \text{ s}$ and $t_{PeP2} = 120 \text{ s}$, respectively. Afterwards, confocal measurements were taken again.

4. Results and discussion

For all parts, a high gloss surface finish was achieved. Furthermore, dross and burr were fully removed and surface roughness values were significantly improved.



Figure 4. stents after PeP (left to right: a), b), c)) (scale is $1000 \mu\text{m}$)

For the only laser-machined stents in group a), a removal of the inner part did only take place at the very ends. An increase in kerf depth could possibly solve this. For this study however, the chemical etching could not be replaced by PeP.

Groups b) and c) showed significant improvements in surface quality. R_z values could be lowered to as little as 5 % of the original roughness after a two minute process.

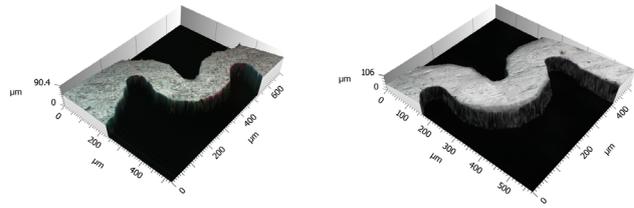


Figure 5. detail group b) (left: before PeP, right: after PeP $t_{PeP} = 30 \text{ s}$)

With $t_{PeP} = 30 \text{ s}$, dross and burr could be fully removed (Fig. 5). After machining for $t_{PeP} = 120 \text{ s}$, material removal was clearly visible and a significant edge rounding took place (Fig. 6). Roughness values have been significantly improved (Table 1).

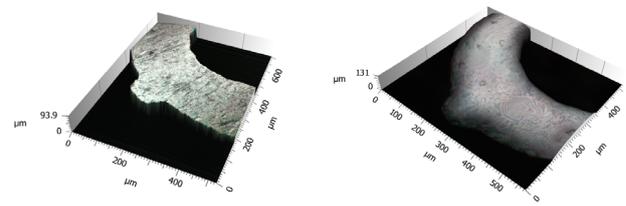


Figure 6. detail group c) (left: before PeP, right: after PeP $t_{PeP} = 120 \text{ s}$)

Table 1 Roughness values (confocally measured) of stents

Group	R_z before PeP	t_{PeP}	R_z after PeP
b)	$1.07 \mu\text{m}$	30 s	$0.318 \mu\text{m}$
c)	$1.71 \mu\text{m}$	120 s	$0.092 \mu\text{m}$

5. Conclusion and future work

The Plasma electrolytic Polishing process was successfully applied in finish machining of biomedical micro devices, in particular cardiovascular stents made of stainless steel. It allows for a significant improvement of surface quality after short processing time and by using easy-to-handle electrolytes.

The combination of Laser machining and PeP is promising, since all burr and dross can be removed in a controlled process environment. Future work in finding optimal kerf depths to eliminate the chemical etching process step, too, will be undertaken. With regard to the controllable removal rate, thinner tubes can be used, saving material and making even more filigree stent geometries feasible.

In a next step, further materials such as Magnesium for biodegradable stents will be assessed.

References

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