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Plasma electrolytic polishing of additively manufactured metallic glass

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Abstract

Plasma electrolytic polishing (PEP) is known as being a more environmentally friendly post-treatment method of metal parts, compared with its conventional counterparts. It is a great solution for polishing complex geometries in a relatively short amount of time. Thus, a large variety of conventional materials in various shapes have been already polished using the PEP technology, e.g., stainless steel, copper alloys, titanium alloys, shape memory alloys etc. However, results on polishing functional materials are not reported as often. One of the reasons for this could be that functional materials are very complex in their chemical composition, which halts the development of electrolytes for the PEP process. A suitable PEP electrolyte in addition to being environmentally friendly must enable the polishing of all alloying components, i.e., no selective polishing due to dissolution of some elements, but not the others, is acceptable. Using unadapted electrolytes can result in increased surface roughness of the polished part or surface defects. Therefore, it is very important to develop such electrolytes that could be used for treating parts with complex chemical compositions.

In this study, for the first-time results of the successful polishing of metallic glass, namely Vitreloy 101+Sn are reported. Three samples with dimensions of length from 10.8 to 15.0 mm, width of 3.1 mm, and thickness of 2.0 mm, were prepared by the means of additive manufacturing. The polishing results were quantified by the means of sample weighting and surface microscopy before and after the PEP. The samples were polished for 2 min, 4 min and 6 min. Sample 3, which was polished for 6 min, attained the highest gloss and surface smoothness.

Keywords: Metallic glass, plasma electrolytic polishing, amorphous materials, high strength and high electric conductivity

1. Introduction

In a number of engineering applications, the final parts surface finish and their quality are of paramount importance, since they determine parts functionality and the length of their service life [1, 2]. Recent advances in part manufacturing enable not only easier manufacturing of complex geometries, e.g., additively manufactured parts, but also development of new advanced materials, such as shape memory alloys (SMA) or other functional materials like metallic glasses [3]. This makes part polishing using conventional methods, like particle blasting, mechanical polishing and/or electrochemical polishing (EP), increasingly harder, since post-processing of the complex geometries is labour and time intensive. Moreover, polishing of multi-material alloys using not suitably adapted electrolytes might result in selective polishing and/or damage of the part surface.

Plasma electrolytic polishing (PEP), which to some extent is similar to the conventional EP, is considered as a more environmentally friendly alternative to conventional EP [4]. This is due to the fact that in the PEP process a water-based non-hazardous salt solution, which is material-specific, is used as an electrolyte. While successful polishing results on a number of conventional materials such as copper, aluminium, various steels and titanium [5–7] have been demonstrated, experimental results on complex alloys, such as Nitinol or metallic glass, are scarce or not available at all. This could be mainly attributed to the difficulty to develop a single electrolyte that is able to polish the full range of elements embedded in a single alloy. A not optimized electrolyte might lead to selective surface polishing, resulting into an increased surface roughness of the part.

In this study, experimental results on successful PEP application for polishing metallic glass samples, namely Vitreloy 101+Sn, are reported. The alloy consists of Cu, Ti, Zr, Ni and Sn [8], making it extremely difficult to post-process due to the different chemical reactivity of these elements. Nevertheless, three additively manufactured samples were plasma electrolytic polished for 2 min, 4 min and 6 min. The polishing results are evaluated by means of surface roughness, optical gloss and reduction in sample mass and dimensions.

2. Materials and methods

2.1. Vitreloy 101+Sn samples

The samples used in this study are shown in Figure 1. One can see that all three samples have small cracks along their longest axis. These defects are attributed to the manufacturing process.

(a) (b) (c)

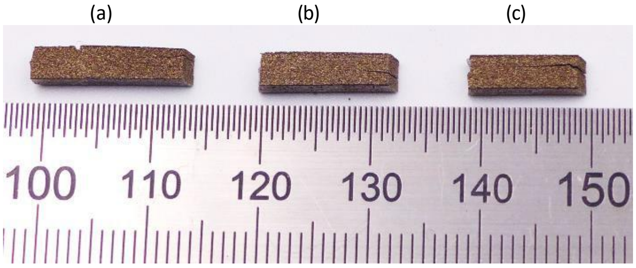

Figure 1. Vitreloy 101+Sn samples (a) Sample 3, (b) Sample 2 and (c) Sample 1 in as-received conditions.

The characteristic dimensions of the samples are given in Table 1.

Table 1. Characteristic dimensions of the analysed samples in as-received conditions.

Sample No.	Mass, *m*, g	Length, *l*, mm	Width, *w*, mm	Thickness, *σ*, mm
1	0.348	10.8	3.0	2.0
2	0.422	12.8	3.0	2.0
3	0.477	15.0	3.0	2.0

2.2. Plasma electrolytic polishing

All samples were polished in two steps. During Step 1, samples were contacted in a vertical position using titanium holder, immersed into the electrolyte and polished for the half of the total polishing time. During Step 2, samples were rotated 180° with respect to *y* axis, immersed into the electrolyte and polished for the remaining time. The applied direct voltage *U* was 338 V and resulting current *I* was approx. 1 A. The polishing conditions are reported in Table 2.

Table 2. PEP conditions for polishing Vitreloy 101+Sn samples.

Sample No.	Time, *t*, s	Temperature, *Θ*, °C		Current density, *q*, A min
		Start	**End**	
1	60	75.0	74.9	2
	60	74.8	73.5	2
2	120	75.0	76.1	2
	120	75.4	74.6	3
3	180	74.6	74.8	4
	180	74.7	76.6	5

From Table 2 one can note that *ΔΘ* of the end and beginning of the PEP process is negative. This is because the thermal losses from the electrolyte to the ambient were higher than the heat gained due to the Joule heating. Therefore, the electrolyte temperature during the process could not be sustained. It is important to emphasise that the external electrolyte heating system is by default kept turned off during the experiments in order to minimise the heat gains and maintain stability of the electrolyte temperature during PEP.

3. Results and discussion

From Figure 2 one can see that the edges of Sample 3, which was polished in total for 6 min, were rounded the most and the surface of this sample appears to be the brightest. It is also noticeable that no obvious crack propagation happened during the PEP process, demonstrating that the PEP process does not affect parts mechanical integrity. The resulting characteristic dimensions of the analysed parts are given in Table 3. One can see that the highest mass reduction is registered for Sample 3, which directly correlates to the process duration and the total surface area of the sample.

(a) (b) (c)

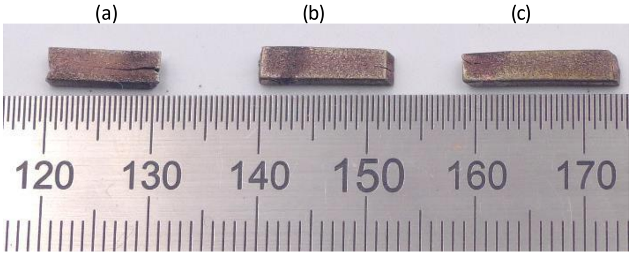

Figure 2. Vitreloy 101+Sn samples (a) Sample 1, (b) Sample 2 and (c) Sample 3 after PEP.

Table 3. Characteristic dimensions of the analysed samples after PEP.

Sample No.	Mass, *m*, g	Mass change, Δm, %	Lenght, *l*, mm	Width, *w*, mm	Thick., *σ*, mm
1	0.342	-1.72	10.6	3.0	1.8
2	0.404	-4.27	12.7	3.0	1.7
3	0.441	-7.55	14.8	2.9	1.7

The data on the surface roughness of the analysed samples is presented in Table 4.

Table 4. Surface roughness *Ra* and *Sq* of the analysed samples before and after PEP.

Sample No.	Before PEP		After PEP	
	***Ra*, µm**	***Sq*, µm**	***Ra*, µm**	***Sq*, µm**
1			3.7	17.4
2	5.7	25.2	2.1	14.4
3			1.5	9.0

Note that the cracked area of each sample was omitted from surface roughness evaluation. From Table 4, one can see that even after total PEP time of 2 min, the surface roughness of the samples is significantly reduced, and after 6 min of PEP, the surface roughness *Ra* is reduced by almost 3.8 times, and *Sq* by 2.8 times.

4. Conclusions

Three samples of metallic glass additive manufactured from Vitreloy 101+Sn were plasma electrolytic polished using a newly developed material-adapted electrolyte. As quantitative evaluation criterion of the effectiveness of the PEP process, a surface roughness of the parts before and after the process was measured. The obtained results demonstrate that the used electrolyte and the process parameters provided satisfactory results already after polishing the parts for 2 min and does not induce further crack development when the parts have defects resulting from the manufacturing process.

Thus, it could be concluded that the applicability of the PEP process was successfully broadened in the direction of post-processing of functional materials such as metallic glass.

The outlook for the future research is a more detailed analysis of the PEP influence on the corrosion behaviour of the metallic glass as well as its chemical composition.

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