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BRIEF REPORT

Plasma electrolytic polishing of additively manufactured metal parts: Optimizing the post processing workflow

[version 1; peer review: 2 approved with reservations]

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Abstract

Additive manufacturing of metal parts is gaining acceptance in industry due to its unique manufacturing capabilities. Higher surface roughness of printed parts is one of the major challenges of this advanced manufacturing technique, which requires a crucial post-processing stage before the components can be used in practice. This study investigates the influence of plasma electrolytic polishing (PeP) and the combination of PeP and particle blasting as a post processing technique for additively manufactured stainless steel samples. The results show a 70% improvement in surface roughness after 10 minutes of particle blasting and 3 minutes of PeP in sequence and presents the possibility of optimizing processing time to achieve better surface qualities with minimal post processing time.

Keywords

Plasma electrolytic Polishing (PeP), Additive Manufacturing (AM), Sand blasting, Surface roughness.

HE This article is included in the Horizon Europe gateway.

Open Peer Review

Approval Status ? ?

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version 1 01 Mar 2024	? view	? view

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Any reports and responses or comments on the article can be found at the end of the article.

H2020 This article is included in the Horizon 2020 gateway.

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Competing interests: No competing interests were disclosed.

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The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Introduction

Additive manufacturing (AM), commonly known as 3D printing, has revolutionized manufacturing through its adaptability and efficiency. This layer-by-layer process simplifies the production of intricate components from digital models that would be laborious using traditional methods. Despite these advances, there are some challenges with metal AM, particularly poor surface quality. Post-processing techniques are essential to meet industry standards. Various methods, including PeP, have emerged to overcome this challenge. PeP, a unique process that combines electrolysis and plasma reactions, quickly delivers a shiny surface. The schematic representation of the PeP setup can be found in Figure 1. Particle blasting is another common technique to clean the printed parts by removing unmelted or partially melted powder clusters from the surface and achieving a better surface quality. PeP of parts with a very high initial surface roughness can be a time-consuming processing technique to achieve the desired lower surface roughness values. This can be solved by combining PeP with other post-processing techniques and determining an appropriate sequence and processing time for each technique to optimize the workflow. This study investigates the effect of PeP on stainless steel samples and looks for the ideal combination with particle blasting for better surface quality.

Methods

Altogether six stainless steel samples were prepared for the experiments and three are shown in Figure 2. Samples were fabricated using the laser powder bed technique at the Technion- Israel Institute of technology. The parts were designed to include some complex features and logos of all the institutes involved in the project, to demonstrate and analyze the capability of the PeP process to improve the surface quality of AM samples. The samples were characterized using the MarSurf CM explorer microscope for surface roughness analysis. In this study, the samples are assigned numbers based on the post-processing cycle[1] (see Table 1).

Particle blasting: Samples 1, 2, 3 and 4 were processed by particle blasting as shown in Table 1. A TWISTER machine from BMF GmbH with a special powder from Vulkan Inox were used for particle blasting experiments.

PeP: PeP can be classified as a special case of anodic dissolution, where material removal is facilitated by both electrochemical and plasma reactions[2]. Figure 1 shows a standard configuration for the PeP process. In this process, the workpiece to be polished is anodically polarized and immersed in a suitable aqueous electrolyte solution with a suitable cathode electrode already placed in the electrolyte bath. The geometry of cathode does not have to mirror that of the workpiece[3].

Samples 4 and 5 were polished using PeP process for 3 minutes. Additionally sample 4 had also undergone 10 minutes of particle blasting before PeP. A 0.3 molar ammonium sulphate solution was used as electrolyte and sulfuric acid was used to maintain the pH of the solution in the range between 2.2–3.0. The experiments were conducted at 330 V and initial electrolyte temperature of 75°C.

Results and discussion

The images of the sample before and after polishing with particle blasting and PeP are shown in Figure 2. It can be clearly seen that the best results were obtained with longer polishing with the PeP process, which was to show the potential of PeP for an additively manufactured part and to demonstrate the gloss of the part after PeP polishing. The surface roughness of the sample before and after polishing is given in Table 2 and the surface images are shown in Figure 3.

The results clearly show that within the first 10 minutes of particle blasting on the printed sample, a 65% improvement in surface roughness (Sa = 19.8 µm to Sa = 6.8 µm) was achieved. Subsequent polishing with particle blasting improved the

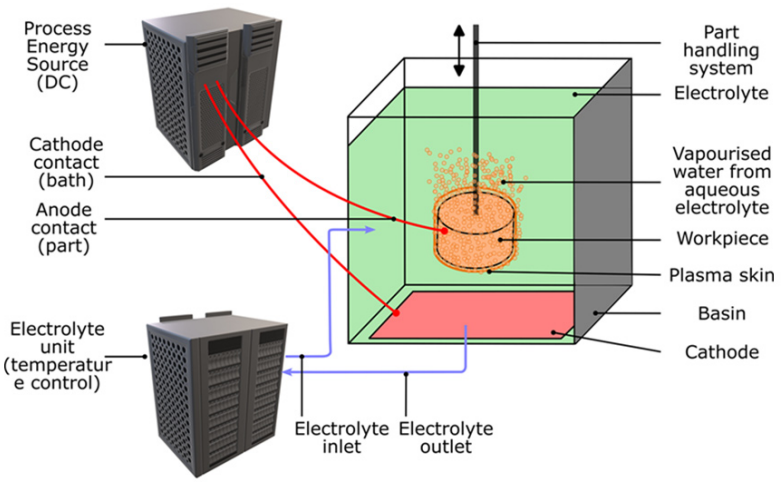


Figure 1. Schematic of PeP setup[4].

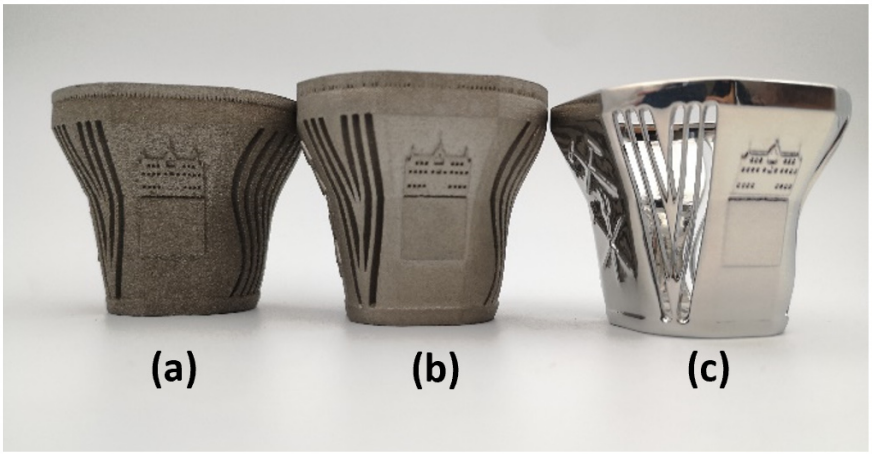


Figure 2. AM stainless steel sample in various stages of post-processing; (**a**) as-built [part 0], (**b**) particle blasting-10 min. [part 1] and (**c**) PeP-70 min. [part 6].

Table 1. Post processing stages of different samples.

Part No.	Process 1	Time (min.)	Process 2	Time (min.)	Process 3	Time (min.)
1	Particle blasting	10				
2	Particle blasting	10	Particle blasting	10		
3	Particle blasting	10	Particle blasting	10	Particle blasting	10
4	Particle blasting	10	PeP	3		
5	PeP	3				
6	PeP	70				

Table 2. Surface roughness before and after polishing.

Part No.	Polishing stages	Sa (µm)
0	As built	19.8
1	Particle blasting-10 min.	6.8
2	Particle blasting-20 min.	6.4
3	Particle blasting-30 min.	5.7
4	Particle blasting-10 min. & PeP-3 min.	5.8
5	PeP-3 min.	13.1
6	PeP-70 min.	2.6

surface roughness to Sa = 6.4 µm and Sa = 5.7 µm after 20 and 30 minutes, respectively.

The result after PeP shows a decrease in surface roughness to Sa = 13.1 µm compared to the initial sample after 3 minutes of polishing and a decrease to Sa = 2.6 µm after 70 minutes of PeP. The combination of 3 minutes of PeP after 10 minutes of particle blasting resulted in a surface with a roughness value of Sa = 5.8 µm. This is interesting because the results obtained are very similar to those achieved after 30 minutes of particle blasting. This shows the importance of PeP as a final polishing method to significantly reduce the post processing time and improve the surface quality.

The results also show that the reduction in surface roughness with higher processing time is much smaller in the case of particle blasting compared to the initial 10 minutes. The combination of particle blasting with PeP as the final stage of polishing proves to be much more efficient than either method alone in terms of polishing time for parts with very high initial surface roughness as in this case.

Sample 6, which was polished with PeP for 70 minutes, exhibits the best surface properties compared to all other test samples. Although the polishing time is much longer, this experiment was performed only to show the gloss and aesthetics that can be achieved with this method. For samples with

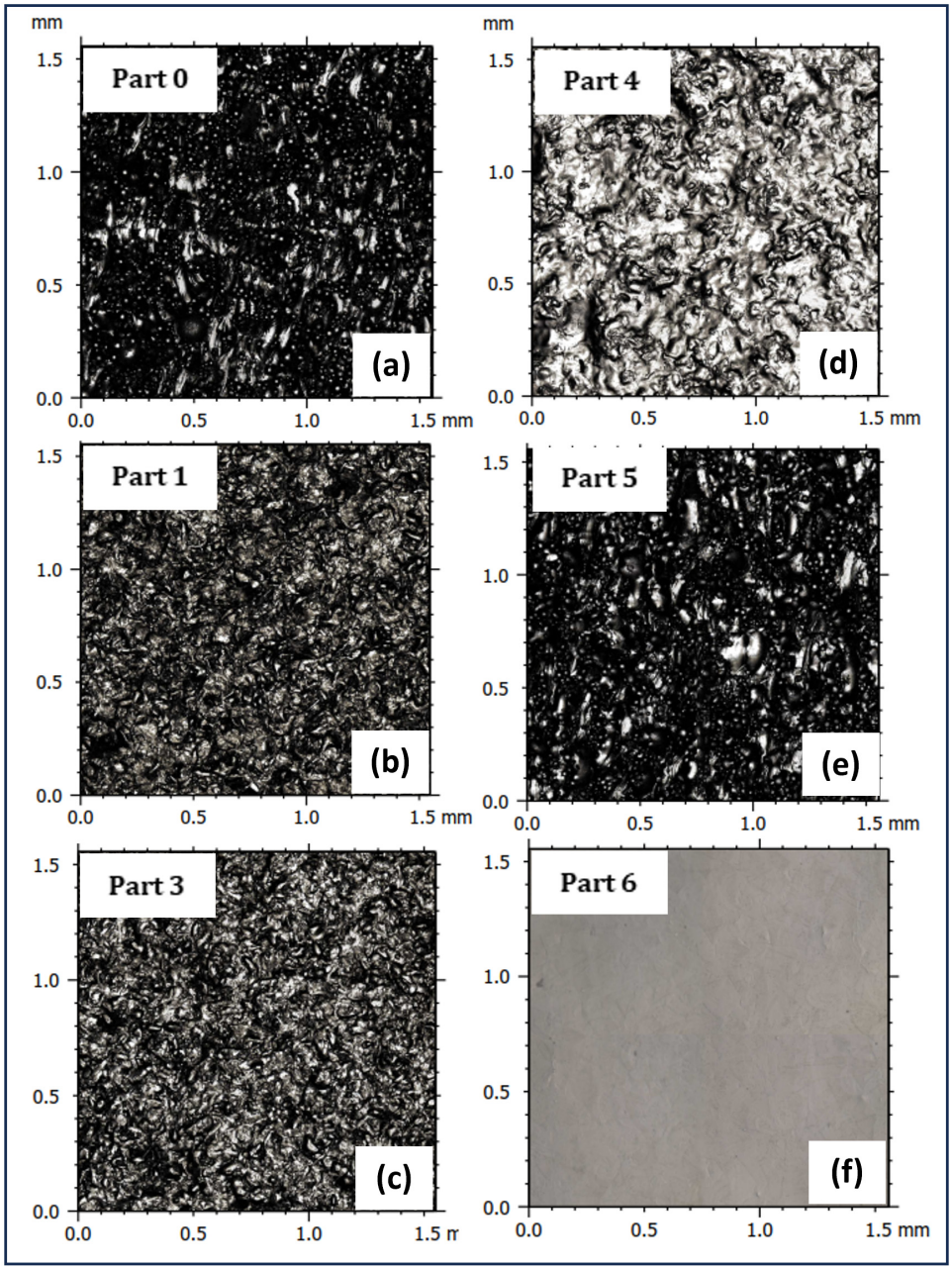


Figure 3. Surface images of samples: (**a**) as built, (**b**) Particle blasting-10 min., (**c**) PeP-3 min., (**d**) particle blasting-10 min. & PeP-3 min., (**e**) Particle blasting-30 min. and (**f**) PeP-70 min.

low initial surface roughness, a highly polished sample can be obtained with much shorter polishing times.

Conclusions

- Results show the effectiveness of using particle blasting and PeP in this sequence for post processing additively manufactured samples with very high surface roughness.

- The influence of particle blasting on the reduction of surface roughness is very large in the first few minutes, and the degree of roughness reduction decreases over time. The PeP process is much more efficient as a final polishing step to improve the productivity of the post processing line than when used alone on parts with high surface roughness.

- The study demonstrates the potential of the PeP process for polishing additively manufactured parts. It also explores the possible combination with particle blasting to optimize the post-processing workflow of AM and achieve the desired surface quality for use in real applications.

Ethics and consent

Ethical approval and consent were not required.

Data availability

Underlying data

EUDAT: Underlying data for 'Plasma electrolytic polishing of additively manufactured metal parts: Optimizing the post processing workflow', https://www.doi.org/10.23728/b2share.a49f1efd2eb440c3851de8b51eb9a45b[1]

This project contains the following underlying data:

- Figure 1: Schematic of PeP setup.
- Figure 2: AM stainless steel sample in various stages of post-processing; (a) as-built [part 0], (b) particle blasting-10 min. [part 1] and (c) PeP-70 min. [part 6].
- Figure 3: Surface images of samples (a) as built, (b) Particle blasting-10 min., (c) PeP-3 min., (d) particle blasting-10 min. & PeP-3 min., (e) Particle blasting-30 min. and (f) PeP-70 min.
- Table 1: Post processing stages of different samples.
- Table 2: Surface Roughness before and after polishing.

Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

Acknowledgements

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Open Peer Review

Current Peer Review Status: ? ?

Version 1

Reviewer Report 09 September 2024

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Summary:
The article aims to explore and optimize the post-processing of additively manufactured stainless steel parts using a combination of two techniques: plasma electrolytic polishing (PeP) and Sand blasting. The study focuses on optimisation of productivity and efficiency of surface polishing, which is a critical challenge in additive manufacturing, by combining PeP with particle blasting.

The authors conducted a series of experiments to assess the effectiveness of different post-processing methods. They measured surface roughness (Sa) after various treatments. The roughness measurements, surface micrographs and visual inspection were analyzed to determine the impact of each process on surface finish quality.

The study found that particle blasting significantly reduces surface roughness after 10 minutes. Longer blasting, instead, decrease the roughness less effectively. A PeP alone was less effective in short durations but showed substantial improvements with prolonged treatment. The combined approach of particle blasting followed by PeP yielded the most efficient result in terms of speed of polishing to achieve 5.8 um Sa.

The authors conclude that the combination of particle blasting and PeP can effectively optimize the post-processing workflow for additively manufactured metal parts. The study suggests that this combined method offers a balanced approach, improving surface finish while potentially reducing processing time. The findings contribute to the ongoing efforts to enhance the quality and efficiency of additive manufacturing processes.

Comments for the Authors:

1. **Experimental Design:** While the experimental design is generally appropriate, considering the potential time and cost limitations associated with producing additive manufacturing samples, a more scientifically robust experimental design could be implemented. For example, conducting experiments with PeP treatments of 10 and/or 13 minutes could provide valuable insights. Such experiments could help evaluate whether sandblasting is

necessary at all. If these treatments achieve a similar Sa of approximately 5.7 µm, it may be more efficient to use a single process rather than combining two, even if the costs are slightly higher. Additionally, if these hypothetical experiments result in even lower roughness, which is possible given that PeP can reduce roughness by at least one order of magnitude Hans-Peter Schulze et al. (2022[Ref - 1]), further investigation into different combinations (e.g., 10 minutes of particle blasting followed by 6 minutes of PeP) would be worthwhile in future.

2. **Complex Features and Logos:** The article mentions the presence of complex features and logos from institutes; however, the effects of the applied treatments on these features were not discussed. This could be of significant interest. For example, in Figure 2, part 6 (c) appears to show that the hole-like features (cavities) have enlarged after 70 minutes of PeP. A discussion of these observations would strengthen the article.
3. **Visual Comparison:** A side-by-side comparison of part 5 and part 6 could be beneficial to visually assess the effectiveness of the combined polishing approach. Including such a comparison could provide additional support for the benefits of the combined treatment method.
4. **Methodological Details:** The methods described in the article are generally comprehensive and detailed enough to be reproducible. However, providing further clarification on certain points could enhance the robustness of the work:
    - **4.1**: In Table 2, including the removal rate (RR) in µm/min or, if not applicable, in mg/min, along with the mass of material removed (in grams) after each cycle/treatment, would be beneficial.
    - **4.2**: More details on the printing parameters used for sample preparation { for e.g. like in Valentina Candela et al. (2022 [Ref - 2]) } should be included.
    - **4.3**: Clarification on how surface roughness was measured, such as the area analysed (e.g., 200 x 200 µm), the standard used (e.g., ISO), the location on the sample where measurements were taken, and whether measurements were repeated in different areas or performed at a single location is needed.
    - **4.4**: Specifications of the powder from Vulkan Inox, if permissible, could be added for better reproducibility.
    - **4.5**: Information on the volume of the electrolytic solution used during PeP treatment, as well as details on temperature management (e.g., whether it was close to 75°C, increased, and then stabilized), could provide useful context for the experiment's conditions.

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Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and does the work have academic merit?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My area of expertise lies in applied electrochemistry, specifically focusing on plasma electrolytic polishing (PEP) applications for superconducting radiofrequency cavities. I hold a PhD in Science Engineering of Materials and Nanostructures from the University of Padova and have conducted extensive research on the study and development of PEP technology for treating complex geometries of copper, niobium, stainless steel, aluminium, and tantalum. Additionally, I have been involved in various research projects on additive manufacturing and its post-processing, including the application of PEP. Currently, I am a technologist at the National Institute for Nuclear Physics - National Laboratories of Legnaro (INFN - LNL), where I am responsible for the application of PEP within the framework of the PNRR MUR project PE0000023-NQSTI.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 06 September 2024

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The paper “Plasma electrolytic polishing of additively manufactured metal parts: Optimizing the post processing workflow” presents a novel approach to addressing a significant challenge in additive manufacturing: the surface quality of metal parts.

The study's main strength is its novel use of particle blasting and plasma electrolytic polishing (PeP) as a post-processing procedure. The authors present a clear approach and quantitative findings, backed up by visual data, that show the possibility for lowering post-processing time while maintaining desirable surface quality. This has exciting implications for industrial uses of additive manufacturing.

However, the study has numerous limitations that should be considered. The tiny sample size and concentration on a single material (stainless steel) limit the findings' generalizability. Furthermore, the surface characterization is confined to a single parameter (Sa), and the study does not investigate how these post-processing procedures may impact other important attributes like as mechanical strength or corrosion resistance. Other notable omissions include the lack of a comparison study with other existing post-processing procedures, as well as the absence of economic feasibility assessment.

The above demerits must be addressed before it is recommended for getting indexed.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
No

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Additive mnaufacturing, Laser-material processing, Digital Twin

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.