

Reducing the Roughness of Internal Surface of an Additive Manufacturing Produced Steel Component by Chempolishing and Electropolishing

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Abstract: Reducing the surface roughness of an additively manufactured (AM) component is one of the most critical factors in determining the suitability of an AM component. As produced surface roughness of an AM component is very high. This prohibits the direct utilization of AM components for the intended applications. For most of the engineering applications, surface roughness must be reduced significantly. Reducing surface roughness is exponentially more challenging for the internal surfaces of a component. This paper reports research in the area of post processing interior surfaces of an AM component. Electropolishing and chemical polishing (chempolishing) methods were applied to reduce the surface roughness of the internal surface. It was found that chempolishing was very effective in simultaneously reducing the internal and external surface roughness of steel AM components for any complicated AM shape and geometry. The electropolishing methodology employed was very effective in reducing the surface roughness of the internal or external surfaces as long as a counter electrode could be positioned in the proximity of the surface to be polished. However, electropolishing produced better performance on the outer surfaces as compared to chempolishing. This paper summarizes research efforts to tackle the critical issue of reducing the surface roughness of complex AM components.

Keywords: Electropolishing, Chempolishing, Additively manufactured, Internal surface finish

Introduction

Additive manufacturing methods are enabling the design and production of classically unproducible and complex functional engineering components[1]. However, the major problem is that the surface finish of as produced additively manufactured (AM) metal components is significantly rough and generally not suitable for direct applications[2]. Quality of surface finishing is critical in determining the sensitivity of an AM component towards crack generation[3],

corrosion[4], fatigue properties [5] and ease of integration with other components. Due to poor surface finish, an as produced AM metal component may not be functionally acceptable in biomedical devices and implants [3], aerospace components, or a variety of other potential industry applications. However, improving surface finish for a complex AM component can be a daunting task[6]. Conventional surface finishing approaches such as machining, extrude honing, and abrasive blasting, may not be suitable for complex AM components with large internal surface areas[6]. Here, solution-based chempolishing and electropolishing[7] surface finishing approaches are discussed for targeting roughness reduction of internal surfaces of 316 stainless steel AM components.

Experimental Method

AM 316 stainless steel samples were produced by the Kansas City National Security Campus. The steel

molybdenum, trace elements, and balance iron. All AM components were produced by direct laser sintering. After completing AM processing, samples typically undergo abrasive blast to remove any loose powder remaining at the surface. Samples were then subjected to solution-based surface finishing. In the first

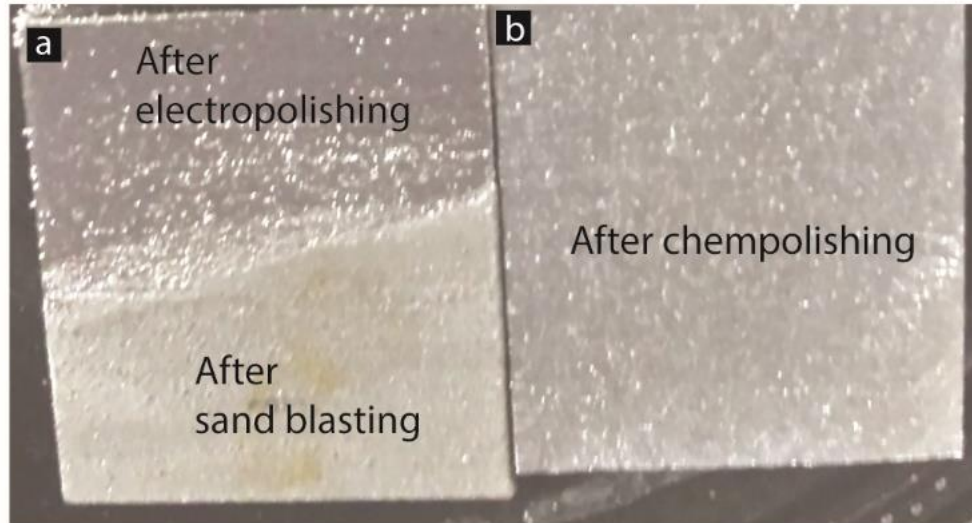


Figure 1: Surface texture of AM component after (a) abrasive blasting and electropolishing and (b) chempolishing.

AM samples were prepared on an EOS® laser sintering based additive manufacturing machine using raw material powder with particle sizes $> 50 \mu\text{m}$. The typical composition of the finished AM components and the powder was 17-19% chromium, 13-15% nickel, 2-3%

chempolishing approach, AM samples were processed at a controlled time and temperature in beakers containing a DS-9-314 solution manufactured by Heatbath Corporation®. This DS-9-314 solution consists of 10-30% phosphoric acid, 1-10% hydrochloric acid, 1-10%

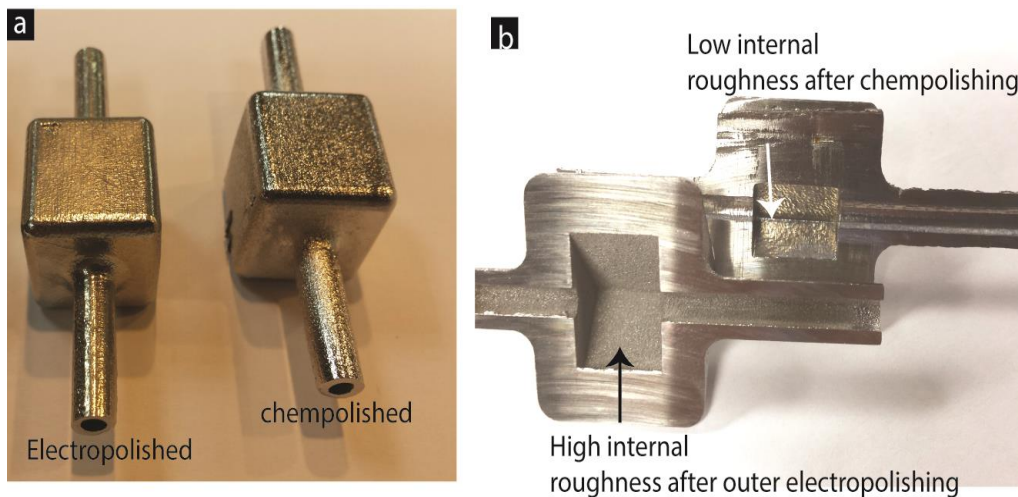


Figure 2: (a) Outer surface texture (b) internal surfaces of AM components with internal volume after electropolishing and chempolishing

nitric acid, and 1-10% proprietary surfactants. Electropolishing was also tested for effectiveness reducing the roughness of internal surfaces of AM components. For this study, four key factors were examined: electropolishing time, temperature, agitation, and electrolyte composition [8-10]. Electropolishing was conducted in a glass beaker with an acidic electrolyte solution composed of a mixture of phosphoric and sulfuric acid. The solution was kept under constant agitation and held at an elevated temperature while a 60 A/dm² current was maintained for 30 minutes. For the electropolishing process, pure lead was used as the counter electrode. To better understand the impact of electropolishing on the surface properties and microstructure, optical profilometry was conducted with a Filmetrics optical profilometer.

Results and Discussion

It was observed that both electropolishing and chempolishing were significantly effective in reducing the surface roughness of blasted AM steel components. After abrasive blasting, the component remained substantially rough and exhibited a grey appearance (Fig. 1a). After electropolishing (Fig.1a) and chempolishing, the surface appeared notably more polished and became much smoother in texture (Fig.1b). Typically, electropolishing produced a smoother surface as compared to the chempolished sample. As such, it was observed that electropolishing was better in reducing surface roughness as long as a counter electrode could be placed in the proximity of a target surface. The example shown in figure 1 is a rectangular AM sample without any internal or hidden surfaces. Both solution-based surface finishing processes were also applied to hollow cubical samples with a cylindrical channel on each end. These collinear channels allowed the electropolishing and chempolishing solutions access to the internal volume of AM components. As with the rectangular sample, both electropolishing and chempolishing yielded significant surface reduction on the outer surfaces (Fig. 2a). Both surfaces became polished in appearance and no longer exhibited the dull color and texture observed on the blasted surface (Fig. 1a). Samples were cross sectioned for the investigation of internal surfaces. The electropolished sample showed exceedingly rough texture on the internal surface (Fig. 2b). Conversely, the chempolished samples showed a smooth and lustrous internal surface, exhibiting a high degree of consistency between internal and external surfaces. It is noteworthy that the internal surface roughness of the electropolished surface was even higher than that of the blasted surface. This is in part because the ~ 2 mm diameter cylindrical channels shown in figure 2a did not allow the predominantly line of sight abrasive blasting process to access internal surfaces effectively. Since electrodes could not practically be positioned in a way to promote sufficient electropolishing on interior cavities, the internal surface in the samples finished close to an as produced

AM surface. An optical profilometry study was performed to provide quantitative data. Optical micrographs were obtained from the as-blasted AM surface (Fig.3a), electropolished surface (Fig.3b), and chempolished surface (Fig. 3c). For the quantitative analysis, measurements were taken to determine the maximum peak height (S_p), maximum valley depth (S_v),

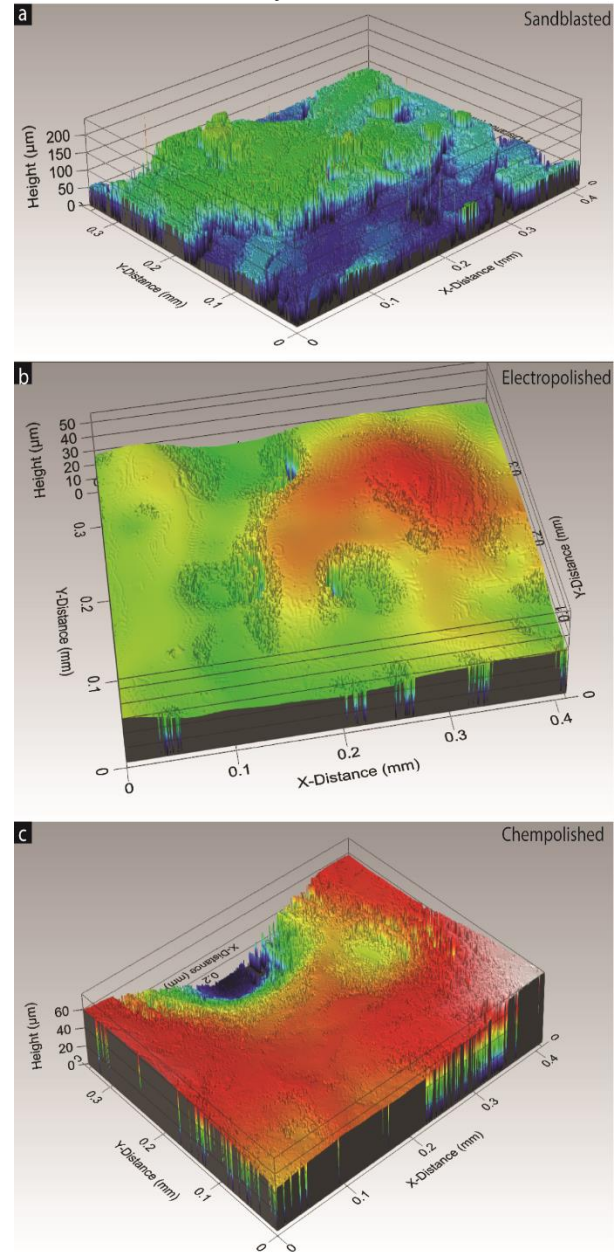


Figure 3: Optical profilometer graph of AM components' surface after (a) abrasive blasting, (b) electropolishing, and (c) chempolishing

maximum height difference between peak and valley (S_z), arithmetic mean height (S_a), and root mean square (RMS) of height (S_q). The surface skewness factor (S_{sk}) and surface kurtosis (S_{ku}) were also determined. These

roughness parameters were recorded on an area of $0.2 \times 0.17 \text{ mm}^2$ at eight different locations with the profilometer micrograph. The magnitude (S_p) was $166.35 \pm 18.65 \text{ }\mu\text{m}$ for the as-blasted AM surface which was reduced to $16.38 \pm 6.65 \text{ }\mu\text{m}$ and $13.48 \pm 5.3 \text{ }\mu\text{m}$ for the electropolished and chempolished samples respectively. Similarly, the depth of valley (S_v) started at $60.12 \pm 20.10 \text{ }\mu\text{m}$ for the as-blasted AM surface and was reduced to $28.12 \pm 8.31 \text{ }\mu\text{m}$ and $35.05 \pm 18.25 \text{ }\mu\text{m}$ for the electropolished and chempolished samples respectively. The difference between the height of the tallest peak and deepest valley (S_z) was $226.44 \pm 17.67 \text{ }\mu\text{m}$ for the blasted AM surface

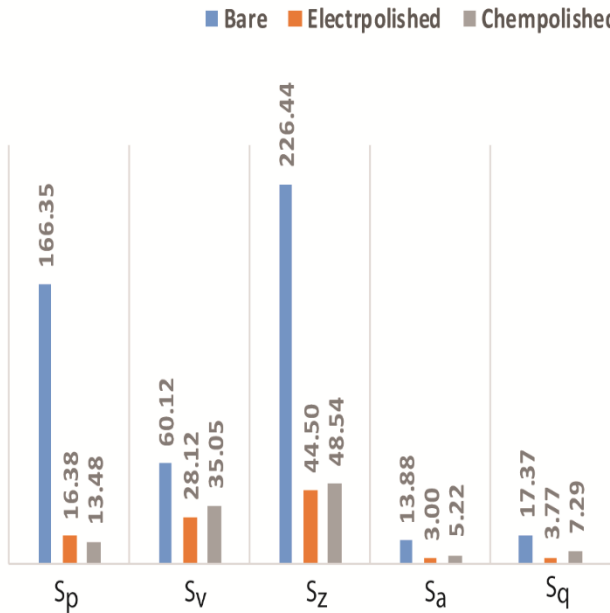


Figure 4: Various surface roughness parameters on blasted, electropolished, and chempolished AM components. All data on graph in μm .

which was reduced to a comparable $44.50 \pm 13.45 \text{ }\mu\text{m}$ and $48.54 \pm 21.41 \text{ }\mu\text{m}$ for the electropolished and chempolished surfaces respectively. The surface roughness parameter (S_a) for the as as-blasted surface was $13.88 \pm 2.65 \text{ }\mu\text{m}$ which was reduced to $3.0 \pm 0.75 \text{ }\mu\text{m}$ and $5.22 \pm 2.46 \text{ }\mu\text{m}$ for the electropolished and chempolished AM surfaces respectively. The RMS roughness (S_q) for the as-blasted surface S_q was $17.37 \pm 3.02 \text{ }\mu\text{m}$ which decreased to $3.77 \pm 0.85 \text{ }\mu\text{m}$ for the electropolished surface and $7.29 \pm 3.58 \text{ }\mu\text{m}$ for chempolished surface. The S_a roughness parameter of the internal surface for the electropolished AM sample (Fig.2b) was measured at a comparatively higher $20 \pm 10 \text{ }\mu\text{m}$ unlike that of the chempolished sample (Fig. 2b) which was similar to its outside surface at $5.22 \pm 2.46 \text{ }\mu\text{m}$ (Fig. 4). The surface skewness factor (S_{sk}) magnitude was 0.10 ± 0.98 for the as-blasted surface which indicates that the number of hills and valleys are almost in the same proportion to one another. However, this parameter became negative for both electropolished and chempolished samples

indicating the dominance of cavities. S_{sk} was -0.29 ± 0.85 for the electropolished sample and -1.16 ± 1.04 for the chempolished sample. The surface kurtosis (S_{ku}) describes the peakedness of the surface topography. If $S_{ku}=3$, then the distribution is ideal Gaussian-like. S_{ku} was calculated for the whole area and determined to be 2.2, 3.4, and 9.6 for the blasted, electropolished, and chempolished samples respectively. This data indicates that a chempolished sample was significantly biased towards having a higher proportional number of valleys.

Conclusion

This study yielded insight into the solution-based surface finishing of AM steel components. Electropolishing provided the smoother surface in comparison to the chempolished treatment; however, electropolishing is limited by the ability to send a counter electrode in tight spaces or intricate geometric features. In such cases, chempolishing is more useful and can significantly improve the surface roughness. Further study is necessary to determine the effect different surface finishing methods have on the mechanical properties of the AM components. Future research will also utilize electron microscopy to provide high-resolution imaging of the different surface finishing processes.

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