Post-Processing Superfinishing of Additively Manufactured Components with Complex Geometries and Internal Features

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ABSTRACT

As-printed AM components carry many inherent challenges and issues that can hinder performance or even lead to critical component failure, hindering access to the benefits described above. These defects include partially sintered/unsintered powders, surface waviness/roughness, and surface and near-surface porosity as artifacts of the printing process. REM Surface Engineering, founded in 1965, has been a leading provider of isotropic superfinishing services in traditional industries for decades. We have recently adapted our existing technologies and developed new technologies to create a superfinishing process capable of remediating all surface and near surface defects on AM components. In a process which combines unique proprietary chemical polishing and chemical/mechanical polishing, we are able to remediate all surface defects, as well as near surface defects, as well as polish internal channels/non-line-of-sight surfaces (something which traditional processes such as machining cannot accomplish).

Keywords: additive manufacturing, chemical polishing, superalloys, surface finishing, surface roughness

1 INTRODUCTION

The 21st century has seen Additive Manufacturing (AM) rise from an interesting novelty with untold potential to a groundbreaking technology at the heart of the 4th industrial revolution, transforming manufacturing across industries. In 2011, Elsevier published 4,523 articles relating to AM. In 2021 they published 23,157[1]. On the business side, the global market revenue from 2014 to 2020 grew from \$4.1 billion to \$12.6 billion USD[2]. AM continues to show numerous benefits: rapid development of prototype designs; the ability to print complex architectures not possible with traditional manufacturing; and the implementation of novel alloys and superalloys with high performance characteristics[3–5]. As AM continues to grow, the potential benefits in industries such as aerospace and space, medical, and energy, just to name a few, will no doubt flourish with improvement in print methods and parameters. However, metal AM is not without its drawbacks, particularly regarding full implementation in highly qualified industries like aerospace and space.

There are four primary drawbacks to metal AM parts: 1) high porosity; 2) poor surface finish; 3) partially sintered/unsintered powders; and 4) tensile residual stresses[6,7]. These issues arise across nearly all metal AM print techniques, hindering performance and deterring applicability of as-printed components. Furthermore, with increasing architecture complexity such as internal channels and lattice structures, the complexity of post-processing to a finished component increases as well due to lack of access and no line of sight. This work will present a brief snapshot of the research REM Surface Engineering in actively performing to overcome these obstacles.

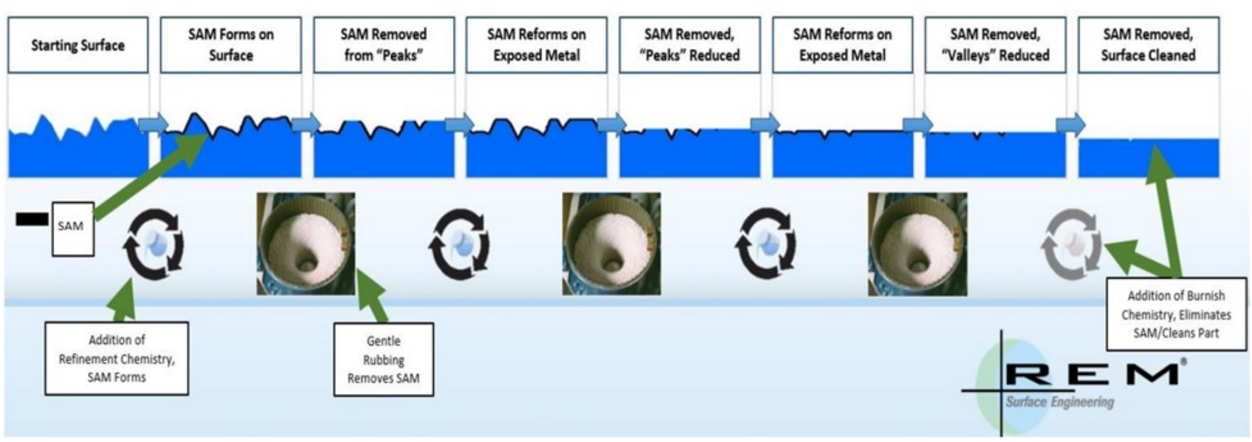


Figure 1. Visualization of propriety REM ISF® Chemical and Mechanical Polishing process, a subtractive superfinishing process capable of removing microscopic amounts of surface material via the repeating cycle of creating/removing a self-assembled monolayer (SAM).

REM Surface Engineering, founded in 1965, has been a leading provider of isotropic superfinishing (ISF®) services for traditionally manufactured parts in numerous industries for decades. Our patented and proprietary chemical and mechanical/vibratory finishing technologies allow for precision-controlled surface finishing of metal components via a subtractive process shown in Figure 1. Our expertise told us that existing methods of post-process surface finishing would not suffice for Metal AM components; thus REM has spent the last several years developing new post-process surface finishing techniques specifically aimed at metal AM components.

2 THE RESEARCH

Four years ago REM set out to find a solution. Building on existing self-funded research, we partnered with NASA on our first SBIR in 2018, focused on the internal and external surface finishing of IN-625 AM components[8]. Our results were definitive and clear: chemical polishing (CP), once formulations had been optimized, showed high success to planarize and address all surface defects, ability to access non-line-of-sight surfaces and internal channels, with a high (but controllable) material removal rate. Chemical mechanical polishing (CMP, see Figure 1) showed the best results for addressing surface and near surface defects, with a controllable material removal rate. As such, a combination of CP + CMP was identified as the optimal finishing technique (OFT), capable of addressing all surface/near-surface defects with minimal overhead in a highly-controllable and repeatable process. Since this initial SBIR project, REM has continued to partner with NASA and then the US Air Force on additional SBIR projects to determine OFTs for Ni-based superalloys[9–11], Al-based alloys[12,13], and Cu-based alloys[14].

CP using proprietary formulations allows for the fast removal of large amounts of surface material (thus removing near-surface defects), removal of residual powder, and smoothing of the metal surface[15]. CP is particularly attractive for internal channels, lattices, and controlling wall thickness. To date, REM has developed effective CP formulations for numerous alloys including, but not limited to, Ti6Al4V, A6061-RAM2, AlSi10Mg, IN-625, IN-718, and GRCop-42. Furthermore, REM is actively investigating CP formulations for new alloys including C103, Haynes 230, Vibenite 480, and Cascadium.

We have applied CP for wall thickness reduction numerous times with success. For example, using processing aides to control the orientation of the components during immersion in a proprietary chemical mixture, we were able to effectively reduce wall thickness from 1.12mm to 0.14mm (Figure 2) on A6061-RAM2 components without damaging the structural integrity and simultaneously improving the surface roughness. This same process was applied to IN-718 components where after 0.0036” of surface material removal (SMR) prominent surface peaks were removed, as shown in Figure 3, and the average surface roughness (Ra) decreased from over 300 µin to under 100 µin.

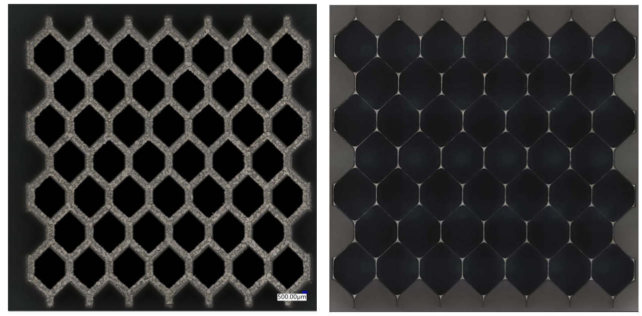
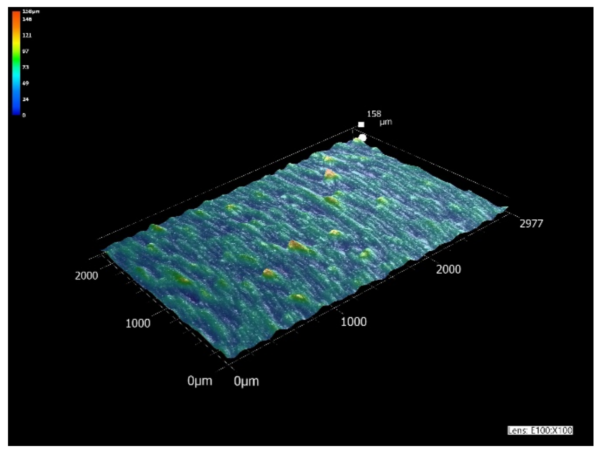


Figure 2. Optical images of A6061-RAM-2 honeycomb-like structure before (left) and after (right) chemical polishing



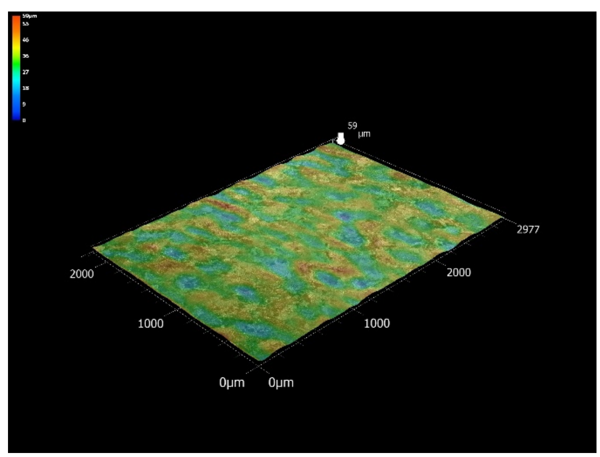


Figure 3. 3D micrograph of LPBF IN-718 as-printed (top) and chemical polished (bottom).

Our work in applying CP to internal channels has also yielded tremendous results. We began with investigating internal channels of GRCop-42 components that had an oxide layer present and a highly granular surface texture (see Figure 4). An optimized formulation was determined

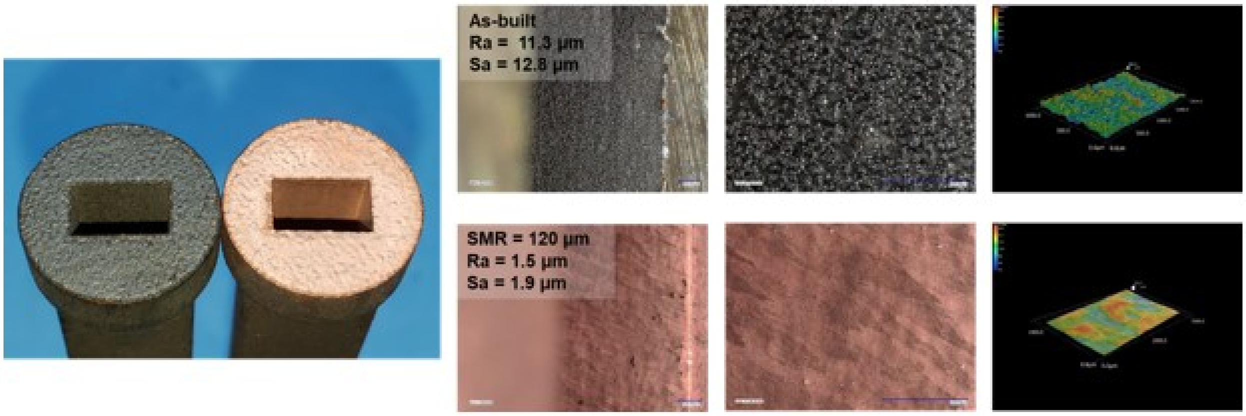


Figure 4: Flow chemical polish testing on coupon with rectangular cross section. Before and after chemical polish comparison.

through the rigorous study of the chemical interactions between species through a statistically based Design of Experiments (DOE) approach using JMP® statistical software. The optimized formula was applied to a test coupon with a rectangular channel. As shown in Figure 4, after 120 µm SMR, not only was the surface roughness drastically improved (starting Ra = 11.3 µm, final Ra = 1.5 µm), but the oxide layer was also no longer present.

In addition to our GRCop-42 work, we have also performed flow-through CP on aluminum-based alloys. In Figure 5, it is shown that CP of A6061-RAM2 tubes with a complex internal channel system led to substantial

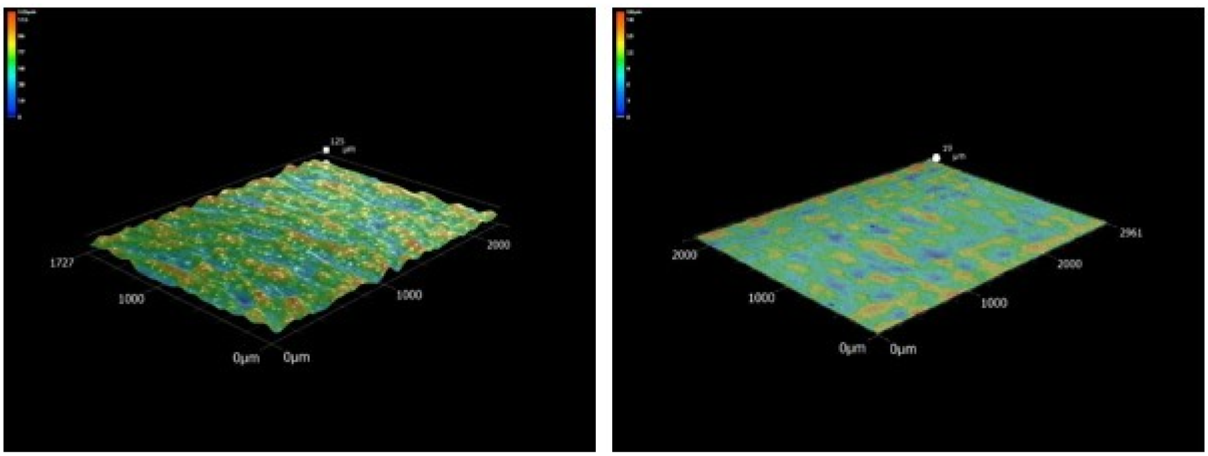


Figure 5. 3D micrograph of internal channel of A6061-RAM-2 part as-printed (left) and after flow-through chemical polishing (right) with SMR = 190 µm.

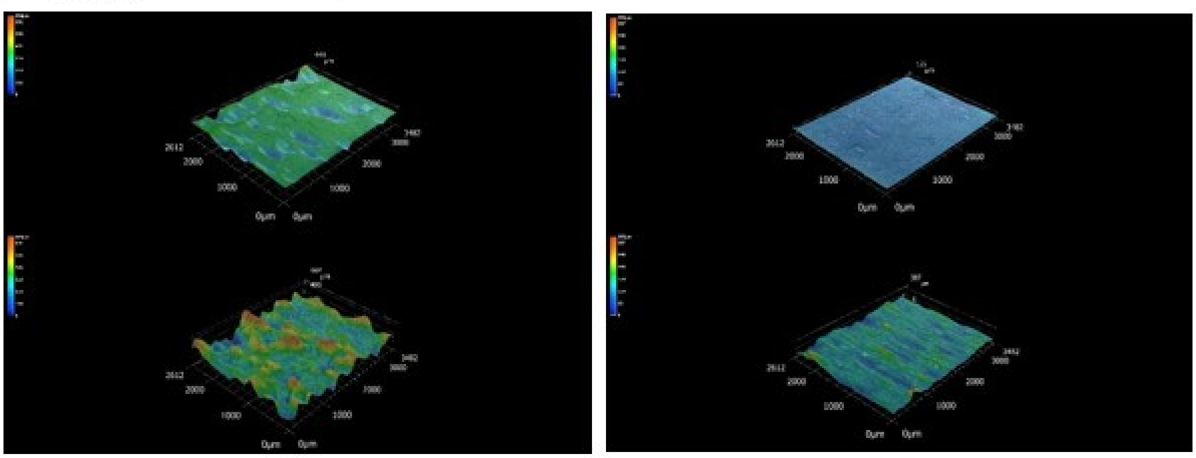


Figure 6. 3D micrographs of as-printed (bottom) and after CP and CMP (top) for downskin (left) and upskin (right) regions of AlSi10Mg internal channels.

smoothening of the highly granular surface (initial Ra = 300-400 μin, final Ra = < 80 μin). A combination of CP and CMP was employed in the processing of AlSi10Mg components, as shown in Figure 6. While these components had significant porosity issues that could not be mitigated through our OFT, the addition of CMP along with CP showed improved planarization over CP alone. This further reinforces the principle of CP being beneficial for the removal of large amount of surface material, while CMP produces improved planarization. Unfortunately many internal channel designs are not compatible with CMP and therefore REM is continually improving the planarization capabilities of our CP formulations.

3 CONCLUSION

CP and CMP post-processing of metal AM components using OFTs developed by REM have shown to be highly valuable as the AM industry continues to grow. As we continue to develop and adapt solutions to meet the needs of our customers and research partners, our catalog of supporting data continues to reveal more and more exciting potential applications for Metal AM in conjunction with our post-process superfinishing technology. The next stages of research continue to grow (literally) to include not only full-scale rocket propulsion component processing capabilities, but also optimizing our technology for installation at customer locations to facilitate fully realized in-situ AM printing capabilities anywhere on Earth, and someday the Moon and Mars

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