Chemical Post-Processing Advantages on Additive Manufactured Parts

The use of high-temperature alloys for additive parts has dramatically increased over the past few years. Nonetheless, while significant improvements have been made to post-processing methodologies in medical and aerospace applications, chemical milling, an existing and well-defined commodity, remains underutilized in the metal additive supply chain.

Additive manufacturing (AM) has a number of strengths and limitations. As a layer-by-layer manufacturing technique, it offers wide-ranging freedom of design and the capability to fuse dissimilar materials in an effective manner. However, AM parts have difficulty passing tensile testing and fluorescent penetrant inspection (FPI) due to high surface texture.

While there are multiple post-production processes available to help remediate these issues such as abrasive flow and electro-polishing, chemical milling offers a number of advantages that should be carefully considered by organizations that utilize additive manufacturing technologies.

Common post-processing metallurgy barriers that are highly amenable to chemical milling solutions include:

- High or thick areas of oxidation or heat-treatment scale, many of which are resistant to common or generic etch solutions
- High surface roughness, which can lead to stress fracture initiation, decreased tensile strength and/or reduced fatigue performance
- Support structure and structure remnants that must be removed
- Partially sintered powder particles on internal channels can increase flow resistance and create undesired turbulence
- Inability to pass fluorescent penetrant inspection (FPI) due to significant variability in surface topology

Chemical milling offers effective and economical solutions to all these barriers.

How Chemical Milling Works

Chemical milling is the controlled dissolution of metal into a chemical bath or solution. It is traditionally performed for weight reduction, surface smoothing, surface passivation or the removal of scale or other undesired surface material characteristics.

The key to this manufacturing technique is "controlled." The common byproducts of chemical milling reactions are heat and gas along with metal salts. It is important to consider these byproducts and associated variables when designing an appropriate milling solution and methodology. Solutions, commonly referred to as baths, have a number of variables that can be controlled, including concentration percentages, solution density, temperature, agitation, and flow. Improperly designed processes and/or poorly controlled variables in the use of this manufacturing technology can result in selective or non-uniform etching, oxide formation, hypermilling, surface flaws, formation of unacceptable metallurgical defects, and other issues that can compromise material properties or part suitability.

Chemical milling is a proven, reliable solution to overcoming these barriers and has been used on conventionally machined parts for many years. Most of the prime aerospace contractors have existing specifications for this commodity, which facilitates acceptance in utilization as a "known commodity."

Benefits of Chemical Milling

Historically, a primary advantage of chemical milling in aerospace is that it permits selective removal processing of fully formed parts that in many cases are too complex for multi-axis machines. Using chemical milling, if the part can be fully submerged in the bath, it can be processed regardless of heat-treat condition, weight, or geometry. Anywhere that liquid can travel, metal can be removed.

This advantage permits removal capability within internal passages that are beyond line-of-sight and therefore potentially inaccessible to traditional machining methods. The speed at which metal is removed, that is the dissolution rate or "etch rate", can be controlled by adjusting one or more of the variables. In some cases, the surface finish can also be adjusted depending upon the alloy.

In an attempt to address some of the unwanted surface conditions or characteristics above, efforts are occasionally made at chemical removal of the entire part surface by means of traditional pre-penetrant etch chemistries. These solutions, however, are designed for very low surface removals (typically 0.0001" to 0.0003"). To achieve the desired improvements of printed surfaces in the ranges of .001" to .010" typically requires excessively long etch times which may introduce detrimental material effects such as; hydrogen pickup and intergranular attack and fracturing.

In contrast, chemical milling solutions are typically designed to remove 0.001” – 0.003” in minutes and specifically formulated to reduce impact on grain boundaries.

Chemical milling is increasingly utilized as a stand-alone or complementary process for high-temperature applications used with AM metal parts and is commonly used today on a wide variety of manufactured alloys, including most alloys of:

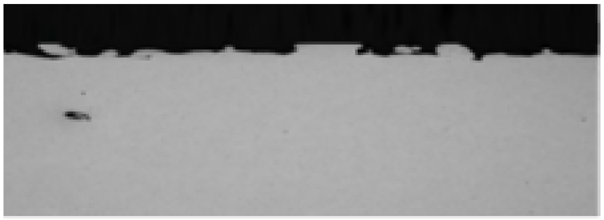
- Titanium
- Aluminum
- Steel
- High-temperature corrosion-resistant Superalloys (Inconel 625, Inconel 718, Haynes 188, and cobalt chrome).

Chemical milling offers a solution for all types of AM metal parts, across multiple platforms using powder bed fusion systems (PBF) or directed energy deposition (DED).

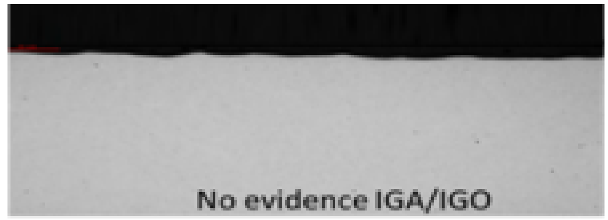
AM parts can present with high and varying surface roughness in the as-printed condition. This is true for both wire-fed DED processes where the large melt pool creates weld-bead-shaped deposits and PBF processes where the surface texture is dependent upon powder particle size, laser melting parameters, layer thickness, and the orientation of the part relative to the build plate. Cracks or voids from porosity, layer overlap, or partially fused metal powders can create significant difficulties for inspection and identification of potential defects.[1]

One of the greatest advantages to chemical milling over mechanical surface finishing processes is that it permits uniform metal removal across the entire part surface, both internally and externally, at the same time. The milling solutions generally tend to have fairly low viscosities and they can access and flow through and around complicated geometries as well as small ports and openings. Chemical milling processes offer controlled, predictable, and repeatable removal rates.

Chemical Milling Effect on the Base Plane



As-Built



5 Mil Removal

Partially sintered material, weld-bead deposits, and high peaks are preferentially dissolved over the base surface plane of the features. This is facilitated by the action of the liquid solution on all surface areas. These partially sintered or raised areas have more surface area than the homogenized base plane and will be dissolved at an increased rate directly proportional to the amount of exposed surface area.

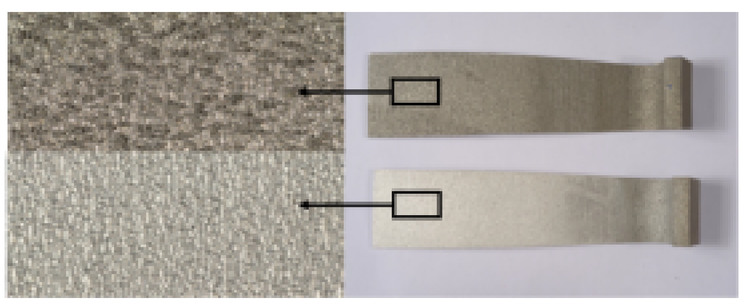
This process is indicative of the chemical milling action on additive parts. The solution flows into the voids in the surface, around partially sintered particles or across the peaks of deposited material, smoothing and removing high points and softening crack sites to a dip or depression, and removing the stress points.

This action is analogous to a sandcastle on the beach, as the surf comes in around it, the sides begin to dissolve into the ocean; as the water rises and overtops the castle, the action of the surf will continue to dissolve the castle while having only a limited effect on the base plane or shore.

Surface Roughness Reduction

As Printed Aluminum

0.012" removal



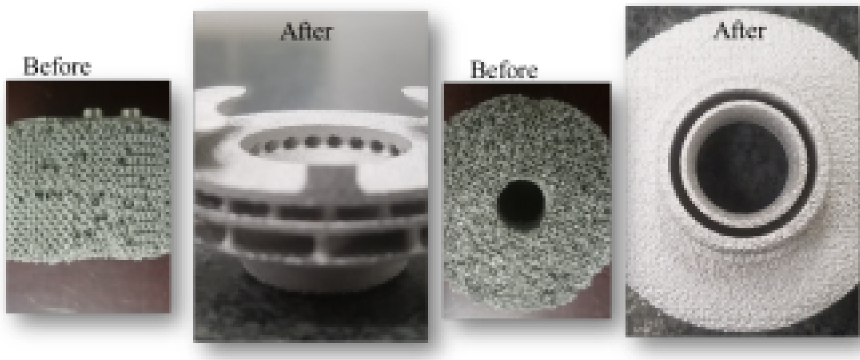
12 mil removal AVE RA before/after Lengthwise 767/342 Lateral 788/277

On average, chemical milling has demonstrated consistent reductions in surface roughness of sixty to seventy percent from as-printed surfaces across all materials and heat-treat conditions.

Removal of Support Structures and Resultant Contact Points

Typically, support structures are removed by mechanical methods, abrasive wheels, physical hand tools, or other cutting tools.

By planning for chemical milling in the design phase and compensating the build accordingly, this process has demonstrated effective removal of support structure while simultaneously providing the benefit of reducing surface roughness and elimination of heat scales. Additionally, the chemical removal of support structures is not limited to line-of-sight access and can therefore be effectively used in areas that would be inaccessible to mechanical means of removal.



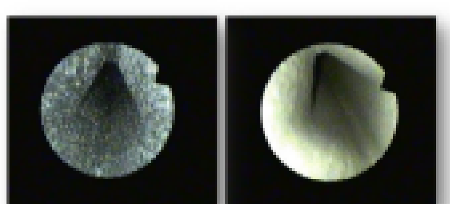
This first example shows a printed Inconel 718 mesh structure with lattice support both internal and external. The part pictured measures roughly 1 ½ inch in diameter by 1 inch in height. This was a proof of concept used to determine post-processing effectiveness and removal depth.

The post pictures show removal of the support structures and an approximate surface removal of 0.005”. As you can see, the internals are clean and uniform.

Internal Passages

The advantage of chemical removal over mechanical or abrasive flow is that chemical milling solutions have very low viscosities, and removals can be either statically or kinetically accomplished while smoothing internal features and eliminating entrained powder and/or partially sintered particles.

Chemical milling solutions have been used in significantly complex and minute passages, not amenable to abrasive flows, with consistently good results.



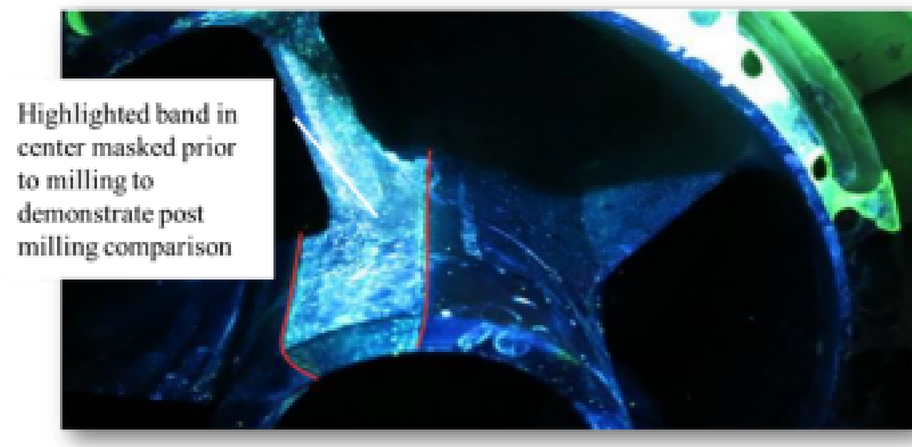
Internal 0.250" passage cleaning

It should be noted, however, that for long and thin passageways, with a length to diameter ratio of in excess of approximately 25:1, mechanical flow of solution through the passages are required to maintain a consistent concentration of reactants and permit the removal of reactant byproducts.

Chem Milling to Improve FPI

High surface roughness makes the flow and removal of penetrant dyes problematic and interpretation unsuccessful. By chemically removing the high points and sharp edges, and smoothing the texture to ensure optimal surface integrity, penetrants can function as intended, yielding successful results.

This part here yielded indications at 0.030” following chemical milling.



Chemically processed milling was inspectable to .030 indications

Rough internal geometries can also make inspection difficult in X-ray and CT scanning. By flowing milling solution through these areas, the internal roughness is reduced and stray partially sintered powder is removed, facilitating the effectiveness of these inspection methods.

While chemical milling has demonstrated significant cost and time savings on additive metal components, some barriers remain:

- Design engineers need to identify the amount of removal expected and compensate during build.
- Blind holes and fully blocked passages are effectively self-limiting.
- The quality of the build has been demonstrated to limit the effectiveness of the process.

In conclusion, chemical milling offers significant advantages over typical AM post-processing techniques. By simultaneously reducing crystalline morphologies, partially sintered powders, and surface roughness, chemical milling can generate significant cost and time savings in the metal additive supply chain.

About Tech Met

Providing the Aerospace, Medical, Military and Commercial markets with precision chemical milling on fabricated components since 1988, Tech Met specializes in complex and precise chemical milling for build to print and custom projects on a wide variety of materials. From aircraft engine components to spinal implants, Tech Met's process control, lean practices and certified six sigma project managers deliver quality assured products that meet the most rigorous specifications, routinely incorporating Lean, Six Sigma methodologies and process control compliance with Nadcap AS7004 & AS7108 standards.

Tech Met is a leading provider of advanced chemical post-processing and surface treatments for the world's most advanced additive manufacturing applications. Specializing in high performance metal alloys and serving the aerospace, medical, industrial, and commercial markets with unprecedented precision and quality.

Tech Met is a 100% Employee Owned Company located in Pennsylvania.

References

1 Mulaner, Jody. "Surface Finish in Metal Additive Manufacturing" *Engineering.com,* December 11, 2020

https://www.engineering.com/story/surface-finish-in-metal-additive-manufacturing. Accessed May 2021