WHITE PAPER

Beyond the Printer: Enhancing Additively Manufactured Parts with Post-Processing

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Executive Summary

Additive manufacturing (AM), also known as 3D printing, enables the creation of complex, customised components through a layer-by-layer process. However, depending on the specific AM technology and material used, the process can present challenges such as surface roughness, dimensional variation, and inconsistent mechanical properties. These issues, while not universal, are common enough that post-processing is often necessary to ensure that parts meet functional and aesthetic requirements. Post-processing techniques, including mechanical abrasion, chemical treatment, thermal processing, and surface coatings, play a crucial role in improving the quality, performance, and reliability of AM-produced parts.

This white paper examines the technical challenges inherent in AM, details a variety of post-processing solutions, and highlights their business and operational impact for manufacturers seeking optimal results.

Background – The Promise and Challenge of AM

Additive manufacturing (AM) is an advanced fabrication technology that builds components directly from CAD models by building up material layer by layer through selective deposition, fusion, or solidification, depending on the technology. This process is governed by digital toolpaths generated from sliced CAD models and executed by coordinated motion control systems. This approach enables unprecedented geometric complexity and customisation, allowing engineers to move quickly from concept to production. AM also eliminates the need for traditional tooling such as moulds, jigs, or fixtures, and supports rapid prototyping and iterative testing.

Despite its advantages which include improved material utilisation, faster lead times, lightweighting (especially for aerospace), and greater design freedom, AM adoption in industry remains constrained by technical hurdles. Chief among these is the suboptimal surface quality and dimensional inaccuracy that can result from the layer-wise process, particularly when printing with metals and high-performance polymers. These issues impact both the functional performance and the structural integrity of final parts, and are compounded by other concerns such as porosity and anisotropy (properties varying by direction).

Key Challenges With Additively Manufactured Parts

According to ISO/ASTM 52900:2021, additive manufacturing technologies are formally classified into seven categories: Vat Photopolymerization, Binder Jetting, Material Jetting, Material Extrusion, Powder Bed Fusion, Sheet Lamination, and Direct Energy Deposition. Each technology exhibits distinct technical characteristics, advantages, and challenges.

- **Surface Quality:** The layer-by-layer approach results in a “stair-stepping” effect, especially on angled or curved surfaces. Surface roughness can be influenced by process-specific parameters such as layer thickness, build orientation, energy source characteristics (e.g., laser power), and feature resolution (e.g., nozzle diameter in extrusion). For example, material extrusion and powder bed fusion tend to produce rougher surfaces than vat photopolymerization or material jetting.

- **Mechanical Performance:** Porosity is a recurring issue in AM parts. It can be either an unintended flaw (apparent porosity) or an engineered feature for specific applications. Unintentional pores weaken parts, especially under fatigue or cyclic loading, and can arise from trapped gases, incomplete melting, or process inconsistencies. Anisotropy, which is directional dependence of mechanical or thermal properties, often results from rapid heating and cooling cycles during printing, which form microstructures that vary with build orientation.
- **Dimensional Accuracy:** Achieving precise, repeatable dimensions is challenging, especially for parts with internal features or complex geometries. Localised thermal gradients, residual stresses, and material shrinkage or expansion during thermal treatment can all contribute to warping, distortion, and dimensional discrepancies between the digital design and finished product.

Why This Matters

Manufacturers seeking to use AM for critical applications (e.g., aerospace, medical, automotive) must ensure that parts meet demanding specifications for surface finish, accuracy, and performance. Poorly controlled AM processes can result in costly rework, increased scrap, or product failures.

The Role of Post-Processing: Turning Prints into Precision Parts

Post-processing refers to the suite of secondary operations applied to AM parts after printing, aiming to overcome inherent process limitations and deliver high-quality, end-use-ready components. These methods can be mechanical, chemical, thermal, or surface-based, and are selected based on part material, geometry, and performance requirements.

Mechanical Abrasion

Mechanical abrasion is one of the most widely used post-processing approaches, with techniques ranging from simple sandpaper polishing to automated tumbling and abrasive flow machining. Sandblasting is a fast, cost-effective method for surface smoothing, though it may cause layer peel-off or embed abrasive residues. More advanced methods, like magnetorheological finishing or abrasive flow polishing, are used for intricate geometries or critical tolerances.

Chemical Processing

Chemical treatments such as chemical polishing or etching, use liquids or vapors of a chemical solution (e.g., acetone for polymers) to dissolve surface asperities and reduce surface roughness. While chemical treatments use specific chemical solutions to react with and remove surface asperities, electrochemical processing employs electrical energy to accelerate chemical reactions, enabling finishing of complex internal features. The effectiveness of chemical techniques depends on solution type, exposure time, and cycle count. Caution is required to avoid over-thinning or loss of dimensional precision.

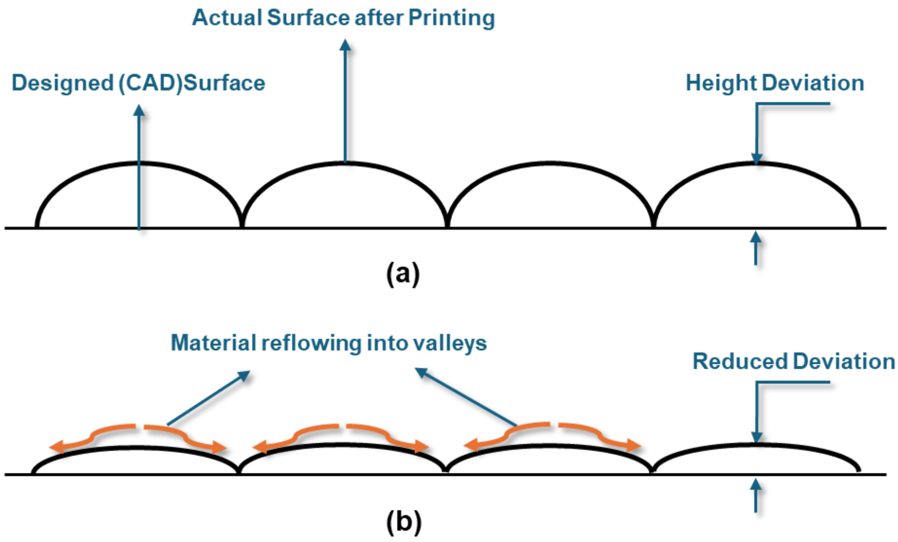

Figure 1: Chemical Treatment Mechanism (a) prior to surface material reflow (b) after surface material reflow

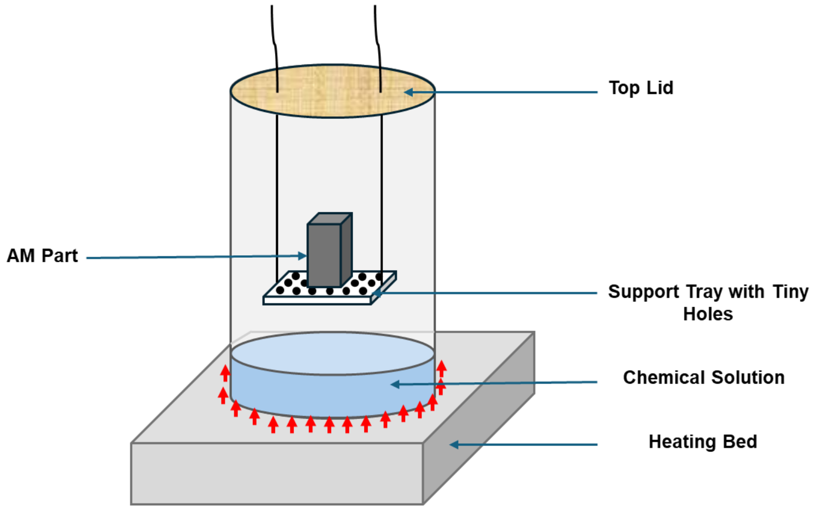

Figure 2: Vapour Smoothening

Thermal Processing

Thermal post-processing, including annealing, hot isostatic pressing (HIP), and aging, improves microstructure and mechanical performance by relieving stresses, reducing porosity, and enhancing ductility, strength, and toughness. Processes like HIP subject parts to elevated temperature and pressure in a controlled environment, closing internal pores and increasing density. Laser-based methods such as laser re-melting or shock peening can locally modify surface and sub-surface properties, further boosting fatigue resistance and surface quality.

Surface Coatings

Applying coatings by spraying, dipping, electroplating, or sputtering adds functional and protective layers, enhancing wear resistance, corrosion protection, and surface finish. In some cases, coatings are used to prepare AM parts for downstream processes, such as investment casting or to impart biocompatibility for medical applications. It is important to note that coatings may add to part dimensions and must be factored into tolerance management.

Key Takeaways:

- No single post-processing method addresses all challenges; optimal results often require a combination of treatments.
- The selection of post-processing techniques should be tailored to the part's intended application, material, and critical properties.

Impact on Business and Operations

Effective post-processing unlocks the full potential of additive manufacturing by ensuring that parts meet or exceed required standards for appearance, functionality, and durability. Businesses benefit through:

- Enhanced product quality and reliability, supporting adoption in high-value sectors.
- Reduced post-production rework and scrap, lowering costs and improving throughput.
- Accelerated time-to-market, as finished parts require less manual finishing and validation.

Example: Aerospace companies use a combination of HIP, machining, and specialised coatings to produce AM turbine blades with high surface integrity and mechanical strength, meeting safety-critical requirements and extending service life.

Future Trends: Automation, Intelligence, and Sustainability

The next generation of post-processing leverages automation, robotics, and artificial intelligence to deliver consistent, high-throughput finishing with minimal human intervention. Automated support removal, robotic blasting, and real-time quality inspection are increasingly common, reducing labour costs and human error.

Sustainability is also a growing focus. Industry leaders are exploring eco-friendly post-processing solutions, such as solvent recycling, reduced energy consumption, and the use of recyclable support materials. Advanced design techniques are minimising waste by reducing the need for supports or enabling easier removal and recycling.

Conclusion – Refine, Strengthen, and Improve

Post-processing is the bridge between the promise of additive manufacturing and its realisation in demanding, real-world applications. Through the careful selection and integration of post-processing techniques, manufacturers can overcome inherent AM limitations, improve part quality, and drive business value.

The shift toward fully automated workflows will redefine production efficiency, reduce costs, and enhance part quality. As automation and sustainability reshape the AM landscape, organisations that invest in advanced post-processing will be better positioned to secure a competitive edge in quality, cost, and innovation.

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