

Selective Chemical Dissolution Strategies for Powder Clogged Residue Clearance in Complex Metal Additively Manufactured Internal Channels

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Abstract: The challenge of residual or caked powder within internal channels compromises the functionality and applicability of additively manufactured metal components. We present a comprehensive solution that combines selective chemical dissolution for powder removal and declogging. This chemical-flow approach employs a self-limiting reaction to selectively dissolve unfused powder without affecting the solid, fused material, thereby preventing material loss in the thin walls and passages, in contrast to chemical milling. We demonstrate the methods efficacy on parts made from various alloys, including AlSi10Mg, Al F357, Al CP1, and IN-718, achieving complete powder removal and substantial improvements in internal surface quality, critical for high-performance applications such as heat exchangers.

Discussion: Metal-based additive manufacturing (AM) enables the possibility of free-form fabrication, allowing designers to produce components with geometrical complexity far beyond the limits of conventional subtractive or formative processes. Among the most promising applications of this capability are high-performance heat exchangers (HXs), which greatly benefit from AM's ability to create intricate internal architectures for efficient heat transfer and lightweight design (Figure 1). Traditionally, manufacturing such components has been highly challenging due to the intricate core geometries that require multiple, costly, and time-consuming assembly steps, including machining, welding, and brazing, to create a complex and intricate structure necessary for efficient heat transfer. These processes not only increase manufacturing cost and lead time but also introduce potential defect sites, such as weld seams and joints, that can compromise mechanical integrity and thermal performance. By contrast, AM enables the fabrication of highly complex HXs in a single build step, eliminating many of these assembly operations through part consolidation. This capability not only enhances structural reliability and thermal efficiency but also opens new design possibilities for compact, high-performance systems across aerospace, energy, and propulsion applications.

Despite these advantages, the production of AM HXs remains constrained by several process-related limitations. One of the most significant challenges is the removal of powder from intricate internal channels inherent to powder bed fusion (PBF) processes. During fabrication, powder becomes trapped within narrow or tortuous flow passages, especially in microchannel and lattice regions designed for enhanced heat transfer (Figure 2). Complete powder evacuation can be extremely difficult or even impossible when channels have diameters that fall below specific thresholds or contain sharp bends, dead-end cavities, or unsupported overhangs. Residual powder

not only obstructs fluid flow but can also lead to significant performance degradation, including reduced thermal efficiency, elevated pressure drops, and potential contamination or corrosion during service. In severe cases, the inability to fully clear trapped powder renders otherwise well-fabricated components unusable. As a result, design strategies, process parameter optimization, and post-processing approaches must be carefully tailored to mitigate powder entrapment while maintaining the functional and structural integrity of the heat exchanger.

To address these powder removal challenges, REM Surface Engineering has developed an innovative post-processing approach based on selective chemical dissolution. This method employs proprietary chemical formulations engineered to selectively dissolve unfused or loosely sintered powder residues within complex internal passages, while leaving the consolidated, fully fused material unaffected. The fundamental mechanism underlying this approach builds on REM's long-established expertise in self-limiting surface reactions. This principle enables precise and uniform material removal without compromising dimensional accuracy or surface integrity. By carefully controlling reaction kinetics and solution chemistry, the process effectively distinguishes between the higher-reactivity surface oxides of trapped powder and the stable bulk substrate, achieving targeted dissolution in regions otherwise inaccessible to mechanical or fluidic cleaning methods. This capability offers a transformative solution for additively manufactured heat exchangers and other complex internal-channel components, significantly improving powder clearance, ensuring consistent flow characteristics, and enabling the reliable deployment of AM designs that were previously impractical due to internal obstruction risks.

The REM powder declogging system is designed to effectively deliver the selective chemical formulations deep into the internal cavities of additively manufactured components. The system operates by pressurizing the chemistry into the part's internal network while simultaneously applying a vacuum at the opposing end, establishing a dynamic flow path that drives the solution through otherwise stagnant or occluded regions. This process employs a controlled sequence of alternating pressure and vacuum cycles, which enhances fluid penetration and promotes the gradual dissolution and removal of trapped powder (Figure 3). Beyond the mechanical forcing of the liquid, capillary action plays a crucial complementary role, once the chemical solution makes contact with the powder agglomerates or caked regions, capillary forces rapidly draw the fluid into the fine interstitial spaces of the powder cake. This accelerated wetting mechanism enables the reactive chemistry to efficiently engage with the powder surface, facilitating uniform dissolution throughout complex, tortuous passages. The combination of chemical selectivity, controlled fluid dynamics and capillary-driven transport enables REM's process to achieve thorough powder

clearance in geometries otherwise inaccessible by traditional cleaning or mechanical removal techniques.

The effectiveness of the selective chemical dissolution process was demonstrated on a PBF-LB/Al F357 triply periodic minimal surface (TPMS) heat exchanger, a geometry known for its extremely intricate internal passages. The REM declogging system successfully removed all residual and trapped powder from the internal network, restoring open and continuous flow paths throughout the component. This included the elimination of deep-seated powder clogs as well as the removal of loosely adhered or partially sintered powder particles that remained bonded to the channel surfaces. Post-process evaluations confirmed complete clearance of powder residues and a clean internal surface finish, indicating that the chemistry effectively targeted unfused material without removing metal from the consolidated substrate (Figure 4). Dimensional inspection and wall-thickness measurements performed before and after treatment revealed no statistically significant deviations, validating the process's non-destructive and self-limiting nature. Furthermore, the method demonstrated robust performance across TPMS architectures with pore sizes as small as 2 mm, achieving complete powder evacuation and clear flow continuity, which highlights its scalability and effectiveness for even the most challenging AM heat exchanger designs.

A second case study was conducted on a PBF-LB/AlSi10Mg heat exchanger featuring a more traditional, multi-channel core architecture with a higher channel density and reduced individual passage diameters compared to the TPMS design (Figure 5). This configuration presented a more severe powder removal challenge, with substantial clogging observed in the central regions of the core where access by conventional cleaning methods was highly restricted. Prior attempts using mechanical vibration, ultrasonic agitation, and fluid flushing techniques proved ineffective at clearing the trapped powder, featuring the limitations of standard post-processing methods for dense, internally complex AM parts. The component was subsequently treated using REM's declogging system for approximately 30 minutes, employing alternating cycles of pressurization and vacuum to drive the selective chemical solution throughout the internal passages. Post-processing X-ray CT scans confirmed the complete removal of powder, even in the most confined regions, with no evidence of wall breach or structural compromise. Moreover, dimensional verification demonstrated excellent geometric fidelity, reaffirming that the selective chemical dissolution approach achieves thorough internal cleaning while fully preserving the part's design intent and mechanical integrity.

Conclusion: These case studies demonstrate the robustness, versatility, and non-destructive nature of REM's selective chemical dissolution process across different alloys, geometries, and channel architectures. The ability to entirely remove trapped powder from both complex TPMS cores and densely packed multi-channel

configurations highlights the method's scalability and adaptability to real-world AM challenges. By combining chemically selective dissolution with a controlled pressure–vacuum delivery system, REM's approach provides a repeatable, production-ready solution for ensuring complete internal cleanliness without compromising structural fidelity. This capability not only enables the realization of next-generation additively manufactured high-performance heat exchangers but also extends to a wide range of AM components with intricate internal flow paths, such as manifolds, combustors, and cooling channels. Ultimately, integrating REM's automated declogging system (Figure 6) into the AM workflow represents a critical advancement toward manufacturing readiness, unlocking the full design freedom and performance potential of metal additive manufacturing for aerospace, defense, and high-performance energy systems.