

The Circular Manufacturing Playbook for Metal Additive Manufacturing

**Reclaimed Feedstock. Domestic Resilience.
Proven Performance.**

Executive Summary

Metal additive manufacturing was built to reduce waste, increase precision, and unlock design freedom. Yet the supply chains feeding it remain largely linear — dependent on virgin mining, globally concentrated extraction, and energy-intensive refinement.

Nickel superalloys, stainless steels, and titanium powders underpin aerospace, defense, energy, and industrial manufacturing. These materials are increasingly exposed to import reliance, geopolitical volatility, price instability, and rising carbon scrutiny.

Manufacturers today are being asked to secure domestic supply, reduce embodied emissions, and maintain uncompromising performance simultaneously.

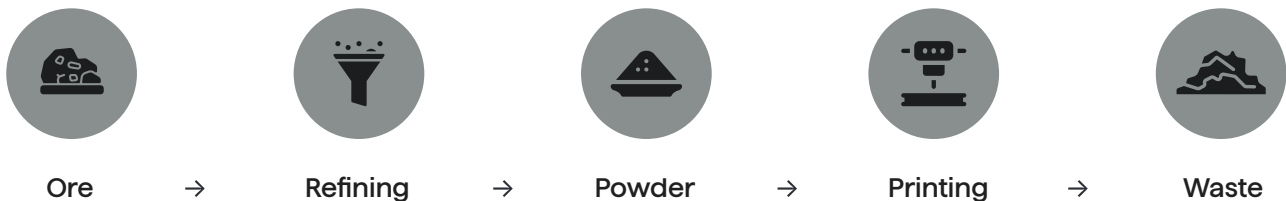
Circular manufacturing offers a structural solution.

By reclaiming high-value scrap, refining it through controlled melt-to-powder processing, and validating performance through rigorous testing and quality systems, manufacturers can reduce supply risk and carbon exposure without compromising additive manufacturing suitability.

Independent academic benchmarking conducted by Rice University evaluated reclaimed M247 superalloy powder against conventionally sourced stainless AM powders. The results demonstrate that reclaimed superalloy feedstock can achieve equal — and in key areas superior — performance during powder bed additive manufacturing recoating.

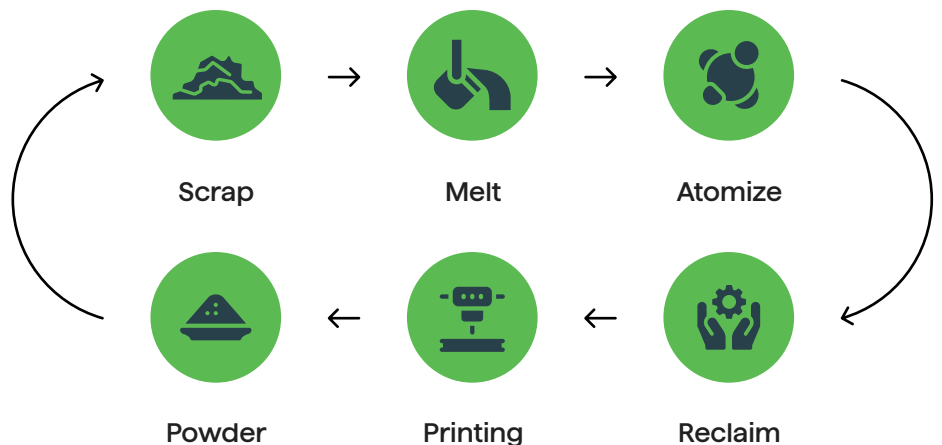
**Circular manufacturing is not a sustainability experiment.
It is a performance-validated supply strategy.**

Linear model



Circular model

Circular manufacturing retains high-value alloy content within the manufacturing ecosystem.



Linear Supply Chains Are Structurally Exposed



Linear Supply Chain Risk

Traditional metal powder production begins with ore extraction. Mining, smelting, refining, melting, atomizing, and shipping. Each step introduces energy intensity, geographic concentration, and supply risk.

For nickel-based superalloys and specialty alloying elements, production is geographically concentrated and increasingly volatile. Import reliance creates structural vulnerability for aerospace and defense programs that depend on stable material supply.

At the same time, carbon disclosure requirements are accelerating. Scope 3 emissions — those embedded in raw materials — are now part of procurement conversations across aerospace, energy, and advanced manufacturing sectors.

Virgin extraction remains one of the most carbon-intensive phases in the material lifecycle.

Additive manufacturing improves material efficiency at the part level. But if feedstock itself depends on fragile global mining systems, risk remains embedded in the foundation.

Resilience must begin at the material source.

Metal Powder Supply Chain

Every step introduces cost, carbon exposure, and supply risk.



Circular Manufacturing

From Scrap to Specification



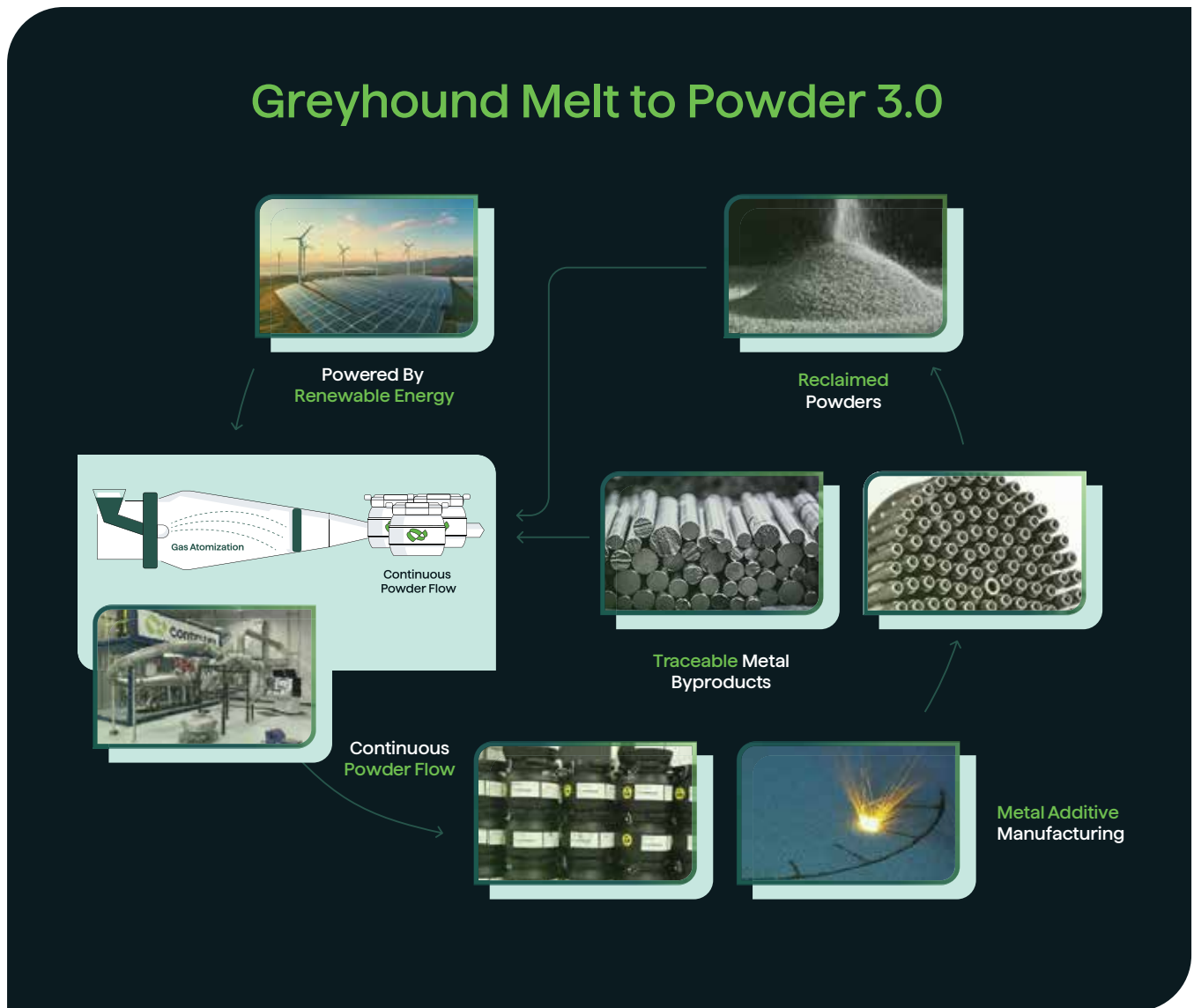
Circular Manufacturing: From Scrap to Specification

Circular manufacturing changes the starting point.

Instead of ore, it begins with high-value scrap—decommissioned components, revert material, excess alloy stock, failed builds, and production of scrap.

Through controlled melting and inert gas atomization, this material can be refined into specification-grade feedstock powder.

At Continuum Powders, this is executed through the **Greyhound Melt-to-Powder (M2P) platform**, which combines cold-hearth plasma melting with inert horizontal gas atomization. This configuration enables controlled chemistry, impurity mitigation, and consistent particle formation.



Greyhound Melt-to-Powder processing converts reclaimed alloy scrap into additive manufacturing feedstock powder.

Circular Manufacturing Advantages

The advantages are structural:



Material Efficiency

High-value alloy content remains in circulation instead of being downgraded or discarded.



Carbon Reduction

Eliminating ore extraction and primary refinement can significantly reduce upstream lifecycle emissions.



Domestic Resilience

Regional scrap streams reduce geopolitical exposure and shorten supply chains.



Cost Stability

Reclaimed superalloys reduce dependence on volatile commodity markets and critical mineral pricing swings.

However, circularity alone does not guarantee adoption. Performance must be demonstrated.



Powder Flow Fundamentals



Powder Flow Fundamentals

In powder bed fusion and binder jetting systems, powder behavior during recoating directly influences part quality.

Feedstock must:

- Flow consistently
- Spread uniformly
- Pack predictably
- Resist excessive compressibility
- Minimize entrapped air

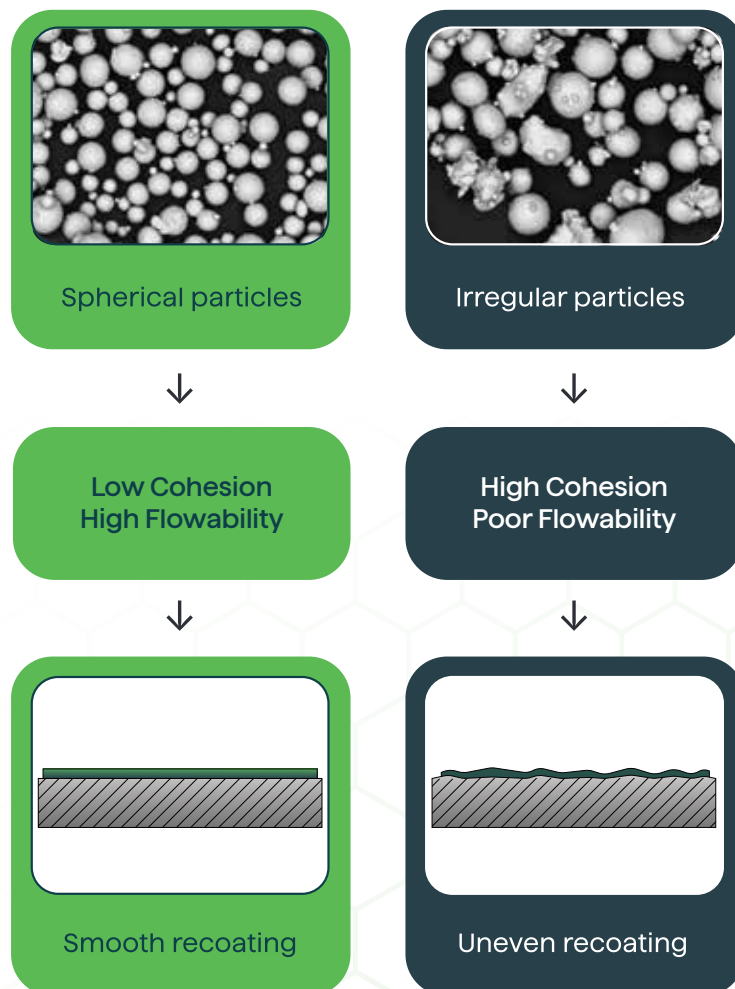
Small differences in density, cohesion, or morphology can influence build stability, parameter sensitivity, and production repeatability.

The central question becomes straightforward: Does reclaimed superalloy powder perform equivalently to conventional feedstock during additive manufacturing?

To answer this objectively, independent benchmarking was conducted by the Rice University Particle Flow & Tribology Laboratory.

Powder behavior comparison

Powder morphology and density strongly influence recoating performance in powder bed additive manufacturing.



Independent Academic Benchmarking

Rice University Particle Flow
& Tribology Laboratory



Study Overview

Rice University evaluated the rheological behavior and additive manufacturing suitability of reclaimed **M247 nickel superalloy powder** relative to two widely used stainless AM powders: **2205 and 316 stainless steel**.

Testing was conducted using **FT4 powder rheometry**, which measures powder flow behavior under dynamic and bulk conditions representative of powder bed additive manufacturing processes. The focus was the **recoating phase**, where powder flow and packing behavior most directly influence layer quality and build stability.

Methodology

The study evaluated several powder characteristics relevant to additive manufacturing:

- Particle size distribution (D10, D50, D90)
- Conditioned bulk density
- Stability Index (SI)
- Flow Rate Index (FRI)
- Compressibility percentage (CPS)
- Additive Manufacturing Suitability factor (AMS)

The **AMS metric** integrates seven normalized rheological parameters to estimate powder spreadability and suitability for powder bed additive processes.

Key Findings

Reclaimed M247 demonstrated the **highest conditioned bulk density** among the materials tested, supporting improved powder deposition behavior and reduced air entrapment during recoating.

The powder also exhibited **very low compressibility (~2%)**, indicating stable packing behavior and minimal disturbance of previously deposited layers. Flow stability metrics further differentiated the reclaimed superalloy:

- **Lowest Stability Index (SI)**
- **Lowest Flow Rate Index (FRI)**

These results indicate consistent powder flow behavior across varying shear conditions. Most notably, reclaimed M247 achieved the **lowest Additive Manufacturing Suitability (AMS) factor**, measuring slightly above **0.6**, while both stainless powders exceeded **0.8**. Lower AMS values correlate with improved powder recoating performance. In practical terms, the reclaimed superalloy demonstrated **equal or superior rheological performance compared to conventionally sourced stainless AM powders**.

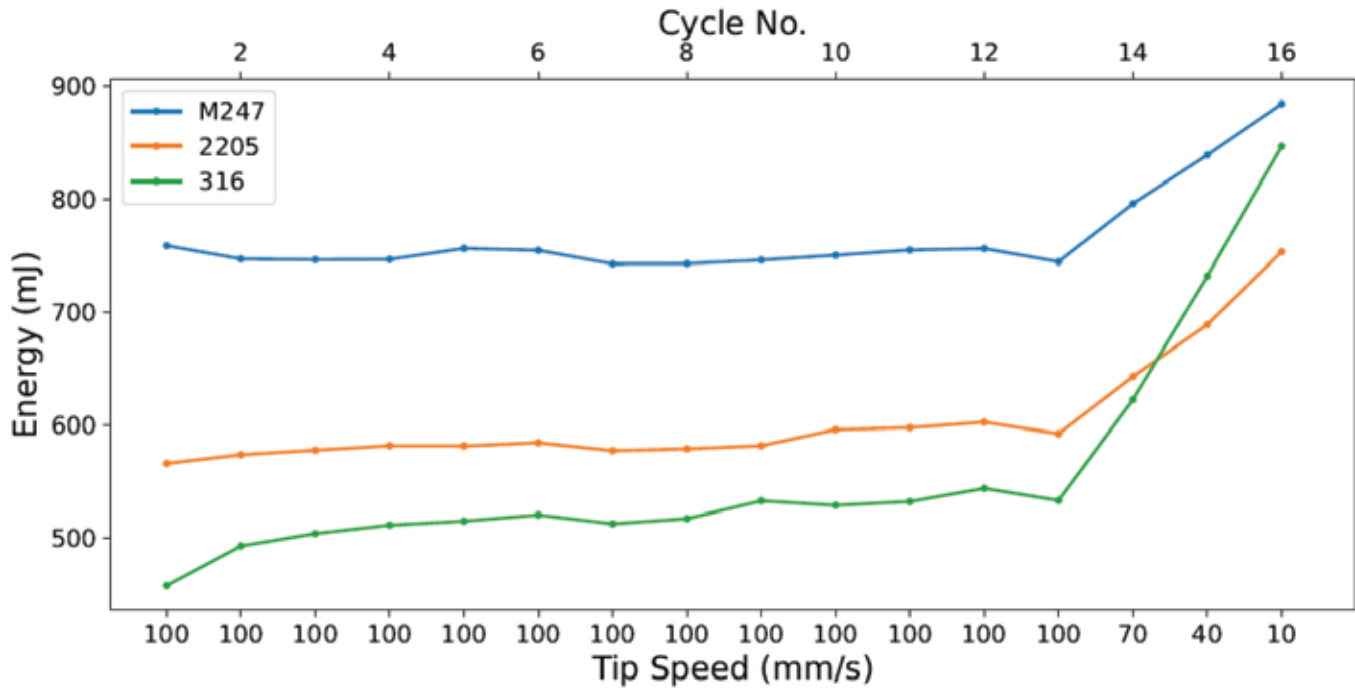
Particle size distribution and bulk density for powders tested in the study

Table 1: Particle size percentiles (D_{10} , D_{50} , and D_{90}), PSD width (span), and conditioned bulk density (ρ_c).

Material	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)	Span	S_w	ρ_c (g/cm ³)
M247	7.44	18.2	48.4	2.25	3.15	5.49
2205	7.60	24.3	53.4	1.88	3.02	4.31
316	7.60	29.9	43.5	1.20	3.38	4.52

Dynamic Flow Testing

Figure 1: Downward flow energies associated with the SVFR test.



Dynamic flow resistance measured during FT4 rheometer testing.

M247 exhibited the highest confined flow resistance due to higher particle density.

The basic flowability energy (BFE) is simply the confined flow resistance of cycle 12, as shown in Fig. 1. M247 possesses a BFE around 750 mJ, and the BFE values of the remaining two metal powders range from 500 to 600 mJ. Flow energy has an intricate relationship with general flowability and spreadability.

Consider two hypothetical powders: Powder A and Powder B. If Powder A and Powder B are very different in terms of their particle size and density, then superior flowability is typically indicated by greater magnitudes of flow resistance. This is because high flow energy is normally associated with coarse and dense particles rather than cohesion. Gravitational forces have a cubic relationship with particle size [25], while cohesive forces showcase a linear correlation with particle size [26]. Therefore, if Powder A has a greater average particle size or

or density than Powder B, its ratio of gravitational forces to cohesion will be greater than that of Powder B, optimizing flowability and spreadability [27, 28, 29]. Alternatively, flow energy is inversely correlated with flowability when considering powders similar in particle size and density.

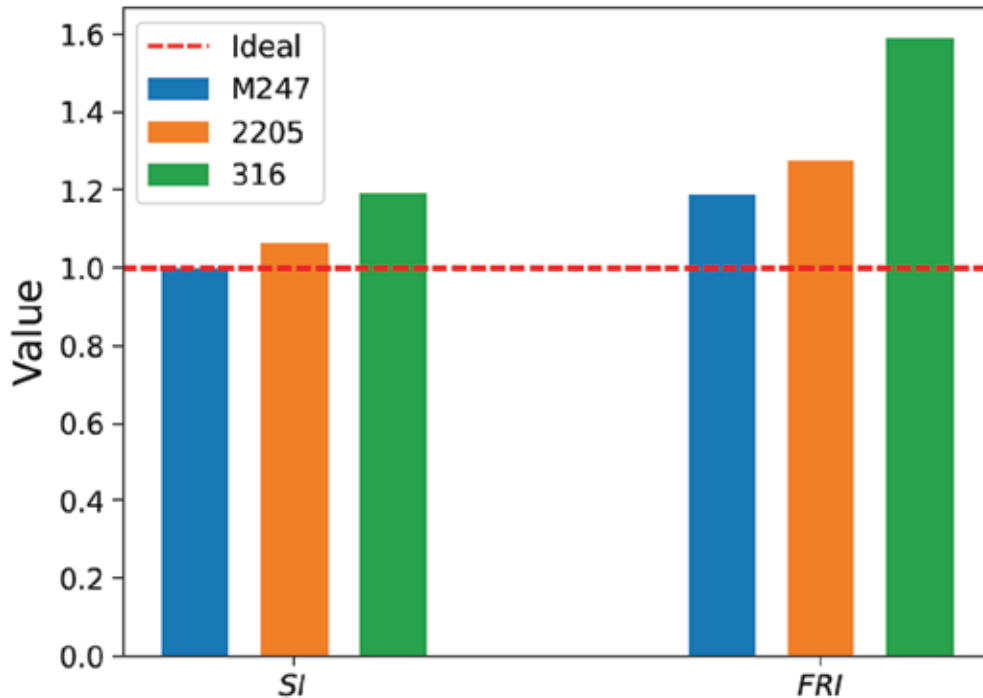
In this case, if Powder B has a lower flow energy than Powder A, this likely signifies that Powder B experiences less opposition to motion from friction and cohesion due to smoother particle surface topologies, more spherical particle morphologies, or less interparticle attraction due to material [30, 31].

Basic Flow Energy

~750 mJ for M247 vs ~500–600 mJ for stainless powders.

Flow Stability

Figure 2: Flow stability indices related to constant flow rate (SI : Stability Index) and variable flow rate (FRI : Flow Rate Index).



M247 exhibited the highest flow stability, indicated by SI values near the ideal value of 1 and the lowest FRI among tested powders.

Flow stability has already been commented on qualitatively, but quantitative results can be seen in Fig. 2. In both the stability and variable region, M247 has the highest flow stability as indicated by the lowest SI and FRI. M247 nearly attains the ideal stability index value of 1.

The powder's very low SI showcases that minimal irreversibilities have been produced by SVFR testing, and its minimal FRI indicates that its flow is weakly dependent on the dynamic conditions. 2205 has slightly less flow stability, followed by 316. The AM spreading phase should be easier and more consistent during repeated use and with varying spreader traverse and rotational speeds for M247 than for the steel powders.

Additionally, it is expected that M247 would require the lowest refresh rate of all tested powders, since its flow behavior is highly reproducible, reducing the amount of unused conventionally sourced

powder material needed for each printing session. In general, M247 should exhibit exemplary AM spreading performance as long as sufficient energy is provided to kickstart flow.

Explain briefly:

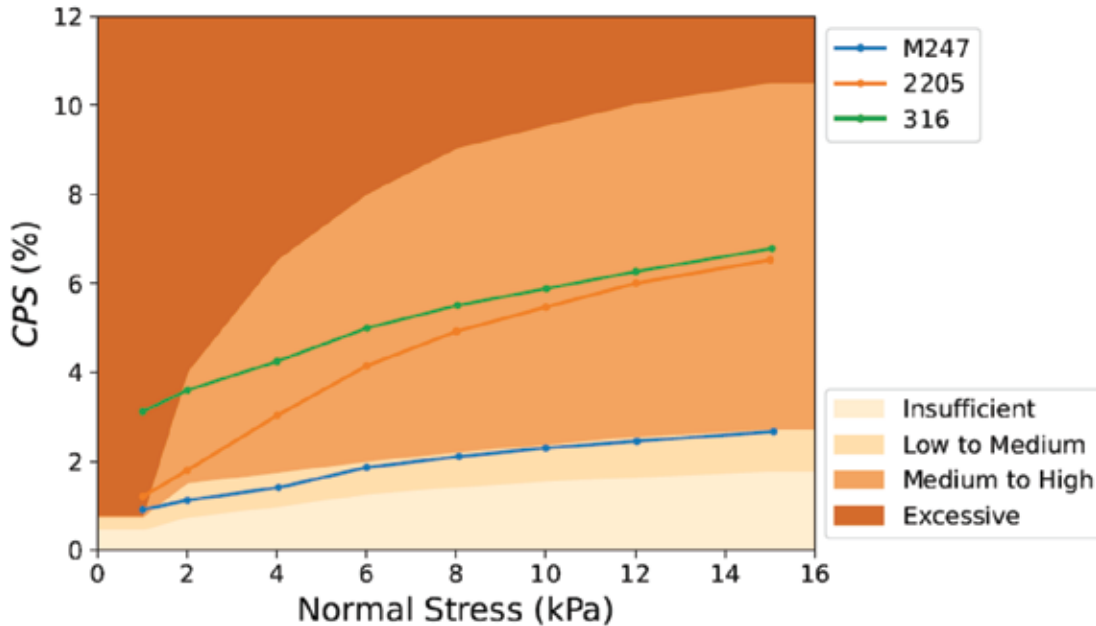
Low SI → stable flow
Low FRI → flow independent of shear conditions

Implication:

More consistent spreading during repeated printing cycles.

Compressibility

Figure 3: Compressibility percentages (CPS) or volume changes of a powder column as functions of compressive stress. Regions of flowability were determined by extensive AM material testing [30].



M247 showed the lowest compressibility (~2%), indicating minimal entrapped air and stable powder packing.

Desktop Metal and Freeman Technology developed an AM spreadability classification system (shown as colored regions in Fig. 3) that includes criteria for the compressibility test [32]. This FT4 test is most pertinent to processes such as hopper flow where stress application from machinery or extensive overlying powder layers is present during flow. Insufficient powder compressibility is a sign of potentially poor powder relocation and packing behavior. Excessive compressibility is common among cohesive materials, since these powders tend to trap pockets of air.

Because these materials are usually less permeable, entrapped air does not simply vent out of deposited powder, but is instead forced out upon compression. Percent changes in powder column volumes are plotted as functions of compressive stress acting normal to the column in Fig. 3. 316 and 2205 steel powders comfortably reside in the medium to high region, with 316 exhibiting more of a linear relationship with normal stress than 2205.

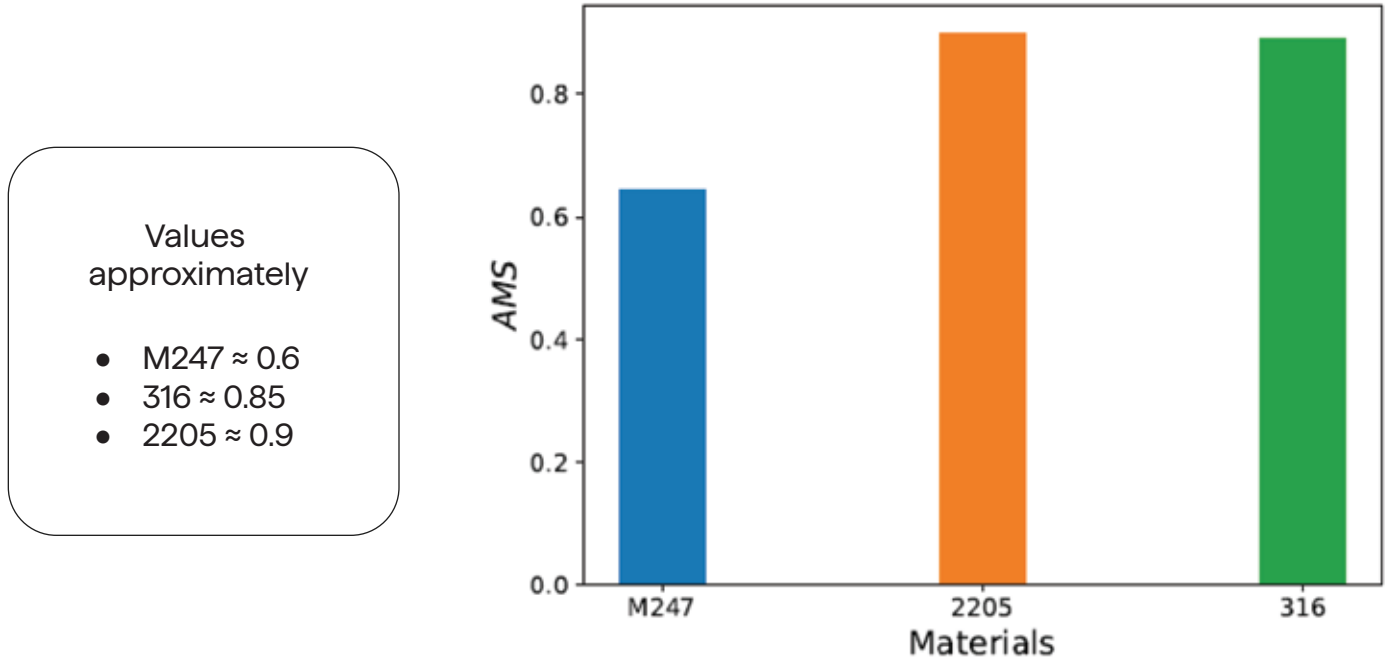
M247 exhibits the lowest compressibility (reaching slightly over 2%) and travels along the boundary between the low to medium and medium to high regions. All materials predominantly occupy the printable regions. Cohesive powders tend to have higher CPS. Therefore, flowability is negatively correlated with this test metric. M247 indicates the lowest powder volume change as a result of normal stress, supporting the claim that it possesses a small amount of entrapped air pockets. M247's moderate compressibility also implies that there should be minimal disturbance of underlying layers during recoating compression.

Low compressibility:

- powder bed disturbance
- air entrapment
- recoating variability

Additive Manufacturing Suitability

Figure 4: Additive manufacturing suitability factors (AMS) for each powder. Lower values correlate with better printing feasibility within the powder recoating phase.



Lower AMS values correlate with improved powder recoating performance. Reclaimed M247 achieved the best AMS factor among powders tested.

Building ASTM-grade metal parts with M247 and other circular manufacturing powders reduces the product carbon footprint and overall material costs. Although powder reclamation can worsen AM suitability, the powder flow behavior of M247, compared with that of 2205 and 316 steels, shows that a material's intrinsic flowability is not always jeopardized by circular manufacturing.

As long as a certain material exhibits excellent flowability, as M247 consistently did across a variety of FT4 powder rheometer tests, reusing scrap parts of that same material only extends its advantages by increasing material efficiency and mitigating international supply chain concerns.

M247 powder's excellent flow performance indicates that it is highly likely to provide part suppliers and customers with an easier, more robust, and more consistent AM printing experience. M247 is a dense, moderately sized powder that performed extremely well with respect to various AM applications including but not limited

to dynamic stability upon repeated use (SI), robustness of flow resistance to various spreading speeds (FRI), and weak underlying layer disturbance caused by powder rearrangement under consolidation (CPS). Printing recommendations can be made for M247, such as the need for a sufficiently high spreading speed to overcome flow resistance and the relatively light influence of a further increase in printing speeds on powder dynamics.

AMS integrates 7 rheological parameters including

- Specific volume
- Compressibility index
- Cohesion
- Flow energy

Operational Implications

For manufacturers operating binder jetting or powder bed fusion systems, these results translate into tangible process benefits:



More stable layer spreading



Reduced variability across spreading speeds



Less parameter trial-and-error



Improved process robustness



Lower refresh rate requirements

Independent benchmarking indicates that reclaimed feedstock can perform reliably in powder bed additive manufacturing environments when processed under controlled conditions.



Conclusion

Independent academic benchmarking demonstrates that reclaimed M247 powder achieves equal or superior rheological performance relative to conventionally sourced stainless additive manufacturing powders.

Circular manufacturing, when executed with controlled processing and quality oversight, does not degrade additive manufacturing suitability.

From Validation to Industrial Execution

Validation confirms feasibility. Execution determines scalability.

Circular manufacturing at production scale requires more than reclamation. It requires controlled melt environments, analytical verification, particle size management, traceability, and repeatable quality systems.

At Continuum Powders, this process is governed by the **OptiVantage framework**, integrating:



Strategic Scrap Sourcing



In-house analytical Chemistry



Controlled Melt Processing



Particle size distribution Management



Lot Traceability



End-to-end logistics coordination

Circular manufacturing becomes viable when metallurgy, atomization science, analytics, and supply chain discipline operate as a unified system. Independent validation establishes technical credibility. Integrated execution ensures repeatability at scale.

Strategic Implications for Advanced Manufacturers

Circular manufacturing aligns three pressures into one solution:



Supply Chain Resilience

Reduced dependence on imported virgin materials.



Carbon Accountability

Lower upstream emissions compared to ore-derived feedstock.



Performance Stability

Validated rheological behavior in powder bed additive systems.

For aerospace, defense, and energy manufacturers operating under long qualification cycles and regulatory scrutiny, material strategy is risk management. Circular manufacturing transforms scrap into specification-grade feedstock while reducing structural exposure to volatility.





The future of advanced manufacturing will not be defined solely by machine capability. It will be defined by material strategy.

Circular manufacturing represents a structural evolution — reclaiming high-value alloys, validating performance through independent benchmarking, and executing with integrated quality systems.

Independent academic validation confirms that reclaimed superalloy feedstock can meet or exceed the rheological demands of powder bed additive manufacturing.

Through disciplined melt-to-powder processing and structured quality control, circular manufacturing can operate at industrial scale. This is not an alternative pathway.

Continuum Powders provides a domestically resilient, performance-validated supply model for advanced manufacturing.



Let's Build Smarter, More Reliable Manufacturing Together

Contact Us Today to Learn More

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