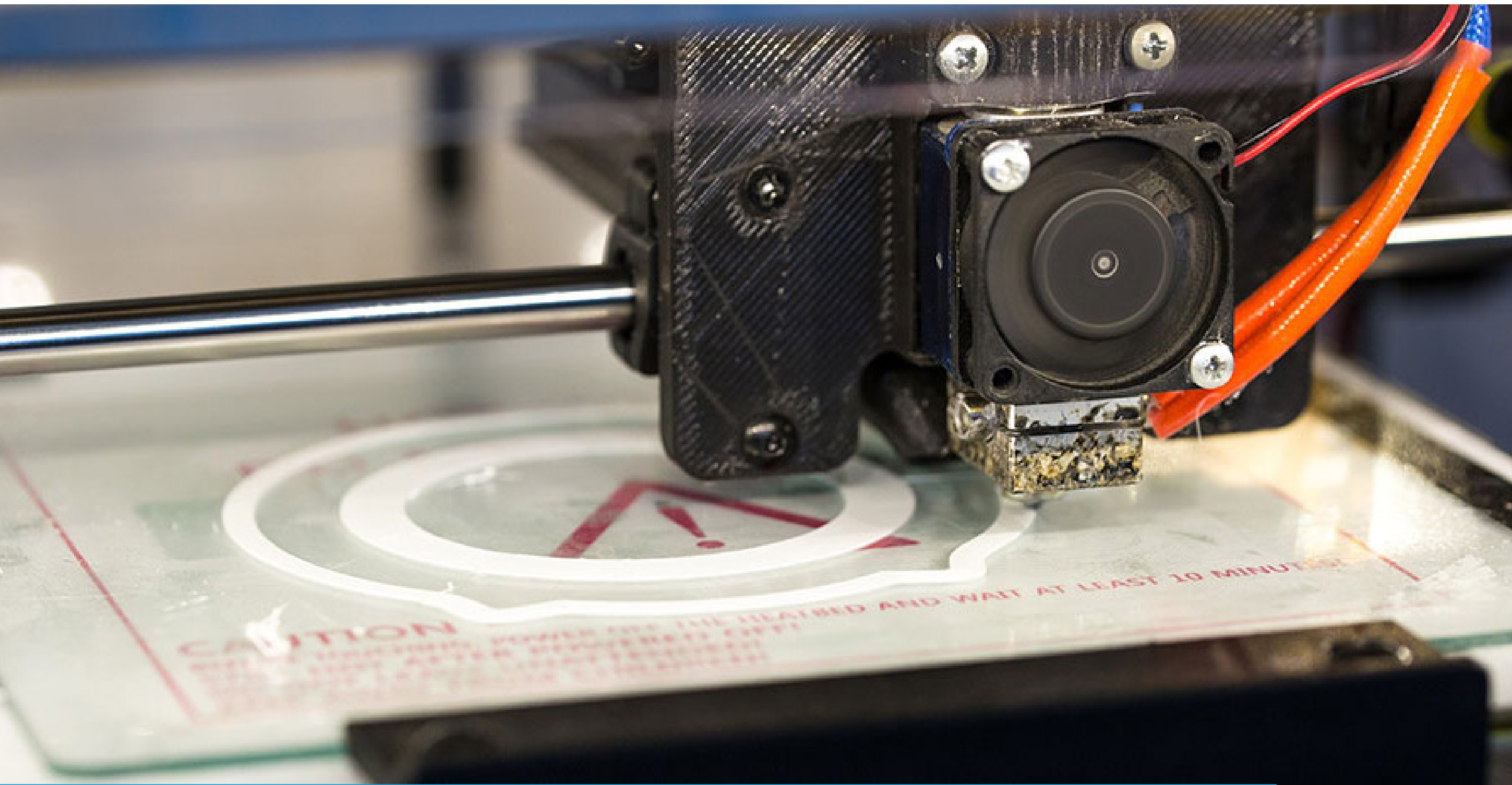


– amixon® whitepaper –

Powder Metallurgy and the Economics of Additive Manufacturing

Metal powder processing technologies for 3D printing

The role of sophisticated mixing equipment in the future of powder bed fusion AM

INTRODUCTION

Towards cost-effective 3D printing

Additive manufacturing (AM) has been teetering on a tipping point for much of the last decade. The technology is here today, and it works. Yet AM continues to be seen by broad swaths of industry as a technology of the future, rather than an accessible and realistic production model for the here and now.

Between greater design freedom, possibilities for on-demand production and prototyping, mass customization, supply chain security, and reduced material waste, 3D printing offers a number of compelling advantages that could help manufacturing companies contend with an uncertain and rapidly evolving market. Across diverse industries, production companies agree this is a technology with the potential to transform the nature of production.

Yet despite the persistent optimism of industry, a relatively steady growth in adoption, and continuous technological progress, AM has yet to reach the mainstream. Conventional manufacturing methods such as injection molding and machining still dominate the production landscape, and there is little indication the rise of 3D printing has meaningfully encroached on their market share.

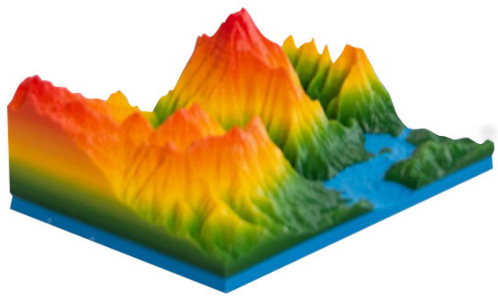
The reason for AM's slower-than-expected rate of adoption boils down to cost. Decades of literature and know-how have optimized casting, molding, and machining processes for cost and efficiency. By comparison, the young field of AM remains uncharted territory when it comes to proof of concept and cost control measures.

The following chapter investigates some of the major obstacles to cost-efficiency in large scale 3D printing that must be optimized before the technology can mature to a point of mainstream industrial adoption.

Industrial mixing technology made in Germany

For nearly 40 years, amixon® has been a market leader in the manufacture of sophisticated, high-precision mixing equipment for diverse processing needs. Made in Germany from stainless steel, outfitted with proprietary technology for optimal hygiene and traceability, and customized to the exact specifications of your products, amixon® mixers offer state-of-the-art bulk material processing solutions for the metal, ceramic, and polymer powders used in additive manufacturing.

Content



amixon® Conical vertical dryer AMT

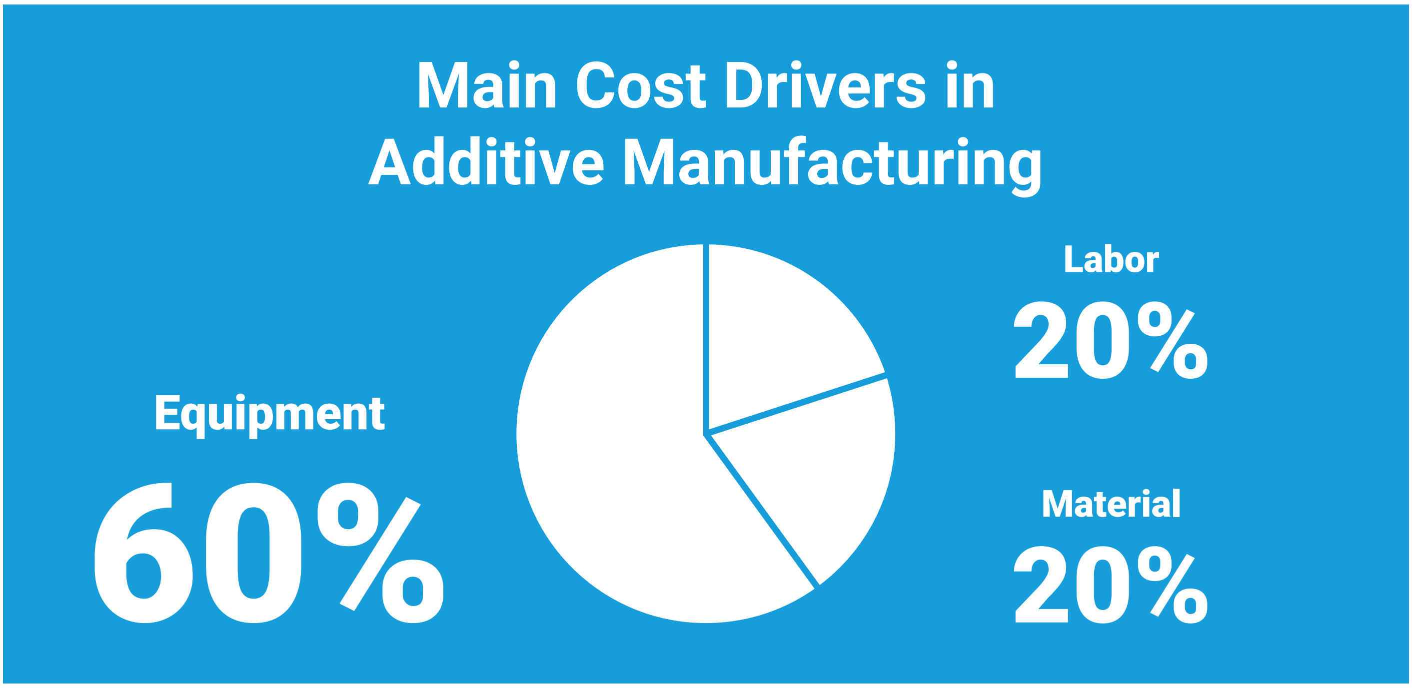
Powder and the economics of 3D printing

Powder bed fusion (PBF) is a subset of additive manufacturing (AM) that involves selectively fusing successive layers of specially conditioned powders to form an exact physical replica of a digital 3D model. PBF has been lauded as an Industry 4.0 technology with the potential to completely transform the industrial economy by enabling on-demand production of parts and mass customized products. But despite the many advantages of AM and nearly a decade of hype driving its continuous development, this production method remains a relatively niche technology that is often too slow and expensive on a per unit basis to find widespread application.

This white paper examines common obstacles to cost-effective 3D printing via powder bed fusion. While the greatest limitations for manufacturers arise from hefty upfront investments in equipment, the cost of materials is often the most scrutinized system component when it comes to AM process optimization. This places pressure on the producers of PBF materials, who themselves must also contend with cost-efficiency challenges. Sophisticated mixing technology can make a meaningful contribution to driving down the costs associated with PBF, both for material producers and manufacturers, so that this transformative technology can become economically viable for a wider range of industry.

1 Major cost drivers in additive manufacturing

Generally speaking, there are three categories of costs that can impede the economic viability of AM for production companies: equipment, labor, and material.



Source: (Bono n.d.)

1.1 Equipment

At an estimated 60% of the component cost, production equipment constitutes the single greatest expense in AM.[1] In addition to the purchase of a precision AM machine, which can cost upwards of $1M USD at greater build volumes, manufacturers should budget for about 10% of the purchase price in maintenance costs and 12% equipment depreciation annually.[2]

Beyond the AM machine itself, large scale 3D printing operations also require a robust supporting infrastructure for material handling and design. Depending on the application, PBF 3D printing may require additional post-processing equipment for cooling, treating, and finishing the printed component. Operating an AM production line also involves considerably more energy than do conventional methods such as machining.[3]

The overall cost of equipment ownership is expected to trend downwards as AM technologies continue to progress, but for the time being, the high financial barrier-to-entry keeps AM a prohibitively expensive technology for many smaller production companies.

1.2 Labor

Labor represents an estimated 20% of the costs involved in AM.[4] Though this figure is not unlike the proportional cost of labor in more traditional manufacturing methods, AM is comparatively slow and comes with the challenge of requiring new skillsets of a workforce tasked with designing, executing, finishing, and performing quality controls on 3D printed components.

For example, 3D-CAD skills alone are not adequate for effective Design for Additive Manufacturing (DAFM), a specialization that involves accounting for the way that 3D printed structures can and cannot support themselves. Employees trained in DAFM can create 3D renderings that are self-supporting, thus eliminating the need for printing extra support material, as well as the additional time, finishing, and material costs this would entail.

As a highly automated process, AM is poised to see a reduction in labor costs over time as more digital and robotic technologies are adopted throughout industry. Furthermore, as the technology matures, technological advancements will make the process faster, and a greater proportion of the manufacturing workforce will develop the skillsets necessary to consistently carry out a labor-efficient 3D printing operation.

1.3 Material

At an estimated 20% of the total cost of 3D printing a component, materials are not the most burdensome expense in AM.[5] However, cost controls and process optimization in AM tend to focus on the cost of materials over labor and equipment. The reasons for this have to do with the high visibility of powder materials as a system component.

As opposed to less tangible AM cost-drivers such as equipment depreciation, ongoing maintenance, energy consumption, and quality assurance, the cost and volume of powder used are relatively easy to measure, understand, and scrutinize. Furthermore, within the context of reoccurring buyer-vendor transactions, manufacturers have more opportunity to pressure their suppliers about the cost of bulk materials. In comparison, there is little they can do to reduce equipment or labor costs.

This lopsided scrutiny on material costs puts PBF powder producers, who themselves must grapple unique cost-efficiency challenges, in a difficult position. In the following chapter, we investigate some of the challenges involved in the production of metal powders for use in PBF.

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2 Cost-efficiency challenges in powder production

There are a range of materials, from ceramics to polymers, from which powders for PBF are made. There are also a number of different techniques for atomizing raw materials to create these powders. We will focus here on techniques utilizing gas atomization to create metal powders, which constitute the most common processes for the production of AM materials.

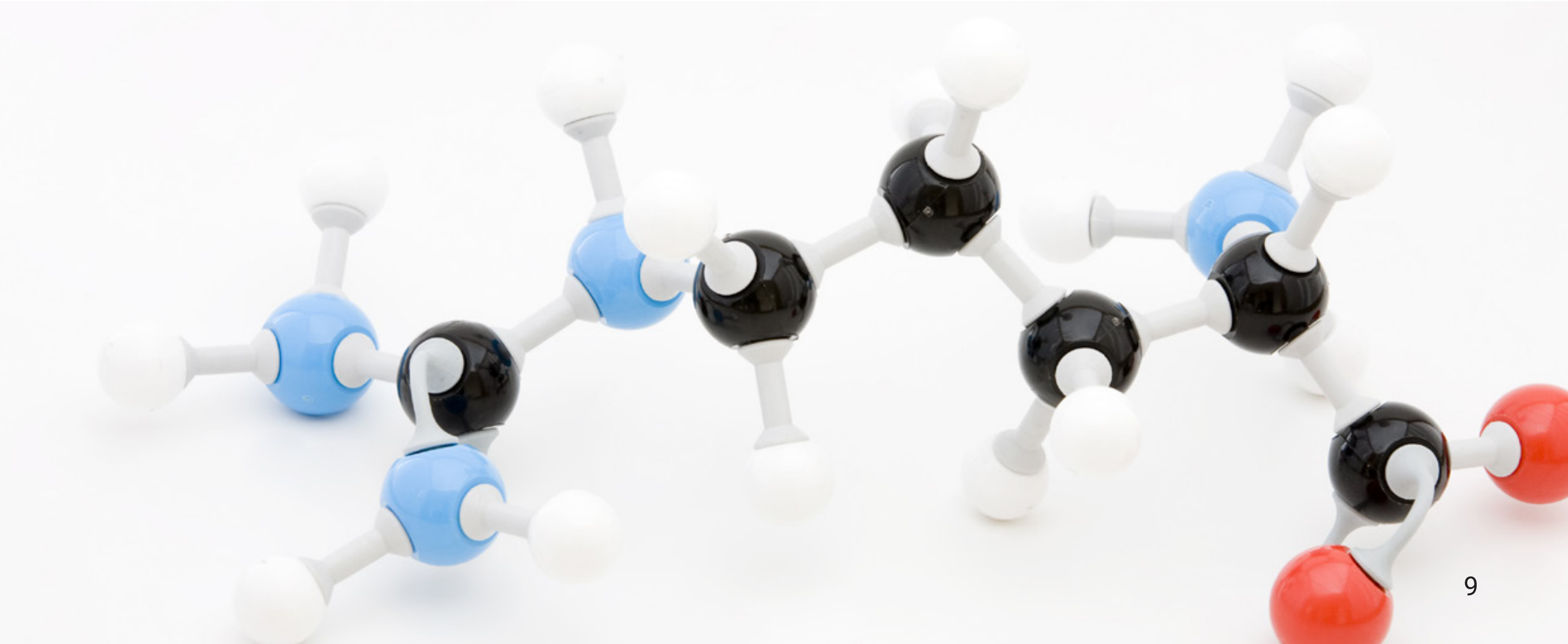
Powder metallurgy is, unlike 3D printing, a mature field that has benefited from many decades of process optimization and know-how. However, the rise of 3D printing has led to an upsurge in demand for specific types of high-value metal powders. For these specialty materials, the last decade has seen per-ton demand grow annually by as much as 10-40%.[6] In working to meet this surging need for some of their most laborious products, powder metallurgists are confronted with a number of challenges to cost-efficient operation.

2.1 Particle size distribution and morphology requirements

The gas atomization process results in particles with varying shapes and sizes ranging from less than 1 µm up to 500 µm. Rates vary by producer, but gas atomization typically yields a much greater volume of large and coarse powders than fine ones. The resulting powders are sieved into batches of similar size and shape before they are conditioned and packaged.

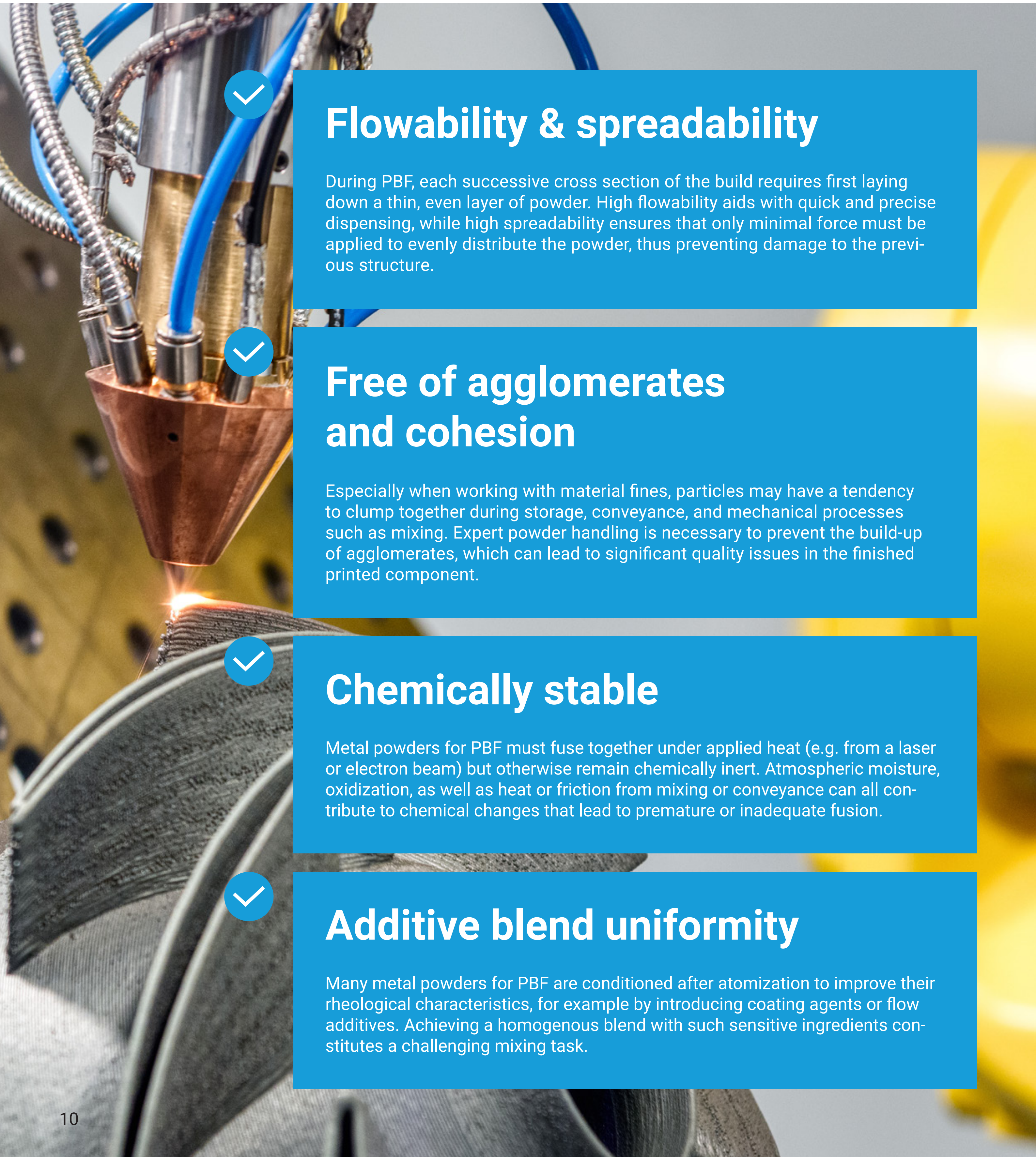
In order to print components with adequate load bearing properties for use in critical applications, PBF requires metal powders that are as spherical and uniformly sized as possible. Furthermore, the majority of PBF processes require extremely fine materials to print effectively, favoring particles approximately 10 µm in size. Powders significantly larger than this are more or less unusable in PBF.

Uneconomical to recycle, huge volumes of larger powders sit in inventory while fines fly off the shelves. This dynamic poses a significant challenge for metal powder producers and impacts the price of their products.



2.2 Rheological properties

Metal powders used in PBF play a key role in both processing efficiency and the quality of a printed component. Especially in critical applications, metal powders for PBF must fulfill specific standards as to their physical and chemical properties. Producers of metal powders must ensure that their materials meet the following demands:



Flowability & spreadability

During PBF, each successive cross section of the build requires first laying down a thin, even layer of powder. High flowability aids with quick and precise dispensing, while high spreadability ensures that only minimal force must be applied to evenly distribute the powder, thus preventing damage to the previous structure.

Free of agglomerates and cohesion

Especially when working with material fines, particles may have a tendency to clump together during storage, conveyance, and mechanical processes such as mixing. Expert powder handling is necessary to prevent the build-up of agglomerates, which can lead to significant quality issues in the finished printed component.

Chemically stable

Metal powders for PBF must fuse together under applied heat (e.g. from a laser or electron beam) but otherwise remain chemically inert. Atmospheric moisture, oxidization, as well as heat or friction from mixing or conveyance can all contribute to chemical changes that lead to premature or inadequate fusion.

Additive blend uniformity

Many metal powders for PBF are conditioned after atomization to improve their rheological characteristics, for example by introducing coating agents or flow additives. Achieving a homogenous blend with such sensitive ingredients constitutes a challenging mixing task.

2.3 Reconditioning excess powder for reuse

Given the end-user's preoccupation with controlling for material costs and the powder producer's chronic shortage of material fines, recycling the excess powder left over after a build job seems like a win-win solution for both parties. Unfortunately the recycling process is not always as simple as collecting extra powders and feeding them back into the 3D printer. In critical applications with high standards for part performance, leftover metal powders must meet high specifications for reuse.

A number of degradation issues can be observed with different metal powders. High-temperature powder alloys like Iconel 718 may become distorted depending on their proximity to the melt, causing some volume of the used powder to assume a morphology too large and/or coarse for reuse.[7] Other materials, such as titanium powders, are susceptible to oxygen pick-up, and can therefore only be recycled a handful of times before their oxygen content is too high for reuse.[8]

Though a handful of techniques for reconditioning are in practice, there are as of yet no qualified methods for the material analysis and reconditioning of leftover PBF materials for reuse. Developing qualified, cost-effective processes for metal powder reconditioning and recycling would be a boon to both powder producers and end-users. There is also room for innovation in conditioning virgin metal powders in a way that primes them for high reusability. With further research and development in these areas, powder producers can make a tremendous contribution to the cost-effectiveness of 3D printing across industry.

The next and final chapter investigates how state-of-the-art mixing equipment can help to address some of the cost-effectiveness obstacles detailed above, including issues of particle size distribution, rheology, and reusability.

There is room for innovation in developing qualified processes for metal powder reconditioning, as well as conditioning virgin metal powders in a way that primes them for reuse. With further research and development in these areas, powder producers can make a tremendous contribution to the cost-effectiveness of 3D printing across industry.

3 The role of mixing technology in the economics of PBF

Mixing, vacuum drying, and reacting equipment plays a crucial role in the production and recycling of metal powders for additive manufacturing. After the metal powder has undergone atomization and sieving, batches of similarly sized particles are conditioned in mixing equipment, where they will obtain the final homogeneity, chemistry, and flow properties necessary to print durable, high-performance components for industry.

In order to reduce processing time and hinder material degradation, blending technology for metal powders must facilitate the homogenization, conditioning, drying, and cooling processes in a single machine. For these applications, mixing technologist amixon® custom-engineers 3-in-1 blenders, reactors, and vacuum dryers that offer unparalleled performance and durability.

Here we outline three central aspects of mixing operations for metal powder production in which amixon® machines are designed to excel, thus helping powder producers improve process efficiency, product yield, and reclamation rates:

3.1 Complete discharge reduces product loss and improves traceability

The ability to reliably separate each charge of metal powders and avoid their intermixing is crucial for batch tracing and quality assurance. Cross contamination between batches can negatively impact the narrow particle size distribution required of metal powders used in PBF, which in turn can lead to serious quality issues in the 3D printed component.

The amixon® AMT is a 3-in-1 conical mixer, dryer, and reactor designed with this challenge in mind. The conically shaped mixing vessel and convex helical blades facilitate the complete discharge of the mixer without segregation. The mixing shaft is mounted and sealed only from the top, out of contact with the metal powders, helping to eliminate the buildup of material residue.

amixon® also engineers flat-bottomed machinery that can achieve superior discharge rates of up to 99.997%. Another 3-in-1 mixer, dryer, and reactor model, the VMT has a cylindrical mixing vessel that can be outfitted with the innovative ComDisc® tool. Installed at the bottom of the mixing shaft, this flexible mechanism lowers to the vessel floor upon discharging. There, it sweeps the bottom of the mixer in a radial fashion, pushing the goods towards the discharge outlet.

The ability to completely discharge a mixer of metal powders is not only essential to preventing contamination and batch tracing issues. It is also economically beneficial as it increases batch yields by ensuring that no valuable material fines are left behind in the mixing equipment.

amixon® Mixer dryer and vacuum dryer VMT

3.2 Expert homogeneity and conditioning

Attaining the specific rheology necessary for effective powder bed fusion is among the most challenging parts of the metal powder production process. As the vessel in which metal powders are homogenized and conditioned, amixon® mixers have an indispensable role to play in creating a product that will perform to high specifications.

The following features of the AMT and VMT mixers, dryers, and reactors facilitate the cost-efficient production of high-value metal powders for use the additive manufacture of critical components:

Gentle yet thorough homogenization

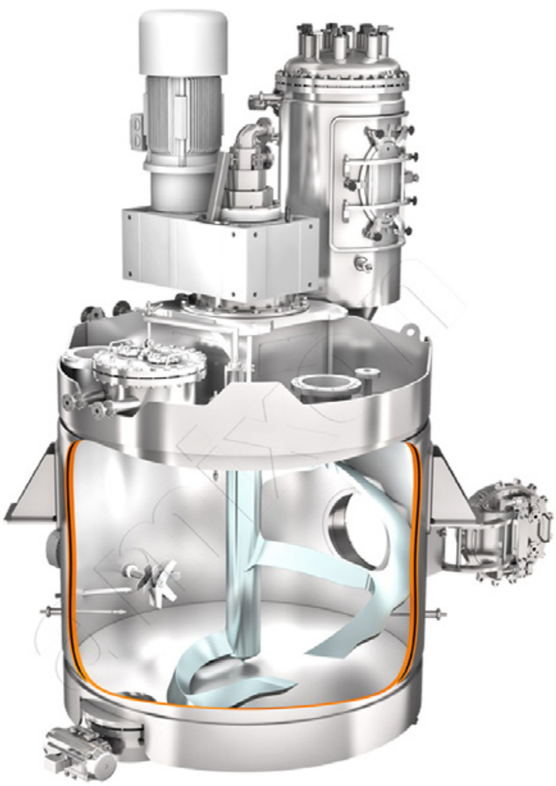
amixon® powder blenders are outfitted with a vertically-mounted helical mixing blade at the center of the chamber. As the blade rotates, a three-dimensional current is generated: metal powders are conveyed upwards along the periphery before sinking gravimetrically along the mixing shaft. This current immerses the entire mixing chamber, ensuring the operation is free of deadspace. Under these conditions, only a low rotary frequency is necessary to eliminate agglomerates and create a perfectly homogenous blend with excellent flowability characteristics, reducing the amount of shear to which the particles are exposed. And as a vacuum- and pressure-tight operation, oxygen and nitrogen levels can be significantly reduced in the mixing goods.

Uniform integration of flow additives

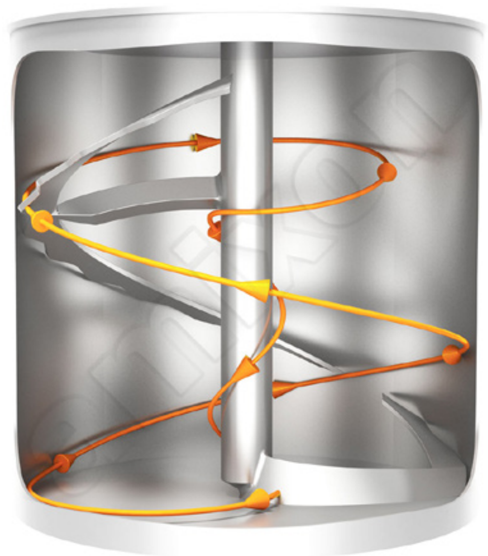
The gentle yet thorough homogenization process carried out by amixon® mixers is ideal for extremely difficult mixing tasks, such the uniform integration of extremely light flow additives like pyrogenic silicon dioxide. Even with their extreme sensitivity to shear and tendency to float to the top of the mixture, such additives are effectively enveloped into the mixing current and homogenously integrated into the bulk powders. Furthermore, innovative discharging mechanisms ensure the additives do not segregate from the bulk materials after mixing.

Multi-step processing for particle coating

A common technique for conditioning especially hygroscopic metal powders is coating the particles in nanoscopic additives in order to prevent the formation of agglomerates. Outfitted with a wide range of processing functions, amixon® mixers, dryers, and reactors are well equipped to handle such precise, multi-step conditioning processes. Homogenously integrating coating agents into bulk ingredients involves first creating uniform levels of moisture within the powder. In order to achieve this, each and every individual particle must be wetted with the coating additive before they are dried under a vacuum. This ensures the coating remains evenly distributed on the surface of each particle, and reduces both the processing time and the heat necessary to achieve the desired results.



Mixer Cross-Section VMT



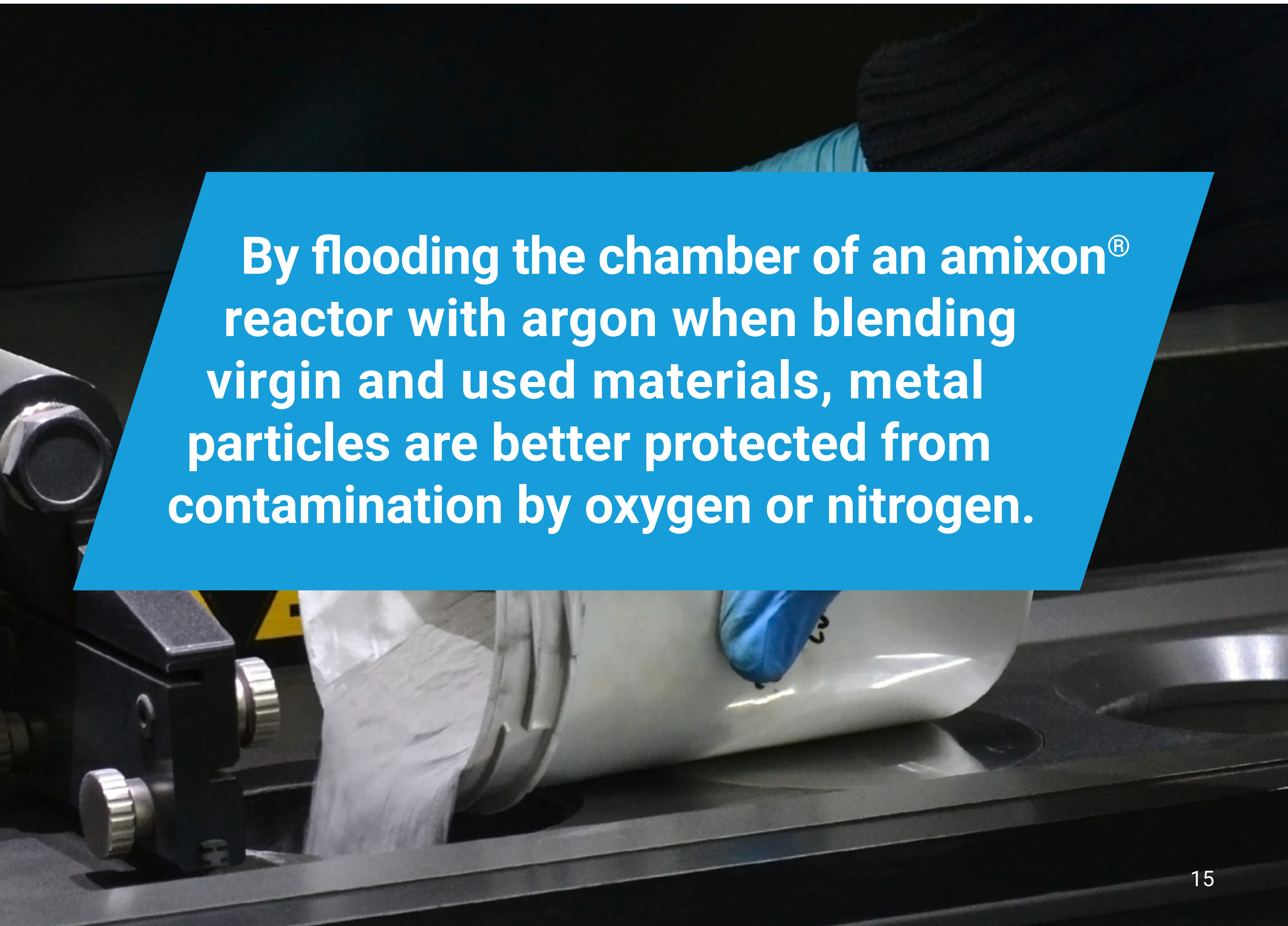
Flow principle VMT

3.3 Solutions for reconditioning and recycling metal powders

Blending virgin material with leftover excess is one of the most widely-used techniques for reconditioning metal powders. Although this process is proven to reduce the oxygen levels in most metal alloys, it is not always adequate for creating recycled metal powder with a high enough quality for use in critical applications such as medical devices or aerospace.[9] While the overall oxygen level of the virgin/reclaimed blend may be up to specification, certain individual particles may continue to display high levels of oxygen content that can negatively impact the printed product.

Despite the limitations of blending virgin material with excess powders, gas-tight mixing vessels are proven to be more effective in reducing contamination pick-up in reused powders.[10] By flooding the chamber of an amixon® reactor with argon during the blending operation, metal particles are better protected from contamination by oxygen or nitrogen, thus improving the quality of the reclaimed materials.

As discussed in the previous chapter, industry is in need of qualified techniques for reliably reconditioning leftover metal powders for reuse. Flexible, high-performance mixers, dryers, and reactors like those from amixon® are poised to aid in the research and development of such cost- and resource-saving procedures. In addition, the development of conditioning techniques that can improve the reusability of virgin materials will also depend in part on mixing equipment offering a wide range of precisely adjustable processing settings. Innovations in these fields could boost the cost-effectiveness of additive manufacturing for both powder producers and end-users, helping 3D printing technologies mature to a level of widespread adoption across diverse industries.



4

Conclusions

For cost-effective powder bed fusion, mixing technology is one piece of the puzzle

Additive manufacturing promises to transform the industrial economy by enabling the rapid prototyping, on-demand production, and mass customization of highly complex components. But before 3D printing can fulfill this ambitious goal, industry players from equipment manufacturers, to powder metallurgists, to production companies must continue to develop innovative ways to optimize various system components along the entire AM production chain.

With continued research, collaboration, and process innovation, the still-young technology of additive manufacturing will in time see increasing rates of adoption throughout industry. For its part, high-performance mixing equipment from amixon® has a meaningful contribution to make in improving the quality and cost-effectiveness of metal powders for use in powder bed fusion.

SOURCES

[1] Bono n.d.

[2] Thomas and Gilbert 2014

[3] Nyameke, et al. 2017

[4] Bono n.d.

[5] ibid.

[6] Dunkley 2019

[7] Samant and Lewis 2017

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[9] Samant and Lewis 2017

[10] Cordova, Campos and Tinga 2019

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