THE CHALLENGES OF HANDLING METAL POWDERS FOR ADDITIVE MANUFACTURE

As this new technology matures, additive manufacturing will create some serious safety and efficiency issues for those handling dense metal powders. Those issues are likely to become more prevalent as the industry moves from one of infancy to a more established manufacturing mode. This article discusses how metal powder vacuum transfer can help alleviate many of these problems.

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The advent of additive manufacture (AM), or 3D printing as it's commonly known, has led to the requirement for safe handling of dense metal powders in an environment where there's typically little experience dealing with the difficulties associated with particulate material transport and containment.

Since the industrial revolution, metal component manufacturing has involved a combination of milling, turning, grinding, and fabricating techniques in a workshop environment where raw materials commonly arrive as bar stock, sheet forms, castings, blocks, or ingots. People involved in these traditional types of "subtractive" manufacturing (metal components are cut out of solid metal materials) using mills, lathes, and machining tools tend to have little knowledge or experience with the powder handling difficulties involved in additive manufacture.

The issues are complicated by the need to carry out several different powder processing functions. Additive manufacture requires material loading, unloading, screening, and recovery in an inert or noninert atmosphere. These functions are different in terms of the conveying and handling needed. This article addresses some of these powder handling aspects that require careful thought and explains how vacuum transfer during the process can help ensure that the AM workplace remains an efficient, clean, and safe area.

The AM process

As the name implies, AM requires the ability to process metal powders by adding thin layers of powdered material, one on top of another, fusing each layer as it's applied, until the desired component is formed. Whether by laser fusion or use of a binder jet, these layers are spread in a method similar to a traditional laser-jet document printer. The process takes place in a build-box on an AM machine. A large proportion of the powder applied in each component layer does not become part of the actual component. This results in costly powder waste and requires that the unused material be recovered and reprocessed. These metal powders are heavy and potentially hazardous to handle.

Originally, loading and unloading AM machines was done manually, in small quantities, and by using smaller-sized containers. However, as AM production rates have grown, the need to efficiently deliver larger powder volumes both to and from the process has led to the need for material handling systems that offer a contained, safe, and user-friendly operation while also optimizing production efficiencies.

Investigating the available equipment options that can meet these requirements reveals that some have limiting factors. Flexible or rigid screw conveyors take up a large amount of floor space because of their need to convey at an angle. Transferring dense materials in a flexible screw conveyor isn't practical since the combination of the open auger and the need for material to act as the auger's bearing results in the auger's compression. Solutions such as aeromechanical conveyors, bucket elevators, and cleated belts aren't feasible, leaving pneumatic conveying and gravity discharge as the two best choices. Considering all the requirements of an AM environment, vacuum transfer can be a practical solution.

Consider all powder handling requirements

The AM process involves several powder handling activities that should be considered before selecting equipment, including:

- Loading new virgin material into the machine
- Unloading excess material from the build-box overspill
- Unloading unused material from the build-area around the finished component — either from within the machine or from an unloading station.
- Screening the excess and unused material
- Blending leftover and virgin materials

FIGURE 1

Load machine with material from storage.

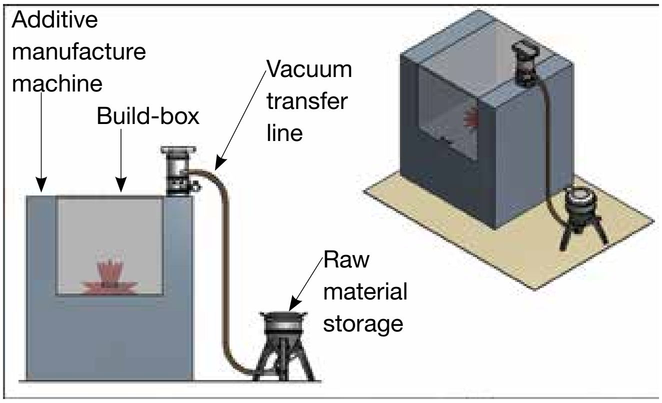
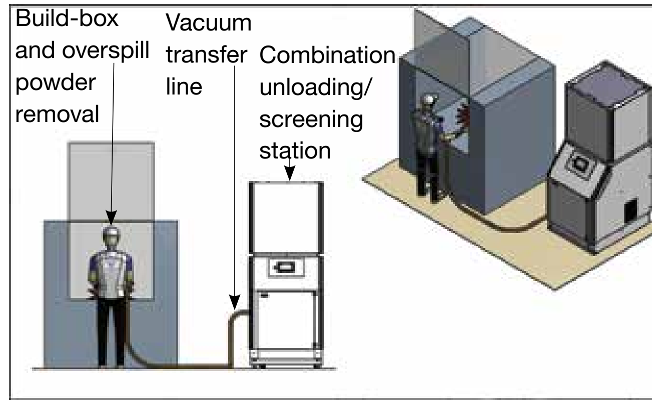


FIGURE 2

Transfer material from build-box to screener.



- Refilling the AM machine with blended and screened materials

Loading virgin material. Supplying virgin metal powder to the machine, as shown in Figure 1, is much like that of loading tablet presses or capsule filling machines. The simplest option uses gravity and involves elevating bins (intermediate bulk containers) of material, as supplied by metal powder manufacturers, above the machine. The container is then connected to the feed hopper inlet and the material is discharged into the machine via gravity. This option sounds simple enough, except the method requires lifting the very heavy material containers, and, hence, requires sufficient space in the work area for a forklift to operate. Some sort of container support structure also is required on the machine to allow hopper docking. In many cases, the ability to do so and maintain inert conditions to prevent metal powder oxidation is added.

Unloading excess and unused material. Unloading overspill from the machine after a component is completed, as shown in Figure 2, necessitates some type of collection hopper supplied by the AM machine manufacturer, as well as a collection point for the overspill. An AM machine's wiping action, which is similar to that of a silkscreen printing process, results in some material being "ploughed" to the end of the build-box area and into the collection hopper. Currently, these collection hoppers are typically small, but as AM production rates rise, so will overspill volumes, necessitating better metal powder collection and handling methods and larger hoppers. This leftover material also requires screening before it can be used for a future component build.

A similar collection function involves collecting unused material surrounding the component. As much as 85 percent of the powder volume within the build box has to be recovered. To achieve this, the manufactured component and the nonfused or *bound* material must be removed and the latter screened for future use. Two common methods currently exist. The first involves simple suction of material and vacuum conveying it from within the build-box, while it remains on the machine. The second method involves removing the build-box on a platen-style station, similar to that used on a CNC milling machine, to an "unloading" station and the subsequent component and powder removal.

Screening, blending, and refilling. Figure 3 shows one option for returning the screened material to the AM machine — in this case from a combined unloading and screening station. The function is essentially the same as the initial AM machine loading but may involve the need to add a blending process prior to the AM machine, where the virgin and the already once-processed powder can be combined.

These powder handling requirements exist for each AM machine, so as more machines are added to a plant, the requirements become more complex. Can the powder handing system handle a group of AM machines while still supporting the production rates? Is a separate powder handling room required to keep the production area free from these powder handling constraints? If a blending operation is needed, what type of blending should it be and where should the blender be located?

Vacuum conveying solutions

Vacuum conveying, in one form or another, is a known technique for collecting powders and particulates. Industrial vacuum conveying systems exist to help meet AM dense metal powder safety and efficiency handling requirements, but not all systems are created equal. Many can't handle volume transfer of dense metal powders with bulk densities as high as 650 lb/ft^3.

The vacuum transfer process is a simple concept. By using a vacuum pump, a vacuum receiver draws material and gas through a conveying line, achieving a

FIGURE 3

Load machine with material from screener.

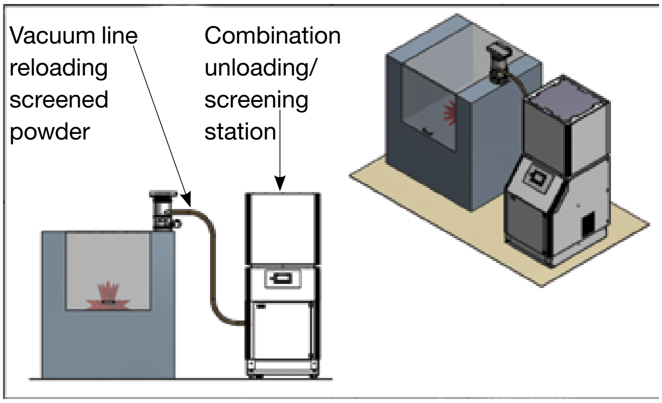
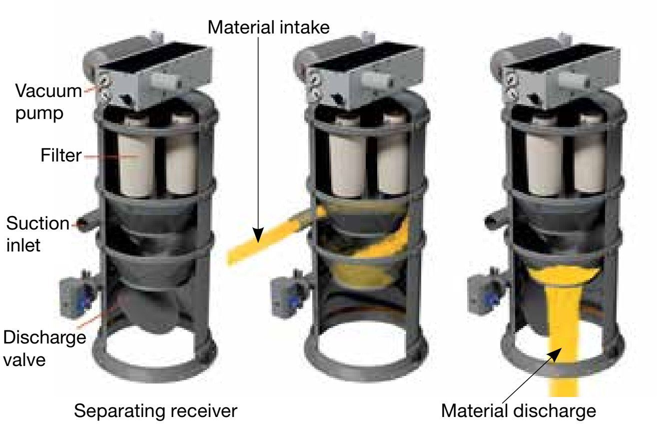


FIGURE 4

Design and sequence of a typical vacuum receiver.



lower pressure at the discharge end of the transfer line and generating air or gas flow from the supply point. By providing a filter system at the discharge point, powder is separated from the airstream and discharged into a receiving hopper. A typical vacuum receiver and its operating sequence is shown in Figure 4.

A large proportion of the powder applied in each component layer does not become part of the actual component. This results in costly powder waste and requires that the unused material be recovered and reprocessed.

For dense metal powders, a conveying system design has several key requirements, including ease of cleaning, minimal material retention, and high-quality filtration down to the submicron particle range. The type of vacuum transfer is particularly critical to successful conveying of dense metal powders. The choice is to either convey using high-velocity airflow, where the powder is conveyed in lean phase, or convey using low-velocity-airflow dense phase transfer, which requires a high level of vacuum. High-velocity airflow when conveying metal powders leads to abrasion and erosion in the conveying line, which can lead to potential contamination of the metal powder itself. As a result, the slower velocity dense-phase conveying option is preferred. To achieve dense-phase conveying, typical vacuum levels of between 15 and 22 inches mercury are needed for transfer. Systems using side-channel (regenerative) pumps or roots-type units aren't suited to this application.

Vacuum receivers have an advantage when conveying metal powders. The units are easily installed either directly on an AM machine or in conjunction with a surplus powder screening system for material collected during the build process. Vacuum units are inherently contained and in the case of AM, one must work with a system that is safe for the transfer of powders with minimum ignition energy (MIE) values as low as 1 millijoule.

Furthermore, the potential exists to build a complete vacuum transfer system or loop allowing one main convey line to supply each AM machine's vacuum receiver with powder and to be serviced and filled by a bulk material supply system that typically can be located in a separate room. This layout or equipment setup is common in food processing facilities.

Recovering powder from the AM machine for screening can be centralized with the option to either locate the process next to its associated machine or in a separate area, away from the AM production itself. Here again, vacuum transfer shows its value since in vacuum systems controlling the feed to the conveyor with a metering valve isn't necessary. Material can be collected from the build-box, the unloading station, or the overspill area and transferred to a screener, where agglomerates are removed before collecting the powder in a bin or conveying the material back to the main powder supply point.

Combination unloading–screening stations can address the requirement to quickly unload an AM machine and begin the next component manufacturing cycle. Initially, AM build time was long so losing production time to unload wasn't particularly critical; however, with AM production rates increasing, unloading time needs to be minimized. In addition, the screening of fine powders can be difficult given the particle size range and the size of screen opening, typically in the 63 micron range, resulting in the process being slower than the vacuum transfer unloading rate. This, in turn, leads to the incorporation of a buffer hopper system to allow rapid unloading where screening times are independent of the unloading, allowing the next AM process to begin without delay. An example

FIGURE 5

Unloading/screening, station.

of a self-contained unloader and screening station is shown in Figure 5.

Inert vs. noninert material transfer

Further complications exist in that some metal powders can be transferred in a normal air atmosphere, whereas others require an inert gas of argon or nitrogen to control moisture and oxidation levels. Vacuum conveying techniques are well established for inert gas transfer applications for loading material into tanks or reactors containing volatiles. Adapting this type of experience and the techniques learned in these applications again points to the importance for AM users to involve knowledgeable powder handling equipment suppliers and experts from an early stage. Of particular importance is the use of closed-loop systems where inert gas use is minimized, oxygen content levels of between 2 and 4 percent are maintained, and steady state conditions can be achieved for safe metal powder handling.

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Explosion and other risk considerations

Metal powders used in the AM process are very fine, typically in the 20 to 45 micron range. They're not healthy for operators to inhale so require full OSHA-compliant personal protective equipment (PPE) clothing. Dense metal powder materials also are abrasive and potentially explosive. As a result, company safety officers who are new to the AM technique will apply risk analysis; however, plant personnel can be limited in their knowledge because they may not be familiar with handling bulk powders. These individuals, for example, may tend to specify electrical classifications such as Class II, Div. 1 or 2 for an explosion risk area rather than considering all 13 of the potential ignition sources that the ATEX code defines. The European ATEX standard, while not strictly applicable in the US, is possibly a complementary standard to use as a guide. It looks at the potential hazards in the process at the pickup point, within the conveying system during conveying, and at the discharge point. The standard applies zone ratings based on potential exposure of the material to an ignition source in sufficient quantity to cause an explosion.

In the US, NFPA 652 and NFPA 484 provide some guidance, although the section on AM is small, with much of the standard of the latter code dedicated to dust collection and vacuum cleaning activities that aren't the same. Undoubtedly, later revisions of the code will add recommendations.

Experienced partners for planning

Given all these factors that contribute to the safe and efficient handling of metal powders during AM, the situation behooves those new to the AM process to involve companies with wide experience of conveying powders, at an early stage in a facility's layout, thereby allowing the entire process to be considered from a practical powder handling perspective. This provides the ability to plan for future additional machines, with the ability to service multiple machines and, of prime concern, to do so safely in a contained system.

Vacuum conveying becomes an obvious choice for handling dense metal powders in AM applications. Using this method allows handling these materials in a contained manner and in systems that are suitable for low MIE-value powders in either atmospheric or inert-gas transfer. Such systems are particularly suitable since they avoid the need for heavy lifting or the use of forklifts in the production area. As with many new technologies and techniques, the involvement of suppliers with experience can avoid considerable production- and employee-related problems as well as expensive mistakes, particularly in areas of safety and cost effectiveness. **PBE**

For further reading

Find more information on this topic in articles listed under "Pneumatic conveying" "Loading, unloading," and "Safety" in *Powder and Bulk Engineering*'s article index in the December 2018 issue or the Article Archive at *PBE*'s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

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