Advances in powder atomization capabilities enable a range of new thermal spray applications.

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Over the last 60 years, significant advances in atomization equipment, techniques, and understanding have improved powder productivity and quality to levels beyond most expectations. This article discusses current atomization capabilities and challenges, and introduces further advancements designed to fuel continued growth for high purity atomized powders into the 21st Century.

The atomization process

Although many different powder atomization techniques and several equipment variations are available, most processes consist of the same basic steps:

- Weigh raw materials and charge furnace
- Heat and bring to molten state
- Pour molten alloy into tundish (or crucible) to consolidate into an alloy stream
- Apply shear force to molten stream to break into droplets
- Collect solidified atomized powder
- Dry powder (if necessary) and perform sizing operations

Like all powder processing applications, thermal spray methods can be sensitive to several powder characteristics that relate to the way the material was atomized. The atomization issues that affect key powder attributes include alloy melting techniques, atomization media and collection, and process cost.

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The synethis alloy is poured into the tundish, where it must be protected from the surrounding air by minimizing exposure of reactive elements, covering with a blanket of inert gas, or melting in an air-tight chamber.

Each of these variables can affect the powder and resultant coating, and therefore must be considered when the goal is to produce coatings that meet quality and cost targets.

Alloy melting techniques

As all atomized powders must be melted prior to being broken into droplets, the reaction between the molten alloy and its environment is critical to the chemical purity of the resultant powder. Typically, the enemy of alloy purity is air and its constituents. Because air is comprised primarily of nitrogen (78%) and oxygen (21%), any alloy containing one or more elements with a strong affinity for nitrogen, oxygen, or other compound-forming gases should be protected from the surrounding atmosphere.

Three common methods help to minimize the interaction between a “furnace melt” and air. The simplest technique is to melt in air and charge the most reactive elements last. This minimizes the exposure time of highly reactive elements such as chromium. Even though this lessens the chances of oxide/nitride formation, it is highly sensitive to variation and operator judgment.

Another common technique involves covering the alloy melt with an inert gas “blanket.” This method, compared with melting in air, significantly reduces the possibility of interactions between the environment and molten alloy. However, the protection is only a thin gaseous cover, still subject to atmospheric gas permeation. Inert gas blanketing...
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Atomization media and collection

Powders can be atomized by high-pressure liquid or gas. The most common types of atomization media are water, nitrogen gas, and argon gas. The interaction between the gas or liquid stream and the molten alloy during atomization can affect the powder's morphology, its solidification rate and microstructure, the percentage of oxides/nitrides precipitated, and the cost of the process. In addition, the atomizing medium has an effect on the average particle size.

Typically, water-atomized powders are produced under a high-pressure, continuous “blast” of water, then collected in a vessel or bed filled with water. Because the alloy stream is broken apart and then rapidly cooled by the water, this type of powder is characterized by dense but irregular shapes and high oxygen content.

In contrast, inert-gas atomized powder usually is spherical and very dense with low oxygen content. Gas-atomized powder benefits from longer solidification time and the lack of oxygen.

Process cost

From the consumer's standpoint, one of the most important factors is the price of the powder, which is closely related to cost of manufacture. Several factors that affect process cost include raw materials, process consumables, throughput, and yield. Depending on the demands and cost constraints of the final application, powder processing costs can be significant factors in the success or failure of a thermal spray solution.

For example, the cost of elemental raw materials is a variable that seldom differentiates suppliers, but has a significant impact on product quality. The practice of using “scrap” or low-purity metals as starting feedstock can save money, but the detrimental impact on the reliability of the coatings produced from sub-par powders can be huge.

Similarly, atomization media costs can be important factors in the production of powders. Water atomization typically is the low-cost alternative versus inert gas processing. Water can be effective in producing powder compositions that are less sensitive to oxygen, or where relatively high O₂ or N₂ levels do not compromise coating performance.

However, in applications where oxides/nitrides do negatively impact the hardness, ductility, corrosion, or strength of a thermal spray coating, a higher cost, higher quality atomization gas such as argon is required. Even though the consumable cost increases, the total cost of the coating, factoring in prolonged service life, typically is more economical. Other powder cost benefits also result from melting under vacuum and processing with argon, including longer furnace and tundish refractory life.

Yield is the other key atomization element that can have a tremendous effect on overall powder cost. Every atomization process produces a bell-shaped distribution. However, each thermal spray process requires a specific distribution that does not necessarily align with the distribution generated from atomization. Not only does the focus on maximizing yields affect material utilization costs, but also it impacts costs associated with throughput, labor, and overhead, as well. Ultimately, yield is the most critical factor in determining the difference in the total cost of a thermal spray powder from one producer to another.

Current issues with atomization

As with any process, certain factors either reduce the effectiveness of the system or, in the worst case, prevent the process from outputting anything. With atomization, the major issues of concern include melt temperature, furnace melt solidification (freeze-ups), particle irregularities, powder impurities, yields, and throughput.

- Melt temperature: Most of the atomization systems in operation today have strict limitations on the maximum melting point to which an alloy can be processed safely. Melt temperature limitations typically are determined by the functional stability of the furnace refractory material. For simple alloys, such as common nickel-base powders or stainless steels, this is not a problem. For targeted “next generation” powders designed to combat oxidation, corrosion, sulfidation, and extreme wear, such limitations are not acceptable. Typically, the refractories have a maximum functional limit of around 1600°C (2900°F). The need to superheat alloys above their melting point prior to pouring and atomizing presents an interesting time/temperature management challenge. The furnace operator must apply enough energy to fully melt the alloy
and keep it molten through the entire atomization process, while dealing with the temperature limits of the refractory materials that line the furnace. Very little margin for error exists. A judgment mistake in either direction can cause a catastrophic failure.

- **Furnace melt solidification:** After the metal has been melted and poured into the tundish, the molten alloy begins to lose heat rapidly. The alloy can solidify and create build-up in the atomization nozzle, causing a blockage or “freeze-up.” Freeze-ups are not only problematic because of the loss of production time, but also because of the excessive downtime related to clean-out and rebuilding the tundish and/or furnace.

- **Particle irregularities:** As stated, the ideal atomized powder for thermal spray is perfectly dense and spherical. Unfortunately, the process does not always yield this type of powder. Many irregularities are caused by interaction of the molten particles during solidification. One example of an irregularity is satellites: one or more small particles attached to larger particles. Other examples are needles: acicular, long thin particles that form due to irregular solidification reactions; geodes: unintended hollow particles; and flakes: flattened particles from molten alloy impacting against the walls of the atomization chamber.

- **Powder impurities:** The thermal spray process is flexible enough to utilize the products of many different atomization variations. However, gas-atomized metallic powders typically are preferred by OEM end-users, as well as by thermal spray coating providers. The reason is superior performance. Gas-atomized powders are cleaner, with fewer impurities and unwanted residual elemental content, and therefore provide a margin for error to the process. Most thermal spray systems are run in air, without the benefit of a controlled environment. The sprayed molten particles are vulnerable to absorbing oxygen and/or nitrogen. This is the exact same condition that exists during atomization.

  Efforts can be made to limit these interactions and mitigate the pickup of unwanted residuals, but it cannot address the impurities already contained in the powder. Thus, if coating purity and performance are required, it can be achieved only by starting with high-purity powder. Argon gas atomization of high-purity raw materials, with inert gas powder collection, represents the highest purity level achievable in the mass production of thermal spray powders.

- **Yields and throughput:** The cost to manufacture thermal spray powders is, in many ways, no different from the production of anything else. The speed and efficiency with which the product is processed has a great impact on its unit cost. Older equipment may still be capable of producing quality materials, but such systems typically lack the controls that would constitute “world class” processing. The compromise of antiquated technology includes lower productivity and, possibly, a higher risk of catastrophic failures.

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New solutions to old problems

Recently identified thermal spray market opportunities have inspired new atomization advances. The driving forces behind these advances are the needs for:

- "Next generation" powders made by the highest quality, fastest, most economical and safest methods
- Advanced atomization technology to produce materials that will help spur "revolutionary" industry growth and support new materials and coatings development
- Continued improvements in powder manufacturing methods and less expensive and more advanced techniques for producing coating materials. Most technological and productivity improvements have focused on gas atomization. This preferred method of powder production has been further improved by specific production and efficiency enhancements designed to address the issues and challenges identified earlier.
- Melt temperature limits have been raised through a combination of modified alloy melting techniques, the identification of better refractory materials, and the design and incorporation of advanced technologies to limit enthalpy loss during material delivery. This new atomization design produces alloys with melt temperatures well above those currently being manufactured by conventional atomization.
- Furnace melt solidification (freeze-ups) can cause the tundish nozzle to plug, creating a system breakdown that results in downtime. Such freeze-ups cause significant losses of productivity and represent a potential safety issue. To address this challenge, one company has implemented a proprietary furnace design that attempts to prevent such occurrences and incorporates a back-up option that responds quickly if the material should freeze up. The prevention effort is controlled by the ability to better maintain melt temperature. Expectations are that this will minimize, if not eliminate, freeze-ups. “Quick exchange” furnaces have been engineered to significantly reduce the turnaround time for a re-start in the unlikely event of a freeze-up.
- Powder irregularities — satellites, geodes, flakes, needles — are being addressed through innovations in the area of gas injection. By researching the way particles interact with their surroundings during atomization, new techniques have been integrated to control particle solidification and gas flow, considerably reducing the interaction between cooling particles. The result is less satellite formation and a reduction in other product abnormalities such as flakes and needle-like particles. In addition, better gas flow and cooling technology also provide improved control over the variables that affect particle size distributions.
- Gas costs are being reduced by recycling. To reduce the cost impact of high-purity gas on the overall process, at least one major powder producer has engineered a state-of-the-art, closed-loop gas recycling system. Gas recycling helps make the entire atomization process more cost-competitive while still providing the unique advantages that gas atomization provides.
- Yields and throughput are being increased by addressing and improving each stage of the manufacturing system. The new atomization capabilities greatly improve product yields and system throughput.

Many significant improvements have been developed and implemented to advance powder atomization technology, capability, and efficiency. However, even greater process improvement is needed. Powder manufacturing methods and thermal spray technology continue to drive forward with innovative applications, increasing the demand and capability for high purity, high performance, low-cost atomized powders. To utilize the unique surface engineering benefits of thermal spray to their fullest potential, advances such as those described here must continue. Development of technology and know-how that enables the production of highly engineered powder solutions at competitive prices will lead to the continued growth of the thermal spray market.

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