The Role of Industrial Gases in 3D Printing of Metal Parts

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Additive manufacturing is transforming manufacturing as we know it, dramatically speeding up the process from initial design to manufactured piece. Parts that used to take weeks to create are now being created in just days. The term "additive manufacturing" encompasses many technologies including 3D printing, which is expanding the options for production efficiency and creating new intricate designs and structures that, until now, were not feasible using traditional methods.

Companies have been using additive manufacturing since the 1980s, primarily for the production of prototypes for testing. In recent years, however, new 3D printing machines have been manufacturing an increasing number of functional metallic parts, particularly in the medical and aerospace fields. Analysts expect the market just for additive manufactured metal products, as well as the market for the powders needed to make them, to continue growing at a rapid pace, reaching $6 billion by 2017. (Source: Wohlers Associates)

The Basics

Additive manufacturing describes technologies that build 3D objects by adding layer upon layer of material, particularly for metals and plastics, and even more recently for concrete. Additive manufacturing technologies commonly use a computer, 3D modeling software, machine equipment, and a layering material. Once a Computer Aided Design (CAD) sketch is produced, the additive manufacturing equipment reads the data and lays down or adds successive layers of material in a layer-upon-layer fashion to fabricate a 3D object, building from the bottom up.

This process allows for the creation of highly complex geometries translated from a 3D CAD file to a finished product in hours and without any tooling, resulting in parts with high accuracy and detail resolution, good surface quality, and excellent mechanical properties.

Metal part printed by TURBOCAM. This process allows for the creation of highly complex geometries.

There are several types of 3D metal printing processes in which industrial gases are used, such as laser metal deposition, direct metal laser sintering, selective laser melting, and electron beam melting. The types of parts that are commonly manufactured with these systems include geometrically complex medical implants, turbine blades, fuel nozzles, gears, bearings, feed units, furniture fittings, and compressors.

When using this method of manufacturing for metal parts, proper gas environment is important to achieve optimal part quality and consistency. Nitrogen and argon are the gases commonly used to provide inert atmospheres during additive manufacturing. Using sufficient flow rate and purge duration helps to avoid undesired chemical reactions and thermal deformation of consolidated parts, as well as ensure a safe production environment. For example, the presence of high oxygen content in the production atmosphere may result in oxidation of the powder metal, leading to poor part quality, clumping of the powder feed, or high porosity in the end product. It may also reduce the amount of recyclable powder for future use.

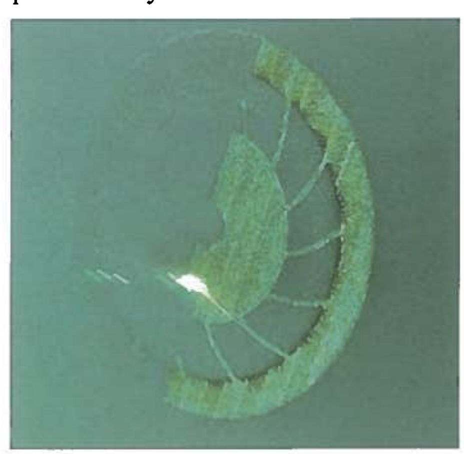
Inerting also allows for safe handling of the combustible dust arising from the powder metal and printing process. Post-manufacturing heat treatments after printing may also require the use of a protective gas environment, depending on the application.

"Air Products is excited to be playing a role in this emerging market," said Justin Rabe, industry marketing specialist at Air Products. "Maintaining the proper gas atmosphere by using gases such as argon and nitrogen helps additives manufacturers efficiently produce quality parts that meet the high-tolerance standards required in 3D printing."

Gas Atmosphere Selection

Of the numerous additive manufacturing technologies, laser printing of dense metal parts is becoming increasingly popular. Similar to laser cladding, the printing process involves powder melting, consolidation, and solidification steps, and takes place in a controlled atmosphere chamber, sometimes under reduced pressures. The selection of printing atmosphere is significant not only for safety when working with pyrophoric, fine metal powders, but also for the recovery of unused metal powder and the physical and chemical properties of printed parts.

The most popular metals commercially printed today include tool and stainless



Direct Metal Laser Sintering (DMLS) process using an argon atmosphere to print a prototype.

steels; nickel- and cobalt-based superalloys; titanium alloys, predominantly those containing aluminum, copper, and nickel; and aluminum alloys, including aluminum-magnesium grades. Additional metal matrix composite and nanostructured steel products are also under development.

Not surprising, the response of this broad range of materials to the composition of printing atmosphere varies drastically. For example, when contacted with nitrogen at high temperature, titanium, aluminum, and steels, or alloys containing reactive additions such as chromium or niobium, form hard nitride precipitates. This is useful for enhancing wear applications, but typically detrimental to corrosion resistance, ductility, and fracture toughness.

Excessive nitrogen may also produce microporosity in certain ferrous alloys. Consequently, in applications where preservation of the original powder composition in the printed product is required, it is recommended that only high purity, totally inert noble gases, such as argon or helium, be used in the chamber. On the other hand, the use of pure nitrogen is acceptable when processing relatively non-reactive powders, such as copper, or printing low-quality steel parts.

The use of helium — a highly thermally conductive, though more expensive gas — offers an interesting option for minimizing the thermal distortion of elongated parts during printing. Helium is often used for post-build cooling of operationally critical aerospace and medical components that are processed under vacuum in electron beam melting applications.

Surface adsorbed water, as well as moisture and hydrocarbon gas contaminants, may result in a lasting embrittlement of printed parts due to the simultaneous oxidation and absorption of hydrogen during printing. Sputtering, excessive metal vaporization, powder slagging, and agglomeration leading to reduced rates of recycling are other symptoms of water vapor and residual oxygen contamination of the work environment. The problem becomes acute with fine-sized feed powders, which are becoming increasingly important in the field due to the advantages they offer, such as higher build rate and improved geometric accuracy. A simple solution involves purging the chamber with high purity gases at a sufficiently high flow rate, something that can be accomplished economically when using a cryogenic liquid supply tank versus the usual gas cylinder supply.

TURBOCAM technician demonstrates the capabilities of their EOS additive manufacturing printer.
(Note: EOS is the world's leading manufacturer of laser-sintering systems, according to their website.)

Proper selection of gas composition, purity, flow rate, and supply system can lead to powder cost savings, improved part quality, and eliminated or reduced post-processing operations on as-printed parts, resulting in an overall lower unit cost of production.

Process Optimization

Air Products recently worked with TURBOCAM International, a world leading manufacturer of precision metal parts for aerospace, automotive, and industrial applications. TURBOCAM uses high purity argon in their 3D printing process, which they have found keeps out more impurities, particularly nitrides, and enables them to deliver a better end product to their customers. TURBOCAM also believes that using argon instead of other gases opens up their options in terms of materials they can use.

Following multiple site visits to gain an understanding of TURBOCAM's overall process, Air Products installed a bulk supply system properly sized to meet TURBOCAM's current business requirements, yet scalable to meet future growth projections.

"Air Products has helped us improve our 3D printing on both an environmental basis and a day-to-day operational basis," said Jonathan Bicknell, General Manager at TURBOCAM. "We previously used cylinders and always had to check purity levels, leaks, and whether we had enough gas to complete the build. With Air Products' bulk system, now we have consistent purity levels and consistent delivery of gas for long builds."

In addition, TURBOCAM has installed Air Products' TELALERT® telemetry system, which enables Air Products to remotely monitor the customer's gas supply and schedule product deliveries when they are needed without any disruption to TURBOCAM's gas supply.

"The purity levels and range of gases we can provide will really enable companies to experiment and grow with 3D printing technology," said Rabe. "Whether customers are in start-up or full production phase, Air Products can meet all of their process needs, volume requirements, and purity certification. We have the application support to understand our customers' overall processes and size their systems and gas supply accordingly."

Conclusion

In the world of rapid prototyping and production of metal components, it is important to have the proper gas atmosphere to efficiently produce quality parts. Air Products has extensive applications knowledge in chemical and physical interactions of metals with gases to help additive manufacturers optimize their gas selection, supply mode, and purity for improved part processing that meets the demanding standards required in 3D printing.

While traditional ways of designing and manufacturing will continue to dominate mass markets, progressive technologies like 3D printing are gaining traction. As more industries and manufacturers find new applications for this innovative prototyping and manufacturing process, the additive manufacturing market will continue to be positioned for rapid growth.

To learn more about how Air Products can help additive manufacturers optimize their 3D printing processes, visit the company's new dedicated website at *www.airproducts.com/3d.*

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