MANAGING SAFETY

IN ADDITIVE MANUFACTURING FACILITIES

Overview

While the promise of so-called 3D printing for consumer applications is getting increasing amounts of media coverage, additive manufacturing (AM) technology is already a reality in modern industrial production. Industries across the spectrum, including electronics and healthcare, automotive, aerospace and defense, and even jewelry are quickly adopting AM technologies for precision tooling and parts manufacturing. As a result, the global industrial market for 3D printing technologies is expected to grow at a compound annual growth rate (CAGR) of more than 29 percent over the next six years, reaching $4.75 billion (USD) in annual sales by 2022.[1]

An important and growing industrial application for AM technologies is in the area of industrial metal additive manufacturing. Industrial metal 3D printing is particularly well-suited for efficiently producing high-value precision parts that are lighter and stronger than similar parts produced using conventional production methods. According to the 2016 edition of the Wohlers Report, a leading source of information about additive manufacturing trends, the growth of industrial metal 3D printing is one of the key drivers in overall growth of industrial additive manufacturing.[2] And, while industrial metal 3D printers accounted for only 7 percent of all industrial 3D printers shipped globally in 2015, this segment represents the fastest growing subset of the overall additive manufacturing printer market.[3]

The introduction of additive manufacturing technologies has the potential to transform modern industrial production, but it also brings new considerations for manufacturers and their employees. These considerations include potential safety risks associated with additive manufacturing production facilities, equipment and materials. The introduction of additive manufacturing capabilities can be particularly complex in existing production facilities with established safety management practices.

This UL white paper discusses safety issues in additive manufacturing, with a specific focus on safety issues associated with metal additive manufacturing. The paper identifies the principle sources of risk associated with additive manufacturing, and then presents a methodology for establishing a safety management system or modifying an existing system in advance of the introduction of additive manufacturing capabilities. The white paper concludes with recommendations on the development of safety assessments for additive manufacturing operations.

About Additive Manufacturing

Additive manufacturing is widely defined as a "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies."[4] It differs from conventional manufacturing technologies and processes that rely on the cutting and shaping of raw material stock, or the molding of raw material in forms or dyes. Instead, the AM process utilizes digital data created by 3D modeling software to guide highly-specialized printing equipment in laying down layer after layer of raw materials, until a finished component or part has been fully formed.

Initially introduced in the 1980s, additive manufacturing is rapidly gaining acceptance as an important and viable manufacturing technology. Today, additive manufacturing actually covers a number of different manufacturing technologies, including 3D printing, additive layer manufacturing, additive fabrication, rapid prototyping (RP) and direct digital manufacturing (DDM). Raw materials used in additive manufacturing include metals, ceramics, polymers, composites and even biological systems such as tissues.

Additive manufacturing technologies can theoretically be employed in virtually any type of production operation. But their most efficient application to date has been in the production of low-volume, machine-intensive components and parts that incorporate high-cost materials. The combination of these factors generally results in products that have sufficient market value to offset the significant capital investment in AM equipment and prototyping capabilities that are required.[5] Some specific examples of current industry applications of AM technology include:

- *Aerospace and defense*—AM-produced parts can be used as components in engines and fuel systems, providing lighter weight and often stronger alternatives to conventionally-manufactured parts.
- *Automotive*—Additive manufacturing has been widely used by original equipment manufacturers (OEMs) for rapid prototyping, speeding the introduction of new and innovative automotive technologies.
- *Healthcare*—Additive manufacturing is being used to create customized prosthetics and implants, as well as in the fabrication of tissues and organs.
- *Fashion*—AM technology is being employed in the production of jewelry and other fashion items comprised of high-value materials and complex designs.

The list of potential industry applications for additive manufacturing can be expected to increase as producers become more experienced in its use and more comfortable in exploring the full potential of the technology.

Safety Issues Associated with Metal AM Production

Although additive manufacturing can provide significant benefits in industrial applications, its introduction also brings with it new concerns regarding the potential safety of AM production-related activities. This is especially the case with activities involving metal components and parts, which often utilize new and innovative metal alloys for which little safety information may be available.

Safety concerns related to metal AM can generally be categorized into one of the areas described in the sections that follow.

Materials

Powdered metal used in additive manufacturing is typically microscopic in size, with particle sizes as small as 100 microns or less. Even under anticipated use conditions, this small size increases the risk of biological exposure, either through direct contact with the skin or through inhalation or ingestion. Direct contact can lead to skin irritation and rashes, and health consequences related to long-term exposure via inhalation or ingestion are largely unknown. In addition, the infiltration of powdered metal in the air could contribute to the creation of a potentially explosive atmosphere inside the production environment.

Equipment

Regardless of the specific type of process employed, metal AM production involves the use of potentially-reactive metal powders that could ignite or explode under standard production conditions. Equipment or metal powder containers or repositories that are not grounded or otherwise isolated from electrostatic discharge (ESD) may be vulnerable to a static event that results in a fire or explosion. Also, certain AM production processes rely on the use of gases such as argon or nitrogen that can displace available oxygen in the vicinity, thereby causing inert gas asphyxiation and depriving operators of sufficient breathable air.

Facilities

In many manufacturing environments, floor space can be at a premium. So production equipment is often tightly grouped to maximize space utilization and increase production efficiency. However, this arrangement can impede the flow of clean air throughout the production facility. This consequence can be further exacerbated by the absence of sensors to monitor oxygen levels or to detect the presence of potentially dangerous gases. And, as noted previously, the presence of mechanical or electromechanical equipment and devices can increase the risk of sparking, resulting in an electrostatic event that leads to a fire or explosion.

Additional Considerations

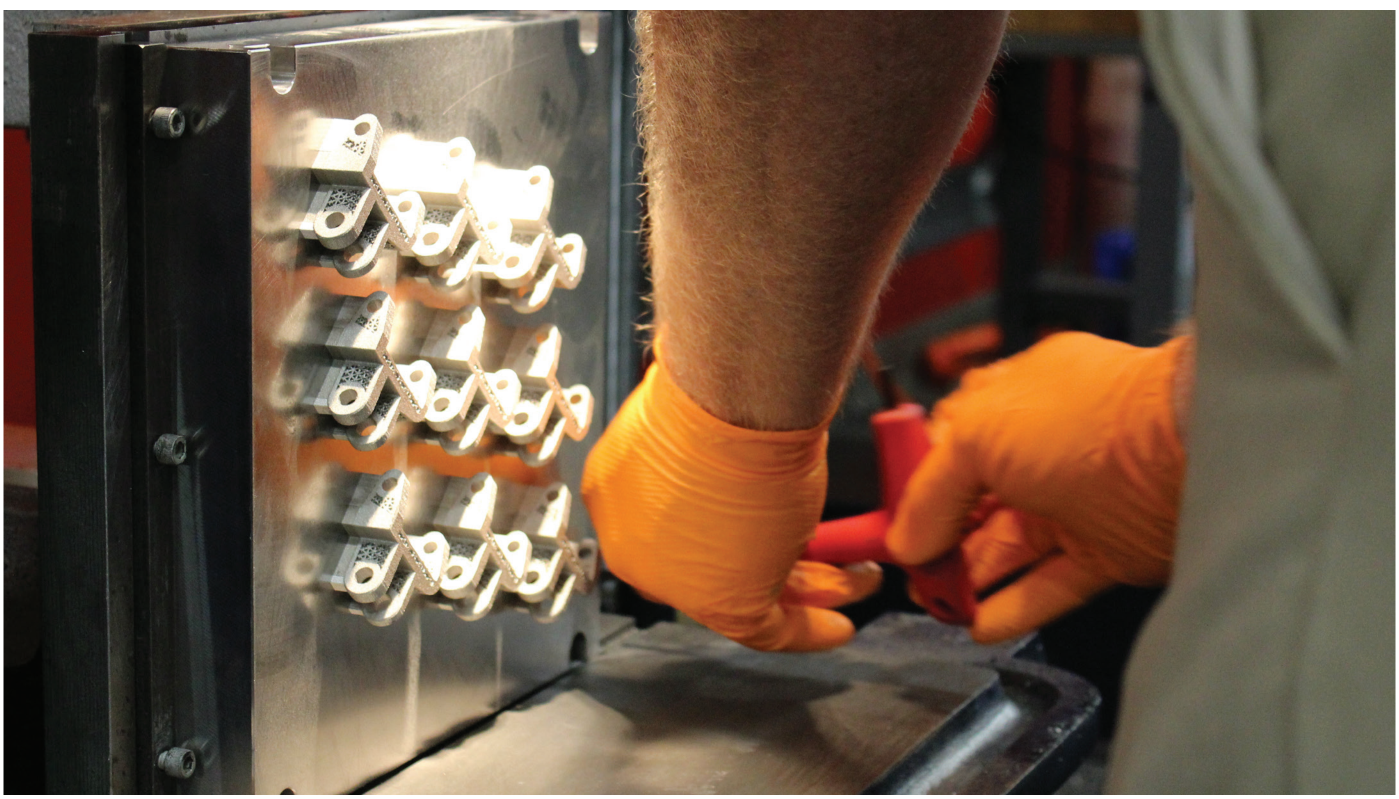
A separate issue related to facilities has to do with the movement and disposal of potentially hazardous materials. Poor or inadequate handling practices can result in leakage or spills of feedstock metal powder, unnecessarily exposing workers to possible health consequences. And improper disposal of spilled materials or cleanup supplies can threaten the quality of water, waste streams and aquatic life.

AM Regulations and Standards

Characteristic of many new technologies, the development of regulations and standards applicable to additive manufacturing has lagged its actual deployment. Part of the explanation for this gap is that new regulations and standards are often based on direct experience with the application and actual use of the technology and processes. However, at the same time, the application of AM materials and processes are still evolving and expanding as practitioners become more experienced with the technology. These realities of AM production further complicate an understanding of the requirements and guidelines that need to be developed.

Despite these constraints, a number of AM-related standards development efforts are underway. To date, ASTM International and the International Organization for Standardization (ISO) have been the primary focal point of AM standards development activities. In 2013, ASTM Committee F 42 and ISO Technical Committee 261 published a "Joint Plan for Additive Manufacturing Standards Development,"[6] which maps out a framework for AM standards development. Together and individually, ASTM and ISO have published at least 14 different AM standards addressing terminology and data formats, materials and testing, with more standards under development.[7]

Additional AM standards development efforts have been undertaken by other groups, including the British Standards Institute (BSI) Committee AMT[8], which has published several AM standards with several more under development, and the Association of German Engineers (VDI), which published VDI 3405 in late 2014.[9] Finally, there is the European Union project SASAM (the Support Action for Standardisation in Additive Manufacturing), which created in 2015 its own roadmap for AM standardization activities.[10]



However, with the exception of VDI 3405, which includes a section on "Safety and Environment," none of the currently published standards directly addresses the issue of safety in additive manufacturing. Instead, safety in AM facilities is governed primarily by jurisdictional regulations that generally apply to all types of facilities and equipment.

To use the U.S. as an example, applicable federal safety regulations include workplace safety laws promulgated by the Occupational Safety and Health Administration (OSHA). The transportation and handling of potentially hazardous materials are addressed in both OSHA regulations and those of the Department of Transportation (DoT). And requirements regarding the generation, transportation, treatment, storage and disposal of hazardous waste is addressed in regulations by the Environmental Protection Agency (EPA). Some U.S. state regulations, notably those in California, may apply different or more rigorous safety requirements to AM-related activities.

So, while safety regulations and standards specific to additive manufacturing have yet to emerge, compliance with the requirements of generally-applicable safety regulations is not optional for AM producers. Failure to comply with safety regulations can result in fines and criminal or civil penalties, and potentially lead to the shut-down of AM facilities. Therefore, taking a proactive and comprehensive approach in evaluating and managing the safety of AM facilities and operations is essential, both for new AM facilities as well as those incorporating additive manufacturing capabilities into existing operations.

Taking a Comprehensive Approach to AM Safety Management

As previously discussed, most safety issues at AM facilities can be categorized into one of three areas, namely, materials, equipment and facilities. Therefore, developing an effective AM safety management plan that addresses safety risks in each of these areas involves a process that:

1. Identifies the hazards;
2. Assesses the severity and likelihood of occurrence of each hazard;
3. Identifies control measures to eliminate completely or mitigate to reasonable levels, the effects of each hazard; and
4. Regularly assesses compliance with the safety management plan.

The following sections discuss each specific step in greater detail.

1. Identify the Safety Hazards

AM-specific safety hazards include fire, explosion and potential toxicity. Specific actions that can be taken to identify these hazards include:

- *Materials*—Identify toxicity, combustibility, instability and reactivity hazards associated with the processing and handling of anticipated AM materials.
- *Equipment*—Identify potential sources of emissions, ignition and radiation hazards.
- *Facilities*—Identify the fire, explosion, toxicity and environmental hazards in facility design, including the storage, handling and disposal of materials, fabrication facilities and their connections.

2. Assess the Likelihood and Severity of Each Hazard

Not all hazards are created equal. Assessing the likelihood and potential severity of each hazard is critical in efforts to prioritize and address them. Some questions to ask about each identified hazard include:

- What is the likelihood of occurrence for an identified safety hazard?
- Does the hazard have the potential to injure workers or damage assets?
- Could the hazard result in a complete or partial shutdown of current operations?
- What are other ways in which the hazard could impact the overall business?
- What would be the estimated cost of remediating harm attributable to the hazard?

3. Identify Methods to Prevent or Mitigate the Effects

The next step in an AM safety management plan is to develop the specific control measures that can be implemented to prevent a hazard from occurring or mitigate its potential effects. A typical approach would include (in descending order of effectiveness: 1) elimination; 2) substitution; 3) engineering controls; 4) administrative controls; and 5) personal protective equipment.

Some specific actions that can be taken include:

- *Materials*—Seek methods that will optimize AM materials for safety and performance.
- *Equipment*—Identify methods to prevent, protect or suppress the consequences of emissions or ignition, such as inerting systems to decrease the probability of combustion, or pressure containment or extinguishing systems.
- *Facilities*—Identify methods to prevent, protect or suppress the consequences of fire or explosion, or toxicity hazards, either through the installation of extinguishing systems, or by incorporating explosion relief or isolation considerations in facility design.

4. Assess Ongoing Compliance

Finally, an effective safety management plan incorporates regular assessments to verify the continued validity of the plan and to help ensure compliance. Specific actions can include:

- *Materials*—Conduct routine evaluations of materials from suppliers to verify conformity with contracted specifications as well as ongoing adherence with material safety best practices.
- *Equipment*—Ensure that AM production equipment is certified for compliance with operations in specific environments, such as hazardous locations and potentially explosive atmospheres.
- *Facilities*—Assess compliance of facility layout and operating practices for compliance with workplace safety regulations.

Summary and Conclusion

Additive manufacturing, and metal additive manufacturing in particular, have the potential to transform industrial production in the development and manufacture of high-quality products, components and parts, and to bring innovative products to market in a more efficient and cost-effective manner. At the same time, safety considerations related to materials and equipment used in AM production are essential to help ensure the health and well-being of workers and society at large. A systematic AM safety management plan can provide a framework for identifying potential risks and developing strategies to minimize or eliminate their impact.

UL's AM Facility Safety Services are designed to help AM technology users manage the risks inherent in AM production and to achieve compliance with regulatory requirements and industry standards. Our four-phase approach includes: 1) site assessment to evaluate and assess the level of risk; 2) development of an implementation plan which details a course of action for mitigating risk and achieving compliance; 3) safety training focused on AM process safety management; and 4) routine audits to help ensure ongoing compliance.

As part of the ongoing effort to foster the continued development of AM technical and business professionals, UL has established the Additive Manufacturing Competency Center in partnership with the University of Louisville in Louisville, KY. The UL AMCC offers hands-on training courses that address AM design set-up, design optimization, machine set up, part production, post processing, part inspection, testing and validation, and facility and process safety.

For more information about UL's facility safety services for additive manufacturing, please contact **AdditiveManufacturing@UL.com** or visit **UL.com/AM**. To learn more about the UL AMCC, visit **UL.com/ULAMCC**.

Endnotes

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