Safety Hazards

Additive Manufacturing

On this page

What is additive manufacturing?

Additive manufacturing, or 3-dimensional (3D) printing, is an umbrella term describing technologies that create precise products using data from computer-aided design (CAD) or 3D object scanner. The objects are built layer by layer instead of through traditional manufacturing techniques such as milling and machining to remove surplus material.

There are several types of additive manufacturing. Common techniques include:

- Material extrusion: involves heating spooled polymers to their melting point and extruding it layer-by-layer to build an object. The layers adhere by controlling temperature or chemical bonding agents.
- Vat polymerization: uses mirrors to direct ultraviolet light through a vat of liquid resin polymer, curing successive layers of resin through photopolymerization.
- Binder jetting: uses a moving head to deposit alternating layers of powdered material and liquid binder (adhesive).

Additive manufacturing was first developed to help organizations create prototypes faster. Using an extensive range of materials, 3D printing can make objects of varying sizes and complexities, including circuit boards, bridges, buildings, and wind turbine blades.

The field of additive manufacturing is still evolving. 4D printing technologies are being developed to create 3D objects that can change or transform over time, leading to possible applications in extreme environments or as biomaterial in healthcare.

What hazards are associated with additive manufacturing?

Potential hazards of additive manufacturing techniques commonly focus on the raw material used and the emissions created during the printing process. At the same time, researchers are still exploring the relationship between exposure to 3D printer emissions and various health outcomes. The short and long-term health effects of exposure to 3D printer emissions are not yet well understood.

Heating raw materials used in 3D printing could expose users to hazardous aerosols and thermal decomposition products such as volatile organic compounds (VOCs) and ultrafine particles (UFPs). The concentration of emitted particles and compounds can vary depending on the type of machine, material, and additives used. An individual's exposure to these substances can also vary based on the number of machines in operation, the size of the machine, their proximity to the machines, and the length of exposure time. Researchers are still studying the character of these particles and compounds that make up these emissions.

For example, 3D printing using polylactic acid (PLA) filaments have been found to emit volatile organic compounds (VOCs), such as formaldehyde, and respirable particulates. 3D printing using acrylonitrile butadiene styrene (ABS) filament also emits ultrafine particles and volatile organic compounds, both of which have the potential to contribute to negative health effects.

Volatile organic compounds associated with 3D printing are usually monomers used to obtain the filament material, such as:

- Styrene a possible respiratory sensitizer and carcinogen
- Methyl methacrylate: a respiratory and dermal sensitizer, and respiratory irritant
- Caprolactam: a potential inducer of contact dermatitis
- Ethylbenzene: a respiratory and eye irritant; affects the nervous system causing dizziness; may cause damage to blood and organs

Ultrafine particles (<100nm in diameter) like those emitted during 3D printing are currently being studied in terms of possible long-term health effects. However, due to their small size, these particles may be able to affect the cardiovascular and respiratory systems, as well as trigger allergic reactions.

What health effects are associated with additive manufacturing?

Health effects of exposure to ABS type 3D printer emissions are currently being explored with in vivo, in vitro, survey-based, and case-specific studies examining the effects on the respiratory system, cardiovascular system, and skin.

Acute exposure: Studies of exposure to 3D printing have associated acute exposure with health effects to the respiratory system, skin, and eye. There have been individual cases reported:

- A worker developed hypersensitivity pneumonitis after exposure to nylon powder-based 3D printing.
- A worker developed asthma while using ABS filaments with 3D printing.
- Two workers developed contact dermatitis while working with epoxy resin-based 3D printing.

Long-term exposure: Using printers more than 40 hours per week has been associated with a self-reported respiratory diagnosis of asthma or allergic rhinitis.

Because research data are not yet conclusive on the health effects of working with 3D printers, it is important to keep the exposure as low as reasonably possible. Therefore, it is important to conduct workplace-specific assessments to determine whether exposure could pose a hazard to worker health.

What can workplaces do to minimize hazards from additive manufacturing?

As with all new technologies being introduced to the workplace, it is important to identify possible hazards and assess their risks. For example, health and safety information can be found in the safety data sheet of raw materials (i.e., filaments, powders, and liquids).

Employers can also measure worker exposure to particles and compounds in 3D printer emissions by conducting air sampling throughout the workday or shift cycle.

If the emitted chemicals are known, workplaces can compare the measured concentrations to accepted occupational exposure limits such as threshold limit values (TLVs) set by the American Conference of Governmental Industrial Hygienists (ACGIH).

Since the make-up of 3D printer-emitted particles is not well-characterized yet, particle concentrations have been compared against the occupational exposure limit of “Total Particulates Not Otherwise Classified” (NIOSH 0500 and 0600 methodologies).

In addition to potential adverse health effects, workplaces should also consider other health and safety hazards associated with 3D printing in their assessment, including electrical and mechanical hazards, heat, and ultraviolet light.

It is also important to consider not only hazards during printing but also during associated tasks including:

- Loading/powering raw filament/powder material in printers
- Direct handling of raw material
- Applying glazes/coats/paints to finished parts
- Cleaning/maintaining printers

- Cleaning/maintaining ventilation equipment and area surfaces
- Drafting and designing prints
- Disposing raw materials/paints/glazes

Control measures

Because additive manufacturing is a relatively new technology, there may not be established safety requirements for organizations to follow. In the absence of standardized safety guidelines, employers should follow the printer manufacturer's operating and safety instructions and apply the principle of ALARA – keep worker exposure as low as reasonably achievable.

No matter the amount of information available about the hazard, it is always important to follow the hierarchy of controls.This hierarchy help workplaces prioritize control methods from the most effective level of protection to the least effective level of protection.

Control measures that workplaces can consider include:

Elimination/substitution

- Limiting the use of higher emitting polymers when possible.

Engineering control measures

- Physically isolating the printer from workers (e.g., using a partial or full enclosure).
- Using local exhaust ventilation to directly remove contaminants at the printer.
- Increasing passive and active room ventilation to decrease the concentration of contaminants in the air.

Administrative control measures

- Increasing workers' distance to the printer while it is in operation and limiting the amount of time spent near the printer.
- Password protecting printer settings to limit equipment access to only trained personnel.
- Establishing standard operating procedures for the setup and use (e.g., limiting the use of temperatures higher than those specified for the filaments used).
- Ensuring regular maintenance of printers as recommended by the manufacturer.
- Educating and training workers on the hazards associated with the 3D printer and how to perform their tasks safely.

Personal protective equipment

- Ensuring appropriate personal protective equipment is available and maintained.

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