Plastic Melting and Safety in 3D Printing

Introduction

Plastic, when burned, emits significant quantities of toxic fumes such as dioxins, furans and carcinogens which are extremely harmful to life. To burn plastic to the point where it decomposes, it is necessary to heat it to a sufficient temperature and for it to catch fire, the polymer molecules must chemically react with the molecules of air.

Additive manufacturing and 3D printing have become rapidly growing technologies to produce precise and intricately designed objects while being relatively cost effective and fast in design and production. An essential step in 3D printing involves melting plastic and extruding it through a nozzle at high temperature. So, does this mean that 3D printing poses a significant safety hazard of emitting toxic fumes during the process?

Consequences of Melting plastic

It is important to consider that melting is not the same as burning. Melting is a physical process that involves the phase transition of a substance from its solid to its liquid state. Burning, on the other hand, is a chemical process usually including oxygen that involves a substance being broken down and changed into different substances [9]. A key difference is in the temperature for both processes. Usually, thermoplastics melt at a lower temperature than that at which they decompose or ignite [1]. They burn only if they are under high temperatures for a prolonged time in the presence of sufficient air. It is also important to note that additives are usually added to plastics to reduce their flammability [10]. Due to this, it is difficult to pinpoint a burning temperature for many plastics.

However, it is still possible for the melting plastic polymers to raise the particulate matter concentration in the surroundings, react with air molecules and emit other toxic fumes such as Volatile Organic Compounds (VOCs). This includes extrusion based thermal processing used in 3D printers. We must consider to what extent they emit fumes, what are the types of these gases and their levels of toxicity.

Studies conducted on the emission of VOCs and their exposure to the environment is limited. There is a 2015 study where the particle emission rates, particle concentration and VOC concentration were measured for the two most used plastics in 3D printing – PLA and ABS [2].

Analysis of particulate matter and VOCs emitted during standard 3D-Printing

The study measured these quantities while operating a 3D printer in a filtered test chamber. For an ABS filament, there was a sizable increase in ultrafine particle (UFP) concentration during the printing operation along with a considerable rise in the total VOC ((TVOC) concentration inside the chamber. The TVOC concentration was measured using the ppbRAE 3000 monitor. For one of the PLA samples used, there was a sizable increase in the UFP concentration as well. However, there was no increase in TVOC amounts detected by them despite the ppbRAE having a least count measurement of 1 ppb. There was a rise in formaldehyde concentration in using both PLA and ABS cartridges. The TVOC concentration was 154.9 ppb on average during the operation of 3D Printing while using ABS [2]. The concentration of each VOC is likely to be below the workplace exposure limits since the limit for formaldehyde alone is 0.75 ppm (750 ppb) in Canada [12].

Despite PLA being the least toxic plastic during standard extrusion, PLA is harder and denser than ABS; it is prone to extrusion jams [3] which may require us to increase the nozzle temperature

further to free the plastic, in which case it is likely for there to be a rise in the emission of fumes.

In such a case where extrusion is being done at high temperatures, monitoring of the fumes could be necessary for PLA as well. [4]. However, normally, under controlled environments where the 3D printer is in a closed chamber and there is sufficient ventilation in the room, risk of exposure to the fumes is minimal [5].

Another study conducted in 2020 also measured TVOC concentrations of three 3D printers being used simultaneously and found that while TVOC concentrations increased considerably, they were still below the Workplace Exposure Limits [6].

Recycled Plastic in Additive Manufacturing

These days recycled plastic is being used for 3D printing which includes PLA, ABS, PET and HIPS. We have already seen the effects of using PLA and ABS as it relates to VOC emission. However, with PET, which is the most recycled plastic [7], there are limited published studies.

There is a 2010 UK study that finds analytics related to extrusion based thermal processing of PET and HIPS. It shows that the VOC concentration in extrusion operation of PET pellets is well below Workplace Exposure Limits (WELs) [8]. For example, the measured quantities of VOCs were all below 32 ppb during PET extrusion while WEL of concerning VOCs such as Benzene and Formaldehyde are 1 ppm [11] and 2 ppm respectively over an 8-hour period [12] in the UK. Similar results were found for the thermal processing of HIPS. It is possible that we have a similar case in additive manufacturing.

None of the studies referenced include any mention of release of dioxins during the thermal processing of plastic.

Polymer type	Recyclable?	Melting Temperature (^{o}C)	Ignition/Decomposition temperature (^{o}C)	Considerable increase in VOCs?	VOC levels below WEL?	Dioxins detected?	Increase in formaldehyde?	formaldehyde levels below WEL?
PLA	Yes	170-180	~450	No	Yes	No	Yes	Yes
ABS	Yes	200	~416	Yes	Likely	No	Yes	Yes
PET	Yes	260	~350	No	Yes	No	Yes	Yes
HIPS	Yes	150-180	~300	No	Yes	No	Yes	Yes

Table 1: Indication of fumes in thermal processing of plastics during extrusion/3D printing based on research studies.

Source: Adapted from [2] and [7]

Solutions

We must consider that thermal processing of plastic is done regularly in factories. Ways of being safe include wearing safety equipment like masks and having respirators ready in case we need to increase temperatures which may release more fumes (circular economy is possible if the respirators are made of recycled plastic). Keeping printers in chambers and cleaning them regularly is useful. Keeping printers in rooms with good ventilation is necessary along with gas absorbents or filters if

required. VOC and particle monitors may be required to inspect air quality during safety inspections. Keeping sensors that detect if certain VOCs or fumes go beyond threshold limits can be useful.

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