STUDENT EDITORIAL

Sustainable Additive Manufacturing: Exploring Challenges and Opportunities of Recycled Plastic Materials in 3D Printing

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Introduction

Polymers play an important role in modern society as they offer a variety of mechanical and chemical properties that make them useful for a wide array of applications such as automotive, agriculture, construction, and packaging. Polymeric materials are inexpensive, lightweight, and durable materials processed into a variety of products that are widely used in industrial and consumer applications, leading to an increase in their production [1]. However, the issue of the non-degradability of plastic materials has caused plastic waste pollution which affects ecological environment as the management of polymers is crucial. One of the proposed ways to reduce plastic waste pollution is to remanufacture, repair, reprocess, or recycle polymer materials into 3D printed feedstock.

In recent years, polymers such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyamide (PA/Nylon), and polycarbonate (PC) have been widely used in producing plastic prototypes for additive manufacturing (AM). Additive manufacturing (AM), also known as 3D printing, has been extensively implemented in various manufacturing sectors such as aerospace, automotive, dental, heavy equipment, medical industries, and consumer goods since the fourth industrial revolution [2]. Over the past few years, an increment of 32% has been reported for the use of 3D printing in the production of machine components [3], leading to numerous social impacts. 3D printing is a process of making three dimensional solid objects from a digital file by producing 3D products layer by layer using feedstock such as wire, filament, or powder without the need of machining. 3D printing offers cheap, fast, automated production without limitations to geometry complexity, high material efficiency, and less waste. A few steps are involved in additive manufacturing: i) Scan an existing object or create a 3D model using computer-aided design, ii) Slice the 3D model with slicing software, and iii) Feed the file to your printer and the model is ready to print [4]. Material jetting, VAT photopolymerization, material extrusion, binder jetting powder bed fusion, sheet lamination, and directed energy deposition are the classifications of additive manufacturing.

The sustainability of recycling plastic waste and the feasibility of using recycled polymeric material feedstock in 3D printing have been focused recently [3,5,6]. Using pure recycled polymeric materials in 3D printing is an efficient way to reduce plastic waste. However, their usage in various applications has been restricted due to pure recycled polymeric materials providing low strength and stiffness, and the properties may be lower after several recycling times. In order to solve this problem, bio-composite (polymers matrix with natural fiber) has been explored [7,8,9]. Although polymer recycling can be achieved in additive manufacturing, the fabrication of the recycled plastic materials feedstock is still very challenging. In this article, the challenges and opportunities of recycled plastic material in 3D printing are reviewed.

Challenges of Recycled Plastic Materials in 3D printing

Recently, some researchers have been focusing on the fabrication of plastic or composite filaments from recycled materials for fused filament fabrication (FFF). However, the usage of recycled materials in 3D printing faces some challenges, leading to the presence of defects in the final 3D printed parts. There are two main challenges when using recycled materials in 3D printing. The first challenge arises from the possibility of contaminants and impurities from previous usage that remained in the recycled materials [10]. These contaminants can restrict proper bonding between layers during the 3D printing process, resulting in poor interlayer adhesion (Figure 1). Consequently, the overall strength and mechanical properties of the 3D-printed part are reduced. Furthermore, contaminants or impurities can interfere with the 3D printing process, causing clogging or inconsistent material flow through the printing nozzle. Consequently, this can lead to various print defects, incomplete layers, or failed prints. Notably, the presence of impurities in recycled materials can create surface defects on the 3D printed part, such as roughness, bumps, or irregularities, which negatively affect the surface quality and functionality of the final product.

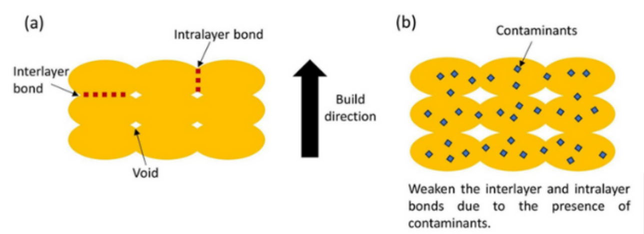

Figure 1: Proposed illustration of two scenarios related to 3D printed parts (a) good interlayer and intralayer bonds, and (b) poor interlayer and intralayer bonds caused by the presence of contaminants in the recycled materials.

The second challenge is the warping defect that occurs when using recycled materials in 3D printing. Warping is a common defect that can occur during the 3D printing of recycled materials. It happens due to the deformation or curling of the printed part (Figure 2), especially at the edges or corners of the part, which is caused by uneven cooling and the uneven distribution of thermal stress in the material during the printing process [11]. According to the report by Tan et al. (2023), poor interlayer bonding is a common problem in 3D printed recycled materials, as it can reduce the mechanical strength and dimensional stability of the 3D printed parts. The poor adhesion between layers makes the part easier to warp [11]. Furthermore, the recycled materials often have different thermal properties in comparison with the virgin materials, leading to uneven cooling and shrinkage during 3D printing, resulting in warping. Moreover, incorrect, or inappropriate printing settings, such as a high print bed temperature, excessive print speed, can cause warping issues in recycled materials [12].

Figure 2: Illustration of 3D printed parts with the warp and curl defects.

Opportunities of Recycled Plastic Materials in 3D printing

Recycling plastic materials is a great choice for 3D printing. Nowadays, many researchers focus on utilizing recyclable plastics into 3D printable materials, which is an excellent approach to reduce the amount of plastic waste in landfills and waterways. Recycling plastic materials offers some benefits over virgin plastic, such as reducing the environmental impact caused by plastic waste disposal. It is also more sustainable as the process of recycling plastic generates less greenhouse gases and uses less energy compared to producing virgin plastic.

The Tokyo Olympic 2020 is a great example of how sustainability can be achieved by recycling plastic materials and using them in 3D printing for applications. The global consumer company P&G collaborated with Tokyo Olympic Organizers to collect an estimated 45 tonnes of plastic waste from communities and recover it from the ocean. They then recycled this waste into recycled plastic resin and used it to fabricate podiums through 3D printing [13].

Recent researches have found that Styrofoam can be recycled and formulated into various types of 3D printable filaments, including plastic blends and composite materials [14-15]. These studies provide a good example of how Styrofoam waste can be transformed into 3D printing materials for sustainability. Additionally, polypropylene, a plastic material commonly used in food containers, can be recycled, and turned into recycled plastic resin. When combined with fibers extracted from chopstick waste, it can be used to print applications, such as face shield frames [11]. As technology advances, the possibilities of converting recyclable materials into 3D-printed objects are endless.

There is almost every type of plastic material that can be recycled and turned into 3D printable materials. Moreover, plastic waste is readily abundant. If recycled plastic materials can be 3D printed into products, this presents an opportunity for promoting recycling, making it a significant step towards sustainability.

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HIGHLIGHTS

What Are The Key Criteria to Have A Safe and Reliable Installation of Composite Repair System?

Is There A Better Way to Detect Wet or Saturated Insulation?

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