Proceeding Paper

3D Printing with Biomaterials—The New Sustainable Future of Textiles? †

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Abstract: Additive manufacturing (AM), also known as 3D printing, encompasses a wide range of techniques for applications ranging from on-demand production to functional prototypes. 3D printing is mainly used in industrial sectors such as aerospace, automotive, medical, dental, construction, art and fashion. Fossil fuel-based materials, such as plastics and metals, as well as concrete, etc., are widely used to produce 3D-printed products. More recently, innovative 3D technologies using new bio-based renewable materials have shown promising results for everyday applications, opening up new opportunities for sustainable 3D printing in the future. This review reports on developments in the 3D printing of bio-based materials, direct or partial printing on textiles, etc., providing considerations, challenges and future outlooks.

Keywords: sustainability; 3D printing on textiles; fused filament fabrication; FFF; recycling; textile manufacturing; bio-based filaments; biodegradability; additive manufacturing; biomaterials

1. Introduction

Additive manufacturing (AM), or 3D printing, is used in various industries, including health, transportation, food and fashion [1–3]. One of the biggest application fields is its ability to produce prototypes quickly and cheaply traditional injection-molded prototypes, which is particularly important for industries such as automotive and aerospace [4]. In fashion, 3D printing has been used to create unique and sustainable pieces that offer a high degree of design freedom in shapes and structures. With 3D printing, it is possible to reduce waste generation in traditional garment production during the cutting and sewing processes. Until now, this type of fashion has been developed for catwalks in the haute couture section. However, there are also challenges associated with 3D printing in fashion, particularly in terms of comfort and flexibility, so the manufacturers have to choose between material and structure-based flexibility [3]. Many 3D-printed objects are relatively stiff when printed as a whole piece, which can be uncomfortable to wear. To address this issue, designers and manufacturers have developed a few techniques, like direct-to-garment printing, partial garment printing and fabric-like printing [4].

Direct-to-garment printing involves printing designs directly onto existing garments, which allows for greater flexibility and comfort. Partial garment printing involves printing individual segments that are then assembled into a larger garment, while fabric-like printing, one of the most versatile techniques, involves trying to imitate textile-like structures, like a knitting, mesh or net structure, with geometrical forms to achieve a higher flexibility by using multiple assemblies. But CAD systems have limitations in adjusting, creating and saving large amounts of data when wrapping linkages over complicated structures [5].

Material-based flexibility is still a small market segment due to the weakness and low tear resistance of current rubber-like materials. The easiest way to create everyday fashion using 3D printing is through the use of 3D-printed flexible, textile-like structures, which are currently the largest part of the 3D printing market [6,7].

2. Biomaterials in 3D Printing

Various resources are found on Earth, including non-renewable fossil fuels and renewable organic biomass. Manufacturing 3D-printed products from biomaterials contribute to sustainability and resource savings by using natural polymers that have similar material properties to their fossil counterparts while offering better sustainability and biocompatibility. In general, the most used thermoplastic is polylactide acid (PLA), a biobased plastic. The second most used is acrylonitrile butadiene styrene (ABS), a fossil-based plastic [8]. To meet the needs of future generations, a fundamental transition to a bio-based economy is required as the demand for and availability of 3D printing continues to grow. This can lead to a rise in waste that is not correctly disposed of or recycled at the end of its lifetime [9]. Therefore, material sustainability is investigated in the following, especially with regard to the use of biopolymers instead of non-biodegradable, fossil-based polymers.

2.1. Bioplastics

To produce biomaterials, in particular bioplastics, various crops are utilized to withdraw starch, sugar, oil or cellulose from soybeans, wood, wheat, perennial grass, maize or potatoes. Then, the crops are transformed into intermediate products of bio-based bulk chemicals via conversion techniques, which are then transformed into various bio-based plastics, e.g., through gasification, which leads to methanol, pyrolysis, results in bio-oil, etc. [10]. Figure 1 gives a visualization of this production.
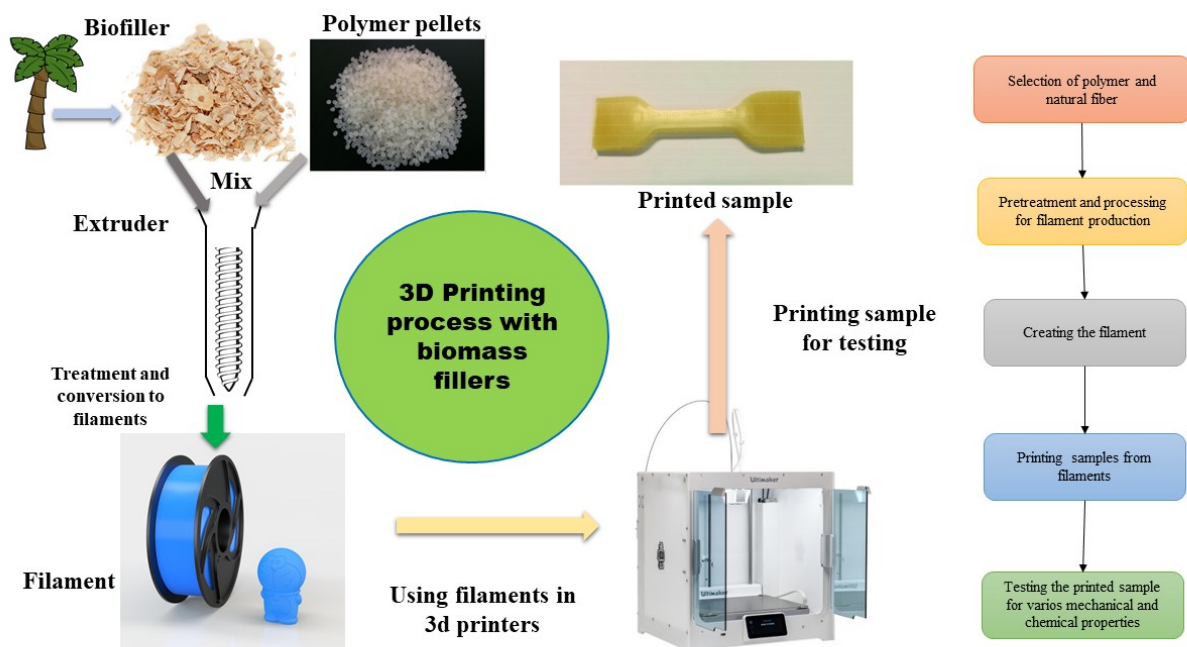

Figure 1. The cycle of 3D printing using natural fibers. Reprinted with permission from Ref. [11]. Copyright 2020 Materials.

2.1.1. Commercially Available Bioplastics

Bioplastic PLA has proven its utility and become the most common material used for 3D printing. Further advances have been achieved with bio-based fibrous materials like wood and hemp, etc., which help progress towards a biodegradable economy [12].

2.1.2. Lignin Filament

TwoBEars, a German start-up, launched BioFila®, a biodegradable filament for 3D printing, in April 2014 with the promise to not use polymers outside of the food chain but rather manufacture biopolymers on the basis of thermoplastic lignin. By changing the temperature of printing, the texture of surfaces can be varied [12]. In general, lignocellulosic materials are considered for the degradation of carbon emissions. Lignin, an amorphous and aromatic polymer, can originate from lignocellulosic biomass [13].

2.1.3. Wood Filament

The inventor from Cologne, Kai Parthy, has developed a new natural fiber filament, a more precise wood filament under the name "LayWood", which permits objects to be printed in a wood design depicting annual rings and which is compatible with the FFF process. The filament contains 40 percent wood fibers and a thermoplastic binder which has similar thermal properties to PLA. By changing the temperature, it is possible to create these wood-looking annual rings. Various color shades can be achieved; light colors at 180 °C and darker shades at 250 °C. Further, Parthy created another innovative 3D printing material in 2018, "GrowLay", a bio-based biodegradable filament that was created to grow biological cultures such as grasses, mosses and fungi [12].

3. The Sustainability of 3D Printing

3D printing technology has been lauded as a key technology to reduce the environmental impact of production and improve sustainability—namely, reduce, reuse and recycle. However, there are also challenges to overcome.

3.1. Factors to Overcome

Additive manufacturing has significantly changed parts of manufacturing, especially prototyping. It is often referred to as a more sustainable way of manufacturing, but there are still major factors to overcome, as procedures of production for various finished goods differ so extensively [13–15].

Recycling additional and undesirable material into feedstock, creating new procedures for material degradation or composting into nontoxic natural biomass is essential. Transforming material waste into novel filaments is an important recycling procedure, in particular for thermoplastics with close resin properties. However, transforming material waste can lead to degradation, which is an irreversible procedure that can lead to a significant change in filament structure and damage to properties [9,16–18].

Most 3D printers' environmental impacts are based on electricity use and not on material choice, but changing power consumption by various plastics did not have a substantial effect in comparison to variation in utilization between devices. A machine's idle time has a rather large impact on variation. Hence, the printer's energy usage holds the uppermost influence in the determination of the total sustainability performance of a polymer. For clarification, "energy usage" incorporates electricity required for printing parts, which also takes into consideration the idle, starting and halt times [14].

Secondly, recent 3D printers use energy mainly generated by power stations from fossil fuels [19]. As a consequence, the advantage of 3D printing can only be fulfilled if machine utilization is adjusted in terms of evading wasted energy through idle time between prints and unproductive print systems. PLA requires less energy consumption for 3D printers because of its lower melting point than ABS and is, therefore, less harmful to the environment than ABS overall. So, ecological influence can be optimized by selecting biobased, biodegradable plastics, but the right utilization has an even more critical part [20].

3.2. Positive Effects

Of course, regarding a new sustainable future, 3D printing has several sustainability advantages. First, looking at the materials and the fact that PLA is currently the most used filament for additive manufacturing with a tendency to increase even more, one can say that the first step of being more sustainable within 3D manufacturing is already complete, but a deeper look into this is still necessary [16]. Unfortunately, the characteristics of biodegradable materials are often misleading if not further defined. A biodegradable plastic such as PLA cannot truly degrade in natural environments, specific conditions of industrial composting, i.e., higher temperatures, humidity levels and the presence of micro-organisms, are needed. It needs to be acknowledged that bioplastics, not just fossil-based plastics, are still plastics that can generate environmental pollution and, first and foremost, microplastics that need proper recycling.

It is already known that 3D printing produces less waste and has lower energy consumption than CM [21]. This is due to several reasons. Firstly, there is less waste because, unlike conventional processes, the parts are not cut out but produced directly in the required size and shape, the consolidation process. Additionally, the design is more efficient, which means that products that are usually made from several pieces can be carried out in one piece, which reduces the overall material used and leads to less waste also due to precisely calculated material demand. Hence, less joining is necessary, which leads to fewer seams and, therefore, better durability. Since printers are small and not stationary, it is possible to position them nearly anywhere and print the pieces locally with practically no emissions [22,23]. So there is no need for big factories, which would require a lot of electricity. The most sustainable way would be a print-on-demand system which would eliminate inventory and avoid unnecessary produced pieces of garments. An additional advantage in manufacturing is that the water consumption is insignificantly small in comparison to conventional methods using natural products for textiles, e.g., cotton or flax [21,22].

In general, 3D printing enables a longer life cycle for the products in use due to the possibility of fixing broken parts easily by simply printing them out and joining them together or directly printing them onto the garments. The biggest point regarding a longer life cycle is probably the individualization of products. Individuals can have their clothing adjusted or designed to their preferences, and in some cases, such as in the shoe industry, customized to meet medical needs, particularly in the midsoles of sports shoes. The financial factor of such personalized items has a longer life cycle due to their perfect fit and aesthetic appeal resulting in people purchasing fewer items, leading to a lighter environmental impact [24].

Recycling is a crucial and complex topic in sustainable fashion, as composting plastics is impossible, and even the PLA process requires a lot of know-how and technology [25]. However, additive manufacturing has the advantage of easily recycling polymers by remelting and printing new pieces, which hinders time- and cost-intensive composting and enables a cradle-to-cradle principle. In addition, waste materials can be recycled and used as filaments, reducing the need for virgin materials and minimizing existing waste. This is already implemented in some bigger companies, e.g., Adidas uses waste from the ocean for the manufacturing of their shoe soles [23,26,27].

4. Conclusions and Future Outlook

To say whether 3D garment printing is sustainable or not is difficult to answer because many aspects must be considered on the material side as well as in the whole life cycle of the product. The use of biomaterials, particularly PLA, is a step forward in the industry, but the misunderstandings surrounding its biodegradability highlight the need for clear communication of required composting methods and a national recycling plan to reduce the harm of plastics. Further research should be undertaken on other possible biodegradable biomaterials which do not depend on industrial recycling but are currently only used as additives in PLA filaments. A cradle-to-cradle system would be the most sustainable approach, but a comprehensive analysis of energy consumption and waste management

must be conducted to evaluate the sustainability throughout the whole life cycle of 3D printing compared to conventional manufacturing methods. For instance, 3D printing can only be completely sustainable when all the energy used comes from renewable sources [14,28]. The approach of individualization and its contribution to sustainability needs more consideration. While individual products have the perfect fit and longer life cycles, the future possibility of mass individualization through accessible 3D printers raises concerns about sustainability [29,30]. Overall, 3D printing in the garment industry opens many doors towards more sustainable production in the future by addressing customers and their consumption behavior and additionally focusing on more sustainable materials and production.

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