Evaluating Bioplastics

The potential of bioplastics in 3D printed applications towards a circular economy

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Antigoni Karaiskou

4621492
A.Karaiskou@student.tudelft.nl

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Focus and restrictions – The focus was placed on evaluating the true viability and environmental impacts associated with bioplastics if embedded in additive manufacturing process, restricted to structural applications.

Abstract – Contributing to the discussion of the circular economy, 3D printing offers the promise of manufacturing with less waste and less energy. However when it comes to material usage the sustainable intentions of additive manufacturing are questioned, since the most common input material is plastic. As a first step to the right direction this paper aims to evaluate the contribution of bioplastics, if embedded in the 3D printing process. By providing the definitions of the terms –bio-based, biodegradable, oxo-degradable- an insight of the basic principles is gained with the focus placed on the various degradation processes. By undergoing current cases where bioplastics are combined with 3D printed applications, their true potential is being explored whereas at the same time questions arise concerning the rate of decomposition if not in an industrial composting facility, the amount of energy that is needed for their manufacture and the land space availability for growing of feedstocks.

Key words – Circular Economy, Biodegradable Bioplastics, Bio-based Bioplastics, Additive Manufacturing

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1 Introduction

In recent years a considerable shift has been made towards using biodegradable materials, due to the increased consumption of fossil-based fuel, resource limitation and environmental impact. During the revised Waste Management Act (Kreislaufwirtschaftsgesetz KrWG) that came into force 1st June 2012, the term *circular economy* was introduced and was defined as the prevention and recovery of waste (Thielen,2014).

3D Printing is claimed to trigger a third industrial revolution, due to its the potential of contributing to the vision of the circular economy by reducing material usage and avoiding building and demolition waste, thus lowering environmental emissions during construction. However, in what extend are the input materials thought to be sustainable? Production of plastics, which is the most common material used in 3D printing has a serious impact on the environment.

When it comes to plastics, considering one kilogram of production, bioplastics manufacture generates 1-4 kg less carbon dioxide by consuming less energy. (Karpušenkaitė and Varžinskas, 2014) Moreover, unlike plastics that derive from fossil fuels, bioplastics are based on organic compounds, and therefore can be part of the full life-cycle design, also known as the “Cradle-to-cradle” approach.

The main objective of this study is to assess the true viability and environmental impact of bioplastics and to explore their potential in 3D printed applications. Therefore the two following questions are being formed:

- are bioplastics a truly sustainable approach?
- does the implementation of bioplastics in 3D printed applications contribute to the “circular economy”?

After providing the definitions needed in order to understand and avoid misinterpretation of the basic terms, some historical data are given. To proceed the focus is placed on the implementation of bioplastics in current construction techniques, in order to limit the range of the bioplastics applications discussed and as a closing point of the first phase the end-of-life scenarios are developed. The second phase contributes to the material problematic of 3D printing process, introducing the most common bioplastic (PLA), as well as developing current and future applications that combine bioplastics and 3D printing techniques.

2 Methodology

In this section the current literature regarding the studies found is summarised. The collection of the sources aim to offer the latest (2013-1016) insight in the advances of bioplastics and 3d printing construction applications. The development of the research conducted for that field in the last decade has exponentially grown, what demanded most recent data collection to avoid outdated input information.

The research was developed in two directions with the final focus being placed on the combination of both towards the model of the circular economy:

1. An overview of the chaotic field of bioplastics was given by the “Introduction to bioplastics engineering” (Ashter, 2016). Further information was collected from e-books found in the TU Delft database, for cross-checking and referencing in order to provide valid definitions for terms usually misused when it comes to bioplastics.

2. For gathering of information on 3D printing as a process towards a circular economy the “3D Printing with Biomaterials: Towards a Sustainable and Circular Economy” (Van Wijk and Van Wijk, 2015) was proved to be particularly important. 3D printing technology applied to construction was further analysed, gathering information from sources at different levels: scientific articles, informative articles. The keywords used for searching are both words that indicate the type of process (e.g., additive manufacturing or 3D print + automated construction; construction scale + additive fabrication / manufacturing).

3 Bioplastics

As stated by Thielen (2014), plastics are the material of choice in many industrial and commercial applications, with their consumption having risen worldwide from 50 million tonnes in 1976 to 235 million tonnes in

2014 and its applications in construction materials claiming 20 percent.

However, plastics that derive from fossil-based feedstocks resist degradation leading to discussions on how to dispose them. In order to protect the environment, there has been a rapid increase in the usage of products that not only decompose into environmental-friendly constituents but are also made from natural renewable resources. According to European Bioplastics (2016) a plastic material is defined as a bioplastic if it is either bio-based, biodegradable, or features both properties. Bioplastics are not just one single material, but a whole family of materials with different properties and applications.

In literature, there has been no consensus on the exact definition of the generic terms biodegradable, bio-based and oxo-degradable, which appear to have multiple and overlapping meanings. Therefore an in-depth review of each term has been provided in the following section.

3.1 Definitions

The definition of bio-based plastics is drawn from the European Committee for Standardization (CEN), which defines them as the plastics that are derived from biomass. Ashter (2016; 26) explains that:

> In general, biomass is referred to biodegradable organic material derived from plants, animals, and microorganisms and is considered as renewable. Some plastics are fully bio-based and may be biodegradable, such as starch and polyhydroxyalkanoates; some may be partially bio-based and biodegradable such as polylactic acid and cellulose, whereas others may be partially bio-based and non-biodegradable such as biopolyethylenetetraphlate, bio-polypropylene, and bio-polyethylene. It is important to understand that the ability of the bio-based plastics to degrade does not depend on its bio-based content but rather on its structure and physical properties.

In order to evaluate the bio-based origin several certificates can be issued. For this process, products that only partly consist of renewable raw materials, are needed to declare their exact bio-based ratio, which can be accurately measured using the radiocarbon method. As stated by Thielen (2014) in Europe the "OK bio-based" (Fig. 3.1) and the "DIN CERTCO" (Fig. 3.2) logo are used, whereas in the USA, the "USDA CERTIFIED BIOBASED PRODUCT" logo (Fig. 3.3) is introduced.

between 20 and 40 % Biobased	between 40 and 60 % Biobased	between 60 and 80 % Biobased	more than 80 % Biobased

Fig 3.1: OK bio-based Logo

Fig 3.2: DIN CERTCO bio-based Logo

Fig 3.3: USDA certified bio-based Logo

The term biodegradable is problematic because it is not informative. The term does not convey any information about the specific environment where the biodegradation is supposed to take place, the rate that will regulate the process (fast, slow), and the extent of biodegradation (partial or total conversion into CO2). As stated by Ashter (2016; 23):

> The European Norm EN 13432 has defined the term biodegradable as the one where degradation mechanism is characterized by the breakdown of organic chemical by microorganisms in the presence of oxygen to carbon dioxide, water, and mineral salts of any other element present (mineralization) and new biomass or in the absence of oxygen to carbon dioxide, methane, mineral salts, and new biomass.

The term biodegradable is also directly associated with different disposal ways such as composting, sewage treatment, denitrification, or anaerobic sludge treatment. The rate of degradation should be consistent with the disposal method (Ashter, 2016). A material must satisfy the following to be termed compostable: mineralization (i.e., biodegradation to carbon dioxide, water, and biomass), disintegration into a composting system, and completion of its biodegradation during the end-use of the compost, which, moreover, must meet relevant quality criteria, e.g., no ecotoxicity (Ebnesajjad, 2013).

The evaluation of composting is certified in Europe by “DIN CERTCO” and “OK compost” that belong to independent certification associations, whereas in the USA the process is governed by the BPI (Biodegradable Products Institute). Figures 3.4 to 3.6 show the most well-known logos. (Thielen, 2014)

Fig. 3.5: Logos for industrial composting (DIN CERTCO)

Fig. 3.3: The OK-Compost-Logo (Vinçotte)

Fig. 3.6: The Compostable-Logo from the USA

European Bioplastics (10-2016), the industry association representing the interests of bioplastics, distances itself from additive-mediated conventional plastics such as so-called “oxo-degradable” plastics, declaring the following:

> The technology of additive mediated fragmentation entails that a conventional plastic is combined with special additives, which are purported to promote the degradation of the product. Yet, the resulting fragments remain in the environment and do not biodegrade as defined in internationally accepted industry standards such as EN 13432 for industrial composting.

3.2 Historical data considering raw materials

Plastics haven’t always been made out of oil. The first plastics were actually bio-based and were alternatives for the valuable and scarce raw materials such as ivory, horn, lapis lazuli, ebony, amber, pearls and coral. Celluloid is considered to be the very first plastic, discovered in 1855 and was used for the production of billiard balls instead of valuable ivory. More bio-based plastics followed such as cellulose acetate, which was used for the famous LEGO building bricks. Nevertheless these bio-based plastics were quickly abandoned in the era of the cheap and abundant oil. (Van Wijk and Van Wijk, 2015)

Only from 1980, did bioplastics become once again a focus of research and development, with the principal interest on biodegradability and compostability, whereas in later years the main interest was shifted towards the renewable resource aspect of the bio-based plastics(Thielen, 2014).

Today, bioplastics are mostly made from so called food crops or 1st generation feedstock, based on carbohydrate-rich plants, such as corn or sugar cane, which requires the least amount of land to grow on and produces the highest yields. However, the production of food crops inevitably generates large amounts of cellulosic by-products such as straw, corn stover or bagasse. Therefore, the bioplastics industry is focussing on non-edible by-products as the source for bioplastics (2nd and 3rd generation feedstock), such as cellulose, with a view to the development of new, innovative materials in future (EUBP, 01-2016).

3.3 Bioplastics in construction sector

In construction and housing sector, bioplastics are used especially for building insulation. Foams made from PLA, as well as natural fibre and cellulose-based blowin insulation materials have already been available on the market for a long time, not to forget the WPC (Wood Plastic Composites, usually with PP as matrix material) used for patio decks and fascia cladding. (Thielen, 2014)

In order to contribute to the circular economy, the end-of-life scenario should be taken into consideration. Thielen (2014) suggests that in the recycling of bioplastics it should always be the priority that both the stored bio-based carbon and the energy contained are recycled in technical recycling installations. The reuse of bioplastic scrap, after its initial use or application depends, as with conventional plastics, on the type of product and the type of plastics in question, as well as the amounts and a suitable recycling system (Fig. 3.7).

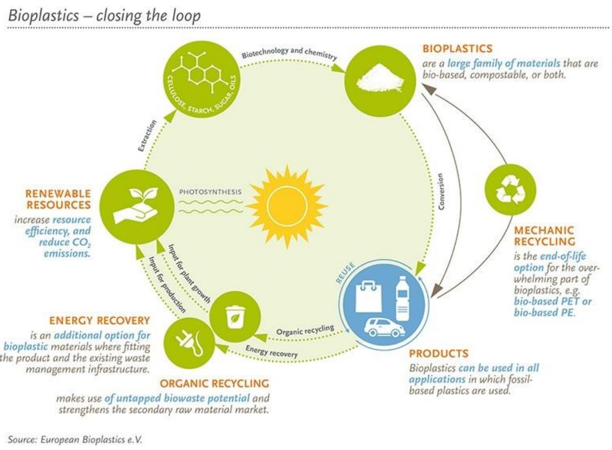

Fig. 3.7: Bioplastics circuit (EUBP, 04-2016)

4 3D printing

According to Goodship (2016) Additive manufacturing (AM), refers to a process by which digital 3D design data are used to build up a component in layers by depositing material; this definition, reflects the huge range of different manufacturing processes and variations of machine that have been developed in recent years. The mainstream media prefer the term 3D printing, as it is reasonably descriptive of the processes used.

A key driver to growth for this technology is the increasing number of available materials for 3D printing. Feedstock materials account for 40% of revenue for the 3D printing sector and are expected to increase further. The two dominant thermoplastics are fossil-based plastic acrylonitrile butadiene styrene (ABS) and bio-based plastic polylactid acid (PLA). (Van Wijk and Van Wijk, 2015).

PLA, generally produced from sugar (sugar beets, sugarcanes, corn), is considered to be the most important bio-based polyester on the market. Processed by compounding, copolymerization, by blending with other bio-based or fossil-based plastics or by adding additives, which however can have an influence on the clarity, the biodegradability/compost ability and the percentage of renewable resources in the product (Van Wijk and Van Wijk, 2015). Unoriented PLA has good mechanical strength and stiffness, but it is also quite brittle. Further modifications to strengthen the thermal and mechanical properties are significant for widening PLA applications in the future(Rivero et al., 2017).

4.1 3D printing in construction sector

In the late 1980s and early 1990s, the 3D printing technology was associated with the term rapid prototyping (RP); it was a faster and sometimes cheaper way of making initial models to check form and fit. Advances in software, process, and materials mean that functional parts can now be manufactured. (Goodship et al., 2016).

Many architects, designers and researchers around the world are developing new technologies and processes to manufacture buildings with 3D printing technologies. The general concept is to print the envelope and internal structure of the walls using plastics. The structure is filled with weight (sand, concrete), isolation material and the infrastructure and other elements are also integrated into this structure. Such designs are built with less material use, and ample freedom in form and flexibility(Van Wijk and Van Wijk, 2015).

4.2 Current bioplastics research combined with 3D printed technology

As Van Wijk and Van Wijk, (2015) investigated, DUS architects are creating a 3D printed canal house in Amsterdam using the “Kamermaker”, a large-scale home printer. They print each room separately and build it together as large Lego-type blocks, inventing the click system. The rooms are connected to the outside façade, which is printed in one piece. The envelope of a wall in particular is on site 3D printed from bio-plastics, leaving space for infrastructure. Manufacturing near the point of demand makes the supply chain and logistics very simple and much more efficient. It offers the promise of lower working capital, eliminating the need for large stocks of raw materials, semi-manufactured parts and labour costs.

Currently, a new bioplastic made from discarded shrimp shells is developed by Scientists at Harvard University's Wyss Institute for Biologically Inspired Engineering, using the remarkably tough yet flexible natural chitin, or insect cuticle. The new plastic, which was made using the processed derivative chitosan from shrimp shells, matches aluminium in strength at only half the weight. It is also biocompatible, biodegradable, inexpensive, and may be molded to a variety of 3D shapes. The need in many industries for sustainable materials that can be mass produced, replacing the fossil fuel–based plastics is critical given the proliferation of non-biodegradable plastic waste discarded every year, much of which is polluting the world's oceans (Brownell, 2016).

6 Conclusions

According to the Ellen MacArthur Foundation circular economy is restorative and regenerative by design, aiming to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. Baring this definition in mind, bioplastics fit in this new economic concept as they help to break away from the linear economy characterized by "make, use, dispose" in favor of a more circular model based on "reuse, recycle or biodegrade". (EUBP, 04-2016) 3D Printing can also fit in the concept of a circular economy, given that the manufacturing process itself can lead to significant material savings, because there is virtually no production waste.

Ongoing research can be used to mutually tune in the 3D printing process with biomaterials. Distributed manufacturing using open-source 3D printers with biodegradable materials has the potential to have lower environmental impact than conventional manufacturing. Under conditions, the combination of 3D printing with bioplastics could result in new and innovate products, realizing a truly sustainable and circular economy. However a list of things should be considered:

- The significant water footprint of bioplastic feedstocks, as well as the risk of deforestation in tropical regions and countries like Brazil, when growing feedstocks like sugarcane. However, recent developments in the world of vertical farming could make this less of an issue (Szaky, 2016).
- The biodegradable rate and extend of the bioplastic input material. Biodegradable bioplastics will only break down in a high-temperature industrial composting facility, not in an average household compost bin.
- Energy consumption and amount of material used. Plastic is a complex, highly refined synthetic material — so why create something that requires a significant amount of energy to manufacture, only to shortly have it completely decomposed into the soil?

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