Bamboo fiber-PLA composite materials for disposable food and beverages packaging tools: a brief review

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Abstract. Disposable packaging tools such as cups/food containers have become popular and commonly used items in today’s society as they offer simplicity, low cost, durability, and convenience for people in carrying/taking their foods. Most of these packaging tools are non-biodegradable products because their materials are mainly composed of plastics and/or their derivatives. Consequently, packaging tools have become one of the primary contributors to the earth’s waste and global warming. Eco-friendly products can be defined as products that are safe and healthy for individuals and communities throughout their life cycle, which includes all processes from production to consumption and up to disposal. Current methods for developing eco-friendly products have mainly relied on using composites of different biodegradable materials that are chosen and combined in such a way that they can complement each other’s weakness or drawback. One of these composites with the potential to replace and address the negative impacts caused by plastics products is the bamboo fiber-PLA (BF-PLA) composite. This paper is intended to briefly discuss the characteristics of as well as various important properties of such a BF-PLA composite to illustrate and motivate its potential future use as an alternative eco-friendly material for producing disposable packaging tools.

1. Introduction
Disposable packaging tools such as cups or food containers have become popular and commonly used items in today’s society as they offer simplicity, low cost, durability, and convenience for people in carrying or taking away their foods everywhere. One important issue which arises from the use of these packaging tools is that most of them are non-biodegradable products because their materials are mainly composed of plastics and/or their derivatives. As a consequence, packaging tools have become one of the primary contributors to the earth’s waste and global warming. In term of waste production, in the UK alone for instance, up to seven million disposable cups that are used every day produce around 30 kilotons of disposable paper cups waste every year [1]. With regard to global warming, plastics production for these packaging tools require high heat processes which in turn contribute to the increase of CO₂ content of the atmosphere. For instance, Polyethylene terephthalate (PET) (i.e., plastics used for water bottles) has a Global Warming Potential (GWP) of 11.3 kilotons of CO₂ with 78.7% of them come from the production stages [2]. As a result, packaging industries are currently known to produce the
highest number of plastic waste with a significant amount of more than three-fold of waste produced by textile industries (cf. Figure 1) [3]. With these major consequences, today’s society has come to the realization of the need and importance of developing ecologically friendly packaging products that are more biodegradable and composed of less (and possibly no) plastics materials.

![Image](Plastics_Waste_Generation_by_Industrial_Sector.png)

**Figure 1.** Plastics waste generated per industrial sector [3].

Ecologically friendly or eco-friendly products can be defined as products that are safe and healthy for individuals and communities throughout their life cycle, which includes all processes from production to consumption and up to disposal [4]. The use of eco-friendly products in daily life such as for food packaging tools is expected to significantly reduce the amount of waste and greenhouse gases emission that would otherwise be produced by plastics-based products. The development of eco-friendly products, however, remains a challenging task to this day due to the difficulties in finding a single material which can match the characteristics/properties of plastics. For this reason, current methods for developing eco-friendly products have mainly relied on using composites of different biodegradable materials that are chosen and combined in such a way that they can complement each other’s weakness or drawback. One of these composites which has the potential to replace and address the negative impacts caused by plastics products is the bamboo fiber - PLA (BF-PLA) composite.

2. **BF-PLA Composites**

The BF-PLA composite is essentially a material composed by *polylactic acid* (PLA) and bamboo fiber. On the one hand, virgin PLA is widely known as cheap biodegradable plastics made from natural fibers such as jute. Virgin PLA, however, cannot be used to make packaging products because it has low impact strength and can easily deform. On the other hand, bamboo has several important characteristics which can complement the PLA. For instance, in term of mechanical properties, bamboo has a high strength with a relatively low density (640 kg/m$^3$) which as a result not only can compensate for the low impact strength of the PLA but also maintain the resulting composite remain lightweight. Furthermore, bamboo is one of the fastest growing renewable plants which only take 3-4 years to reach maturity and is abundantly available around the world [5]. In 2008, bamboo forests around the world reached up to 22 million hectares, with Asian countries supplied up to 65% and Indonesia contributed around 5% of them. The resulting combination of bamboo and PLA characteristic within the BF-PLA composite is also non-toxic because its raw materials are made of natural fibers and therefore provides a promising material suitable for making packaging products. Today, some companies have begun producing packaging products made from BF-PLA composites. **Figure 2** shows examples of such products made by *Bioheroes* [6].
Figure 2. Disposable packaging products from bioheroes [6].

The manufacturing processes of BF-PLA composite generally begin with the stacking of PLA and bamboo fibers in alternating layers. The stack is typically molded for two minutes at a temperature of 160 °C and then compressed at 1.05 MPa for three minutes under the same temperature. After compression, the composite is then cooled down to the room temperature [7]. The BF-PLA composite can also be recycled after disposal by crushing and then re-mixing it with virgin PLA. The resulting mixture will then be processed with conventional injection or extrusion methods to produce the so-called Recycled BF-PLA [5].

Table 1 shows that the overall mechanical strength properties of the BF-PLA composite are significantly better than those of the virgin PLA, with a notable increase in impact strength of up to 270%. This table also shows that the impact strength of Recycled BF-PLA remains higher than that of the virgin PLA. These obtained increases in mechanical strength properties are in particular important in the making of packaging products as they ensures that the products can retain their shape and keep the food inside safe. When needed, the composites can be furthered strengthened by exposing them to heat treatment at 140° [8].

| Specimen      | Tensile Strength | Flexural Properties | Elongation at Break (%) | Impact Strength (J/m) |
|---------------|------------------|---------------------|-------------------------|-----------------------|
|               | Strength (MPa)   | Modulus (MPa)       | Strength (MPa)          |                       |
| Virgin-PLA    | 61.58 ± 2.22     | 3.38 ± 0.08         | 105 ± 0.05              | 2.3 ± 0.72            |
| BF-PLA        | 80.64 ± 1.8      | 5.92 ± 0.26         | 143 ± 1.59              | 6.68 ± 0.1            |
| Recycled BF-PLA | 74.64 ± 2.64   | 4.9 ± 0.58          | 156 ± 2.8               | 4.28 ± 0.22           |

The potential of BF-PLA composite to help reduce global warming may be inferred, for instance, from its melting point and decay rate properties. More specifically, the BF-PLA composite has a melting point of 154 °C which makes it stronger than the virgin PLA while remains easy to be shaped. Such a melting point value in particular is significantly lower than those of conventional non-biodegradable plastics (e.g. PET has a melting point of 260 °C). Furthermore, when used to produce up to 1000 water bottles with individual size of 500ml, the PLA has a net GWP value of 32.14 kg CO₂ while PET has GWP value of 46.55 kg. Therefore there is a difference in the resulting GWP value up to 14.41 kg CO₂ [9]. These essentially suggest that not only it can reduce the CO₂ emission, but the use of PLA may also...
reduce fossil energy demand because it requires only around 700-800 MJ to produce 1000 cassava-based PLA while PET needs up to 2120 MJ (i.e. up to 1320MJ reduction) [10].

Furthermore, the decay rate of products made of BF-PLA composite is also faster than those products made from virgin PLA. As shown in Figure 3, while virgin PLA decays faster in controlled condition (i.e. 45% weight loss of virgin PLA and 20% weight loss of BF-PLA in 30 days), the BF-PLA somehow decays faster in real conditions (that is 8% weight loss and negligible loss of virgin PLA in 70 days). The combination of such melting point and decay rate characteristics thus suggests the potential reduction of global warming that can be achieved by the use of products made from BF-PLA composite which would otherwise be made worse by products produced from conventional plastics.

Aside from the aforementioned advantages, the BF-PLA composite also has some limitations in terms of non-mechanical properties and manufacturing process. In term of its manufacturing, the extraction of bamboo fiber remains challenging due to its high strength property. At present, such an extraction is usually done by either mechanical and/or chemical methods [11]. While each method has its own advantages and disadvantages, the mechanical extraction methods are currently viewed to be more environmental friendly than those of the chemical methods as since the former does not produce chemical which potentially hazardous for the environment. In addition, mechanical extraction methods also offer other benefits such as require relatively low energy consumption, need smaller space for installation/operation and can use young age bamboo (2-8 months). Nevertheless, chemical extraction methods also has their own advantage, for instance they can produce bamboo fiber with better properties such as reduced moisture absorption [12].

Aside from the aforementioned extraction issues, the use of bamboo also often encounters moisture problem which occurs due to its porosity level which can achieve up to the value of 75.31±1.12 %. Furthermore, bamboo can also reach up to 52-55% absorption rate value on its surface within three (3) second which in practice can be troublesome as it may potentially weakens the structure of the resulting BF-PLA composites [13]. Nevertheless, there exist several candidate techniques that can potentially be used to reduce the moisture absorption property of the bamboo [14]. For instance, as shown in Figure 4, methods such as maleic anhydride (BMAE), permanganate (BPPE), benzoyl chloride (BBOE), benzyl chloride (BBYE), and pre-imregnated bamboo (BPIE) that are often used in bamboo-epoxy (BE) composites may potentially be adopted as chemical treatment to reduce the moisture absorption over time of bamboo.

Figure 3. Percentage weight loss of virgin PLA and BF-PLA. (a) Virgin PLA in controlled condition; (b) virgin PLA in real condition; (c) BF-PLA in controlled condition; (d) BF-PLA in real condition [7].
3. Conclusion and Future Prospect

BF-PLA composite is a biodegradable material that can be used to replace the use of plastics in food and beverage disposable packaging as it has high strength, non-toxic and also light enough to be used for takeout foods, which makes it convenient enough to compete with plastic disposable packaging. This composite also can be used again after disposal to help reduce the number of generated plastic waste and, when compared for instance with the PET-based composite, can reduce the CO₂ emission up to 30% and reduce fossil energy demand up to 60%. The potential disadvantage of using bamboo include issues in their extraction method which in certain case may affect the properties of the resulting composite and issues regarding their moisture absorption properties which in the long term can make the resulting product become weaker. However, there currently exist several approaches which can be used to address these issues which among others include the use of chemical treatments such as maleic anhydride, permanganate, etc.

Although eco-friendly products can help reduce the problem of global warming, it remains challenging to replace all plastic based products with eco-friendly alternative products because people often prefer to have/use something that they are familiar with. Therefore, more campaigns are needed to make people more familiar with a variety of eco-friendly products which can be used to replace common plastic products. More campaigns to raise public awareness in the future need to include and emphasize more personal and short term effects of the use of plastic products as to instill urgency to start the shift to eco-friendly products. Once people get more familiar with the existence and benefits of eco-friendly products, it is then reasonable to expect that the markets can slowly change its policy and replace the common practice of using plastic products into more eco-friendly products.

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