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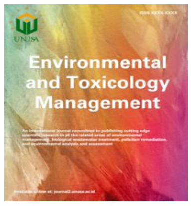

Green technology of natural fiber reinforced bio-composites as alternative sustainable product

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Abstract

Proactive strategies are being opted by metallurgical, foundry and manufacturing industries with respect to their experiences working with product designing based on product life cycle assessments. Without the consideration of the potential impacts on the life cycle, the development of new products would barely be sustainable. “Green” composites or bio-composites are fully degradable composites mainly consisting of a blend of biopolymer matrix and natural fibers which act as a reinforcing phase. In this study, natural bio-composite was reviewed as an alternative sustainable product. The types of natural fibers were also described as raw material of natural bio-composite. In addition, development natural fibers nowadays were mentioned. Furthermore, the application of natural fiber reinforced bio-composites was also presented.

Keyword :
bio-composite, natural fibers, green composites, green technology, sustainable technology

1 Introduction

With the continued growth in the world’s population, the development of new products has become a priority and issue of global interest. The consumption of natural resources at an alarming rate is a direct consequence from the rapid population growth (Ashby, 2012). The environmental balance is affected by the direct pressures exerted from the traditional fabrication and application of products. It has also led to the change in demands concerning product development in various markets. Thus, a more sustainable approach must be taken into account in product development. However, more proactive strategies are being opted by metallurgical, foundry and manufacturing industries with respect to their experiences working with product designing based on product life cycle assessments (Alayon et al., 2017).

Life cycles assessments have become a dependable tool in determining new product designs. Without the consideration of the potential impacts on the life cycle, the development of new products would barely be sustainable (Gmelin and Seuring, 2014). One of sustainable product is bio-composite. Bio-composite is affordable material and easy to obtain. Over the last decade, there has been a rising interest towards bio-composite, especially composites which were derived from poly matrixes and fibers from natural resources, generally plant origin. Thus, the emergence of bio-composite materials as an alternative in the production of new sustainable products has been well accepted.

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Bio-composites are made up of different materials and is applied in various types of engineering as well as reinforcement jobs. “Green” composites or bio-composites are fully degradable composites mainly consisting of a blend of biopolymer matrix and natural fibers which act as a reinforcing phase. These bio-composites can be made up from various blends of natural fibers, such as abaca, kenaf, hemp and flax (Takagi et al., 2014; Xia et al., 2015; Scarponi, 2015; Ravandi et al., 2016). Applying bio-composite from natural waste including natural fibers for several industries can reduce biomass waste in environment.

There are several industrial applications of bio-composites, with most of them being in the automotive industry. Due to their renewable properties, the research and development of these bio-composites as well as their applications have increased steadily and have reached a wide spread in area. Having the combination of low price, highly biodegradable, readily available and their ability to substitute other compounds that require regular reinforcements such as glass and carbon fibers have made them very popular (Ramesh et al., 2017; Vaisanen et al., 2017). The usage of bio-composite materials is also common in the oral and dental industry. The bio-composites are used in various tissue engineering and is applied in restorative works. This is mainly due to their superior mechanical properties, being biodegradable and their biocompatibility (Nejatian et al., 2017). Although the thought of bio-composites is popularly referred to resin-based composites, the dental restorative materials are mostly made up of polymer blends and ceramics.

2 Types of natural fibers

Natural fibers which are used in bio-composites have gained interest and attention from both the academic world and the industrial fields, mainly being the automotive and the construction sectors (Grand View Research, 2018). It was evident that the environmental concerns and issues related to the unsustainable production processes of synthetic fibers and polymers drove the increased interest in natural fibers. The limited recyclability of conventional composites and their end of life disposal methods are also a main issue as they will create waste due to their inability to be recycled. Natural fibers can be classified into several groups, such as vegetal or lignocellulosic, mineral and animal ones. Animal fibers which are most common are silk and wool, which are widely used in the textile industry. Vegetal group of fibers are most commonly used as reinforcement in polymer composites (Summerscales et al., 2010).

There are two main suitable vegetal fiber sources to be used in composite materials, with bagasse which is obtained from sugarcane or cereal straw as an example of agricultural waste products/by-products and plants that are cultivated intentionally for the extraction of fibers such as textile fibers. Leguminosae have also been experimented with, especially grasses and urticaceae due to their availability and spontaneity. Thanks to their properties and availability, bast fibers particularly in hemp, flax and kenaf are considered to be most promising. Due to the growing demand for vegetable fibers from the industrial sectors, there is difficulties faced by the level of production in meeting the demands. Moreover, the quantity of by-products from the commodity crops are increasing. This is good as they are cheap and renewable resources which are suitable for fiber production. In a study done, it was found that roughly around 2000 million tons of by-products were being produced globally annually from major crops consisting of corn, wheat, rice, soybeans and sugarcane. Considerable amounts of cellulose are then able to be extracted from the by-products in the form of fibers and can be used as potential fillers in composites. The availability of the fibers from the by-products can be a huge help in enhancing the sustainability of the fiber industry whilst increasing the value as well as the income from the agricultural crops.

As for future perspectives on natural fibers, it is essential to address the durability of the resulting composites, outdoor applications especially as we should take in account weathering action in both long and short term (Sarasini and Fiore, 2018). There seems to be a lack of confidence in the structural performance of natural fibers as the adoption of natural fibers at a large scale in the industry seems to be slow and lackluster. The growth of natural fiber composites is indeed increasing and a very bright future for bio-composites can be foreseen. With this in mind, natural fiber composites which hare based on less common natural fibers can be beneficial to the society. The natural fiber composites can be applied directly in rural societies, especially in regions where these uncommon fibers are abundant. The biological and biodegradable nature of these products means that they are environmentally friendly with perceived environmental and economic benefits. However, the success heavily depends on the backing and support of the local government as well as public intervention.

Natural fiber is subdivided based on their origins whether it is from plants, animals or minerals. Cellulose is what plant fibers are comprised of whereas animal fibers are made up of different proteins such as hair, silk and wool. The different types of plant fibers are bast fiber, leaf or hard fiber, seeds, fruits, wood, cereal straw as well as other types grass fibers. However, special attention is highlighted on lignocellulosic fibers. There are three primary chemical constituents in lignocellulosic fibers are namely cellulose (a-cellulose), hemicelluloses and lignin. The compositions and structures of lignocellulose fiber vary widely as it is dependent on the species of the plant, its age, the climate as well as the soil conditions. The properties and the applications of the lignocellulosic fillers and fibers are all determined through the information gathered on their chemical compositions. Cellulose is essential in all lignocellulosic fibers. Hemicellulose is the second most abundantly found organic matter on earth after cellulose. Studies have shown the moisture content of hemicellulose was 2.6 times more than lignin (Bledzki and Gassan, 1999). The structure of hemicellulose is more complex as compared to cellulose or lignin, and it is bound to oth of them by covalent and non-covalent bonds within the cell wall. The interactions between the components cause the rigidity and flexibility of the cell wall to increase. Lignin is a polymeric natural product which arises from enzyme-initiated dehydrogenatice polymerization of three primary precursors, which are transp-coumaryl, trans-sinapyl and trans-coniferyl (John and Thomas, 2008). Lignin fills in the empty spaces between pectin, cellulose and hemicellulose which are present in the cell wall. It is a three-dimensional polymer which is made up of aromatic units which contain high intramolecular bonding (John and Thomas, 2008). Lignin is partially covalently bonded to hemicellulose and is encrusted in the cell walls. It is also covalently bonded with the chemical substituents which are the backbone of the hemicellulose. Chemical substituents such as arabinose, galactose and 4-O-methylglucronic acid are linked covalently to lignin. Due to lignin being insoluble in water, amorphous, having a hydrophobic binding capacity and not being able to be broken down into monomeric units, the hydrophobic lignin system affects the properties of another network.

The soaring prices of raw materials for the engineering and production of plastics have forces the early transition into more sustainable natural reservoirs as well as the use of natural redeemable materials for the development and fabrication of polymer composites (Jawaid and Abdul Khalil, 2011; Puglia et al., 2005). The use of synthetic fibers is at an all-time high in the reinforcement industry. However, natural fiber reinforcements have gained much momentum to substitute certain synthetic fibers in various applications (Chand and Fahim, 2008). The combination of polymer matrices with the natural fibers from both renewable resources as well as non-renewable sources are able to produce polymer composites which are comparable and competitive with synthetic composites. Sustainable and eco-friendly polymer products are able to be produced from biodegradable plastics as well as bio-based polymer products. For some developing countries, natural fibers play a pivotal role in the economic income. For example, the production of cotton in some West African countries, the production of jute in Bangladesh and sisal in Tazmania (Jawaid and Abdul Khalil, 2011).

As for countries which have scarcity of forest resources, agricultural crops have been utilized in the developments and research purposes on the polymer composites. An example of agricultural crop which is exploited is bamboo, which is found in abundance in Asia and South America. It is considered as a sustainable natural engineering material and has emerged as the backbone for socio-economical status of society. Bamboo is traditionally used in multiple living facility and tools as it has high strength due to its weight. Its strength is due to the longitudinal alignment of fibers. Bamboo fibers naturally possess fine mechanical properties, however is brittle in nature when compared to other natural fibers as there is extra lignin content which covers the bamboo fibers. The sustainability for the future generation is dependent on the current industrial development as it portrays to the eco efficiency of industrial products and their manufacturing processes.

Materials which are high performance and biodegradable can pave a way for new platforms for sustainable and eco-efficient advanced technology products which can compete with the existing synthetic products. Sustainable, eco-friendly and well-designed products comprised from natural sources are projected to replace the dominant petroleum/synthetic products in the market. The utilization of bamboo fiber for fabrication and bio-composites can help in starting a revolution to sustain the natural resources. Thus, bamboo can be utilized in advanced engineered product development which can be used in multiple sectors and applications. The integration of bio-composite materials in daily use items such as house hold furniture, lightweight car components or sports equipment can be an alternative as the low cost, availability and aesthetic designs will be a driving force to transform the present into a sustainable future.

3 Development natural fibers nowadays

The development of new materials which are innovative has been driven by the continuous growth of ecological and environmental consciousness. The increasing concerns towards the environment as well as sustainability issues have been key in establishing new improvements in green materials through the development of bio-composites within the field of polymer science (La Mantia et al., 2011; Satyanarayana et al., 2009). The ease of disposing and composting of the bio-composites without harming the environment have made the more favorable over synthetic fiber-based polymer composites in certain sectors. Municipal solid waste (MSW) landfills is currently the dominant waste disposal option in multiple countries around the globe. However, it was found that 70% of MSW collected throughout the entire region of Australia was disposed of or sent to landfills in the year 2002 (Laner et al., 2012). Studies have shown that 10 to 30% of waste received at landfill sites globally withstood of debris from construction and demolition jobs (Fishbein, 1998). The production of materials from renewable feedstocks is expected to undergo and increment of 5% in 2004 to 12% in 2010, upwards of 18% in 2020 and around 25% in 2030. It was also expected that two-thirds of the global industry would eventually be based on renewable resources. Considerable attention has been drawn towards the use of lignocellulosic fibers such as hemp, oil palm, flax, jute, banana as well as kenaf as potential substitutes to synthetic fibers, which are glass and carbon fibers (Dicker et al., 2014; Zini and Scandola, 2011).

The utilization of natural fiber related to its properties The use of natural fiber reinforced bio-composites have also been applied in the aerospace and packing industries, where high load carrying capacity is not required. Furthermore, it was reported by the US Department of Agriculture (USDA) as well as the US Department of Energy (DOE) that 10% of basic chemical building blocks were targeted to compromise from renewable resources by the year 2020 and is expected to at least hit 50% by 2050 as there will be less hurdles to their usage (Mohanty et al., 2002). The several attracting properties that natural fibers possess over their synthetic counterparts include their relatively high specific strength, free formability as it can conform to its surroundings, low self-weight which is a pillar to its strength and their substantial resistance to corrosion and fatigue. However, natural fibers are not a problem-free alternative as they do have some negative traits which are the high moisture absorption and their highly anisotropic nature (Jawaid and Abdul Khalil, 2011).

The mechanical properties of natural fibers have been studied on and incorporated into multiple thermoplastics (PHA and PLA) as well as thermosets (polyester, epoxy and phenolformaldehyde). All the studies on the natural fibers have indicated that the adhesion between the fiber-matrix had a huge impact on the final mechanical properties of the bio-composites. This was due to the fact that the stress transfer between matrix and fibers determined the reinforcement efficiency (John and Thomas, 2014). However, it was evident that the there is high contents of cellulose, hemicelluloses, lignin and pectins in natural fibers, which indicates that natural fibers tend to be an active hydrophobic material. Among various composite materials, the usage of natural fiber-reinforced bio-composites are common as low-cost materials which contains functional structural properties. This is indeed due to the degradation and depletion of petroleum-based composites which paved the way and switch to renewable resources-based materials (Shanks et al., 2004).

4 Application of natural fiber reinforced bio-composites

In the field of orthopedics, biomaterials and bio-composite are commonly used in the construction of prosthetics as well as other medical devices which replaces or augments parts of the human body. Other than bio compatible, the bio-composites used possess physio-mechanical properties as well as adequate thermal stability. The use of poly (methy methacrylate) (PMMA) as bone cements has been common and it has a long credible history in implant fixation (Chen et al., 2012). It is one of polymers which is extensively researched on in the dentistry field. PMMA is also widely used in the fabrication of dentures as it is bio-compatible and aesthetically pleasing. In addition, other properties which PMMA possess is having low water absorption and containing low levels of toxicity. In the context of specific application, the high mechanical properties allow the bio-composites to withstand the chewing forces as well as the wear inside of the mouth (Karthick et al., 2014). One of the main issues which is faced in the application of PMMA as cements or implants is the poor desirable mechanical properties. Low fracture and resistance to fatigue is some of the concerns for the use of PMMA. There has been multiple different proposes which suggest that the mechanical properties of PMMA as cement and implants can be enhanced and improved on, with the addition of particles or fibers as reinforcement being thee most promising (Kanie et al., 2000; Sheafin and Tanner, 2015). The mechanical properties of PMMA have been reported to be enhanced to desirable levels through some fillers which are silica, titanium, carbon fibers, zirconia and stainless steel fibers. It was also reported that the general mechanical properties which includes the overall strength as well as wear resistance were able to be improved through the implementation of nanofillers. The compressive strength, diametrical tensile strength and fracture and wear resistance is reported to be much better in nanocomposites. The polymerization shrinkage is also lower, coupled with high translucency and high polish retention. However, it is crucial to note that the improved mechanical properties heavily rely on the interfacial interaction between the polymeric matrix with the filler and its dispersion within the matrix. Seashells have been reported to have potential to be used as filler in PMMA for denture applications (Karthick et al., 2014). Seashells are natural ceramics and are known to be bio compatible for fillers. They have also been implemented in other polymeric materials such as polypropylene and polyethylene (Gonzalez et al., 2005). Present studies have explored the compressive strength of PMMA-seashell based bio-composites and it was found that the addition of filler sizes significantly affected the compressive strength, making it even stronger. Filler sizes ranging from micron to nano size regimes worked best in enhancing the compressive strength of PMMA-sea shell based bio-composites.

Between the various fibers used in the implementation of natural bio-composites, agave fibers stand out as they are high characterized with high mechanical properties such as high tensile strength, good stiffness and high toughness. In addition to that, they have shown to have low damageability, good thermal insulation, low skin irritability, low embodied energy as well as very low cost. Despite having high interest, agave fibers are only being included in non-structural applications in various industrial fields. In the automotive, naval and civil industries, both the lightness and low cost are more favored over any other composite material reinforced by synthetic fibers (Zuccarello et al., 2018). In practices, materials which are used for non-structural purposes are constituted by green thermosetting or thermoplastic matrixes, which are then reinforced by short or discontinuous agave sisalana fibers which are oriented randomly (Zuccarello et al., 2018). As an overview, they are manufactured by a molding or extrusion process. They possess relatively low mechanical properties as well as sufficient stiffness (Zuccarello et al., 2018). Although there have been various recent researches targeted towards the implementation of high-performance bio-composites which can be applied in structures, the preliminary improvement of fiber properties and the development of new environmentally friendly or renewable high performing bio-composites which are reinforced by agave fibers have not yet been fully achieved. Several researches have shown ways to improve the mechanical strength of agave fiber reinforced bio-composites and was heavily linked with the study of hybrid bio-composites, which are three or four component bio-composites in which glass fibers, other natural fibers or both are added to the agave fibers. Unfortunately, this approach has given limited results in previous studies, especially when the strain failure values of the added fibers are vastly different from the agave fibers (1.5% to 3%), coupled with high values of critical volume fraction of the added fibers (Agarwal and Broutman, 1998). In detail, the studies done have shown how glass hybridization of bio-composites produced from polypropylene matrix led to improvements of the strength against tensile, impact failure and flexural, whereas the stiffness of tensile and bending were not changed a lot (Jarukumjorn and Suppakarn, 2009). Recently, there have been proposed processes which can improve the performance of the bio-composites reinforced by agave fibers, where nanomaterials are used to increase the fiber matrix adhesions or the increase of the tensile properties by injection of resin within the sub-fibers.

5 Conclusion

Although the implementation of bio-composites is common nowadays, replacing the conventional composites with natural composites which have comparable structural and functional stability relating the challenge in multiple industries. For this reason, the commercialization of bio-composites is expected to be improved and used in the future. The non-recognition of bio-composites is one of the main issues and problems in the commercialization of natural fiber reinforced bio-composites. However, recently research and developments for natural fiber-based composites have been in development especially in developing countries, where these fibers are abundantly available. This issue has been solved and overcome by multiple countries, particularly in the European region. Challenges faced by material scientists in accordance to accept criteria for these bio-composites being their questionable levels of performance and cost. The exploitation and identification of the various applications for bio-composites has paved the way for new avenues, both of academicians and industries to develop a sustainable module as well as for future application of bio-composites. Natural fibers can be separated and classified into different types based on their origins as well as their own properties, such as their strength and weaknesses. The development of bio-composites is primarily set up a new generation of fiber reinforced composites, which are both eco-friendly as well as safe in their application. Therefore, bio-composites which are reinforced by natural fibers can be considered to be a valid alternative or in some cases, superior to synthetic fiber composites.

Declaration of competing interest

The authors declare no known competing interests that could have influenced the work reported in this paper.

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