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Bio-composite materials potential in enhancing sustainable construction

Mohammad Farid Alvansaz Yazdi[a], Rozana Zakaria[b,*], Mushairry Mustaffar[b], Muhd Zaimi Abd. Majid[b], Rosli Mohamad Zin[b], Mohamad Ismail[b], Khairulzan Yahya[b]

[a]*Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor 81310, Malaysia*
[b]*Construction Research Alliance, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia*
Email: *rozana@utm.my*

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ABSTRACT

According to the sustainability principles, building should have zero-embodied energy in order to minimize the amount of carbon. In previous practices, construction materials have been composed with non-recyclable materials and after demolition of buildings the debris were put on different landfills. Nowadays, most of the material manufacturers have shifted their concerns to produce materials by using renewable resources, and also gained opportunity in utilizing wasted streams. The proposed biomaterials have been produced using natural fibers which reinforce biodegradable polymeric, in which naturally occurring aliphatic thermoplastic polyesters are produced by microbes via bacterial fermentation in carbon-rich environments. The composite material produced exhibits comparable properties to structural grade wood and is rapidly biodegradable in specific anaerobic conditions, at the end of its useful life. Using anaerobic digester sludge from local wastewater treatment plants as the biodegradation medium, the material decomposes into biogas that consists mostly of inert gases and, of particular interest, methane, which can be captured and used either as a biofuel or as a closed-loop carbon source. This paper documents bio-based composite material development, durability issues, anaerobic biodegradation, and potential industrial applications.

Keywords: Bio-composites; Sustainable building construction; Construction industry

1. Introduction

Bio-composites usually consist of a combination natural fibers like hard and soft wood, or non-wood fibers like rice straw, flax, sisal, banana, pineapple, and also sugar cane with polymer matrices from both renewable and nonrenewable resources.

The term "bio-composites" covers: (i) petroleum derived, non-biodegradable polymers like polypropylene, polyethylene, polyester, epoxy or vinyl ester reinforced with biofibers; (ii) biopolymers (e.g. PLA, PHA) reinforced with biofibers; and (iii) biopolymers reinforced with synthetic fibers such as glass or carbon. Biopolymers reinforced with biofibers, generally considered to be more environmental friendly, are sometimes called "green composites". Table 1 shows the development of bio-composite products from renewable resources.

During recent years many researchers have investigated bio-composites, especially in the field of construction and building as they have many advantages over old materials like their weight which is very low, and also manufacturing costs can be

*Corresponding author.

Table 1
Development of bio-composite products from renewable resources

Renewable	-Crops -Revival -Purposely grown to produce fibers	Bio-composites
	-Agro-waste -Recycle and reuse -Minimizing of waste	

reduce dramatically. Nowadays not only contractors, but also people who want to buy homes are attracted to use bio-composites for different purposes like decking as well as fencing. Table 2 shows the developmental stages of bio-composite values in the construction industry of Malaysia, according to [1]. Bio-composites are used in a wide range of applications and contribute to the growth of various industries. The bio-composite industry value chain spans a full range of activities, from the preparation of raw materials from biofibers and binder production to the manufacture of end products. Bio-composite products need to be further developed in Malaysia as a long-term strategy to develop the tremendous wealth of biofibers that are currently under utilized.

According to the United States environmental protection agency, Prairie Village, [2] majority of people in charge of construction and also people in charge of materials used in buildings have great impacts on ecological footprints. As an example, in the USA 40% of the landfill relate to construction and demolition (C&D) materials. These kinds of materials usually consist of 30–50% wood, drywall, and also different plastic components [3]. According to the holistic analysis of solid waste materials in the USA, 40% or 96 million tons of the total landfills relate to the construction-related activities like construction as well as demolition. The US Government in recent years has focused on reusing and also recycling of materials related to C&D activities. The materials which have been used in construction activities before that were not recyclable and reusable and may be replaced by bio-composite materials. For several years bio-composite materials have been used in construction industry like baths, vanities, cladding, different decoration parts as well as finishing. According to [4], the construction industry has been ranked as the second largest consumer of the polymer composites by using 35% of available products in the market.

Several advantages of using bio-composite type of materials in buildings were discovered in ancient times.

Table 2
Development process and value chain of bio-composites industry in Malaysia [1]

Natural Recourses	Manufacturing	End-user of bio-composites
Natural fibers -Wood waste /saw dust -Kenaf -Oil palm based fibers -Coconut -Rice husks	Value added products -Conventional composites -Particle and fiber composites -Wood/nonwood composites -Natural fiber reinforced polymers composite	-consumer bio-composites -Industrial bio-composites -Advanced bio-composites
Research and development		
Training and education		

In 3,000 BC, some Sumerians used bitumen as a special kind of organic binder which acted as a water repellent when it was mixed with clay and straw. Famous architects of Romans required highly developed materials, and decided to invent chemical materials which were obtained from different natural resources.

Bio-composite materials for construction should provide acceptable stiffness, strength, ductility, and also durability of buildings. While, different bio-based materials would incorporate mechanical properties of special application in building, specific target applications happen due to the clear difference between morphology and also chemical components used in natural fibers and also biopolymers consisting of polyhydroxybutyrate [5].

In Asian countries it seems very common to use bamboo fibers. After the Second World War, in Kyoto, Japan, people started to use bamboo fibers for different construction purposes [6]. Bamboo fibers were used in a variety of composition panels. According to Chen et al. [7], in Taiwan the possibility of making three layers of board by using bamboo as well as waste wood was investigated. In different Asian countries, other types of biofibers were used for different purposes like particleboards which were made by using bagasse and soybean stalks as well as hardboards which were made from different Thai hardwood and also different types of coconut fibers. In the context of India, inorganic boards were developed for different purposes; additionally, researchers used different kinds of materials by using industrial as well as agricultural waste materials which can be combined with cement. These kinds of combined materials were used for composition boards, tiles of the floor, roof sheathing, and also weatherproof coating [8]. In the Middle East countries, especially in Egypt, rice straw was considered as one of the most important lignocellulosic materials for producing fiberboards. In comparison with wood fibers, rice straw has a low quality as it has high percentage of non-fibrous materials which are embedded in it [9]. It should be added that in the Middle East countries other types of agricultural fibers like bagasse, hemp, cotton, and also kenaf are usually used for manufacturing hardboards which have better characteristics in comparison with straw containing materials [10].

2. Methodology

2.1. Content analysis

Composites are related to materials which are usually used in the field of engineering by combination of one or more things. These different combined elements, when observed through a microscope, are seen as remaining separate and distinct within the finished structure, yet the combination creates a completely new material. The properties of newly designed composites are different from those of the original constituent materials acting independently. In fact, a new type of composites has more advantages compared to the old ones [11]. According to Table 3, composites consist of two elements: (1) matrix (or binder) and (2) reinforcement.

Composite materials have been used in the construction industry for 1000s of years. For more than 2000 years, straw has been used in order to reinforce different types of bricks which are still common in construction industry today. Also, some evidences show that metal were used for reinforcing concrete beams in Greece for more than 1000 years. Polymer composites related to different multi-phase materials which have been produced by combination of polymer resins like polyester, vinyl ester, and also epoxy to produce aesthetic features. Fibers have been used for reinforcing the polymer and improving mechanical shapes like stiffness and also strengths.

Polymer composites have been used for different purposes in the construction industry, like bath and also vanities. During recent years fiber composite materials have been used for structural loads and also considered as suitable and competitive choice for reinforcing current civil structure for replacing steel in concrete and in civil structure.

2.2. Critical analysis

Almost all people in charge of construction related issues are sure about the usefulness and also profitability of bio-composite materials in the construction industry. By reviewing the literature, we can find different reasons for the feasibility of this issue in the construction projects.

2.3. Cost

Cost can be classified in two different types, namely short-term and long-term costs. Short-term costs consist of design, construction, and installation, while long-term costs consist of maintenance, modification, deconstruction, and disposal. Also, we have direct cost like materials and production, and indirect costs like interruption to traffic, depreciation, value resale, and impact on environment.

Now fiber composite materials are more expensive compared to materials which had been used in

Table 3
Composite classes [11]

No.	Name	Advantage	Disadvantage	Application
(1)	Bio-composites	Decreasing the amount of the costs, decreasing amount of density, logical and specific kind of strength and also stiffness, non-exotic economically, less usage of energy	___	Structural and nonstructural assemblies [12]
(2)	Ceramic composites	High strength and strength-to-density ratio, low density, toughness, improved fatigue strength, improved stress rapture life	Brittleness, cost, lack of structural, load-bearing abilities	Military technologies, aerospace industries, auto industries, sports, electronics, building industry
(3)	Polymer composites	It has strength of tensile, high stiffness, high toughness of fracture, high amount of abrasion resistance, decreasing cost, low amount maintenance, construction simplicity	Less mount of thermal resistance, more thermal usage, not stiff in the perpendicular way	Building/construction, medicine, aerospace, automotive, civil/marine engineering
(4)	Metal composites	High strength and toughness, high stiffness, high shear strength, wear resistance, abrasion resistance, fire resistance, low coefficient of thermal expansion, good electrical conductivity, low density, durability, low maintenance, shape flexibility, high ductility	Poor resistance to seizure and galling, higher cost of some material systems, relatively immature technology, limited service experience	Building/construction, aerospace, automotive

construction sites before. It may have some reasons like: high price of raw materials and also their processing, using imported materials which have tax and also shipping [13]. But, because of the different uses of these materials in the life-cycle most of the builders are still eager to use them at their sites.

In Malaysia, most of fiber composite materials have been imported from different countries all over the world and their prices directly relate to the economic changes of those countries as well as the transportation costs. Generally speaking, using bio-based materials is more expensive than conventional materials, but as these materials are environmentally friendly and do not have any bad impact on life and based on their advantages in their durability of construction sites, it is strongly recommended to use them in construction projects in Malaysia and other developing countries to become closer to the international standards.

2.4. Production costs

Most of the production techniques of fiber composites relate to aircraft, marine, and also car industries. The construction industry is completely different in this way that producers are concerned with large-scale structures. So, manufacturing methods for fiber composites are not appropriate for construction industry.

Two different techniques have been used in application of composites in the construction industry. The first one has been offered by [14] which suggest a methodology for the evaluation of using different advanced composites in construction. People in charge should use analytical hierarchy process in order to evaluate project needs, management, producer, and maintenance. So in this method a producer analyzes a project from different aspects and starts to use composites if it seems logical and beneficial to him and to his project. This method has a big gap and shortcoming in which it does not allow comparison between tangible and intangible issues.

The second method which has been proposed by [15], analyzes initial costs, maintenance costs, operating costs, replacement costs, disposal costs, and other kinds of costs like taxes and management costs. By using this method a builder can compare advantages of new and existing materials in the structure. So,

by using the mentioned techniques different people in charge of construction issues can make a decision to use or ignore composites in their buildings.

It is very important to pay attention to the fact that using bio-composites depends on biofibers that are used in them. It should be noted that using biofibers in construction materials has several advantages like low-module elastically, high-moisture absorption, and validity in mechanical and physical properties. In short, components of biofibers that resulted from the cell wall components caused different problems in production of bio-composites, so it is strongly recommended to improve and use natural fiber properties by modifying the basic chemistry of the cell walls.

3. Bio-composite gap in construction

3.1. Durability of bio-composites

According to Hayes et al. [16], fiber-reinforced polymer composites have several advantages over traditional composites. Some of the advantages over the conventional materials are influence of moisture, ultraviolet radiation, chemical attacks, dynamic loadings, freeze thaw cycle, and destruction of properties of the materials through physical aging. According to Goldstien [17], using fiber-reinforced polymer composites significantly increases durability of projects. As a result it seems beneficial to use reinforced polymer composites in construction sites as it increases the durability of the project to a large extent.

3.2. View of bio-composite from a long-term perspective

In order to choose construction materials, a contractor or builder should pay special attention to green requirements and practical features of materials like stiffness, affordability, durability, versatility, and easy way of using it. Each conventional construction material has one of the mentioned features, but none of them has all of the mentioned features. An important goal of manufacturers is to develop materials that not only meet the main requirements of construction materials, but are also environmentally sustainable. Although they seem to be environmentally friendly, they have high costs. As an example production of glass, carbon, and aramid needs high consumption of energy, and in the case of glass, it should be derived from non-renewable resources. Resins are very environmentally friendly compared to some materials like metal.

A good and outstanding characteristic of composite materials relates to their inherent capability to be combined with two or more basic components to produce a bulk material that has better characteristics than the base materials. It should be noted that methods, systems and standards of using sustainable issues should be developed to a large extent to have materials in the construction industry which are applicable to new types of fiber composites.

4. Conclusions

According to the above discussion, researchers investigated different sustainability issues in materials that can improve sustainable construction. As it is clear from the discussion above, there is a large variety of materials to choose from and new materials are constantly being innovated. Material selection is a compromise between competing attributes. Yet, the environmental attribute is becoming more and more important if we want to preserve our planet [18]. The green building materials, such as bio-composites is one of the appropriate techniques applied in building or construction sector where it has higher potential to enhance sustainable building and protection of the environment [19]. Furthermore, it helps in improving the indoor air quality through suitable bio-composites, and can thus reduce the amount of emission of carbon dioxide, sulphur dioxide, and nitrogen dioxide. From green building materials, green construction, eco-community, and others, building and construction industry are the complete circle of healthy and efficient sustainable construction, so as to gradually achieve "human health and global sustainability" [20]. Therefore, bio-composite materials are considered as a very important factor in the construction industry. These days most of the people in charge encourage implementing bio-composites activities which seem to be logical and also cost-efficient for parties, consumers, and producers [21]. Vast activities should be done in order to speed up the process of sustainable construction industry in this country. Attention should be paid to those bio-composite opportunities which can protect the environment as much as possible [22].

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