Chapter 19

Bamboo Based Biocomposites Material, Design and Applications

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56057

1. Introduction

Bamboo or *Bambusa* in botanical has 7-10 subfamilies of genres and there are 1575 difference species ranging from the type of wood to bamboo herb. However, each particular species of bamboo has different properties and qualities [1]. Bamboo is easily accessible globally, 64% of bamboo plantation, as can be seen in Figure 1, originated from Southeast Asia, 33% grown in South America, and the rest comes from Africa and Oceania [2]. Bamboo productions dated back to thousands of years ago and thus they are rich with traditional elements. Bamboo naturally, suitable for varieties of uses and benefits. Bamboo often used as materials for constructions or used as the raw materials for the production of paper sheet, they are also used to control erosion and also for embellishments. Therefore, bamboo plant is sometimes regarded by some people as having positive features towards life such as properity, peace and mercy [3]. Recently, issues relating to environmental threatened the life cycle of the environment globally due to the countries using various types of materials that are not biodegradable by industrial sectors globally. It has becoming a serious matter since it is closely related to the Product Lifecycle Phase resulted from extraction or deposition of waste materials that are not disposed properly [4-5]. Increment of logging activities for variety of purposes has resulted to the failing of absorbtion of carbon dioxide emission by the forest of which large amount of CO_2 are released into the atmosphere trapping the heat withing the atmosphere (green house effect) and causing the global warming.

Bamboo as the great potential to be used as solid wood substitute materials, especially in the manufacturing, design, and construction usage. Bamboo properties of being light-weight and high-strength has attracted researchers to investigate and explore, especially

Figure 1. Bamboo plantations in China [10].

in the field of bio-composite bamboo and is acknowledged as one of the green-technology that is fully responsible for eco-products on the environment [6]. Agricultural biomass solid wood made from bamboo have been identified by many researchers as the largest source of natural fiber and cellulose fibre biocomposite, which are provided at minimal cost and will bring a new evolution into production chain and manufacturing world [7]. Bamboo uniqueness are recognized as the source of raw materials that can be processed and shaped into the form of a number of commodities such as veneer, strips, lemon grass and fibre, and also it gives a new dimension, particularly in terms of its value of diversity in the production of bio-composite products. Advancement in science and technology, has led the materials used in manufacturing industries using raw materials from agricultural biomass to replace the use of solid wood and other non-biodegradable materials to improve manufacturing productivity and availability. High elasticity and strength of bamboo are suitable for the construction industry, and bamboo has proven to serve as a foundation structure [8-9]. The creation of bio-composite fibre board is also used in wall construction and are potentially to contribute of making cost effective home possible. Use of bio-composite material is seen increasingly high and the use bamboo as an alternative can be seen in productions such as furniture, automotive and other related productions. The natural colours of bamboo is unique compared to solid wood and other materials. In fact, the effect of the texture and tie on the outer skin of bamboo has the exotic value and at the same time creates a unique identity in the design, particularly furniture.

2. Bamboo biocomposites

2.1. Classification and development of biocomposites

The long-term global impact of furniture production has forced researchers to find solutions to various problems via research and development [11], and this search has given birth to the idea of using bamboo based biocomposite materials. The bamboo based biocomposite industry is important for improving both the quality of manufacturing and production as well as research and development [12-14]. Examples of some of the biocomposite materials that have proven their quality on the international market are medium density fiberboard, plywood and bamboo veneer each of which have been widely used in manufacturing furniture and other products. Distinctive properties of bamboo fiber reinforced biocomposite natural increase and flexural tensile strength, ductility and greater resistance to cracking and larger than a better impact strength and toughness of the composite [15]. All these properties are not accessible in other types of wood-based materials.

2.2. Conventional biocomposites

- Chipboard and Flakeboard

Bamboo chipboard is formed of bamboo shavings as elementary units, which are dried, mixed with certain amount of adhesive and waterproof agent, spread, shaped and hot-pressed at a proper temperature with proper pressure. Shavings are made of small-sized bamboo culm and bamboo wastes. As negative effects of green and yellow matter on adhesion are weakened after shaving, the adhering quality of bamboo chipboard is high. The supply of raw material for making bamboo chipboard is abundant and its production is an effective way to raise utilization ratio of bamboo resources, as can be seen in Figure 2. Bamboo chipboard is produced using water-soluble phenol resin, such a product has higher water tolerance, higher modulus of rupture and modulus of elasticity, and lower moisture expansion in thickness (compared with wood chipboard). Bamboo chipboard can be used as a kind of material for engineering construction. At present, it is mainly used for making ordinary concrete forms.

For the sake of improving utilization ratio of bamboo resources the stems of small diameter and of less known species, stem tops and all bamboo processing residue are used to make bamboo chipboard. The manufacturing process is designed following the technology of wood particleboard; rolling, cutting, chipping, re-drying, gluing, spreading and hot-pressing. The supply of raw material for making bamboo chipboard is abundant. All small bamboo stems of less known species and residue of bamboo cutting on groove land can be used for production. The utilization ratio of raw material for chipboard production is high, from 1.3 ton of raw material 1 m^3 of chipboard can be produced [16]. The technology and equipment for bamboo chipboard production are similar to those of wood particleboard. It is recommended to develop bamboo chipboard for improving the utilization ratio of raw material and the economic performance of enterprise. Bamboo chipboard manufactured with phenol formaldehyde resin is of comparatively high strength and MOE, low expansion rate of water absorbing. In case of need the products can be strengthened by adding bamboo curtain or bamboo mat to the surface. Such products have broad prospect.

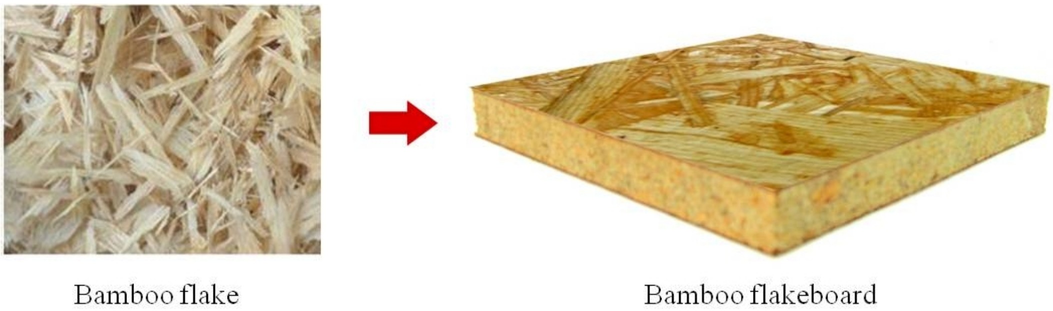

Figure 2. Bamboo flakeboard made from bamboo flake

- Plywood and Laminated

Plywood has been introduced in its application in 1865, since the plywood manufacturing sector began to rapidly developing era, focusing on making buildings and making the walls of the first aircraft using plywood [17]. Instead of plywood, plybamboo is now being used for wall paneling, floor tiles; bamboo pulp for paper making, briquettes for fuel [18]. Plybamboo is a special category in the wide variety of bamboo-based panels. Figure 3 shows plybamboo produced from layered of bamboo veneers with certain desired thickness. Thick strips have higher rigidity; they can hardly be deformed to fill up the blank space between strips even under high pressure therefore leads to the formation of lower the Modulus of Rupture (MOR) and adhering strength. Previously, wood is used to make bottom boards over a long period of time. However, plybamboo was now identified new alternative of make bottom boards. This is because plybamboo is a high quality and have great length which meets following requirements viz low weight, high rigidity, proper friction coefficient (to keep cargo and passengers from sliding) and doesn't rust. Besides, the manufacturing process of plybamboo was found is less laborious and consumes fewer adhesive than other types of composites. The strength, wear ability and rigidity of plybamboo are higher than those of ordinary plywood, thus, plybamboo has a wide prospect in automotive, building industries and engineering construction as well [19].

Due to bamboo's natural hollow tube shape, it is not possible to connect bamboo members with existing standard connections. As a result, it has been of interest to make bamboo available in shapes more suitable to current structural applications. This interest led to the development of Laminated Bamboo Lumber (LBL), which is usually produced as a board of rectangular cross-section [20]. Generally speaking, LBL is produced by flattening bamboo culms and gluing them in stacks to form a laminated composite. The aiming of this research is to examine a new low-technology approach for the fabrication of LBL in an effort to assess the feasibility of using this approach to produce an LBL product that is suitable for use in structural applications. Mechanical properties of bamboo based laminates need to be investigated thoroughly so that the full potential of bamboo as a functionally graded composite could be utilized. This publication reports the mechanical properties evaluation of 5-layered bamboo epoxy laminates [21]. Therefore, the purpose of the present research was to manufacture five types of laminated bamboo flooring (LBF) made from moso bamboo (P. edulis) laminae and investigate their physical (dimensional stability) and mechanical properties (bending properties) by ultrasonic wave techniques and a static bending method [22].

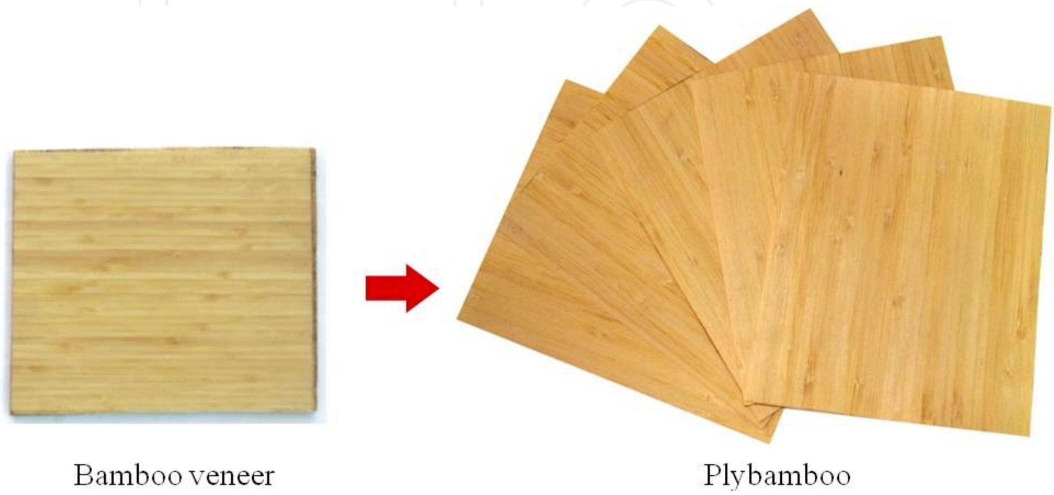

Figure 3. Plybamboo from bamboo veneer

- Medium Density Fibreboard

Medium Density Fiberboard (MDF) is a dry-formed panel product of lignocellulosic fiber mixture of certain synthetic resin such as urea formaldehyde resin (UF), phenol formaldehyde resin (PF) or isocyanate binder [23]. MDF was used commercially in 1970 with the advancement of technologies and materials at that time. However, MDF belongs to the type of wood that is not durable and do not require a very high resistance such as tables, rack, storage and others. In a certain period of time, the MDF can change shape, especially when exposed to water and the weight is too heavy. Presently, the majority of MDF producers in Malaysia are using RW as their major raw material. In order to find alternative of woods due to the arising illegal logging, renewable sources; bamboo fibres is used to produce agro-based MDF. Since bamboo itself has 1250 species, hence each bamboo fibres used in manufacturing MDF is expected not the same. Until now, researchers still in the middle of trying new species of bamboo for examples bamboo *Phyllostachys pubescens* [24-25] and *Dendrocalamus asper* [26] in producing MDF.

Extensive and ongoing research of MDF exhibited with the manufacturing overlaid bamboo fibres board panels using stylus method [27]. This research quantifies the surface roughness of the panel to have better overlaying of the substrate [28] was aiming to evaluate the influence of fibre morphology, slenderness ratios and fibres mixing combinations on the mechanical and physical properties of agro-based MDF using bamboo and bagasse fibres, as shown in Figure 4. It was observed that bamboo fibres had better mechanical performances and were more slender fibres in comparison with bagasse fibres. It appears that manufacturing MDF from bamboo which is non-wood species would provide profitable and marketable panel products in Thailand. Therefore, such panels are not only environmentally friendly but also alternative ways convert under-utilized species into substrate panel products for furniture manufacture.

Figure 4. Bamboo Medium Density Fibreboard (MDF) from bamboo fibre.

- Hybrid Biocomposite

The incorporation of several different types of fibres into a single matrix has led to the development of hybrid biocomposites. Recently, bamboo fibres was also gaining attention to be hybridized with more corrosion-resistant synthetic fibres (glass, carbon or aramid fibres) in order to tailor the composites properties according to the desired structure under consideration. Since synthetic fibres degrade at a much slower rate or does not degrade at all, inclusion with natural fibres may lead to green environmental balances with improvement in performances. Hybrid bamboo-glass fibres composites exhibit enhancement in terms of stiffness, strength and moisture resistance properties. Meanwhile, durability of bamboo-glass fibres composites under environmental aging was improved compared to pure composites [29-30]. Capability of bamboo to produce seven types of shapes encompasses silver, stripes, laths, veneer, particles, strands until bamboo fibres gives a huge impact in creating valuable hybrid biocomposites based on bamboo itself for various applications. In India, continuous ongoing research generates new hybrid bamboo mat veneer composites (BMVC) made from bamboo mats in combination with wood veneer [31]. In BMVC, wood veneer was placed in between bamboo mat. Results revealed presence of woven bamboo mats, BMVC has different mechanical properties along and across the length of the board thereby the properties are comparable to the plywood structure. Instead of bamboo mat, hybridization of bamboo curtain and bamboo mat with wood veneer was limited panels made in China for mainly used in rail coaches. Bamboo mat were also further utilized and commercialized by incorporate with bamboo particleboard for other applications, as can be seen in Figure 5.

Besides, new hybrid biocomposites product mades from bamboo strips and wood veneer bonded with PF resin were also developed. A symmetrical structure with flat and smooth

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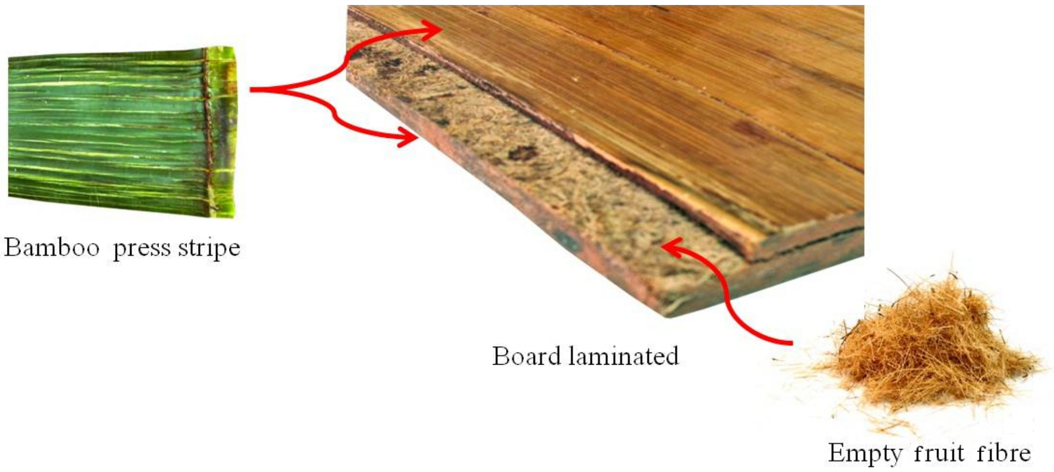

Figure 5. Crushed bamboo stripes laminated with empty fruit fiber.

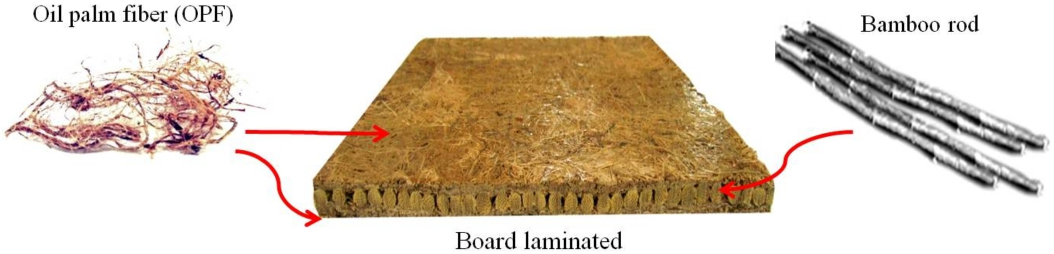

Figure 6. Samples of hybrid biocomposites board. Oil palm fiber laminated with bamboo rod.

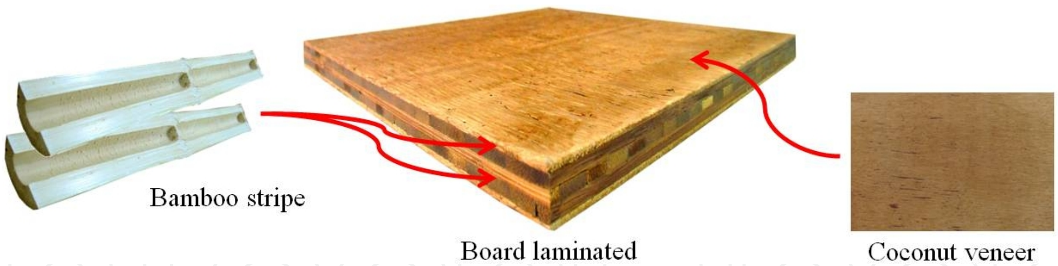

Figure 7. Coconut veneer laminated with bamboo stripe.

surface results from the combination between bamboo strips, bamboo particle and wood veneer plays important role as new material used for concrete formwork and side board of trucks. On the other hand, hybridization between bamboo and other natural fibres were also become a new approach in bamboo development progress. For example, as shown in Figure 6, bamboo rod was stack together with OPF fibres, coconut veneer and bamboo stripe as shown in Figure 7, respectively in order to produce high performances composites and gives variety in design and applications as well.

2.3. Advanced Polymer Biocomposite

- Thermoplastic Based Bamboo Composites

The most common reinforcement of bamboo fibres used today is thermoplastic polypropylene matrices [30]. Apart from various types of bamboo form, bamboo strips have higher cohesive strength than extacted bamboo fibres. For this reason, bamboo strips was reinforced with non-woven polypropylene aiming to produce ultra-light weight unconsolidated composites [32]. Non-woven web allow us to reinforced materials in their native form [6-8] and utilize the unique properties of the reinforcing materials. It was found, bamboo strips-polypropylene (BS-PP) composites has better properties including high flexural, high acoustical properties and good sound dampening that makes them suitable and ideal raw material to replace fibres glass currently used for automotive headliner substrates. Several components can be manufactured using biocomposites such as door insert, trunk liners, pillar trims, parcel shelves and load floors for automotive and field roofing, walling and profiling for building, as can be seen in Figure 8. Some research articles studied the effect of bamboo charcoal addition in the polyolefin thermoplastic polymer [33]. Bamboo charcoal has innumerable pores in its structure making it an excellent medium for preventing static electricity buildup and absorbing volatile chemicals. Taking into consideration these two advantages, bamboo charcoal was chosen as promising material to enhance the water absorption and electrical conductivity of the polyolefin. In another interesting study, bamboo fibres were undergoing autohydrolysis processing as method for obtaining soluble hemicelluloses-derived products reinforced with polylactic acid (PLA). This composite was made with spent autohydrolysis solids presented a markedly reduced water uptake. SEM of reinforced samples showed a satisfactory compatibility between phases, confirming the potential of composites made up of PLA and bamboo fibres as an environmental friendly alternative to conventional petrochemical thermoplastics.

Figure 8. Profiling (a) and roof (b) made from bamboo composites reinforcement thermoplastic.

- Thermoset Based Bamboo Biocomposites

Potential and interest of bamboo used in thermoset composites as expected has the same trend as thermoplastic composites. Previous research studied effects of bamboo fibres reinforced polyester matrix towards various testings for instance tensile and flexural properties [34], dielectric properties [35] and fracture properties [36]. Besides, influence of moisture absorption during storage and composites manufacture of bamboo fibres reinforced vinyl ester was studied by [37]. In another interesting research, bamboo fibres reinforced epoxy composites was subjected to wear and frictional environment in order to achieve widespread acceptance to be used in many applications [38]. It was claimed that, wear volume was superior when the fibres was orientated anti-parallel to the sliding conterface [39]. In another view, bamboo strips epoxy composites was found to be interesting materials to be applied in marine sector worldwide, [40] have produced bamboo boat hull using vacuum bagging and compression moulding process. Figure 9 shows after undergoing several test, this products was confirmed exhibit excellent mechanical properties including material ageing and resist to the marine environment. Exploitation of bamboo epoxy composites was further applied in manufacturing surfboards. Decks of bamboo surfboards are up to 4 layers of bamboo/epoxy laminate in hi-stress areas over a 60 psi medium density foam. Results indicated bamboo decks tend to not dent from normal use unlike glass boards.

Figure 9. Manufacturing process of bamboo boat hull for water sports activities [40].

- Elastomer Based Biocomposites

Exponential uses of bamboo fibres were expanding into elastomer composites area as new viable alternative filler reinforcement. Short fibres are used in rubber compound due to the considerable processing advantages, improvement in certain mechanical properties and to economic consideration. Addition of short bamboo fibres into elastomer polymer matrix especially natural rubber (polyisoprene) promising great mechanical performances of composites manufactured [41-42]. It was found, bonding agent (silane, phenol formaldehyde and hexamethylenetetramine) plays an important role to obtain good adhesion between fibres and rubber. Results revealed composites properties for instances, hysteresis, fatigue strength, modulus, elongation at failure, creep resistance over particulate filled rubber, hardness, cut, tear and puncture resistance were enhanced. The newest report shows the extraction of cellulose nanowhiskers from bamboo fiber waste were use as a reinforcing phase in natural rubber matrix in producing bio-green nanocomposites [43]. The most excellent starting material for production of nanowhiskers is residue from paper production (bleached pulp fibres). In this study, the processing of cellulose nanocomposites was done via a latex based master batch preparation followed by mill-compounding. It was found to be a viable route to produce rubber based nanocomposites, which can potentially be scaled-up to a commercial scale process.

Applications of elastomer composites included tires, gloves, V belts, hoses and complex shaped mechanical goods. As for tires manufactured, Carbon black has been extensively used for obtaining improved initial modulus and durability [44]. Carbon black mainly used as a reinforcing filler in tires starting from 20th century produced a 10-fold increase in the service life of tires. Apart from various types of natural fibres, bamboo also can be burned in furnace for certain temperature and heat to be synthesized into carbon black formed [45]. Since then, carbon black has remained established the major reinforcing material for use in tires as well as other rubber products. Generally, incorporation of carbon-black comprises about ~30% of most rubber compounds. As people playing more and more attention to environmental protection, therefore utilization of various natural fibres especially bamboo as filler as replacement of burned fossil fuels in natural rubber polymer matrix creates greener tires produced, as shows in Figure 10. In addition, physical and mechanical properties of tires manufactured were enhanced with very satisfactory levels in terms of abrasion resistance and improved a lot of resistance to tread. Thus, exploitation of bamboo was no doubt creates improvement in development of elastomer biocomposites.

Figure 10. Green tire made from bamboo carbon black.

2.4. Inorganic based biocomposites

Inorganic bonded plays important role in the construction industry. Generally, inorganic bonded composites can be formed using three types of inorganic binders consists of gypsum, portland cement, and magnesia cement can be applied for producing shingles, blocks and bricks. In this rapidly developing world, there has been a clear trend toward investigate alternative additions for the manufacture eco-efficient blended cement composites. To meet this satisfaction, utilization of lignocellulosic materials for instance bamboo and oil palm fronds remains an exciting and innovative technology as cement replacement [46]. Figure 11 shows the bamboo cement-boards (BCB) were produced from bamboo flake types *Bambusa Vulgaris* from Malaysia. A bamboo-cement ratio of 1:2:75 and 2% aluminum sulfate alone or in combination with sodium silicate was possible to produce a board which satisfied the strength and dimensional stability requirements of international standards which can be used in a wide range of infrastructure construction applications.

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Besides, gypsum bonded particleboards Brazilian giant bamboo (*guadua magna*) has been manufactured by Priscila C. de Araújo 2011 [47]. Results revealed, bamboo cement boards presented higher bending strength and lower moisture content than bamboo gypsum boards. Despites, generally bamboo cement composites and bamboo gypsum composites have superior performances viz higher strength, good weathering resistant ability, good fire resistant and sound insulating as well as containing no synthetic adhesives which will lead to free emission of formaldehyde and other noxious chemicals [48]. Apart from the bamboo structure itself, utilization of bamboo leaf ash as supplementary cementing material for the production of blended cements has been studied by Moises Frias et al 2012. This study has generated the other new possibility in utilizing other side of bamboo structure which is a bamboo leaf in concrete and cement industry. Cement and concrete panels produced can be used for a wide range of applications in the building, housing and other commercial/infrastructure projects for instance wall, partition, roof and pillar materials as well. Further, bamboo as construction materials using bamboo sticks as replacement of steel was studied by Khosrow Ghavami and Mahzuz [49-50].

Figure 11. Inorganic cement board made from inorganic carbon.

3. Biocomposites as potential material in design

Since 1865, the use of agro-based biocomposite material in the manufacturing sector has been introduced and its use has increased consequent to the acceptance of positive users of composite materials [51]. This focusing on sustainable economic stability and protect the corresponding sustainable base resource and environment. Until now, engineer and designers have been succeeded in convincing consumers towards the level of quality and durability of biocomposites material produced through the design. Biocomposites is made of two or more materials combined together to create a new and effective material in terms of quality and production process, based on references relating to the past problems. Activities hybridizing an element of progressive thinking to challenge basic human search for the truth behind the reason for any of the material itself [52]. In the process of biocomposites production, specific characteristics of each original material can be increased or decreased to give the desired effect and this is the reason to why many materials can be found developed through the process of biocomposites, for example, bamboo for product development [53-54]. In the era of science and technology, the use of bamboo has increased its research and development (R&D) to exploit the advantages of bamboo as a fiber substitute other materials because of the advantages of bamboo are sustainable and renewable over time [7, 55]. Many researchers believe that a combination of high-tech applications will be the future standard for the international manufacturing market. Various companies involved in the composites industry began to grow bamboo and compete brings innovative ideas in producing bamboo products from bamboo bicomposites as composite deck, composite bamboo fence, bamboo composite deck tile, bamboo composite bins, bamboo deck accessories [16, 56]. The transformation through creativity and innovation are also on the run, especially in Asian countries such as Japan, China, India, Philippines, Thailand and Malaysia [57-58]. Southeast Asia, the cultivation of the highest quality bamboo has gained attention from many parties, especially the government and the firm of research [52, 59]. Emphasis on innovation is very important because it will not only create jobs but to promote competitiveness [60-61]. Before the design process, the manufacturers able to move to the highest level with the help of four aspects of design, quality, identity, and raw materials. Four aspects are interrelated with each other in the manufacturing industry. Therefore, the cooperation between researchers, engineers, designers and marketing necessary to ensure that products produced in the limelight from customer [62]. Failure of one of the four aspects of the products produced will fail in the market. There are some examples of products that failed in the market not because of poor quality or less attractive design but use less material to meet customer needs [63-64]. In the second stage some product evaluation process will be conducted to identify the level of quality of the products and fulfill the quality standards [65].

Technical assistance, infrastructure improvements to the farm, machinery and factory equipment in place which needed to develop a revolutionary product in the bamboo industry composite. Products such as biomass fuel pellets, particle board, and composite applications are designed with a combination of bamboo fiber to produce strong and durable strength to the conventional wood, steel, and plastic [13]. The physical properties of bamboo are tapered, hollow, have a node at varying distances, easily shaped and not perfectly round bamboo can be a major factor to be alternatives to other sources [16]. Physical property makes bamboo is often chosen as the lead in the design of the building structure as to fit the shape of bent bamboo is not difficult. This is because bamboo can be used in both situations either green bamboo or dried bamboo, because bamboo has determined its shape will remain for long without mindfully stretches [66-67]. Bamboo biocomposite always thought to compete with the strength of steel as well as having the advantage of aesthetic value compared with other materials. Steel production requires the use of fossil fuels is high, therefore, emissions in the steel manufacturing industry increasingly apparent, studied to understand the mechanical behavior of bamboo reinforced concrete members and explain the differences in the structural properties of steel reinforced concrete, reinforced concrete and bamboo. In this chapter, several tests bamboo reinforced concrete beams and columns that run in the laboratory report.

Excellent research to understand the mechanical of behavior bamboo reinforced concrete and explain the differences in the structural properties of steel reinforced concrete and bamboo has been proved by researchers [53]. Composite panels using natural fiber made from bamboo reinforced cement have great potential due to their better strength, dimensional stability and other characteristics compared to panels made from several plantation timbers [31].

Bamboo fiber has an inner impact of natural color and texture is interesting, original, versatile, smooth surface, low cost and sustainable. An example of innovative bamboo research is the design of a Spring Chair based on the elements of swift motion, transforming bamboo's strength and flexibility to produce a reaction from the design, a unique structure as the primary feature of a complete biocomposite material designed by Anthony Marschak [68]. Nowadays, different designers from manufacture company compete each others to create something modern, stylish, beautiful and outstanding product in the market used bamboo biocomposite. The use of bamboo as biocomposites in the design is usefull to create a better experience for the end user, giving more attractive design and allowing efficient manufacturing systems produced as an alternative. Biocomposite bamboo as modern material is a different experiment and does not constraints to the limit of creative thinking [69]. Biocomposite market acceptance of the use of bamboo in furniture manufacturing, automotive, construction and interior decoration is becoming in demand and easily can be found in international furniture fairs and interior design exhibitions every year [54, 69-70]. It is obvious that biocomposite bamboo material has the tendency to tackle resource-efficient challenges, creating virtually no waste when processed properly and at the same time increased the product market, while also promoting the use of sustainable materials [71-72].

4. Commercial applications

In recent years, the use of bamboo has been enhanced to exploit bamboo as a renewable wood fiber. Evolution in theoretical and applied research on bamboo-based products has increased year by year and expanded its use in almost all applications, especially in building, furniture, product, transport, packaging and others. Bamboo composite was accepted in the global market in applications replacing traditional wood interior and exterior products [36]. This proved the strength of bamboo is found 10 times stronger than wood materials [73]. Various positive advantages found in composite products from bamboo as dimensional stability, longevity, weather resistant, high impact resistant, low maintenance, non-toxic, low flame spread, etc. [34]. Table 1 shows the innovative design and application of bamboo fiber biocomposites in various categories.

4.1. Construction applications

Wood has been used as a building material for thousands of years, otherwise the use of bamboo as the main material in construction activities in Southeast Asia have taken place since the era of human civilization began to grow. Community in the early days to know about the benefits of plant bamboo and consider the benefits of life [3]. The use of bamboo in construction design has long proven its excellence by building houses one hundred percent use of natural bamboo. Mechanical properties, durability, suitability as a good absorber of heat and access to source material made it famous and still used until now [74-75]. This is evident based on the tensile strength required in the development of the bamboo bridge before the first world war again. The suspension bridge was first created using bamboo to cross the river and business relations. At that time, the bamboo used classic exterior use only bamboo, which is four times as strong as the interior. Bamboo bridge was built in India, South America, while in Colombia, using a bamboo bridge and cable tension structure created by the tensile strength of up to 3,200 kg/cm2 using Guadua bamboo species [67]. Innovations in bamboo technology offer new opportunities for large-scale construction of this sustainable material. From long-range beam cross laminated laminated bamboo panel, joinery, bamboo has proven to be safe and durable for city buildings and homes and it proved to be used in major cities around the world, from Europe to United States and Southeast Asia [76]. Many architects and designers convince bamboo as the most environmentally friendly in the world. Scientific and technological progress have resulted in hybrid biocomposites from bamboo has the capability to produce various types of reinforced veneer that has a big impact, particularly for construction [6]. Many bamboo transformations were produced by scientists to improve the quality of the various aspects of bamboo, for example in China, bamboo is used in the design of the roof with the tip covered with decorative tiles to protect from rain water, add neatness and aesthetic value to the roof [3]. Various techniques have been developed to produce a strong roof support system. In the Philippines the roof function improved by using the split bamboo roof and produce a soft surface to facilitate the flow of air and water in bamboo [77]. Roof architecture is most suitable as roofing solutions at the time. Design prefabricated truss system has a frame will be covered with bamboo board, lath and plaster to create a waterproof roof and can last up to 15 years with regular maintenance.

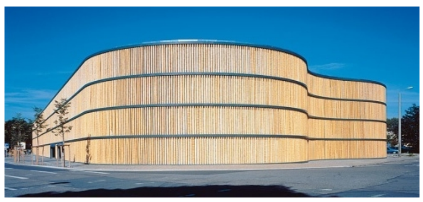
The natural beauty of bamboo aesthetic usage has led bamboo to be widely showcased as part of the collections globally. Bamboo has been widely accepted to be more than just the material by the architects and designers but also can be used to decorate and embellish. Bamboo has the same technical performance comparable to the solid wood, concrete, and steel but release smaller carbon footprint [7]. Because of its eco-friendly property, bamboo is often alternatively used as concrete reinforcement. Many studies have been conducted to determine the feasibility of using bamboo to reinforce concrete with flat symmetric structure decisions and smooth surface from a combination of bamboo strips, bamboo and wood veneer particles play an important role as new material is used for concrete formwork [72]. New biocomposite hybrid product made of bamboo strips and wood veneer bonded with PF resin was developed as a result of ongoing research. Prominent architects bamboo, a renowned architect Oscar Hidalgo comes from Chinchina, Colombia make bamboo as the main material in the construction work and thus make bamboo as a symbol of art in every creation. Advantage and uniqueness of unusual bamboo plants, Oscar then has dedicated his whole life to bamboo research. Research on the structural integrity and aesthetic value in bamboo has brought Oscar to Asia, Costa Rica, Brazil, and elsewhere to study this plant and build some experimental structure. He was the first to use a variety of beam culma and uses a unique bolt system as the introduction of concrete in intends to create very strong joints for construction. All in all, Oscar recommend the use of bamboo in housing construction because many of the problems associated with bamboo can be reduced by creating laminated bamboo strips.

In 1942, Oscar has made a study of the use of bamboo laminates in ski pole was commissioned by the government of the United States (U.S.). At that time the bamboo laminate floor tile products applied with a very good quality for heavy floor traffic with soft strips of bamboo from remote culma and can be used safely [67]. Bamboo also excelled as a reinforcement of concrete tested because many studies have been able to determine the possibility of using hybrid bamboo to reinforce concrete in the future [47, 78]. However, ongoing research necessary to solve some other problems of resistance if the water in the bamboo because bamboo can break concrete durability when experiencing the process of expanding and then shrinking.

4.2. Interior design applications

Bamboo biocomposites has excellent impact on creating interior design that has a commercial value of its own way. Biocomposite use in the production of various bamboo products for exterior and interior which have a good demand in the global market. Most users realize the greatness of this material and support the efforts of sustainable for nature in everyday life. This is further enhanced by its excellence as an innovative material to get recognition from various quarters, proving that hybrid bamboo material can overcome other types of materials from various aspects such as physical, mechanical and aesthetic [6]. Nowadays, various types of hybrid bamboo-based products have been produced, from the design of the ceiling, walls, floors, window frames, doors, stairs and up to the home decorative accessories. Bamboo can create special effects, as well as using bamboo joinery can be bent or straightened by heating and clamping. Based on the previous research, a typical wall section created with bamboo stud where distance is determined by the thickness of the bamboo boards which are used in the study [79].

For example, when a board of 1 cm is used, the distance for each stud is 40cm. Bamboo boards are attached, and two layers of plaster are used. Another wall system utilizes the bamboo studs as described above, is by using small pieces of bamboo attached together with 1 1/2-2" nails. Then, the attached bamboos are plastered with a mixture of clay / straw outside the system, this is known to be heavier than the previous example. The prefabricated nature of the bamboo wall panel system which are pre-built on the ground leads to better housing development [80]. Interior design most impact on the industry for interior decoration and architecture is Madrid Barajas International Airport, Spain also it has been recognized the world as a Sustainable Building 2011 [81]. Richard Rogers, designer of the world's most prestigious airports that designs consist of 200,000 m2 ceiling lath gently curved laminated bamboo, the bamboo industry's biggest project in the world. International Airport was built using laminated bamboo laths from all walks of bamboo veneer. Richard Rogers has managed to apply the design process in yield designs with the use of materials and finishes that can create a unique passenger experience, exciting and the atmosphere is peaceful and quiet. Although the simplicity of the concept of architectural features terminal, it still gives comfort to passengers. Therefore, interior design use hybrid bamboo could be emulated by other designers in meeting the demands of the 21st century, so that the designs produced will be efficient, economical and functional.

Category	Year	Inventor/ Designer	Design Name	References	Design
Furniture	2006	Anthony Marschak	Spring Chair	[68]	
	2009	Kenyon Yeh	Jufuku Stoo	[88]	
Automotive	1999	Automotive Manufacturer (Audi, BMW, Peugeot, Volvo, etc.)	Automotive Components (Cloth seats, floor mats, dashboard, door panels, etc.)	[19, 86, 89]	
	2010	Kenneth Cobonpue & Albercht Birkner	Pheonix Bamboo Concept Car	[87, 90]	
Interior Design & Construction	2002	HPP Architects	Parking Garage, Leipzig Zoo, Germany	[76]	

Category	Year	Inventor/ Designer	Design Name	References	Design
	2005	Richard Rogers	Barajas Madrid International Airport, Spain.	[81]	

Table 1. Innovative design and applications from bamboo fiber biocomposites in various categories.

4.3. Furniture applications

The design is a mechanism to display an awareness of the importance of the needs and quality of life through creative and innovative ways. Revenue awareness now, a lot of furniture design in the market focused on the continuity between current needs and environmental concerns to ensure the life cycle assessment as a result of product benefit. Bamboo materials importance to environmental sustainability supported by success in applying design furniture designer to include design elements with environmental relationships to enhance the product in order to gain market attention [82].Many countries have started to establish research and development-based furniture such as the Malaysian government established the agency Forest Research Institute Malaysia (FRIM) for more in-depth research to help the furniture industry because Malaysia is the largest exporter of furniture to more than 100 countries. The Chinese government also provides support and assistance to help establish Chinese Association Ecomaterials materials scientists who research on how to design, produce, reuse, disposal and recycling of materials in an environmentally. Bamboo biocomposite proved by many researchers to have high benefits as an alternative material for the production of furniture and other components. A variety of new furniture designs have been produced using smart materials is based on the proven quality furniture compare to solid wood material. High innovation in bamboo fiber can improve the durability even bent and shaped materials such as solid wood other [66]. Research and development in making advanced bio-based furniture products around the world are able to produce continuous improvement in product innovation success. Initiatives to increase the use of bio-composite value highly praised and encouraged for these materials to reduce environmental impact, improve innovation and advanced technology in the manufacturing process.

Bamboo also has the characteristics of materials and textures are very useful for designers to create a unique design and original, it is imperative that users reacted positively [83]. Now, many examples related to bamboo furniture that can be used as an important consideration in choosing furniture bamboo [55]. There are several designs of amazing furniture use bamboo material simplicity, many furniture designers prove bamboo materials is not only resilient and pliable, but tremendously powerful internal and external. For example young designer

Kenyon Yeh, a designer has produced designs stool named Jufuku from Japanese word means duplication or repetition. Stool Jufuku clearly emphasizes the best quality bamboo to produce designs without parts or fasteners, where each piece of bamboo on Jufuku Stool is made from a single structure shape which is then repeated to complete each form of the object but the result is still beautiful in a simple, minimalist and attractive. The famous designers Anthony Marschak discovered the magic of bamboo while looking for ideas as versatile materials other than solid wood for his design for Spring Chair. Spring Chair is produced from renewable resources has become a sustainable furniture and other luxury furniture comparable. Strength and flexibility of bamboo materials to create natural bending very important in the design and ergonomic nature [68]. Spring Chair bamboo bending technique: made from one continuous sheet, the surface of the first three curves are made to suits the human contour seats. Bamboo biocomposite manage to stand out as a versatile and able to provide a beautiful surface finish, elegant, unique structure and interesting links suited to any modern home. Beauty can be seen in Spring Chair as the pioneer era of the rise of modern bamboo.

4.4. Automotive applications

Natural fiber has experienced rapid growth in the automotive market, especially in Europe and Southeast Asia. Biocomposite based innovation increasing every year in the global research arena because it promises a reasonable cost and performance compared to competing technologies. The first Industrial Revolution progress in transportation with the creation of steam-powered ships and aircraft engines. In 1930, a second industrial revolution is an important era in the manufacture of car compartment using fiber as an alternative to existing materials. Famous automobile inventor, Henry Ford also supports the use of materials from natural fibers start to bring progress in the era of automotive construction. European Union (EU) and the countries of Asia also supported by issuing guidelines in the global automotive manufacturing industry [84]. A study shows that low cost natural fiber bamboo materials are highly potential to be used in automotive parts [84]. Guidelines made in 2006 ordered all automotive manufacturers to produce automotive plastic reinforced using natural fiber. In addition, the European Union (EU) targeting 80% of the vehicle compartment must be reused or recycled and the amount should be increased by 2015 to be 95%. Through previous research has produced various components of the car which has been designed using natural fibers as the main component. Research continues to generate new bamboo mat veneer composite hybrid (BMVC) where bamboo mate was used as the face and back layers of wood veneer and the core layer. In addition, bamboo mat with wood veneer panels used in train carriages. Natural fiber composites with thermoplastic and thermoset matrices have been widely used in the manufacture of door panels, rear seats, headliners, package trays, dashboards, and the interior of the car manufacturers' world [85]. This is supported by many researchers who have proven quality and effectiveness of bamboo as an alternative material in the automotive manufacturing industry.

To make the strip used to laminate, soft bamboo for interior issued by plane, leaving the external hard drive to strip lamination. Natural fibers such as bamboo offers benefits such as reduction in weight, cost, reliance on sources other materials, and has the advantage that can be recycled. However, few studies on technical and mechanical material of bamboo fiber are still being studied by scientists and engineers before getting the confidence to allow large-scale manufacturing, especially to the outside of the car body. In the 21 century, bamboo fiber has become crucial for the development and design (R & D) products [86]. Earlier bamboo has been used to build boats and zeppelins. In aeronautics research, the structure of the kite and early aircraft were built using materials from bamboo fiber because it is lightweight and very strong. The aircraft made entirely of bamboo were built in the Philippines, while the Chinese use in their aircraft during World War II [40, 86]. In 2010, Kenneth Cobonpue designers from the Philippines and Albercht Birkner branded products from Germany managed to create a 'Phoenix', the first car in the world is made of bamboo and natural fiber that can be recycled [87]. Phoenix uniqueness is reflected in his designs made using small bamboo stacked and tied neatly. Use bamboo turned into products with the quality of its own internal and external design makes the Phoenix has a high aesthetic value. Biodegradable materials challenge the notion compact, durable materials in vehicle design. It looks at cheaper and ecological option replaces the shell, on the other hand build and explore the relationship between technology and nature in the bamboo concept car. In fact it can be used as laminated wood, with a bamboo laminate edge is much lighter in weight.

5. Sustainable product and development of bamboo biocomposites

There has identified three key areas that will be noticed in connection with products and sustainable development, ecology, economy and technology is all that should always give priority in life, as shows in Figure 12. All levels will impact specific, largely due to the materials involved in the different stages. This concept can be described as a wise balance between the demands of society's increasing demand for products, the preservation of forest health and diversity of material resources and benefits.

5.1. Ecology capital

In addition to improving environmental quality through the development of a sustainable supply chain resources, and better towards reducing CO_2 and almost zero net greenhouse gas emissions. From previous time, environmental issues is not high on the public agenda, but it is an exciting challenge that can lead to new solutions through the design and prove a wise economic choice. Solid wood product work has been in existence since the era Neolitic [91]. Artisans from many cultures have developed a technique to design and style this way many conventional furniture and rooted in human culture. In addition, problems such as a lack of material resources and the population increases each year is the main reason why designers need to focus their attention on the development of new materials design from bamboo fiber as technology and marks the progress of evolution in style. Product development will help consumers to see the potential of bamboo biocomposites products as part of our culture and heritage, and to enhance the status in our society [16]. From the results of studies carried out in Europe, it can be concluded that the bamboo fiber reaches "CO_2 neutral or better". However, the level is far more excellent if used in bamboo producing countries such as China and India

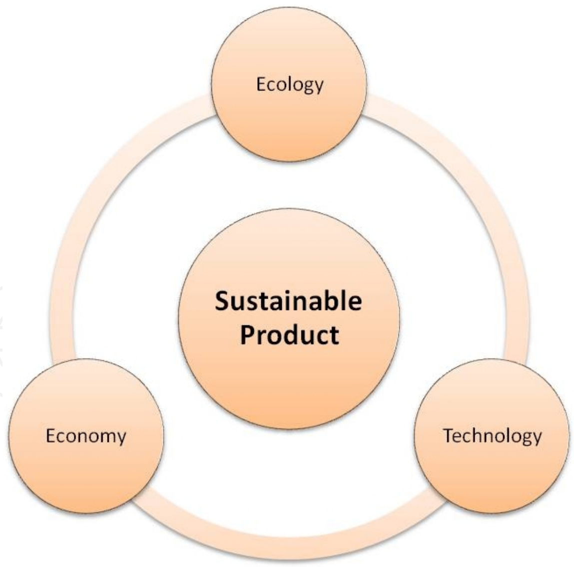


Figure 12. Three elements to support the sustainable product.

to have a lot of bamboo material resources and ecosystem [92]. Bamboo has roots that spread underground in all directions; land turned into solid and protects us from landslides and earthquakes by heavy rains. This means that the stand of bamboo should be treated as common ground for the public community. Economic trade market incomes only concern about the cost of production, otherwise cost disposable products used completely overlooked. This is one of the main reasons why the serious problem of waste disposal and environmental disruption has been caused recently.

5.2. Economic capital

Bamboo will be considered as one of the most useful resources to maintain sustainable economic development. Successful product development technical or physical demand is insufficient. Factors such as reputation, fashion products, trend, cost and other factor should also be taken into account when developing a sustainable product. An example of addressing this problem is for the exchange of ideas between the designers, engineers, socialists, scientists and marketing experts. Transformation of low-impact materials considering the material is important. Renewable materials, nontoxic materials, and materials that can easily be recycled all the smart choice to shift the perception of beauty designer different reference frames. At the same time, a potential new market in the development of sustainable solutions will be increased globally [93]. The design, which is a practical activity but also part of the culture and research, can make a significant contribution not only to design products and services that require creative community, but also to the development of a more general transformation of the materials industry [94]. To realize sustainable economic development, we need to consider the costs associated with not only the goods but also non-tradable goods such as environmental protection and natural resources. In the case of the total cost of producing bamboo bamboo including the cost of disposable copied and will be cheaper than making chemicals. In addition

http://dx.doi.org/10.5772/56057

to bamboo has a better variety of mechanical, anti-bacterial applications and industries that make it an excellent resource for sustainable economic development [95].

5.3. Technology

The history of technology in keeping pace with the development of human culture since Paleolithic times. Through the events in the movement era of human civilization shows some technology is starting created slowly the impact of human knowledge about materials, science and technology. Since the world is faced with many serious problems such as global warming, acid rain, soil erosion, the financial crisis, extinction of flora and fauna habitat and others, which these problems are caused by human behavior-oriented manufacturing profit that could be marketed. Global manufacturers rich with knowledge of high technology need to consider a sustainable technology in each manufacturing process. Over the years, manufacturers already accept green technology at several countries to support the environment. Green technology is important because not only it can increase the profit, but to maintain the ecology, source materials and people will be able to enjoy a peaceful life until next generations. In order to develop a sustainable product, it is important to know the aspects of technology. Sustainability issues have recently become considerations when consumers choose to use green products in everyday life. In other words, the materials and design are very needed as an intermediary with the user in maintaining the quality of life and maintain as it reflects our cultural values [96]. Therefore, other materials needed as an alternative to meet these needs [84]. Therefore, the introduction of new technology in the sciences material is needed to maintain the momentum of the global manufacturing market.

Today, most people recognize that solid wood resources are limited and the progressive consideration must be given to the processing of biomass. Manufacturers need to change the manufacturing process of current technology to build a sustainable world and a strong economy [93]. To be a sustainable ecological community, the values of life we have to change along with the way of life that we see the product from different reference frames. Since bamboo provides a number of specific characteristics, it becomes a typical example to make our communities sustainable and rich thru technology.

6. Conclusion

From this chapter, it is concluded that the new development in innovation bamboo biocomposites from the natural fiber need to be more highlighted. The biodegradability and recyclability of design based material could be the critical problem in the next decade. In addition to the increase of population, the regulation forced manufacturer to use natural fiber in further products. Low cost, environmentally friendly, accessible and easy production of natural fiber composite are attractive benefits for design development and applications. A collaboration between scientist and designer is important to archive the quality materials, produce good design and has implications not only for the companies but also for consumers and the society.

Good design combines the capabilities of a balanced approach in terms of material, commercial design, environment, technology, idealism, and humanitarian concerns will generate benefit product for Life Cycle Assessment without the effect of the ecological system. In other hand, product value can be increased with the use of a material and design that reduces simultaneously the environmental impact and cost effective if manufacturers completely support new material mechanical properties and explore that have the potential to meet the requirements of a new future. The advantages of renewable bamboo fiber and biodegradable at the end of the product cycle including safetyness during handling and processing, and also as a resolution to the problem of resources reduction of other materials. The importance of awareness of the diversity of natural resources such as bamboo can generate new economic resources while protecting natural forests for future generations.

Acknowledgements

The authors highly acknowledge and pay gratitude to the Universiti Sains Malaysia, Penang for providing Research University Individual (RUI) grant 1001/PTEKIND/811195 that made this work possible.

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