Development of Utilization Alkali-Treated Bamboo Fiber as a Strengthener in Thermoset and Thermoplastic Composites

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Abstract. The increasing concern over environmental problems and the demand for renewable raw materials continues to increase, making researchers must find the right solution to overcome these problems. One solution is to reduce the use of synthetic fibers, which can replace natural fibers. This article is to review the use of bamboo fiber as a reinforcement to improve the physical and mechanical properties of composites, starting from the manufacturing process to its future potential. The matrix, which usually used as a binder of bamboo fiber, is thermoset and thermoplastic. As time goes by, the matrix becomes more popular. The method of making composites with Hot Press has a significant effect on composite results. The preparations and parameters involved during the process of making bamboo fiber composites with thermoset and thermoplastic matrices have a considerable impact on the results of the physical and mechanical properties of composites. Alkali treatment can eliminate hemicellulose, lignin, wax, and oil, which cover the surface of the outer walls of natural fiber cells and increase the surface roughness of the fibers, thereby increasing the bond between the polymer and the fiber. The determination of fiber composition variation plays a significant role in the physical and mechanical properties of composites. Too much pressure can damage the fiber, while too low pressure results in poor lamination consolidation. The processing temperature results in a better interface wetting between the fiber and the matrix. Holding time produces a more reliable bonding interface by removing the air gap that induced during pressing between the fiber and the matrix, thereby increasing tensile strength and modulus. The utilization of bamboo fibers to reduce synthetic fibers has opened opportunities for academics and industry to design sustainable modules to utilize bamboo fibers in the future. Making bamboo fiber-based composites with thermoset and thermoplastic matrices can reduce environmental problems and can be developed into effective biocomposites. Added with the advantages of thermosets and thermoplastics such as resistance to heat and chemicals even in extreme environments, flexible and recyclable, so that it has good potential in the future.

Keywords: Bamboo, Composite, Hot Press, Thermoplastic, Thermoset

1. Introduction

Increased concerns about environmental problems and the depletion of fossil resources make researchers have to find solutions as quickly as possible to overcome these problems [1]. Added with the demand for sustainable and renewable raw materials continues to increase [2]. One solution is to
reduce the use of synthetic fibers (for example, carbon fiber, fiberglass, nylon), which can replace natural fibers. There during this, synthetic fiber is difficult to decompose and cause pollution in the environment. In contrast, natural fibers are lightweight, renewable, biodegradable, cheap, low energy requirements, abundant, and durable and elastic [3, 4]. Natural fibers obtained from renewable sources have a smaller negative impact on the environment than petroleum-based materials [2]. Natural fibers are increasingly in demand in the field of polymer science, which has great potential because of rising concerns about the environment and the global energy crisis [5]. Increased interest in natural fibers is also due to awareness of the environmental impact of the use of synthetic materials, and all properties possessed by natural fibers can meet the economic growth of the industry [6].

Synthetic fiber materials cause many environmental problems, but these problems open up opportunities for research into other materials such as green composites [7]. Natural fibers have adequate mechanical properties so that they are an excellent ecological alternative to glass, carbon, and other synthetic fibers for use in making composites [8]. The potential of biodegradable composites is at its peak because of its superior properties such as renewable character, lightweight, cost-effectiveness, comparable specific strengths, CO2 absorption, good mechanical strength, acoustics. Thermal insulation properties, which can use as alternatives to synthetic fibers [9]. While synthetic composites cause many problems, such as environmental problems, over strength or excess strength in specific applications, and require expensive costs [10]. Green composites or natural composites believed to overcome these problems [9].

Wood-Plastic Compositeites (WPCs), where lignocellulosic fillers act as reinforcement, has many advantages, such as low cost, high specific strength, and modulus. Also, renewability, biodegradability compared to reinforced composites containing inorganic fillers [11]. The exploitation of bamboo fiber in various applications has opened new opportunities for academics and industry to create sustainable modules for the use of bamboo fiber in the future [12]. Bamboo is one of the most significant renewable natural resources, which can use as a substitute for non-renewable synthetic fibers in biodegradable polymer composites (biopolymers) [9]. Bamboo has abundant profit potential as a natural fiber resource [7]. Bamboo is an underutilized material that can be used more efficiently in structural or engineering products [13]. Also, it becomes a renewable bioresource whose utilization is not yet maximal [14]. Several studies have shown that bamboo has good prospects for strengthening thermoplastic composites, which are promising substitutes for wood-plastic composite products to reduce the depletion of wood sources [15].

There has been a rapid development in research and innovation in the field of natural fiber composites [16]. There is also an increase in demand for polymer matrix composites in aerospace, automotive, and building construction because of the use of composites that are stronger, stiffer, and lighter [17]. However, it still has many difficulties such as a mismatch between fiber and matrix, tends to form aggregates, weak interface adhesion, not resistant to moisture, low melting point, and fireproof capability. To limit it to broader use, it is, therefore, necessary to further research [17].

Several studies have conducted to overcome these problems, including research on the tensile strength of putung bamboo (Dendrocalamus asper) fiber composites with epoxy due to the effects of alkali treatment, composite manufacturing, and water absorption [7]. There is also research on increased strength and toughness in bamboo composites with Ultra-High Molecular Weight Polyethylene (UHMWPE) [19], synthesis of nanotubes from H2Ti3O7H2O and their effect on flame retardance of bamboo fiber composites with High-Density Polyethylene (HDPE) [20], and physical and mechanical properties of polyethylene composite waste with wood fibers have also been studied [21]. A study shows various applications of polyaniline (thermoset) can be applied in various fields such as electricity, electronics, thermolectric, electrochemical, electromagnetic, electromechanical, electro-luminescence, electrorheological, chemical, membrane, and sensor [22, 23]. Because of the full application of thermosets and thermoplastics, this has good prospects for further research.
2. Bamboo fiber
Bamboo fiber has a relatively high strength; the angle of microfibrils is small, cheap, and can be used as an amplifier in polymer matrix composites, replacing synthetic fibers to some extent [24]. Bamboo has cellulose content of 73.83%, hemicellulose 12.49%, lignin 10.15%, water extract 3.16%, and pectin 0.37% [12, 25]. Microfibrillation cellulose maximizes polymer mechanical properties such as tensile strength and modulus more efficiently than is achieved in conventional micro or macro composite materials [26]. Because bamboo fiber has a large enough cellulose, bamboo fiber has a good chance to be made into a natural composite material or a green composite. A study of the bamboo species Guadua Angustifolia shows the shape of bamboo fibers (Figure 1) [27]. As a natural nanocomposite, bamboo has a multinode and functional gradient structure, macroscopically, and microscopically. The fiber spreads the outer and inner surfaces [28].

![Figure 1. Bamboo microstructure [27].](image)

3. Parameters that affect the composite results
The physical and mechanical properties of bamboo fibers can make improvements by alkali treatment [3]. Also, the mixing of variations in raw materials plays a significant role in the physical and mechanical properties of composites [29]. In making composites using a hot press, the most significant effect on the tensile strength results of composite materials is the effect of processing temperature, pressure, and holding time [17, 30]. The fiber angle also affects the composite results, the direction of the fiber, which is more parallel with the force applied, the better the strength of the composite.

3.1. Alkaline treatment
Chemical method techniques applied to the surface of natural fibers make it possible to produce superior fibers that use to form new composite materials for lightweight applications [31]. The alkali treatment is one of the most commonly used chemical methods, namely to remove lignin, waxes, and oils that cover the surface of the outer walls of fiber cells, on natural fibers when used to strengthen thermoplastics and thermosets [32]. In one study, it proves that after alkali treatment, cellulose strength was maximal, while hemicellulose, lignin, and wax levels decreased [33]. The alkali treatment also increases the surface roughness of the fiber, thereby increasing the bond between the
polymer and the fiber [3], and effectively reduces water absorption, increases the moisture resistance of composites, and minimizes the reduction in tensile strength [28]. Fibers that are not treated with alkali will reduce the bond between fibers and matrices in hybrid composites compared with fibers that treated with alkali [35, 36].

The treatment of bamboo fibers can increase the tensile and flexural of the resulting composite [37]. In contrast, the alkali treatment of wood composites increases the hardness and impact strength of the composite results [29]. The treatment of coconut fiber also proves good bonding and attachment of coconut fiber composites with the HDPE/NBR matrix, which results in better tensile strength to the composite results [38]. For the treatment of pineapple fiber, it can increase the adhesion between hydrophobic polymer (HDPE) and natural hydrophilic fiber (pineapple) [39]. Alkaline treatment is mostly done by some researchers using sodium hydroxide (NaOH) because, in general, using NaOH is quickly processed, inexpensive, and the results are excellent [40]. Hot water and NaOH concentrations of 10% produce an increase in mechanical strength due to increased surface adhesion between the matrix and the fiber [41].

3.2. Variation in fiber composition
The amount of fiber composition variation is significant to produce a good composite with mechanical equipment [42]. The addition of natural fibers to plastic composites increased significantly in dimensional stability and elongation resistance due to the hydrophobic nature of natural fibers. It increased the compatibility of fiber particles and polymer matrices at the interface surface [11]. However, if the added fiber is too much, a bond in the composite will decrease to the lack of matrix tasked with binding fiber. Mixing variations in raw materials play a significant role in the physical and mechanical properties of composites [29]. The features of the hybrid composites of the two elements can be estimated by the mixture rule, as shown in equations (1) and (2) [43].

\[ P_H = P_1V_1 + P_2V_2 \]  
\[ V_1 + V_2 = 1 \]

Where, \( P_H \) is the property to be analyzed, \( P_1 \) is the first element property, and \( P_2 \) is the second element property. \( V_1 \) and \( V_2 \) are the first volume fraction and the second element. In one study, natural fiber composites with the HDPE matrix stated their tensile strength and hardness decreased with increasing fiber variation, but tensile modulus increased with increasing fiber variation [39].

3.3. Hotpress
The method of making composites with the hot press has a significant effect on an increase in tensile strength of up to 37% compared to the lay-up method [7]. Forming an optimal combination of parameters using the hot press is very useful for manufacturing in the engineering field [7]. Hotpress also produces a balance between mechanical properties, cost, environmental impact, reducing CO\(_2\) emissions and saving energy [44], and increase the thermal stability of antibacterial bio board samples [14]. Thermoplastic-based composite materials (polypropylene, nylon, acrylic) can be repeatedly softened and reshaped with hot press applications [45]. Hotpress also provides a low-cost alternative to producing composites [46]. In contrast, the parameters that most affect the hot press method on the composite results are the effect of processing temperature, pressure, and heating time [17]. These parameters show a notable increase in mechanical properties [47]. In other studies, mold temperature, compressive pressure, and holding time was proven to be interrelated parameters that affected composite performance [48].

3.3.1. Pressure.
Pressure has a significant impact on the efficiency of the composite finish. Too much stress can damage the fiber, while too low pressure results in poor lamination consolidation [7]. An increase in excess weight also results in lower tensile strength and modulus because the material becomes stiffer, pushing more matrix material to the side, which leaves many fibers not bound by the matrix [49].
good pressure determination uses to ensure an excellent bonding interface between the fiber and the matrix and avoid the fiber structure from being damaged, which will affect the performance of the biocomposite [48]. In bamboo fibers, processing pressure produces a significant effect on tensile and flexural strength, but not significantly on impact strength [9]. At too high a pressure, bamboo fiber is not compressive and less flexible, matrix resin extruded from the composite, which results in an insufficient amount of resin between fibers at high pressure [2].

3.3.2 Temperature and heating time.
The processing temperature has the most significant effect on mechanical testing because it determines the strength of the composite [9]. Temperature also has the most noticeable impact on the compression ratio and recovery of bamboo, followed by time, thickness, and moisture content [13]. An increase in temperature results in a better interface wetting between fiber and the matrix, which is associated with an increase in tensile strength and modulus. [49]. The selection of hot press temperature is in the range of polymer melting temperature and natural fiber degradation temperature [48]. Heated fiber particles show better strength, as well as in water absorption and creep resistance testing of recycled High-Density Polyethylene composites. The water content of (Wood Plastic Composite) WPC decreases significantly with increasing pressure temperature, while the reduction in water absorption and swelling thickness occurs at WPC heat treatment temperatures of 160°C [11]. In other studies, pressing at high temperatures (180°C and 210°C) for a long time (30 minutes and 40 minutes) results in a higher compression ratio, as well as a lower recovery ratio after equilibrium [13]. In the best antibacterial bio board (ABB) samples made from bamboo vinegar (BV) and bamboo macromolecules obtained by pressing heat at 165°C for 10 minutes [14].

3.3.3. Holding Time.
Holding time is the least important consideration that is associated with adequate pressure and temperature in producing composites [48]. The longer holding time causes an increase in resin depolymerization and a decrease in flexural properties. At a short holding time, the optimal fiber volume fraction not reached. Thus, there must be an optimum containment time to produce the highest-performance natural fiber-reinforced composites [2]. Holding time provides a more reliable bonding interface by removing the air gap that induced during pressing between the fiber and the matrix, thereby increasing the tensile strength and modulus [49]. The combination of hot press process parameters which obtain maximum tensile strength occurs at 200°C, 3 MPa pressure, and 8 minutes holding time [17].

4. Bamboo fiber as a composite reinforcing material with thermoset and thermoplastic matrices
Many studies have carried out using bamboo fibers as reinforcing materials for composites. The results of the research are different due to differences in materials, variations, and the manufacturing process. At the beginning of its use, the matrix used was mostly thermosets. But as time goes by, it starts to turn to thermoplastic matrices, because thermoplastic-based composite materials can be repeatedly softened and reshaped [45]. In general, including thermoplastics, polypropylene (PP), polyethylene (PE), polystyrene (PS), and PVC (polyvinyl chloride). As for thermosets, they are polyester, epoxy, phenol-formaldehyde, and vinyl ester [32]. The primary purpose of using bamboo fibers in composites that use synthetic fiber matrices is to reduce the use of synthetic fibers that are increasingly disturbing the environment.

4.1. Usage on the thermoset matrix
Bamboo Fiber Reinforced Composite (BFRC) with a thermosetting matrix, namely epoxy, unsaturated polyester, and vinyl ester by hand-lay-up method, the fibers were treated with alkali first. The results showed an increase in the surface roughness of the fibers, which increased the bond of fibers and polymers in BFRC [3]. At 10%, NaOH concentration with 48-hour immersion duration produces the highest tensile strength (319.52 MPa), the most excellent thermal stability, and the highest charcoal
residue (6.4%). BFREC with 40% fiber volume fraction shows the most upper tensile strength (119.39 MPa) and flexural strength (161.58 MPa) compared to bamboo fibers reinforced by polyester (BFRPC) or vinylester (BFRVC). A study of composites using ultra-high molecular weight polyethylene (UHMWPE) bamboo fibers and epoxy matrices using polymer crystallization methods, produces a weak interface bonding, but increases in strength and toughness, and gives a broader idea for the preparation of high-performance fiber composites/resin [19]. Another study of bamboo fibers with alkali treatment using the vacuum molding method produces high-performance composites with bamboo fiber microstructure and shows better fire retardance. [1]. In the Petung bamboo composite with HDPE matrix, it states that the alkali treatment effectively reduces water absorption and minimizes the decrease in tensile strength. The hot press method has a significant effect on increasing tensile strength up to 37% compared to the lay-up method [7] and many other studies that use thermoset matrices because of its advantages, such as resistance to heat and chemicals even in extreme environments.

4.2. Usage on the thermoplastic matrix

The bamboo fiber composites treated alkali with HDPE matrix, which made with a hot press temperature of 230°C for 10 minutes under a pressure of 0.2 kPa. The results show an increase in the tensile, flexural, and hardness of the composites and prove that the treatment of bamboo fibers is suitable for strengthening HDPE [37]. Research on bamboo particle composites with polypropylene made from various bamboo stem fractions, producing high-value composites [15]. Other studies on bamboo fiber with HDPE matrix doped H2Ti2O5H2O by using the hot press method, affect the morphological characteristics, form a cross-linked structural network, improve thermostability, thermal oxidation stability, and fire resistance from composite results [18]. Research on other bamboo fibers by the hot press method states that if the pressure is not too high, then the flexural strength and flexural modulus will increase. As time goes by, more and more thermoplastic matrices use, because they are flexible and can be recycled. So the thermoplastic matrix has good potential in the future.

5. Conclusion

Composites made from natural fibers that act as reinforcement have many advantages, such as low cost, specific strength and high modulus, abundant availability, renewable, and biodegradability. Compared to composites made from synthetic fibers, which cause many environmental problems and other adverse impacts as opposed to natural fibers. Bamboo has quite a lot of cellulose, so it is excellent to use as material for making composites with a polymer matrix. The utilization of bamboo fibers in applications to reduce synthetic fibers has opened opportunities for academics and industry to design sustainable modules to utilize bamboo fibers in the future.

The method of making composites with the hot press has a significant effect of increasing tensile strength, produce a balance between mechanical properties, cost, environmental impact, reduce CO2 emissions, and save energy. Forming an optimal combination of parameters using the hot press is very useful for manufacturing in the engineering field. Preparation before hot press and parameters involved during the process of making bamboo fiber composites with HDPE matrices have a significant effect on the results of physical and mechanical properties of composites, that is:

- Alkali treatment can remove hemicellulose, lignin, wax, and oil, which cover the outer walls of natural fiber cells and increase the surface roughness of the fibers, thereby increasing the bond between the matrix and the fiber.
- The determination of fiber variation plays a significant role in the physical and mechanical properties of composites.
- Too much pressure can damage the fiber, while too low pressure results in poor lamination consolidation.
- The processing temperature and heating time have the most significant effect on the results of mechanical testing because they determine the strength of the composite. Higher temperatures
produce a better interface bond between the fiber and the matrix, which is associated with an increase in tensile strength and modulus.

- Holding time produces a more reliable bonding interface by removing the air gap that induced during pressing between the fiber and the matrix, thereby increasing tensile strength and modulus. Making bamboo fiber-based composites with thermoset and thermoplastic matrices can reduce environmental problems and can be developed into effective biocomposites. Added with the advantages possessed by thermosets and thermoplastics such as resistance to heat and chemicals even in extreme environments, flexible and recyclable, so that it has good potential in the future.

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