Utilization of Bamboo Fiber in the Development of Environmentally Friendly Composite – A Review

G Pramudi¹, W W Raharjo¹, D Ariawan¹, Ubaidillah¹, Z Arifin¹

¹Mechanical Engineering, Sebelas Maret University of Surakarta 57126 Indonesia

Abstract. This paper will review the parameters that affect the tensile strength of the use of bamboo fibres in thermoplastic composites. Natural fibres considered to be more environmentally friendly and easily degraded than synthetic fibres. Bamboo has a tensile strength that is not inferior to synthetic fibres. The tensile strength of bamboo fibres influenced by the parameters from the original physical properties of bamboo. The parameters that influence are species, age, and bamboo parts. This difference generally caused by lignin content in bamboo fibres. Lignin content will reduce the tensile strength of fibres. Therefore, bamboo fibre treatment applied as an effort to reduce lignin levels. Various treatments with chemical solutions have bee proven to reduce lignin levels. The selection and proper treatment of bamboo fibres will increase the tensile strength of the fibre. There will also affect the bond between the fibre and the matrix. However, in general, the relationship between natural fibres and thermoplastic matrices is bad. There is because there is no match between natural fibres and thermoplastic matrices. So, the selection of a matrix that matches the characteristics of the fibre must be considered. Pure and recycled matrix have very different characteristics and tensile strengths. In this paper, We have reviewed various sources of bamboo fibres, mechanical properties, modification of bamboo fibres, and effects of treatment on bamboo fibres. The main applications of bamboo have bee summarized as well as effective use as reinforcement for composite polymers.

1. Introduction
Composite is a structural material consisting of two or more elements combined at a macroscopic level and does not dissolve from one another. One constituent is called a matrix, and reinforcing reinforcement is called fibre [34]. Composite materials have been many developed because they are easily varied to obtain the desired characteristics. The use of composites in various fields encourages the creation of fibre composites by their application. Development matrix of composite materials is divided into thermoplastic and thermoset.

Thermoplastic material dominates development as a composite matrix. The event is inseparable from various advantages compared to matrix thermoset. Thermoplastic material has low water absorption properties, high toughness, a short and simple manufacturing process, also can be reprocessed as recycled material [9, 24]. Thus, the thermoplastic material is an outstanding candidate as a composite matrix. Thermoplastic materials that are widely developed are high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and polylactic acid (PLA). Various fibre alloys have bee applied to create composite materials with desired properties.
The use of high strength fibre embedded in the polymer matrix will increase the strength of the polymeric material [3, 6].

The selection of composite filler will affect the physical or mechanical properties of the composite. Besides, the choice of fibre needs to consider the concepts of ecological safety and the use of renewable materials. So that natural fibres are chosen as an alternative to replace synthetic fibres as composite reinforcement. The use of synthetic fibres poses environmental problems and human health hazards in the manufacturing process compared to natural fibres [11, 33]. The use of synthetic fibres can be a threat in the future forces an increase in the use of natural fibres. When compared with natural fibre, synthetic fibres (Glass Fibre) has high strength but not environmentally friendly.

![Figure 1. Comparison Between Natural Fiber and Glass Fiber [27]](image)

The natural fibre is a fibre derived from animals/plants. The main advantage of natural fibres is the long-term sustainable for supply. Besides that, natural fibre was chosen because it is easily degraded, so it is safer for the environment compared to synthetic fibres. Natural fibre composites have characteristics lightweight, water-resistant, chemical resistant, high durability, resistant against electricity, and high corrosion resistance, low manufacturing costs, high specific modulus, and moderate mechanical properties [63, 74]. Various natural fibres that have inherent tensile strength as composite reinforcement among them Jowar 302 Mpa [59], Coir 593 Mpa, Hemp 690 Mpa [38], Bamboo 738.5 Mpa [15] and Jute 583 MPa [31].

Currently, bamboo is widely used by local people as handicrafts, furniture, kitchen equipment, construction of houses, industry, food, paper industry, laminated wood, and composite laminates [4] bamboo as a natural fibre that has the potential to become a composite fibre. Bamboo is a natural fibre that has a lower cost than other natural fibres [10]. High tensile strength is also a priority for the use of bamboo fibre [23, 64]. Bamboo fibre thermoplastic composite is developed as an environmentally friendly material with high tensile strength. Even the rHDPE-bamboo-composite fibre 21% higher compared to rHDPE-hemp composite [2, 69]. Besides, natural fibre composite waste is more environmentally friendly, so it can be reused. PLA-bamboo fibre composites can be reprocessed as composite materials, although the tensile strength is lower than the first composite [28].

However, in general, natural fibres exhibit relatively weak interaction of fibres and matrices in bonding interfaces which results in a substantial decrease in composite properties [61]. So it is necessary to pay attention to the nature of the bamboo fibre. Various parameters that affect the environment of bamboo, such as the type of bamboo, treatment bamboo fibre, age of bamboo, even parts of bamboo have their respective characteristics. Naturally, bamboo fibre has more excellent mechanical strength, but the additional lignin content that covers bamboo fibre affects physical properties [36]. The reinforced by statements about the chemical components (cellulose, hemicellulose, and lignin) which inhibit the tensile strength of fibres [76, 83]. The selection of the right parameters will produce a fibre with maximum ability. In this paper, we will discuss the parameters that affect the tensile strength of bamboo as a potential for composite natural fibre so that the best parameters can be chosen according to the desired composite properties.
2. Bamboo Fiber
Bamboo is a plant that belongs to the family Poaceae (Gramineae) which grows in the tropics and subtropics some of the fastest-growing plants in the world. Each bamboo tree grows around 120cm per day to reach a height of 15 ± 35m in a period of 2 ± 4 months [58]. This rapid growth makes bamboo a renewable material that is an overflow in nature. Higher bamboo production compared to other natural fibres, is a consideration for its use. At present, bamboo production reaches 30,000 tons in the world [49]. In Indonesia, the amount of bamboo reaches 5 tons per hectare with 56 types of bamboo and 29 types of bamboo that have not been identified [5, 41]. Even Indonesia is the second-largest bamboo export country in the world that reaching 269 million dollars [36]. The average cost of each ton of bamboo fibre is cheaper compared to other fibre [55].

The abundant amount of bamboo in nature has been widely used by people, mainly rural areas. The use of bamboo is mostly for daily needs, especially in rural areas which are used as building materials for houses, construction, handicrafts to food. This makes bamboo as versatile non-timber forest product that can be utilized in all fields. This utilization cannot be separated from the characteristics of the resilient and robust nature of bamboo. Even bamboo fibres have mechanical properties comparable to conventional fibres. In addition to excellent mechanical properties, bamboo has a long-term sustainable supply at a low cost, biodegradable and is an environmentally friendly material [65]. Bamboo has unique characteristics. Plants that belong to the grass family but have resilient and robust woody stems. Investigations about the power of bamboo have been carried out to see the power of bamboo.

3. Treatment of Bamboo Fiber
Natural fibre has unique characteristics, especially bamboo. Parameters influence the strength of bamboo. Each parameter will affect the basic properties of bamboo fibre. There are various treatments to improve the tensile strength of bamboo fibres. In general, treatment is carried out to control the chemical content of bamboo fibres. High lignin content results in low fibre strength [86] so that the treatment is applied as an effort to maximize the strength of the bamboo fibre.

The most commonly used treatment is alkali. Alkali treatment uses NaOH solution to remove hemicellulose and lignin in bamboo fibres. Alkalization using sodium hydroxide (NaOH) can eliminate cellulose and lignin levels. This treatment can clean the surface and increase its roughness so that the adhesion of the fibres in the polymer matrix increases [73]. Loss of hemicellulose and lignin will cause crystallinity of cellulose which increases tensile strength and modulus of fibre. The results show that 5% of NaOH treatment can increase tensile strength by 43% and modulus of elasticity by 41% [85]. The results show that 5% of NaOH treatment can increase tensile strength by 43% and modulus of elasticity by 41%. This treatment modifies the structure of cellulose crystals from monoclinic to polymorphic. Therefore the loss of hemicellulose and lignin, which increases the surface roughness of the fibre and increases mechanical retention [18]. This applies to almost all-natural fibres. Immersion of bamboo fibre in 18% aqueous NaOH makes the surface of the fibre rougher because of the removal of lignin and cellulose, which results in increased tensile strength [51].

The use of potassium permanganate (KMnO4) has been used as a treatment of bamboo fibre. The addition of higher levels of KMnO4 increases the tensile strength of PVC / BF composites. Potassium permanganate can modify the surface of the fibre so that the tensile strength increases. The solution that increases will be more hydrogen gained so that the resistance increases. Permanganate solution will be reacted with an aldehyde group that is synthesized to produce a carboxyl group[68]. The use of sodium hydroxide at 17% can eliminate lignin up to 97%. Steam explosion of the alkaline solution will destroy the content of hemicellulose and lignin. This is caused by cleavage of the lignin and cellulose ether bonds so that the microfibers separate [72].

Aside from being a bamboo treatment, chemical solutions can be used to get bamboo fibres from the stems. Taking of bamboo fibre using NaOH solution has a higher tensile strength compared to mechanical means. The increase in fibre can reach 67.7% [17]. The tensile properties of fibres with
chemical solutions are increased due to reduced hemicellulose and lignin so that tensile strength increases. Mechanical fibre retrieval will damage the middle lamella, thereby reducing the tensile strength.

4. Parameters that Affect Bamboo Fiber

Various parameters determine the mechanical properties of a composite. The difference in the tensile strength of bamboo fibres occurs in the original nature of bamboo fibres. Therefore, the choice of basic bamboo parameters needs to be considered. Various studies have been conducted to determine the basic properties of bamboo fibre. So it can be anticipated in order to get the maximum strength from the composite bamboo fibre.

4.1. Age of Bamboo

The difference in bamboo age will affect the strength of the fibre, although not too significantly. Moso bamboo species experienced an increase in tensile strength at the age of 0.5 - 2.5 years, reaching 38.9% [79]. Whereas up to the age of 8.5 years, the average tensile strength of fibres reaches 1.54 Gpa and the modulus of elasticity is 33.86 Gpa. However, the highest yield of tensile strength is known at the age of 2.5 - 4.5 years which is able to reach nearly 1.8 Gpa [82]. This difference is influenced by the size and number of bamboo fibre holes. It is known that the size of bamboo fibre is smaller than wood fibre, and the number of holes is smaller. This also affects the structure of the higher density in the older fibres.

This statement is reinforced by the results of observations for Green bamboo with an average tensile strength of 43.56 Gpa and a modulus of elasticity of 1.60 Gpa. As stated before, Green Bamboo also has the highest tensile strength at 2-4 years of age, which is almost 1.7 Gpa. As for bamboo Burma, the average tensile strength was 53.54 Gpa, and the modulus of elasticity was 1.41 Gpa. Different from before, Burmese bamboo was observed to have the highest tensile strength at the age of 1 year. However, the difference in tensile strength to the age of Burmese bamboo is not significant [60]. This difference shows that bamboo fibre develops rapidly in less than a year due to lignification. The difference in lignin content in bamboo species is very influential. Lignification causes cell wall thickening, which improves the tensile strength of fibres. The smaller the content of lignin will increase the tensile strength of natural fibres [86].

4.2. Section of Bamboo

The length of bamboo can reach more than 6 meters. Along the bamboo, stem has a different chemical content. This is related to the different strengths of a bamboo stick in each part. Along with bamboo stems have different densities. The density will continue to decrease until the top of the bamboo [42]. The bottom of bamboo has the highest density, so the strength of the bottom of bamboo is highest compared to the middle and top.

![Figure 4.2](image-url) a. Tensile Strength of Parts of Bamboo; b. Modulus of Elasticity of Parts of Bamboo [84] and [8] mesin-123
The difference in strength due to density occurs in all types of bamboo. This density will affect the results of the tensile strength and modulus of elasticity of bamboo. The difference in strength shows that there is a decrease in strength in the bamboo from bottom to top. The decrease occurred due to the lower number of hemicellulose and lignin in the upper part of bamboo [84]. However, the results are reversed in Gigantochloa atrorubens bamboo, which shows that the highest tensile strength is in the upper bamboo [52]. Although this insignificant difference shows that the unique bamboo parameters are difficult to estimate. So it is necessary to have research that shows in detail the strengths of each bamboo.

4.3. Species of Bamboo

The selection of the right type of bamboo will also affect the strength of the fibre. Figure 4.1 shows that the type of bamboo affects the tensile strength of the bamboo fibre. Paying attention to mechanical strength and being aware of the environment, bamboo can potentially be a good natural fibre for strengthening composites.

![Figure 4.3 a. Tensile Strength of Bamboo Species; b. Modulus of Elasticity of Bamboo Species](image)

Based on the graph shows the tensile strength and modulus of elasticity are different in each bamboo species. This difference comes from the original physical properties of bamboo. The original physical characteristics of bamboo are affected by fibre density, age of bamboo culms, layers of bamboo, bamboo height, and growth conditions vary between species. In addition, the chemical content plays a major role in this difference in tensile strength. The effect of high or low content of lignin and cellulose on bamboo is a major factor. High modulus values indicate single fibre stiffness associated with lignin content, plant fibre structure, and extraction methods[54]. Each type of bamboo contains different lignin and hemicellulose [71]. This affects the tensile strength of fibres.

5. Thermoplastic Composite Bamboo Fiber

Thermoplastics are plastic polymer materials that are formed at high temperatures and harden during the cooling process. When the thermoplastic reaches the glass transition temperature or melting point, the polymer will soften to become thick. After starting the cooling process, the polymer will become a solid such as glass or semicrystalline [14]. The processing temperature starts at a temperature of 120°C for polyethylene. However, temperatures can rise as high as 345°C for high-performance engineering thermoplastics. This is due to the high viscosity of thermoplastic so that there will be more emphasis on the manufacturing process of composite components [22]. Thermoplastic polymers can melt at certain temperatures depending on the type of thermoplastic polymer so that the polymer can be reshaped through reheating according to the mould. However, when the thermoplastic polymer is reprocessed, it will break the polymer chain, which affects the physical properties of the polymer [7]. The use of thermoplastic polymers as composite matrices has been widely developed. Development is carried out to improve strength and resistance to various forms of degradation attack from fungi and...
microbial agents. Even though the use of thermoplastic in bamboo fibre reinforced composites is not easily biodegradable, good selection of fibre will reduce the amount of polymer used so that it can reduce the waste of nonbiodegradable polymers.

![Figure 5.1 Tensile Strength of a Composite Bamboo Fiber Matrix](image1)

Bamboo fibre, as a potential composite reinforcer, was investigated to increase the strength of the composite. Investigation shows that the addition of bamboo fibres to the polymer will affect the tensile strength of the fibre. The addition of bamboo fibre to HDPE strength increases to 51.88% [81]. This is because the adhesion of the fibre and matrix interfaces increases so that the transfer stress efficiency increases. Different results on the addition of bamboo fibre to LDPE precisely reduce the tensile strength of the fibre by 4% [21]. The decrease is caused by poor adhesion to the matrix because it is less homogeneous. Addition, fibre does not always increase the tensile strength of the composite. This is because tensile properties depend on fibre orientation and fibre/matrix interface adhesion. Increased fibre mass will result in higher agglomeration. So there is a decrease in bone density to the addition of fibre [19]. Based on the graph shows that the highest composite strength in PP / BF is capable of reaching 148.3 MPa. This is because the PP / BF interface ties are good. However, the strength is low on the strain, so it is easy to experience failure due to fracture [75]. This result is much higher compared to other natural fibre composites. PP composite/corn fibre showed an average tensile strength of 20.86 Mpa and composite PP / Abaca fibre 34.5 MPa [39, 77].

![Figure 5.2 a. Tensile Strength of Composite Thermoplastic; b. Modulus of Elasticity of Composite Thermoplastic](image2)
In general, the addition of bamboo fibres to the thermoplastic matrix can increase the tensile strength of the composite. This is shown in the composite strength value is higher than the original value of the matrix so that the function of bamboo fibres as an amplifier is fulfilled. The addition of bamboo fibre to thermoplastics increases the efficiency of voltage transfer to the bond interface area. This is a factor in increasing the tensile strength of fibres [81]. This result is proven in HDPE / BF, which has a higher tensile strength compared to other natural fibres such as HDPE / Ramie and HDPE / Cuarua composites [12, 46, 47]. The same thing is shown in the previous literacy, which shows that the composite thermoplastic (PLA) bamboo fibre has a higher tensile strength compared to bamboo fibre composite epoxy [48]. However, bamboo fibre composites produce lower tensile strength compared to bamboo fibres themselves. This is because the fibre density in composites is lower. This problem arises because bond natural hydrophilic fibres and hydrophobic thermoplastic matrices do not occur, which results in an unexpected appearance of material properties [44].

6. Composite Thermoplastic Hybrid Bamboo Fiber

Various developments have been carried out to find the desired characteristics of bamboo fibre composites. The method of combining both natural and synthetic fibres began to be investigated to investigate the mechanical properties. The use of strong synthetic fibres is difficult to stop. So that a solution arises for combining natural fibre and synthetic fibre to increase fibre strength. The use of natural fibre and synthetic fibre has its respective advantages and disadvantages. Comparison of natural and synthetic fibres can be seen in table 6.1

| Aspects       | Property       | Natural Fiber | Synthetic Fiber |
|---------------|----------------|---------------|-----------------|
| Technical     | Mechanical properties | Moderate | High            |
|               | Moisture sensitivity | High    | Low             |
|               | Thermal sensitivity | High    | Low             |
|               | Resource        | Infinite   | Limited         |
| Environmental | Production      | Low        | High            |
|               | Recyclability   | Good       | Moderate        |

However, not many studies have investigated composite thermoplastic bamboo fibre hybrid synthetic fibres. Research that investigates PP / BF / Glass alloys which shows that there is an increase in strength compared to PP / BF and PP / Glass [62]. Another finding that incorporates bamboo fibre on coir in polypropylene matrices precise reduces tensile strength compared to PP / BF by 25% [75]. Hybrid composite natural fibre, especially bamboo, needs to be developed in order to find alloys with high strength and more environmentally friendly. So that in the future, the use of natural fibre as an amplifier needs to be developed in order to reduce the use of synthetic fibre composites. The combination of hybrid natural-synthetic fibre with the dominance of natural fibres is expected to provide high strength and more environmentally friendly.

7. Application of Polymer Bamboo Fiber Composite

Natural fibre, as a composite reinforcement, has been widely used in various production sectors. The use of various natural fibres has received a positive response in the industry. Natural fibre composites are used because they are cheaper and lighter. The use of natural fibre composites in the automotive and aviation fields has enormous potential. At present, the structure of Airbus aircraft 53% using polymer composites [25]. In 2004 BMW had been used 10,000 tons of natural fibre in vehicle production [37]. The lightweight of natural fibre composites is a top priority in its use. This matter can reduce fuel consumption in the vehicle. The use of natural fibres in the automotive field is generally applied to auto parts such as bumpers, brake linings and couplings.
However, the use of bamboo fibre composite has not been able to penetrate the use of natural fibres in the industrial sector as in the automotive sector, which is dominated by the use of wood fibre. Though bamboo has high potential as a composite fibre because it is strong and lightweight, the investigation of bamboo fibres shows that composite bamboo fibres can be part of a car framework [53]. The use of bamboo fibre composites can replace glass fibres for headliners in the automotive sector [32]. The use of natural fibres in the automotive sector in 2020 is expected to reach 350,000 tons or an increase of 74.2% since 2012[16]. This is a great potential in developing bamboo fibre composites for the automotive industry sector.

8. Conclusion

The use of bamboo fibre in a thermoplastic matrix can increase the tensile strength of composites compared to other natural fibres. Increased tensile strength varies depending on the parameters that affect. The tensile strength is influenced by the natural physical properties of bamboo. The differences in bamboo species give a big picture. The choice of bamboo age has a significant effect. The selection of bamboo parts shows a real difference. Bamboo at the bottom of the average in all species has a higher tensile strength compared to other parts. Chemical treatment can improve high tensile strength. This is caused by the reduction in lignin content due to chemical treatment. These parameters have a big role in determining the tensile strength of thermoplastic composites of bamboo fibres.

References

[1] A. H. D. Abdullah, N. Karlina, W. Rahmatiya et al., “Physical and mechanical properties of five Indonesian bamboos,” in 1st International Symposium on Green Technology for Value Chains 2016, 2017.

[2] A. A. Ahmad Kamal, N. Z. Noriman, S. T. Sam et al., “The Influences of Different Bamboo Filler Loading on Tensile Properties and Impact Strength of RHDPE/BF Composites,” IOP Conference Series: Materials Science and Engineering, vol. 557, pp. 012069, 2019/06/28, 2019.

[3] M. H. Ahmad Khairi, S. A. Mazlan, Ubaidillah et al., “The field-dependent complex modulus of magnetorheological elastomers consisting of sucrose acetate isobutyrate ester,” Journal of Intelligent Material Systems and Structures, vol. 28, no. 14, pp. 1993-2004, 2017/08/01, 2017.

[4] E. Akinlabi, K. Anane-Fenin, and D. Akwada, "Applications of Bamboo," pp. 179-219, 2017.

[5] E. T. Akinlabi, K. Anane-Fenin, and D. R. Akwada, Bamboo : The Multipurpose Plant, Johannesburg, South Africa: © Springer International Publishing AG 2017, 2017.

Figure 7.1 Graphs of Use of Natural Fiber in the Automotive Sector [56]
[6] G. R. Arpitha, S. M R, and B. Yogesha, “Review on Comparative Evaluation of Fiber Reinforced Polymer Matrix Composites,” Advanced Engineering and Applied Sciences: An International Journal, vol. 4, pp. 44-47, 08/01, 2014.

[7] M. Asim, M. Jawaid, N. Saba et al., "1 - Processing of hybrid polymer composites—a review," Hybrid Polymer Composite Materials, V. K. Thakur, M. K. Thakur and R. K. Gupta, eds., pp. 1-22: Woodhead Publishing, 2017.

[8] D. Awaluddin, M. A. M. Ariffin, M. H. Osman et al., “Mechanical properties of different bamboo species,” MATEC Web of Conferences no. 138, pp. 01024, 2018/07/01, 2018.

[9] S. A. Aziz, Ubaiddihah, S. A. Mazlan et al., “Implementation of functionalized multiwall carbon nanotubes on magnetorheological elastomer,” Journal of Materials Science, vol. 53, no. 14, pp. 10122-10134, 2018/07/01, 2018.

[10] J. Bachmann, C. Thidalgo, and S. Bricout, “Environmental analysis of innovative sustainable composites with potential use in aviation sector—A life cycle assessment review,” Science China Technological Sciences, vol. 60, no. 9, pp. 1301-1317, 2017/09/01, 2017.

[11] I. Bahiuddin, S. A. Mazlan, I. Shapiai et al., “Constitutive models of magnetorheological fluids having temperature-dependent prediction parameter,” Smart Material Structures, vol. 27, pp. 095001, September 01, 2018, 2018.

[12] L. Banowati, B. Hadi, and R. Suratman, “Tensile Strengths of Random Ramie Yarn/HDPE Thermoplastic Matrix Prepreg Composites,” DEStech Transactions on Computer Science and Engineering, 11/17, 2016.

[13] D. S. Bavan, and G. M. Kumar, “Potential use of natural fiber composite materials in India,” Journal of Reinforced Plastics and Composites, vol. 29, no. 24, pp. 3600–3613, 2010.

[14] A. Birca, O. Gherasim, V. Grumezescu et al., “Introduction in thermoplastic and thermosetting polymers,” Materials for Biomedical Engineering: Thermoset and Thermoplastic Polymers, 2019.

[15] S. Biswas, Q. Ahsan, A. Cenna et al., “Physical and mechanical properties of jute, bamboo and coir natural fiber,” Fibers and Polymers, vol. 14, no. 10, pp. 1762-1767, 2013.

[16] M. Carus, A. Eder, L. Dammer et al., “Wood-Plastic Composites (WPC) and Natural Fibre Composites (NFC),” Nova-Institute: Hürth, Germany, pp. 16, 2015.

[17] H. Chen, H. Cheng, G. Wang et al., “Tensile properties of bamboo in different sizes,” Journal of Wood Science, vol. 61, no. 6, pp. 552-561, 2015/12/01, 2015.

[18] M. M. E. Costaa, S. L. S. Meloa, J. V. M. Santosa et al., “Influence of physical and chemical treatments on the mechanical properties of bamboo fibers,” in 3rd International Conference on Natural Fibers: Advanced Materials for a Greener World, ICNF 2017, Braga, Portugal, 2017, pp. 457-464.

[19] O. O. Daramola, A. D. Akinwekomi, A. A. Adediran et al., “Mechanical performance and water uptake behaviour of treated bamboo fibre-reinforced high-density polyethylene composites,” Heliyon, vol. 5, no. 7, e02028, 2019/07/01/, 2019.

[20] N. Defoirdt, S. Biswas, L. D. Vriese et al., “Assessment of the tensile properties of coir, bamboo and jute fibre,” Composites Part A: Applied Science and Manufacturing, vol. 41, no. 5, pp. 588-595, 2010/05/01/, 2010.

[21] P. Delgado, S. Lana, E. Ayres et al., “The Potential of Bamboo in the Design of Polymer Composites,” Materials Research, vol. 15, pp. 639-644, 08/01, 2012.

[22] M. Duhovic, and D. Bhattacharyya, "8 - Knitted fabric composites," Advances in Knitting Technology, K. F. Au, ed., pp. 193-212: Woodhead Publishing, 2011.

[23] R. Dunne, D. Desai, R. Sadiku et al., “A review of natural fibres, their sustainability and automotive applications,” Journal of Reinforced Plastics and Composites, vol. 35, no. 13, pp. 1041-1050, 2016/07/01, 2016.

[24] A. Z. El-Sonbuti, Thermoplastic – Composite Materials, Janeza Trdine 9, 51000 Rijeka, Croatia: InTech, 2012.
[25] D. Evrard, and F. Alonso, “FAST-Flight Airworthiness Support Technology,” *Airbus technical magazine*, 2013.
[26] I. O. Eze, I. C. M. PhD, and M. U. O. PhD, “A Comparative Study of Some Mechanical Properties of Bamboo Powder Filled Virgin and Recycled Low Density Polyethylene Composites,” *Academic Research International*, vol. 4, no. 11, 2013.
[27] O. Faruk, A. K. Bledzki, H.-P. Fink *et al.*, “Progress Report on Natural Fiber Reinforced Composites,” *Macromolecular Materials and Engineering*, vol. 299, no. 1, pp. 9-26, 2014/01/01, 2014.
[28] M. Fazita, K. Jayaraman, D. Bhattacharyya *et al.*, “Disposal Options of Bamboo Fabric-Reinforced Poly(Lactic) Acid Composites for Sustainable Packaging: Biodegradability and Recyclability,” *Polymers*, vol. 7, 07/12, 2015.
[29] G. Han, Y. Lei, Q. Wu *et al.*, “Bamboo–Fiber Filled High Density Polyethylene Composites: Effect of Coupling Treatment and Nanoclay,” *Journal of Polymers and the Environment*, vol. 16, pp. 123-130, 04/01, 2008.
[30] M.-p. Ho, K.-t. Lau, H. Wang *et al.*, “Improvement on the properties of polylactic acid (PLA) using bamboo charcoal particles,” *Composites Part B: Engineering*, vol. 81, pp. 14-25, 2015/11/01, 2015.
[31] T. Hojo, Z. Xu, Y. Yang *et al.*, “Tensile Properties of Bamboo, Jute and Kenaf Mat-reinforced Composite,” *Energy Procedia*, vol. 56, pp. 72-79, 2014/01/01, 2014.
[32] S. Huda, N. Reddy, and Y. Yang, “Ultra-light-weight composites from bamboo strips and polypropylene web with exceptional flexural properties,” *Composites Part B: Engineering*, vol. 43, no. 3, pp. 1658-1664, 2012/04/01, 2012.
[33] M. Jawaid, and H. P. S. Abdul Khalil, “Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review,” *Carbohydrate Polymers*, vol. 86, no. 1, pp. 1-18, 2011/08/01, 2011.
[34] A. K. Kaw, *Mechanics Of Composite Materials --2nd*, France: CRC Press Taylor & Francis Group, 2006.
[35] H. P. S. A. Khalil, M. S. Alwani, M. N. Islam *et al.*, “The use of bamboo fibres as reinforcements in composites,” *Biofiber Reinforcements in Composite Materials*, O. Faruk and M. Sain, eds., pp. 488-524: Woodhead Publishing, 2015.
[36] H. P. S. A. Khalil, I. U. H. Bhat, M. Jawaid *et al.*, “Bamboo fibre reinforced biocomposites: A review,” *Materials & Design*, vol. 42, pp. 353-368, 2012/12/01, 2012.
[37] A. G. Koniuszewska, and J. W. Kaczmar, “Application of Polymer Based Composite Materials in Transportation,” *Progress in Rubber, Plastics and Recycling Technology*, vol. 32, no. 1, pp. 1-24, 2016/02/01, 2016.
[38] H. Ku, H. Wang, N. Pattarachaiyakoop *et al.*, “A review on the tensile properties of natural fiber reinforced polymer composites,” *Composites Part B: Engineering*, vol. 42, pp. 856-873, 06/01, 2011.
[39] N. R. Kumar, C. H. R. Rao, P. Srikant *et al.*, “Mechanical properties of corn fiber reinforced polypropylene composites using Taguchi method,” *Materials Today: Proceedings*, vol. 2, no. 4, pp. 3084-3092, 2015/01/01, 2015.
[40] F. K. Liew, S. Hamdan, M. R. Rahman *et al.*, “Thermomechanical Properties of Jute/Bamboo Cellulose Composite and Its Hybrid Composites: The Effects of Treatment and Fiber Loading,” *Advances in Materials Science and Engineering*, vol. Volume 2017, pp. 10, 2017.
[41] M. Lobovikov, S. Paudel, M. Piazza *et al.*, *World bamboo resources - A thematic study prepared in the framework of the Global Forest Resources*, Rome: Electronic Publishing Policy and Support Branch 2007.
[42] X. Londoño, G. C. Camayo, N. M. Riaño *et al.*, “Characterization of the anatomy of Guadua angustifolia (Poaceae: Bambusoideae) culms,” *Bamboo Science and Culture*, vol. 16, no. 1, pp. 18-31, 2002.
[43] T. Lu, S. Liu, M. Jiang et al., “Effects of modifications of bamboo cellulose fibers on the improved mechanical properties of cellulose reinforced poly(lactic acid) composites,” *Composites: Part B*, vol. 2014, no. 62, pp. 191–197, 2014.

[44] R. Malkapuram, V. Kumar, and N. Yuvaraj Singh, “Recent Development in Natural Fiber Reinforced Polypropylene Composites,” *Journal of Reinforced Plastics and Composites*, vol. 28, no. 10, pp. 1169-1189, 2009/05/01, 2008.

[45] R. Mirski, P. Bekhta, and D. Dziurka, “Relationships between Thermoplastic Type and Properties of Polymer-Triticale Boards,” *Polymer*, vol. 11, no. 1750, 2019.

[46] S. Mohanty, and S. K. Nayak, “Short Bamboo Fiber-reinforced HDPE Composites: Influence of Fiber Content and Modification on Strength of the Composite,” *Journal of Reinforced Plastics and Composites*, vol. 29, no. 14, pp. 2199-2210, 2010/07/01, 2010.

[47] J. A. d. Morais, R. Gadioli, and M. A. De Paoli, “Curaua fiber reinforced high-density polyethylene composites: effect of impact modifier and fiber loading,” *Polímeros*, vol. 26, pp. 115-122, 2016.

[48] A. P. Morales, A. Güemes, A. Fernandez-Lopez et al., “Bamboo–Poly(lactic Acid) (PLA) Composite Material for Structural Applications,” *Materials* vol. 10, no. 1286, 2017.

[49] T. Ngo, “Natural Fibres for Sustainable Bio-Composites,” 2018.

[50] P. Nguyen Tri, C. Sollogoub, and A. Guinault, “Relationship between fiber chemical treatment and properties of recycled pp/bamboo fiber composites,” *Journal of Reinforced Plastics and Composites*, vol. 29, no. 21, pp. 3244-3256, 2010/11/01, 2010.

[51] P. Noorunnisa Khanam, H. P. S. Abdul Khalil, M. Jawaid et al., “Sisal/Carbon Fibre Reinforced Hybrid Composites: Tensile, Flexural and Chemical Resistance Properties,” *Journal of Polymers and the Environment*, vol. 18, no. 4, pp. 727-733, 2010/12/01, 2010.

[52] G. Oka, A. Triiwiyono, A. Awaludin et al., “Effects of Node, Internode and Height Position on the Mechanical Properties of Gigantochloa Atroviolacea Bamboo,” *Procedia Engineering*, vol. 95, 12/31, 2014.

[53] K. Okubo, T. Fujii, and Y. Yamamoto, “Development of Bamboo-Based Polymer Composites and Their Mechanical Properties,” *Composites Part A: Applied Science and Manufacturing*, vol. 35, pp. 377-383, 03/01, 2004.

[54] L. Osorio, E. Trujillo, A. W. Van Vuure et al., “Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/epoxy composites,” *Journal of Reinforced Plastics and Composites*, vol. 30, no. 5, pp. 396-408, 2011/03/01, 2011.

[55] P. Peças, H. Carvalho, H. Salman et al., “Natural Fibre Composites and Their Applications: A Review,” *Journal of Composites Science*, vol. 2, no. 4, 2018.

[56] P. Peças, I. Ribeiro, H. Carvalho et al., “Ramie and jute as natural fibers in a composite part: a life cycle engineering comparison with an aluminum part,” *Green Composites for Automotive Applications*, 2019.

[57] E. Pérez, L. Famá, S. G. Pardo et al., “Tensile and fracture behaviour of PP/wood flour composites,” *Composites Part B: Engineering*, vol. 43, no. 7, pp. 2795-2800, 2012/10/01, 2012.

[58] K. L. Pickering, *Properties and performance of natural-fibre composites*, North America: Woodhead Publishing Limited and CRC Press LLC, 2008.

[59] A. V. Ratna Prasad, and K. Mohana Rao, “Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo,” *Materials & Design*, vol. 32, no. 8, pp. 4658-4663, 2011/09/01, 2011.

[60] D. Ren, Z. Yu, W. Li et al., “The effect of ages on the tensile mechanical properties of elementary fibers extracted from two sympodial bamboo species,” *Industrial Crops and Products*, vol. 62, pp. 94-99, 2014/12/01, 2014.
[61] N. Saba, P. M. Tahir, and M. Jawaid, “A Review on Potentiality of Nano Filler/Natural Fiber Filled Polymer Hybrid Composites,” *POLYMERS FOR ADVANCED TECHNOLOGIES*, no. 6, pp. 2247-2273, 2014.

[62] S. K. Samal, S. Mohanty, and S. K. Nayak, “Polypropylene—Bamboo/Glass Fiber Hybrid Composites: Fabrication and Analysis of Mechanical, Morphological, Thermal, and Dynamic Mechanical Behavior,” *Journal of Reinforced Plastics and Composites*, vol. 28, no. 22, pp. 2729-2747, 2009/11/01, 2008.

[63] T. P. Sathishkumar, P. Navaneethakrishnan, S. Shankar et al., “Characterization of new cellulose sansevieria ehrenbergii fibers for polymer composites,” *Composite Interfaces*, vol. 20, no. 8, pp. 575-593, 2013/11/01, 2013.

[64] M. K. Shabdin, M. A. Abdul Rahman, S. A. Mazlan et al., “Material Characterizations of Gr-Based Magnetorheological Elastomer for Possible Sensor Applications: Rheological and Resistivity Properties,” *Materials*, vol. 12, no. 3, 2019.

[65] A. U. M. Shah, M. T. H. Sultan, M. Jawaid et al., “A Review on the Tensile Properties of Bamboo Fiber Reinforced Polymer Composites,” *BioResources*, vol. 4, pp. 11, 2016.

[66] Z.-P. Shao, C.-H. Fang, S.-X. Huang et al., “Tensile properties of Moso bamboo (Phyllostachys pubescens) and its components with respect to its fiber-reinforced composite structure,” *Wood Sci Technol (2010)*, no. 44, pp. 655–666, 2010.

[67] K. Sheng, M. Adl, H. Wang et al., "Polyvinyl Chloride Composites " Encyclopedia of Composites, Second Edition, L. N. a. A. Borzacchiello., ed.: John Wiley & Sons, Inc., 2012.

[68] K. Sheng, S. Qian, and H. Wang, “Influence of potassium permanganate pretreatment on mechanical properties and thermal behavior of moso bamboo particles reinforced PVC composites,” *Polymer Composites*, vol. 35, no. 8, pp. 1460-1465, 2014/08/01, 2014.

[69] S. Singh, D. Deepak, L. Aggarwal et al., “Tensile and Flexural Behavior of Hemp Fiber Reinforced Virgin-recycled HDPE Matrix Composites,” *Procedia Materials Science*, vol. 6, pp. 1696-1702, 2014/01/01, 2014.

[70] S. Subyakto, E. Hermiati, N. Masruchin et al., “Injection Molded of Bio-Micro-Composites from Natural Fibers and Polyactic Acid,” *2017*, vol. 2, no. 1, pp. 6, 2017-08-31, 2017.

[71] S. Sugesty, T. Kardiansyah, and H. Hardiani, “Bamboo as Raw Materials for Dissolving Pulp with Environmental Friendly Technology for Rayon Fiber,” *Procedia Chemistry*, vol. 17, pp. 194-199, 2015/01/01, 2015.

[72] S. Tanpichai, S. Witayakran, Y. Srimarut et al., “Porosity, density and mechanical properties of the paper of steam exploded bamboo microfibers controlled by nanofibrillated cellulose,” *Journal of Materials Research and Technology*, vol. 8, no. 4, pp. 3612-3622, 2019/07/01, 2019.

[73] D. T. Tavares, C. J. Antunes, F. Ferreira et al., “Biofunctionalization of Natural Fiber-Reinforced Biocomposites for Biomedical Applications,” *Biomolecules*, vol. 10, no. 1, 2020.

[74] A. Ticoalu, T. Aravinthan, and F. Cardona, “A review of current development in natural fiber composites for structural and infrastructure applications,” in Southern Region Engineering Conference, Toowoomba, Australia, 2010.

[75] L. Q. N. Tran, C. Fuentes, I. Verpoest et al., “Tensile Behavior of Unidirectional Bamboo/Coir Fiber Hybrid Composites,” *Fibers*, vol. 7, no. 62, 2019.

[76] Ubaiddillah, H. J. Choi, S. A. Mazlan et al., “Fabrication and viscoelastic characteristics of waste tire rubber based magnetorheological elastomer,” *Smart Materials and Structures*, vol. 25, no. 11, pp. 115026, 2016/10/18, 2016.

[77] F. Vilaseca, A. Valadez-Gonzalez, P. J. Herrera-Franco et al., “Biocomposites from abaca strands and polypropylene. Part I: Evaluation of the tensile properties,” *Bioresource Technology*, vol. 101, no. 1, pp. 387-395, 2010/01/01, 2010.

[78] H. Wang, K. Sheng, J. Chen et al., “Mechanical and thermal properties of sodium silicate treated moso bamboo particles reinforced PVC composites,” *Science China Technological Sciences*, vol. 53, no. 11, pp. 2932-2935, 2010/11/01, 2010.
[79] H. Wang, G. Tian, W. Li et al., “Sensitivity of bamboo fiber longitudinal tensile properties to moisture content variation under the fiber saturation point,” Journal of Wood Science, vol. 61, no. 3, pp. 262-269, 2015/06/01, 2015.

[80] K. M. Wong, BAMBOO The Amazing Grass, Malaysia: International Plant Genetic Resources Institute (IPGRI), 2004.

[81] Y. Xian, D. Ma, C. Wang et al., “Characterization and Research on Mechanical Properties of Bamboo Plastic Composites,” Polymers, vol. 10, pp. 814, 2018.

[82] H. Yan-hui, F. Ben-hua, Y. Yan et al., “Plant Age Effect on Mechanical Properties of Moso Bamboo (Phyllostachys Heterocycla Var. Pubescens) Single Fibers ” Wood and Fiber Science, vol. 44, no. 2, pp. 196-201, 2012.

[83] S. Yusuf, F. A. Syamani, W. Fatriasari et al., “Review on Bamboo Utilization as Biocomposites, Pulp and Bioenergy,” IOP Conference Series: Earth and Environmental Science, vol. 141, pp. 012039, 2018/03, 2018.

[84] P. Zakikhani, R. Zahari, M. T. b. H. H. Sultan et al., “Morphological, Mechanical, and Physical Properties of Four Bamboo Species,” BioResources; Vol 12, No 2 (2017), 02/15/, 2017.

[85] K. Zhang, F. Wang, W. Liang et al., “Thermal and Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites,” Polymers vol. 10, no. 608, 2018.

[86] S.-Y. Zhang, B.-H. Fei, Y. Yu et al., “Effect of the amount of lignin on tensile properties of single wood fibers,” Forest Science and Practice, vol. 15, no. 1, pp. 56-60, 2013/03/01, 2013.