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The Role of Composites for Sustainable Society and Industry

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Abstract

In the last few decades, the global community's demands are getting stronger for more environmentally friendly materials. Natural fiber reinforced composites have been applied as reinforcement in concrete, sound absorbers, buildings, aeronautical, aerospace, sanitation, electronics, bridge decks, interior, automotive, sports equipment and furniture industries, modular structures, and others. Natural fibers are receiving high attention due to their sustainability, environmental friendliness, low density, low cost, low abrasiveness, renewability, and biodegradability, as well as contributing to the consumption of CO2 gas. As reported by many researchers, Indonesia has several natural resources for natural fibers such as bark fiber, leaf fiber, seed/fruit fiber, grass fiber, stalk fiber, and wood fiber.

Keywords: Composite, Natural fiber, Biodegradable material, Sustainable material

1. Lignocellulosic Based Composite: Potency and Challenge in the Future

Composite materials are attractive because they combine materials properties in ways not found in nature [1]. Considering the global environmental concerns, there have been much efforts to provide eco-friendly and biodegradable materials for composite products [2]. Generally, composites based on lignocellulosic/natural fibres can be divided into the following groups: conventional panel bonded composites (particleboard, fiberboard, insulating board), mineral bonded composites (gypsum board, cement board), and natural fibres reinforced polymers (nonwoven textile-type composites). As for reinforcement, natural fibers can eventually be used to replace glass fibers in diverse fields, such as aircraft, guitars, automotive, interior, decks, furniture, electronic components, artificial joints, structural or non-structural [1], [2].

Natural fibers are getting high attention due to their sustainability, ecofriendly nature, low density, low cost, low abrasive, renewability, and biodegradability, as well as contribute to the consumption of CO_2 gas [1]–[3]. There are several major types of natural fibers: bast fibers, (jute, ramie, flax, rattan, hemp, kenaf), leaf fibers (abaca, banana, sisal, and pineapple), seed/fruit fibers (cotton, coir, kapok), grass fibers (bamboo elephant grass); stalk fibers (rice, corn, wheat stalk), and wood fiber [1], [2]. The properties of natural fibers can vary depending on the source, age and separating technique of the fiber, however exhibit comparable specific strength and stiffness compared to glass fiber [1]. For example, bast fibers are usually have high tensile strength and stiffness, light weight as well as easily available, therefore is more applicable for automotive and building industries. Other factors that are also influence the behavior of fibers, such as their length, physical properties (e.g., dimensions, defects, structure, and cell wall thickness), cellulose content, and spiral angle of the cell layers [3]. The natural fibers are mainly composed of lignin and sugar-based polymers (i.e., cellulose and hemicellulose) and small number of other materials such as starch, extractives, protein, and inorganics. Those chemical components of fiber are known to have significant effect on the bonding properties with matrix.

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The main problem identified with natural fibers, namely, susceptibility to biodegradability, dimensional instability, and the incompatibility between fiber and matrix due to the hydrophilic nature of fibers and hydrophobic nature of polymer macromolecules, which leads to undesirable properties of the composites. It is therefore various fiber-polymer interface modification is considered to improve their bonding properties with different matrices, such as alkaline, silane, acetylation, benzoylation, peroxide, maleated coupling agents, sodium chlorite, acrylation and acrylonitrile grafting, isocyanate, stearic acid, permanganate, corona, and fungal treatments [3], [4].

The other main component in composite is matrix/resin/adhesive, that is responsible to hold the reinforcing materials together by surface connection [3]. Two classifications of resin are petrochemical-based and bio-based resins. The two major types of petrochemical-based resins are thermoplastics and thermosets [3], [5], while bio-based resins are polymers that are fully or partially obtained from renewable resources. These bio-based resins have advantages such as recyclable, renewable, safe, and environmentally friendly. However, their production cost is higher than that of petrochemical-based resins [3]. Each resin has its own bonding mechanism which also affects the final properties of the composite. To improve the affinity and adhesion between fibers and thermoplastic resin in composite production, additives such as chemical coupling agents or compatibilizers have been employed [4].

It can be pointed out that a better understanding of the molecular structure and interfacial interaction between the resin/matrix and the fibers and the relationship between the structure and property would be a major breakthrough in this area of research [6]. The key points to prepare a good composite is dependent on three important factors, i.e. characteristics of the adhesive, properties of the natural fibers, and the technology of manufacture of the composite. This also means that the choice of production process will be an important step for the application stage in the composites industry.

2. Natural Fiber-Reinforced Composites: Role and Solution for Society and Industry

Community demands for materials that are more environmentally friendly for global problems are increasing. Natural fiber-reinforced composite materials such as sisal fiber-reinforced composites, corn husk fiber-reinforced composites, coconut fiber-reinforced composites, and others, have received attention from the public and industry because of the potential advantages that exist in their use, such as higher strength, lighter weight, more durability, rehabilitating existing structures, higher performance, seismic enhancement, unique requirements of defense systems, space systems, and marine environment [7]. Currently, natural fiber-reinforced composites have been applied as reinforcement in concrete, sound absorbers, buildings, aeronautical industries, aerospace, sanitation, electronics, bridge decks, interior, automotive, sports equipment, and furniture, modular structures, etc [7]–[10].

For society and industry, natural fiber-reinforced composites have a role in solutions that seek to extend the life of existing structures, efficiently maximize the benefits of potentially limited non-renewable resources, develop new structures that achieve superior service life with minimal maintenance, weather resistance, and avoiding the environmental, social and economic impacts associated with replacement and new construction [8]. The benefits of this composite can be realized from its physical characteristics and potential so that its service life exceeds traditional materials. Then, the lightweight of the composite can reduce construction costs to a lower level, increase construction speed and minimize environmental impact [11], [12]. Furthermore, the high mechanical properties of composites mean that less material is required to achieve the same performance as traditional materials so that resource use and waste production can be minimized. Regardless of the technological progress achieved, there are obstacles in developing and implementing the technology. In addition, the characterization of durability required innovation in production costs and minimize environmental impact [12], [13]. The required life extension of the use of composites to offset any economic, social, and environmental concerns needs to be measured. The choice of composite will depend on environmental, economic, socio-political factors, and may not always provide an ideal solution; however, there is a need to objectively measure the advantages and disadvantages of natural fiber composites compared to other materials.

3. Composite Cylinders: An Important Contribution to Weight Reduction of Natural Gas Vehicles

In 2020, the market demand for global natural gas vehicles (NGVs) is 29,793.76 thousand units and is expected to grow 3.3% from 2021 to 2028 (see **Figure 1**) [14]. The market's interest in natural gas is driven by its lower price and more environmentally friendly footprint compared to conventional fossil fuels such as gasoline, diesel and LPG [15]. Since the natural gas pressure in the cylinder reaches 200 bar (20 MPa), steel-based cylinders (type 1) contribute to the total weight of the vehicle significantly, and they still dominate the Cylinders installed in vehicles today. However, now a composite-based cylinder has been developed (type 3 and type 4) which can reduce cylinder weight by up to 70% and increase mileage up to 12% [16]. Type 3 composite cylinders are made from high-strength fibers wound around cylinder liners and bonded together by resins such as epoxy (see **Figure 2**). Type 4 cylinders are fully encased in a composite reinforced plastic layer to withstand the full pressure load. The Type 4 design is attractive because it is the lightest of all designs. In the future, and perhaps not for long, there may be a new type of composite cylinder with a superior design to reduce overall weight. Engineers in research institutes, academia, and cylinder manufac-turers are working hard to make a better contribution [17], [18], not only to an eco-nomically acceptable cylinder design, but also to a sustainable transportation society. **Would you like to take part?**

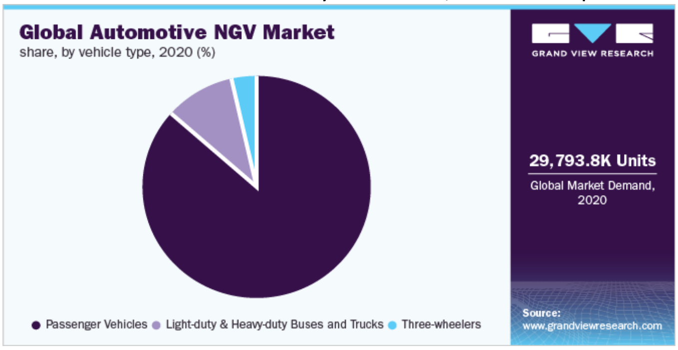

Figure 1. Global automotive NGV market in 2020 [14]

Figure 2. Composite Cylinder from NEIL [16]

4. Bamboo Utilization for Both Bio- and Green Composites Reinforcement

Synthetic polymer composite materials such as CFRP and GFRP had successfully contributed to humankind in terms of lightweight structure. Unfortunately, they had also left environmental problems especially in their after use through landfilling and incineration methods. Today, global warming and environmental issues continue in line with global community concern for healthier lifestyles. One of the lifestyles is green materials utilization such as bio- and green composites. Those are two kinds of engineering materials based on natural fibers reinforced both synthetic and natural-based matrix, respectively. Synthetic matrices are those man-made polymers from petrochemical products such as polyester and epoxy (thermoset) as well as polypropylene and polyamide (thermoplastics). Meanwhile, natural polymers come from starch, gluten, chitosan, and vegetable oil based. Natural fibers are lignocellulosic fibers that are produced naturally from plants such as bananas, bamboo, hemp, and jute.

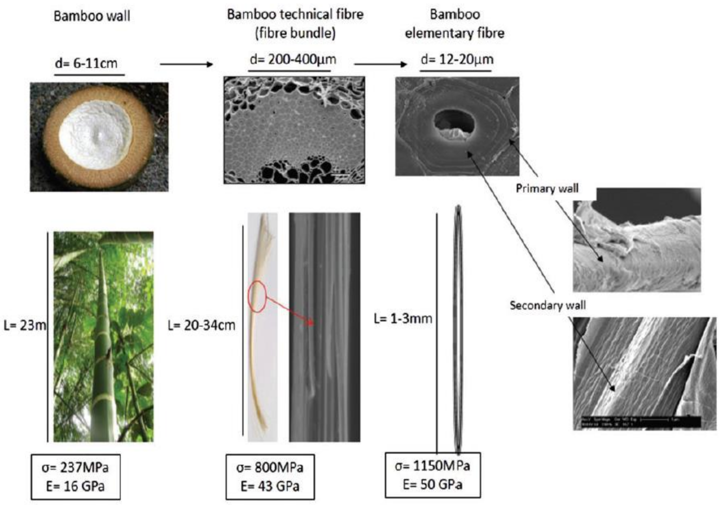

Figure 3. Bamboo mechanical properties based on hierarchical structures [19]

Bamboo as a plant or its fibers represents a natural composite due to its structures comprising matrix and reinforcement as shown in **Figure 3**. Bamboo fibers, extracted from its culm, are comprise of technical (100~200 microns) and individual (< 30 microns) fiber forms [19], [20]. Bamboo fibers have the potential to utilize as reinforcement for environ-mentally friendly compo-sites due to their high specific strength, low-temperature processes, renewable, zero CO2 emission, and low cycle plantation. Osorio, Zakikhani, and Khalil stated in their research that bamboo fibers' strength is comparable with those of glass fibers [21]. Bamboo fibers are also potential for lightweight composite automotive parts in terms of their high specific strength which can contribute to the speed and lower fuel consumption [22]. Unfortunately, bamboo fibers, as well as the other natural fibers, have high water absorption and low compatibility matrix properties which can reveal some composite problems such as voids, fiber-matrix interface, and swelling. To overcome these problems, solution efforts are still developing by researchers around the world in terms of fiber extraction (chemical, mechanical, and chemo-mechanical methods), surface fiber (alkalization, permanganate) treatments, matrix toughen (epoxy-silica nanoparticles), manufacture techniques (VARI, CM, HLU) as well as fiber hybridization (bamboo fibers combine with other natural fibers) [23]–[27]. These are big opportunities for Indonesian researchers to take apart, especially due to Indonesia as a country that has 135 of 1250 world bamboo species [28].

Authors' Declaration

Authors' contributions and responsibilities

The authors contributed resources to the research in the following capacities:

- **Ragil Widyorini -** Lignocellulosic Based Composite: Potency and Challenge in the Future.
- **Nasmi Herlina Sari -** Natural Fiber-Reinforced Composites: Role and Solution for Society and Industry.
- **Muji Setiyo -** Composite Cylinders: An Important Contribution to Weight Reduction of Natural Gas Vehicles.
- **Gunawan Refiadi** - Bamboo Utilization for Both Bio- and Green Composites Reinforcement

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References

[1] R. D. S. G. Campilho, *Natural fiber composites*. CRC Press, 2015.

[2] A. K. Mohanty, M. Misra, and L. T. Drzal, *Natural fibers, biopolymers, and biocomposites*. CRC press, 2005.

[3] A. Gholampour and T. Ozbakkaloglu, "A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications," *Journal of Materials Science*, vol. 55, no. 3, pp. 829–892, 2020.

[4] A. N. Papadopoulos, "Advances in wood composites iii." Multidisciplinary Digital Publishing Institute, 2021.

[5] A. Pizzi, A. N. Papadopoulos, and F. Policardi, "Wood composites and their polymer binders," *Polymers*, vol. 12, no. 5, p. 1115, 2020.

[6] M. Nagalakshmaiah *et al.*, "Chapter 9 - Biocomposites: Present trends and challenges for the future," in *Woodhead Publishing Series in Composites Science and Engineering*, G. Koronis and A. B. T.-G. C. for A. A. Silva, Eds. Woodhead Publishing, 2019, pp. 197–215.

[7] E. Vázquez-Núñez, A. M. Avecilla-Ramírez, B. Vergara-Porras, and M. del R. López-Cuellar, "Green composites and their contribution toward sustainability: A review," *Polymers and Polymer Composites*, p. 09673911211009372, 2021.

[8] L. S. Lee and R. Jain, "The role of FRP composites in a sustainable world." Springer, 2009.

[9] N. H. Sari, *Material teknik*. Deepublish, 2018.

[10] N. H. Sari, I. N. G. Wardana, Y. S. Irawan, and E. Siswanto, "Corn Husk Fiber-Polyester Composites as Sound Absorber: Nonacoustical and Acoustical Properties," *Advances in Acoustics and Vibration*, vol. 2017, p. 4319389, 2017.

[11] A. B. Pereira and F. A. O. Fernandes, "Introductory Chapter: The Importance of Composites in the World," in *Renewable and Sustainable Composites*, IntechOpen, 2019.

[12] F. M. AL-Oqla and M. A. Omari, "Sustainable biocomposites: challenges, potential and barriers for development," in *Green biocomposites*, Springer, 2017, pp. 13–29.

[13] L. Suárez, J. Castellano, S. Díaz, A. Tcharkhtchi, and Z. Ortega, "Are Natural-Based Composites Sustainable?," *Polymers*, vol. 13, no. 14, p. 2326, 2021.

[14] "Automotive Natural Gas Vehicle Market Size Report, 2021-2028," *Grand View Research*, 2021. https://www.grandviewresearch.com/industry-analysis/automotive-natural-gas-vehicles-market/toc (accessed Aug. 03, 2021).

[15] E. Debondue, "Glass composite cylinders offer benefits for CNG vehicles," *Composite Application*, 2011. https://www.materialstoday.com/composite-applications/features/glass-composite-cylinders-offer-benefits-for-cng/ (accessed Aug. 03, 2021).

[16] NEIL, "Metal Mate _ Neil Composite CNG Cylinders (CNG Type 3)," *Automotive NGV Gas Cylinder*, 2015. http://metal-mate.com/wp/products/automotive-ngv-gas-cylinder/neil-composite-cng-cylinders-cng-type-3/ (accessed Aug. 03, 2021).

[17] R. Taccani, G. Maggiore, and D. Micheli, "Development of a process simulation model for the analysis of the loading and unloading system of a cng carrier equipped with novel lightweight pressure cylinders," *Applied Sciences (Switzerland)*, vol. 10, no. 21, pp. 1–23, 2020, doi: 10.3390/app10217555.

[18] K. R. Kashyzadeh, S. S. R. Koloor, M. O. Bidgoli, M. Petrů, and A. A. Asfarjani, "An optimum fatigue design of polymer composite compressed natural gas tank using hybrid finite element-response surface methods," *Polymers*, vol. 13, no. 4, pp. 1–15, 2021, doi: 10.3390/polym13040483.

[19] L. Osorio, E. Trujillo, F. Lens, J. Ivens, I. Verpoest, and A. W. Van Vuure, "In-depth study of the microstructure of bamboo fibres and their relation to the mechanical properties," *Journal of Reinforced Plastics and Composites*, vol. 37, no. 17, pp. 1099–1113, 2018.

[20] E. Castanet *et al.*, "Structure–property relationships of elementary bamboo fibers," *Cellulose*, vol. 23, no. 6, pp. 3521–3534, 2016.

[21] D. Jones and C. B. T.-P. of B. B. M. Brischke, Eds., "3 - Nonwood bio-based materials," Woodhead Publishing, 2017, pp. 97–186.

[22] G. Refiadi, I. S. Aisyah, and J. P. Siregar, "Trends in lightweight automotive materials for improving fuel efficiency and reducing carbon emissions," *Automotive Experiences*, vol. 2, no. 3, pp. 78–90, 2019.

[23] A. J. Kinloch, A. C. Taylor, M. Techapaitoon, W. S. Teo, and S. Sprenger, "Tough, natural-fibre composites based upon epoxy matrices," *Journal of materials science*, vol. 50, no. 21, pp. 6947–6960, 2015.

[24] Y. Swolfs, I. Verpoest, and L. Gorbatikh, "Recent advances in fibre-hybrid composites:

materials selection, opportunities and applications," *International Materials Reviews*, vol. 64, no. 4, pp. 181–215, 2019.

[25] G. Refiadi, Y. Syamsiar, and H. Judawisastra, "The Tensile Strength of Petung Bamboo Fiber Reinforced Epoxy Composites: The Effects of Alkali Treatment, Composites Manufacturing, and Water Absorption," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 547, no. 1, p. 12043.

[26] G. Refiadi, N. Bayu, H. Judawisastra, and M. Mardiyati, "Serat Bambu Petung (Dendrocalamus asper) Teralkalisasi sebagai Penguat Komposit Polimer," *Jurnal Selulosa*, vol. 8, no. 01, pp. 1–8, 2018.

[27] K. Koschek, "Design of natural fiber composites utilizing interfacial crystallinity and affinity," *Composites Part A: Applied Science and Manufacturing*, vol. 69, pp. 21–29, 2015.

[28] "Dendrocalamus asper (PROSEA)." Nov. 06, 2021, [Online]. Available: https://uses.plantnet-project.org/en/Dendrocalamus_asper_(PROSEA).