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Mechanical Properties of Polypropylene Composites with Different Reinforced Natural Fibers – A Comparative Study

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ABSTRACT

Developing environmentally friendly and recyclable natural fiber-reinforced polymer composites has recently attracted researchers' attention and interest. Herein, a comparative study was conducted to compare the mechanical properties of polypropylene (PP) composites with different natural fiber reinforcement, including palm fiber (*Arenga pinnata*), rice straw (*Oryza sativa*), coconut husk (*Cocos mucifera*), old world forked fern leaves (*dicranopteris linearis*), and snake plant (*Sansevieria trifasciata*). This study aimed to compare the influence of the five natural fiber materials on the tensile strength and flexural strength of PP composites. The natural fibers were chemically treated with a 5% NaOH solution for 2.5 hours. In the preparation of composites, polypropylene as the matrix is heated to 300 °C and mixed randomly with natural fibers. The test results indicate that the composite with the highest tensile strength (38% higher than the lowest) and flexural strength (102% higher than the lowest) is obtained using the PP composite with reinforced rice straw fiber. In contrast, the PP composites with palm fiber have the lowest tensile strength (72% from the highest tensile strength) and the lowest flexural strength (UFSmin) (62% from the highest flexural strength) corresponds to the PP composites with coconut fiber. This study revealed that the flexural strength of all composite samples was greater than that of pure PP.

Keywords: polypropylene, natural fibers, tensile strength, modulus young, flexural strength.

INTRODUCTION

The aerospace and automotive industries are always searching for lighter and more durable materials to increase the effectiveness and reliability of their systems. Composite materials, particularly polymeric composites with reinforcing fibers, have proven to be an excellent solution to this demand due to their high strength, stiffness, and low density (Cavalcanti et al., 2019). Plastics are ubiquitous in the environment, making global plastic pollution a significant environmental issue. Polypropylene (PP), Polyethylene (PE), Polyvinyl Chloride (PVC), Polyurethane (PUR), Polyethylene Terephthalate (PET), and Polystyrene (PS) make up 81.2% of the 370 million tonnes of plastic produced worldwide in 2019 (Esterhuizen & Kim, 2021). Only 6% of plastic waste is recycled annually, while 28% is released directly into the environment. When plastics in the environment degrade, microplastics (5 mm) and nano plastics (100 nm), which interact with living things and pose a growing threat to the environment, can be produced (Wu et al., 2021). Nonetheless, the fact that pollution is worsening globally must also be considered. As a result of the increase in buildings, rainforests, and wildlife are destroyed, exacerbating environmental issues such as the greenhouse effect, global warming, and ozone depletion caused by the combustion of plastic fuels. Consequently, people should focus more on the immediate measures to save the environment and protect nature. Adopting sustainable practices is one of several methods for reducing pollution. Waste reduction, reuse, and recycling programs, or 3R programs, alternative strategies include substituting plastic fibers for composites reinforced with natural fibers (Tan, Chan, & Koay, 2021).

Due to their combination of high strength, high stiffness, and low weight, fiber-reinforced plastics (FRP) are being increasingly utilized in fabricating various structures. Typically, they are made with epoxy glue and synthetic fibers. Most of the time, these substances are referred to as high-performance composite materials. Using natural fibers (NFs) as reinforcement in composite materials is a common strategy for various applications due to the sustainability of the material. This NF has numerous benefits, including the ability to replace certain synthetic fibers. In addition, this NF has been incorporated into biocomposites. The advantages of natural fiber-reinforced polymer composites (NFRPCs) over synthetic materials include light weight, biodegradability, low cost, and high quality (Khalid et al., 2021).

Polypropylene (PP) is considered a great choice as the matrix in fabricating composite materials due to its advantages, such as excellent chemical and high-temperature resistance. In addition, as a semi-crystalline thermoplastic with good resin properties, it is compatible with natural fibers. These advantages make it ideal for several applications, such as trays, funnels, buckets, bottles, and instrument jars routinely sterilized (cleaned) in clinical settings. Polypropylene is a colorless polymer with superior mechanical properties to polyethylene (Maddah, 2016). In comparison, straw is one of the most accessible renewable natural materials. Straw fiber benefits from being inexpensive, renewable, and biodegradable. As a reinforcing agent for composite materials (Qi et al., 2022), corn, wheat, rice, and barley straw have received much attention in recent years. The composite materials have two parts, the first is filler that functions as a reinforcing element, and the second is the main component that determines the properties of the material. Several natural fibers have been used separately in the previous study, such as banana fiber (Bekraoui, El Qoubaa, Chouiyakh, Faqir, & Essadiqi, 2022), pineapple fiber (Rahman, Das, & Hasan, 2018), abaca fibers (Paglicawan, Emolaga, Sudayon, & Tria, 2021), and so on. Natural palm fiber has a black base color and possesses several qualities, including the fibers' resistance to acids and salts found in salt water as well as their ability to last a long time (Mohd Roslim, Sapuan, Leman, Ishak, & Maleque, 2017). These fibers were chosen because the materials are easy to obtain, abundant in nature, and not harmful to health. The use of composite fibers is expected to overcome the environmental problems that may arise from the many composites still made from plastic materials (Okunlola, Arije, & C, 2018; Widyasanti, Napitupulu, & Thoriq, 2020).

On the basis of the description above, the authors were interested in comparing the tensile strength, Young's modulus, and flexural strength of polypropylene composites using different natural reinforce fibers, including palm fiber (*Arenga pinnata*), rice straw (*Oryza sativa*), coconut husk (*Cocos mucifera*), Old world forked fern leaves (*Dicranopteris linearis*), and snake plant (*Sansevieria trifasciata*).

EXPERIMENTAL SECTION

Materials

Polypropylene was purchased from the Sinar Pelangi Etirisstore store (Bandung, Indonesia), whereas 5% NaOH solution was purchased from ROFA Laboratory Center (Bandung, Indonesia). All the natural fibers of palm fiber (*Arenga pinnata*), rice straw (*Oryza sativa*), coconut husk (*Cocos mucifera*), Old world forked fern leaves (*dicranopteris linearis*), and snake plant (*Sansevieria trifasciata*) were collected from the environment around the city of Medan (Indonesia).

Preparation of natural fibers

The old world forked fern leaves, coconut husk, and snake plant leaves were soaked in water for 45, 30, and 14 days, respectively, so that they were soft and the fiber could be easily separated as well as taken out (S et al., 2021). The palm fiber and rice straw could be directly washed without soaking, because they are already fibers.

Drying of natural fibers

The as-obtained natural fibers were soaked in a 5% NaOH solution for 2.5 hours to improve the surface properties (Hoang, Pham, & Yum, 2020; Khan, Rahamathbaba, Mateen, Ravi Shankar, & Manzoor Hussain, 2019). The bond between the matrix and the fiber became stronger and more stable so that the mechanical strength of the composite increased, especially its tensile strength. After soaking for the specified time, the fibers were cleaned with distilled water.

Preparation of natural fibers

After the soaking process was completed, the next step was drying for about 5-10 hours. The fiber was dried naturally by leaving it in the open space under the Sun to remove any solvent (Cichosz & Masek, 2020). Five different natural fibers were ready to be used to fabricate composites. Figure 1 demonstrates the process of natural fiber preparation using coconut husk as an example.

Preparation of specimen

The pure polypropylene in pellet form was placed in a 500 mL beaker. Then, polypropylene and each fiber were poured into a ceramic container before being placed in the furnace and heated at 300°C for 30 minutes. The fiber orientation used in this study is random. Next, a releasing agent was sprayed on the bottom side of the mold (124 × 36 × 8 mm). After the PP melted, it was immediately poured into the mold and then manually compressed. The composite material was then removed from the mold and allowed to cure for 24 hours at room temperature. The composite was cut according to the standard test size for mechanical testing. The PP and natural fibers ratio was 95% and 5%, respectively.

Test standard preparation

Polypropylene and fiber in blocks with a length of 124 mm were cut to a length of 120 mm and a width of 22 mm for tensile testing and 12 mm for flexural testing (Sherwani, Zainudin, Sapuan, Leman, & Abdan, 2021). Then, polypropylene and fiber with a thickness of 8 mm were thinned using a pregrinder to have a thickness of 5 mm. After that, the edge of the surface of the block that had been cut was polished with sandpaper to make the surface smooth. Finally, the composite was cut into pieces according to the ASTM D-3039 and ASTM D-790-03 standards for the tensile and flexural strength tests, respectively (Nossa, Bohórquez, Pertuz, Sánchez Acevedo, & González Estrada, 2019; Raj, 2021). Each test per specimen was conducted three times; thus, there were 30 composite specimens in this study.

RESULTS AND DISCUSSION

Tensile strength

Figure 2 shows the tensile strength of PP composites with different reinforced natural fibers. It can be seen that the highest tensile strength was obtained using the rice straw fiber with a value of 7.9 MPa. Meanwhile, the lowest tensile stress of 5.7 MPa was obtained for PP composites and palm fibers. This is due to the different contents of rice straw. In Indonesia, rice straw is usually sprayed with salt water (Marjuki, 2010), which affects its properties. The research of Jiang et al. stated that the saltwater content of the fiber could help reduce hemicellulose and lignin as well as increase fiber crystallinity, consequently improving the fiber-polymer compatibility (Jiang, Du, & Wang, 2021). In addition, the cellulose content is different, where rice straw has 44.9% cellulose which is higher than palm fiber (43.8%) (Asyraf et al., 2022). The results show that the composition of (95:5) % PP and rice straw fiber provides

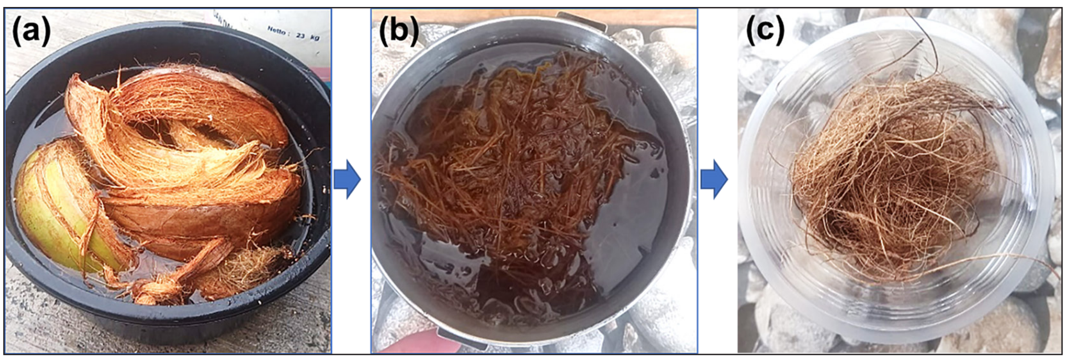

Figure 1. Preparation of natural coconut fiber (a) coconut husk soaked in water, (b) the soft coconut husk soaked into NaOH solution, and (c) the dried coconut husk fiber

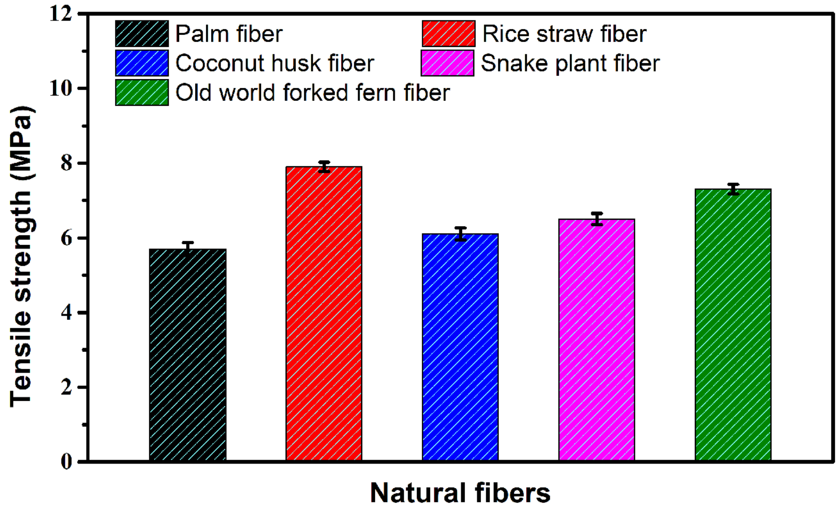

Figure 2. Histogram of tensile strength of PP composite with different reinforced natural fibers

the highest tensile strength among other fibers. This is due to its low lignin content of 12.5%, so the bonds between the fiber molecules and the matrix are well established (Ma et al., 2021). At the same time, the PP and *Arenga pinnata* fiber composites provide the smallest tensile stress, because the lignin content in the fibers is quite high, about 43.09%, so the molecular bond of the fiber with the matrix becomes more difficult to form.

Strain

Figure 3 compares the maximum elongation of the PP composite with different reinforced natural fibers. The strain in this test measures the dimensional change that occurs due to tensile stress. It can be seen that the highest strain of 0.75% was obtained in the PP composite and rice straw fiber. In contrast, the lowest strength of 0.06% was obtained on the PP composite and snake plant fiber. It is well known that incorporating natural fibers with PP leads to a general strengthening of mechanical properties. This is because the composite material is subjected to tensile forces, and the polymer matrix transfers those stresses to the fibers through the interface between the two components, resulting in the composite being able to withstand greater forces before fracture. In this case, rice straw and coconut husk fibers outperform snake plant, palm, and old world forked fern fibers, assuming that PP has stronger interfacial forces.

Modulus young

Figure 4 compares the modulus young of PP composite with different reinforced natural fibers. It can be seen that the highest elastic modulus of 0.116 GPa was obtained from PP composites with

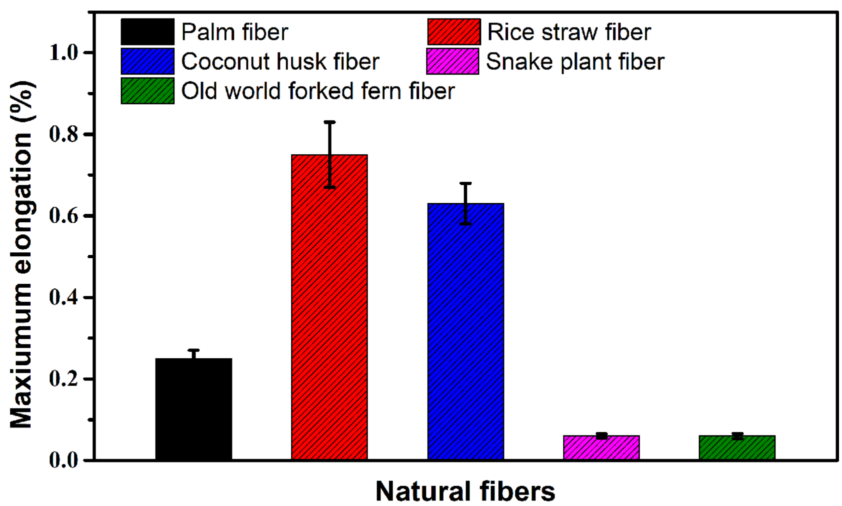

Figure 3. Maximum elongation of PP composite with different reinforced natural fibers

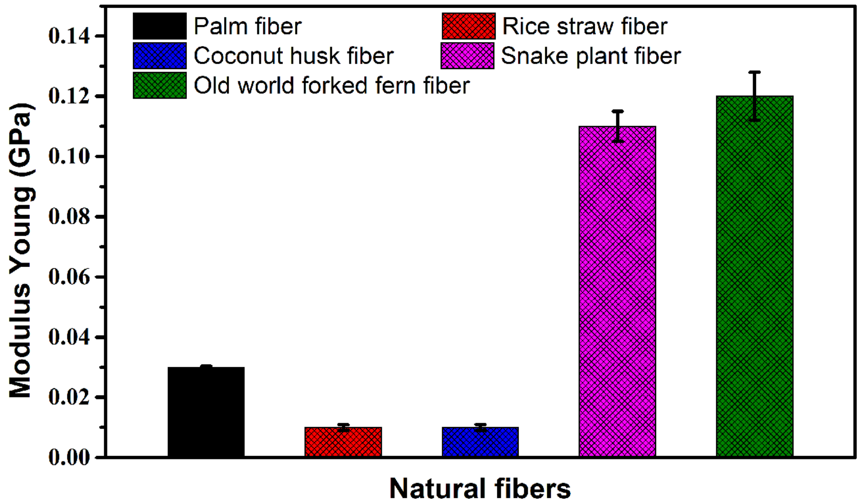

Figure 4. Modulus Young of PP composite with different reinforced natural fibers

old world forked fern fiber. The lowest modulus young of 0.097 GPa was obtained on PP composites and coconut fiber. Two composite samples exceed the standard tensile strength of pure polypropylene in general (0.033 GPa) (Awad, El Gamasy, Abd El Wahab, & Abdellatif, 2019), snake plant fiber (0.104 GPa) and old world forked fern fiber (0.116 GPa). The difference in Young's modulus value is related to the stiffness aspect, where the role of PP as a binder determines the increase or decrease in stiffness value after being combined into a composite. The strong interface between fiber-reinforced PP has been reported to reduce stiffness due to cracks passing through the interface, creating interface separation such as delamination and debonding (Gassan & Bledzki, 2000). On the basis of the previous discussion, the lowest maximum elongation is in snake plants (0.06%), and rice old world forked fern fibers (0.06%). However, in contrast to the modulus young value, both outperformed the other fibers. Therefore, it is assumed that the strength of the fiber interface with PP affects the modulus young value.

Flexural strength

The flexural strength of PP composites with different natural fibers is presented in Figure 5. According to the test results, the highest and the lowest flexural strength values were 139.6 MPa and 69.1 MPa. The order of flexural strength was rice straw fiber> palm fiber> old world forked fern≥ snake plant fiber ≥ coconut fiber. Overall, all composite samples exceeded the flexural strength standard of pure polypropylene in general, which was 37.232 MPa.

In the previous study by Widodo et al. using an Arenga Pinata Fiber-reinforced Polyester

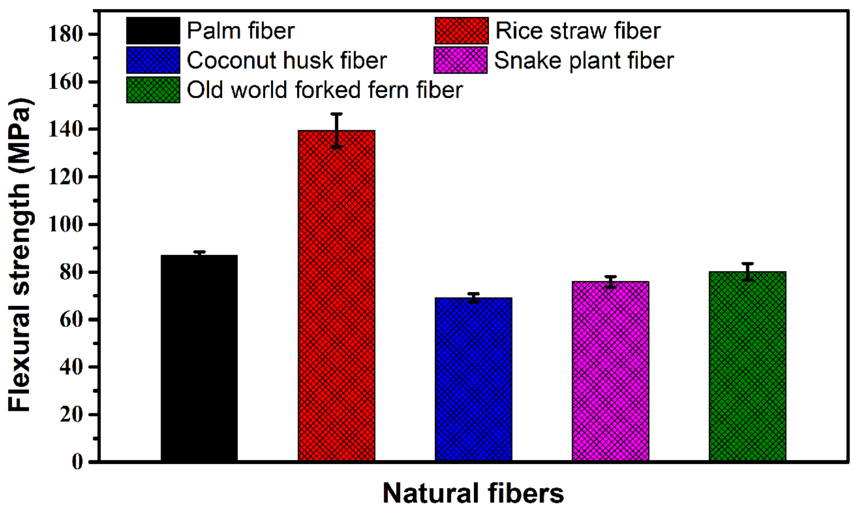

Figure 5. Histogram of the flexural strength of PP composite with different reinforced natural fibers

composite and treated by alkaline solution with 5% NaOH solution for 2 hours of soaking time, the mechanical properties of the highest flexural strength was 24.03 MPa (Widodo, Robi, Nugroho, & Al-Janan, 2020), whereas in this study it was 86.9 MPa. Another study on the mechanical properties of PP composites with coconut fiber reports that flexural tests on the coconut fiber treated with KOH yielded the highest flexural strength value of 46.33 MPa (Agbabiaka, Oladele, & Daramola, 2015). It can be seen that the currently obtained result was higher, with a value of 69.1 MPa. The flexural strength of the considered PP composite with rice straw fiber (139.6 MPa) was also significantly higher than the flexural properties of rice straw reinforced polyester composites (55.08 Mpa). It can be seen that the previous research reference using the polypropylene matrix still had more optimal flexural strength result than using the polyester matrix (Prasad, Rao, Kumar, & Rao, 2006). Then, the obtained findings were compared to the research conducted by Shieddieque concerning the preparation and characterization of snake plant fiber/high-impact PP biocomposites for automotive applications such as interior and exterior trims. Shieddieque et al. obtained the tensile strength of pure PP specimens and snake plant composite with a 15% fiber volume fraction of 59.77 MPa (Shieddieque, Mardiyati, & Widyanto, 2021). This result was higher than that obtained in this study by using a 5% snake plant volume fraction of 6.5 MPa. A recent study shows that a 5% fiber fraction yielded less optimal test results than the 15% fiber fraction used in previous studies. However, based on this study, 5% fiber improves mechanical properties compared to pure PP.

CONCLUSIONS

In summary, 95% PP composites were successfully fabricated with an additional 5% reinforced natural fibers and compared their tensile strength, Young's modulus, and flexural strength. The PP composites reinforced with rice straw fiber had the highest tensile strength and flexural strength with values of 7.9 MPa and 139.6 MPa, respectively. Using PP composite-reinforced old world forked fern fiber, the highest modulus achieved was 0.116 GPa. Thus, it was found that the rice straw fiber obtained the highest tensile strength and modulus young. The highest flexural strength was obtained using snake plant fiber. All composite samples exceeded the standard of flexural strength of pure polypropylene.

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