Penerbit Akademia Baru

Malaysian Journal on Composites Science and Manufacturing

Journal homepage:

https://akademiabaru.com/submit/index.php/mjcsm

ISSN: 2716-6945

Utilization of Rice Husk Fiber Blended Recycled Polyethylene Terephthalate for Manufacturing RHF/R-PET Polymer Composites

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ARTICLE INFO

Article history:
Received 6 October 2024
Received in revised form 4 February 2025
Accepted 21 February 2025
Available online 30 March 2025

Keywords:
Rice husk fiber; R-PET; polymer; composite; tensile strength

ABSTRACT

In response to the growing global awareness of the environmental crisis, a natural fiber-blended polyethylene material is being developed for the production of polymer composites. This research focuses on harnessing abundant waste materials such as Rice Husk Fiber (RHF) and Recycled Polyethylene Terephthalate (R-PET) in Malaysia to create RHF/R-PET polymer composites. The main goal of this study is to identify and characterize the optimal composition of RHF/PET polymer composites suitable for deck panel applications. The research investigates various composition ratios of RHF fibers, ranging from 5 to 20 wt/w% when blended with R-PET sourced from recycled bottles produced at Angkasa Kowaris Plastics Sdn Bhd. This study holds significant importance in the development of an environmentally friendly polymer composite material, utilizing abundant natural resources approaching RHF fibers found in Malaysia. The study includes physical and mechanical testing of samples with different RHF fiber composition ratios. The findings reveal that the ideal combination for producing polymer composites for deck panels is achieved at a 20 wt/wt% ratio of RHF/R-PET. This composition provides good matrix bonding between RHF and R-PET with density and porosity at 1.043 g/cm3 and 0.076%, respectively. It also exhibits a maximum tensile strength of 12.53 MPa, exerting a force at 138.90 N with a maximum stress of 14.8 N/mm2. Additionally, 20 wt/wt% gives a higher Young's modulus value at 12.12 MPa. For bending strength 20 wt/wt% was achieved at 19.78 N with a maximum stress of 10.45 MPa. The incorporation of RHF fibers in fiber-reinforced composite applications offers economic benefits due to their renewability, biodegradability, and cost-effectiveness compared to manufactured fibers. This approach has the potential to contribute significantly to Malaysia's economy by providing a waste material alternative to raw materials while maximizing the utilization of RHF fibers and R-PET waste resources.

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https://doi.org/10.37934/mjcsm.16.1.245257

1. Introduction

Composite materials offer a versatile solution to meet diverse design requirements, owing to their excellent mechanical and physical properties. When natural fibers (NF), like agricultural waste, are combined with materials such as plastics, these composites exhibit superior performance compared to other materials. NF, often considered as biomass, is abundantly available from agricultural waste but only about 10% of it finds use as alternative raw materials in various industries, including biocomposites, automotive components, and biomedical applications. NF possesses renewable and degradable characteristics, and it has gained attention due to its cost-effectiveness, high strength-to-weight ratios, low density per unit volume, and acceptable specific strengths [1].

NF tends to be more cost-effective than synthetic fibers and poses fewer health and environmental hazards during composite manufacturing. Among the most commonly used NF polymer composites is Wood Polymer Composite (WPC). WPCs are engineered to address the inherent limitations of natural wood while enhancing qualities such as tensile properties, durability, and resistance to bio-deterioration. In the United States, WPCs have gained widespread usage, with typical panels being composed of a blend of wood flour and plastics, allowing them to be processed similarly to 100% plastic-based products [2]. WPC is a broad term encompassing composite materials made from wood-based components such as timber, veneer, fibers, or particles combined with polymers, which can be thermosetting or thermoplastic, like Polyethylene Terephthalate (PET). PET is a thermoplastic polymer derived from the monomer ethylene, belonging to the polyolefin resin family. It holds a dominant position in the global polymer market due to its favorable characteristics, including high elongation at break, excellent chemical resistance, effective water and oxygen barrier properties, lightweight nature, and cost-efficiency [3]. The combination of PET with wood elements has garnered significant interest in both academic and technological circles, as it merges the remarkable qualities of wood with the versatility, processability, and mechanical attributes of PET.

The primary issue identified in the study is deforestation, as wood flour is extensively utilized in the composite industry. Additionally, wood faces significant challenges related to water resistance due to its natural hygroscopic nature. Furthermore, wood is susceptible to termite infestations as cellulose is released, and it can become excessively brittle at specific compositions or temperatures, thereby diminishing the quality and sustainability of WPC products [4]. Regarding reinforced plastics, certain materials like Polyvinylchloride (PVC), commonly used in WPC products, pose environmental and safety concerns. PVC emits toxic gases, including chlorine, which can be harmful and burns vigorously when exposed to fire [5]. The utilization of virgin plastics in WPC also has detrimental environmental effects, contributing to pollution and increased demand for petroleum resources, which are depleting. Nowadays, researchers explore secondary recycling involves the reprocessing of PET plastic waste from recycled bottles into products for uses that are different from the initial material through mechanical processes [6]. However, in the context of WPC applications, there's a growing interest in exploring alternatives to wood, such as Rice Husk Fiber (RHF).

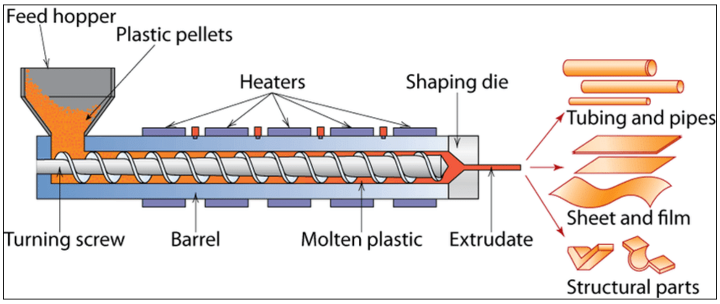
RHF is considered an attractive natural material due to its high production yield and potential for reducing tree cutting. Approximately 0.20 tons of rice husks are generated for every ton of rice produced, and rice milling is a major industry in several countries, including China, India, Indonesia, Australia, Malaysia, and Bangladesh [7]. Rice husks find various uses, including in composite materials, insulation, fuel, and fertilizers. NF such as RHF is favored for their robust mechanical properties, low material cost, lightweight nature, abundant availability, renewability, environmental friendliness, recyclability, and biodegradability. Composite materials, particularly those incorporating natural fibers like RHF, offer a promising avenue for addressing diverse design needs while considering environmental sustainability and cost-effectiveness [8]. These materials leverage the unique properties of both the natural fibers and the polymer matrices, providing a versatile and eco-friendly solution for various industries and applications.

2. Literature Review

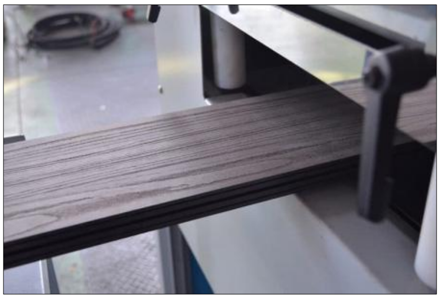
Polymer composites are versatile composite materials composed of wood flour or fibers mixed with thermoplastic resins, such as polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polylactic acid (PLA), or polyvinyl chloride (PVC). These composites may also contain a small amount of biopolymer or other additives that serve as an alternative matrix for reinforcement [9]. The key characteristic of polymer composites is the infusion of monomers into the fiber such as wood, which polymerizes within the material, transforming it to meet specific processing requirements for various applications. These composites can also include inorganic fillers and lignocellulosic components. Polymer composite materials offer a wide array of advantageous properties, including specific tensile and bending strength, resistance to wear, durability, lightweight nature, and enhanced mechanical capabilities [10]. These attributes make polymer composites highly suitable for a sustainable range of engineering applications.

The construction industry has embraced polymer composite materials due to their exceptional molding performance and wood-like texture. They are extensively used for exterior applications such as deck flooring, railing, fencing, landscaping, roofing, window frames, and furniture [11]. Despite wood fibers within the material having some moisture absorption, polymer composites exhibit superior decay resistance. Mechanical performance can be further enhanced through acetylation treatment. polymer composites are easy to work with, can be shaped and framed to specific requirements using conventional woodworking tools, and can be securely nailed [12]. Despite these advantages, ongoing research and technological developments in the production industry aim to improve polymer composite's performance and expand its applications. Polymer composites are typically created by blending the fiber with a heated thermoplastic resin, with the fiber-to-plastic ratio affecting the material's melt flow index. Two primary production processes are extrusion and compression molding, although injection molding is also an option. Extrusion involves subjecting the polymer to heat and shear forces to combine with fiber and additives, resulting in compounded material plastic pellets. These pellets can then be extruded into tubing and pipe profiles, sheet and flat film, or structural parts sectioned profiles of desired dimensions for specific purposes as shown in Figure 1 [13].

Marsi *et al.,* focused on utilizing fibers from oil palm empty fruit bunches (PEFB) in polyester matrices for reinforcement. The porosity results indicated that increasing fiber content raised the percentage porosity in untreated oil palm EFB-reinforced polyester composites from 3.43% to 7.16% at different fiber loadings [14]. Yafei *et al.,* investigated the effects of SEM image of various additives, including nano-SiO_2, Rice Husk Ash (RHA), and bagasse ash, on the friction coefficient and wear resistance of high-density polyethylene (HDPE) reinforced with lignocellulosic fibers. They found that fillers improved wear resistance, with nano-SiO_2 having the most significant effect. RHA outperformed bagasse ash due to its higher SiO_2 content [15]. Basalp *et al.,* studied recycled Wood Polymer Composites (r-WPCs) made from different recycled plastics and wood from household waste. Compatibilizers like maleic anhydride grafted polyethylene (MAPP) improved interfacial bonding and reduced voids in the composite, enhancing mechanical properties [16].



(a)



(b)

Fig. 1. (a) Manufacturing process of polymer composites; (b) deck panel polymer composite [13]

Zhang *et al.,* research on the bending strength of Wood Polymer Composite (WPC) and biochar polymer composite (BPC). In the case of BPC, High-Density Polyethylene (HDPE) acted as an adhesive, penetrating the surface openings of the rice husk (RH) and facilitating entanglement and contact between RH powder particles. This interaction resulted in increased bending strength up to a 50 wt% RH powder content. However, beyond this threshold, the bending strength started declining due to increased aggregation, leading to stress concentration and defects in the composite. Moreover, RH biochar-filled composites exhibited higher bending strength compared to RH powder-filled composites, mainly due to their distinct composition absent in WPC. The strength increased with higher RH biochar content, peaking at 70 wt%. RH biochar limited HDPE chain mobility, reducing the matrix's deformation ability in the elastic zone [17]. In another study by Zhang *et al.,* they investigated High-Density Polyethylene (HDPE) reinforced with fibers from rice husk, peanut husk, and walnut husk shells. It is demonstrated that fiber content reached 40%, and the composite's bending strength significantly improved. The addition of fibers reduced the gaps between them, allowing HDPE to distribute evenly within the biomass powder, effectively acting as a binder. The fibers were tightly encapsulated in HDPE, creating a strong interface. Among the different composites, rice husk/HDPE composites exhibited the highest bending strength, surpassing walnut shell/HDPE and peanut husk/HDPE composites. The bending strength of plant fibers primarily depends on their cellulose content, with higher cellulose percentages resulting in stronger fibers. Cellulose serves as the backbone of plant fibers, and increased cellulose concentration enhances the bond between plant fibers and the matrix [18].

Neher *et al.,* conducted a study on banana fiber (BF) reinforced High-Density Polyethylene (HDPE) composites, analyzing how various parameters were affected by the addition of banana fiber. The figure reveals that BF-HDPE composites with a continuous oriented fiber arrangement exhibit significantly higher tensile strength compared to those with a continuous bidirectional fiber arrangement. For continuously aligned fiber orientation, the percentage change in tensile strength relative to 0% fiber is 47.9% (for 5%), 131.30% (for 10%), 236.45% (for 15%), and 277.37% (for 20%). In contrast, continuous bidirectional fiber orientation results in a percentage change in tensile strength relative to 0% fiber of 5.08% (for 5%), 15.38% (for 10%), and 40.92% (for 15%) (for 20%). The study found that BF-reinforced HDPE composites with 20% fiber content exhibited the highest tensile strength, measuring 55.7 MPa. This could be attributed to the uniform dispersion of fibers and a stronger interfacial bond with the matrix [19]. Raghu *et al.,* investigated the mechanical properties of composites combining Rice Husk (RH) and Polypropylene (PP). Composites with high fiber loading exhibit poor impact strength due to the inherent stiffness of natural fibers, leading to stress concentration and reduced impact resistance. The attachment of RH to the matrix also stiffens polymer chains, further reducing impact strength. However, impact modifiers can enhance impact strength for specific applications. The brittle failure at the fiber interface absorbs more impact energy in modified composites, resulting in increased impact strength for composites treated with coupling agents [20].

The novelty of this study is to determine the mechanical, thermal, and physical properties of the RHF/R-PET composites that provide potential applications in deck panel applications and performance characteristics. The limitation and boundary of this study in material variability of RHF and R-PET processing methods and composite formulation focuses on specific applications suitability of RHF/R-PET composites as deck panels application.

3. Methodology

In the manufacturing process of RHF/R-PET Polymer Composite, the materials required are Rice Husk Fibre (RHF) and recycled Polyethylene Terephthalate (R-PET). R-PET is obtained from Angkasa Kowaris Plastics Sdn. Bhd. in Shah Alam, Selangor are prepared in containers before sample production. This study involves the preparation of four RHF/R-PET polymer composite samples with different composition ratios of RHF and R-PET according to Huang *et al.,* tabulated in Table 1 [21].

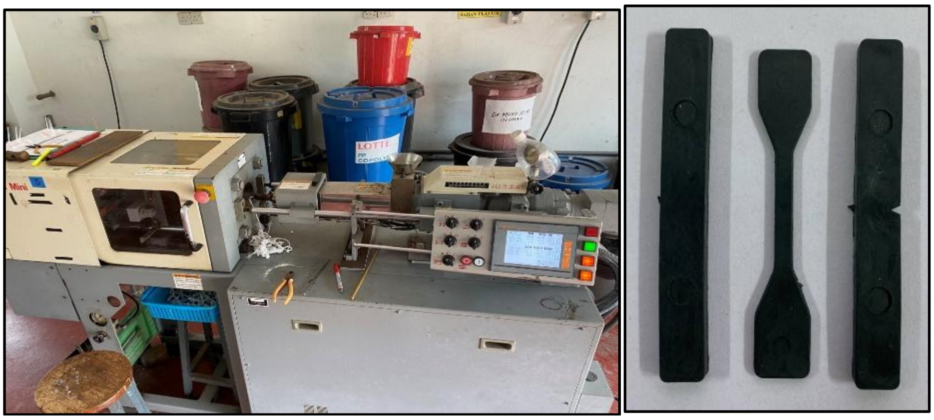
Table 1
The composition ratio of RHF/R-PET polymer composite

Samples	Composition ratio (wt/wt %)	RHF (gram)	RPE (gram)	RHF/RPE polymer composite (gram)
A	5%	2.1	39.9	42.02
B	10%	4.2	37.8	42.02
C	15%	8.4	33.6	42.02
D	20%	10.5	31.5	42.02

Various techniques are employed in the proper procedure to prepare these samples. The initial step involves the use of Thermogravimetric analysis (TGA) to assess the thermal stability of recycled PET, which exhibits a melting temperature ranging from 127°C to 140°C. Subsequently, the Brabender Measuring Mixer, located in the Polymer Laboratory at UTHM, is utilized to blend the recycled RHF and R-PET. This machine is designed to produce lump-sized samples of recycled RHF and R-PET by batching and mixing them together following the ASTM D2538 standard. The mixer operates at a speed of 25 rpm, with a melting temperature set at 140°C. To achieve an optimal mass ratio of 400g for each material, the procedures are repeated at least ten times for each feeding ratio. Next, a Polymer Crushing Machine is employed to crush the composition ratio of RHF and R-PET to produce pallet-shaped known as RHF/R-PET resin as shown in Figure 2. These samples are intended for use in the injection molding process. The final step in sample preparation involves producing samples according to the test specimen requirements using an injection molding machine. The NISSEI NP7 hybrid high-performance injection molding model manufactures samples for tensile, bending, and impact tests in accordance with test standards. The machine operates by heating the RHF/R-PET resin materials to a melting point of 140°C, making the process straightforward. The RHF/R-PET resin is fed into the melting screw of the machine and flows into the mold, which is customized based on the RHF/R-PET polymer composite sample specifications for mechanical testing in Figure 3.

(a) (b) (c)

Fig. 2. (a) Brabender measuring mixer; (b) Blended RHF/R-PET, (c) Pallet-shaped RHF/R-PET resin



(a) (b)

Fig. 3. (a) NISSEI NP7 hybrid high-performance injection molding; (b) RHF/E-PET polymer

4. Results and Discussion

4.1 SEM Microstructure Analysis

Figure 4 displays microstructure images at a 200x magnification for different samples within the RHF/R-PET composites: (a) 5% Rice Husk Fibre (RHF), (b) 10% RHF, (c) 15% RHF, and (d) 20% RHF. These microstructure analyses were conducted on fracture surfaces of specimens following Charpy Impact tests. In Figure 4(a), corresponding to the 5% RHF content, plastic deformation filaments are visible. This is attributed to the low RHF content, resulting in predominantly R-PET particles, creating a smooth and uniform surface. However, the relatively ductile nature of this sample, with higher polymer content, fails to meet composite requirements, resembling individual polymer behavior. Figure 4(b) representing the 10% RHF sample exhibits minimal fiber strands between the fiber-matrix reinforcement. Numerous voids in the image indicate poor interfacial interaction and adherence in the matrix, confirming polymer-matrix incompatibility [22].

Conversely, Figure 4(c) with 15% RHF content displays an improved interfacial region between filler and matrix due to increased fiber strands. Nevertheless, some areas reveal small cavities between the fiber and polymer regions due to inadequate fiber content. The optimal SEM analysis result is observed in Figure 4(d) with 20% RHF content. This sample retains a substantial amount of fiber strands post-impact testing. The higher fiber content showcases excellent matrix-polymer interfacial adhesion and particle distribution within the matrix. Consequently, higher RHF loading increases the sample's hardness and brittleness, enhancing its mechanical strength. Thus, a 20% RHF content is ideal for RHF/R-PET polymer composites for deck panels.

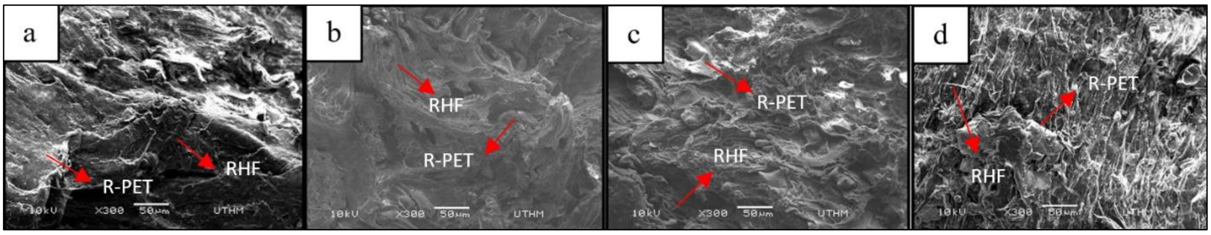
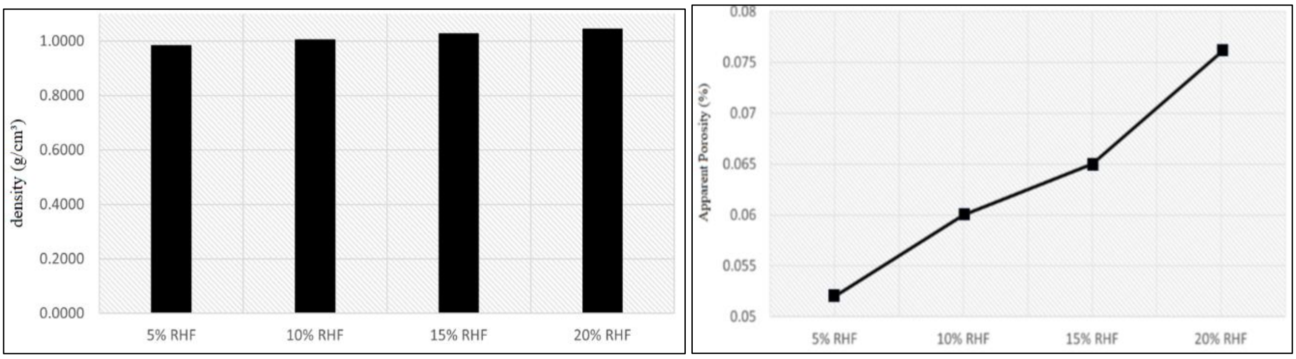


Fig. 4. SEM microstructure analysis of RHF/R-PET polymer composites samples: (a) 5% RHF; (b) 10% RHF; (c) 15% RHF; (d) 20% RHF

4.2 Density and Porosity Analysis

Figure 5(a) presents density values for various percentages of RHF/R-PET polymer composite samples. The 5% RHF sample exhibited the lowest density at 0.9834 g/cm³. Subsequently, the density increased with RHF content, with 10% RHF at 1.0047 g/cm³, 15% RHF at 1.0262 g/cm³, and the highest density recorded for 20% RHF at 1.0437 g/cm³. This density pattern aligns with studies by Ejiogu *et al.,* noted that lower fiber content of RHF, increases void content, reducing composite density due to poor matrix-phase interaction and adhesion, highlighting polymer-matrix incompatibility [23]. However, if RHF content is significantly lower, as referred by Manas, *et al.,* the composite closely mirrors PE's density (0.92 g/cm³), exhibiting almost polymer-like characteristics [24]. Ugochukwu *et al.,* explained that increased cross-linked density with higher natural fibre loading stiffens the polymer chains, making the composite more brittle and rigid, thereby reducing its resistance to breakage [25].

Figure 5(b) shows the apparent porosity of different RHF percentages in RHF/R-PET polymer composites. The lowest porosity, 0.052%, was recorded for the 5% RHF sample, followed by 10% RHF at 0.060%, 15% RHF at 0.065%, and the highest at 0.076% for 20% RHF. The graph explains a nearly linear increase in apparent porosity with a rising RHF percentage. Kassim *et al.,* observed that increased apparent porosity in fiber-reinforced materials arises from the formation of fiber-matrix interfacial regions and concurrent void formation. Higher porosity with increasing fiber content leads to fiber clustering during mixing, trapping water-filled gaps that eventually transform into voids within the composite [26].



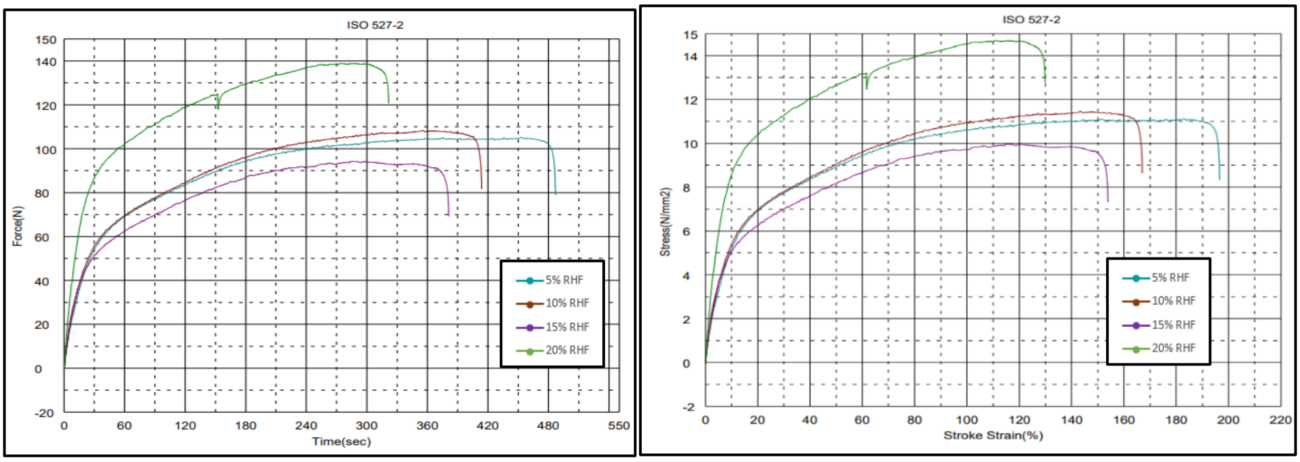
(a) (b)

Fig. 5. (a) Density result; (b) apparent porosity of RHF/R-PET polymer composites

4.3 Tensile Strength Analysis

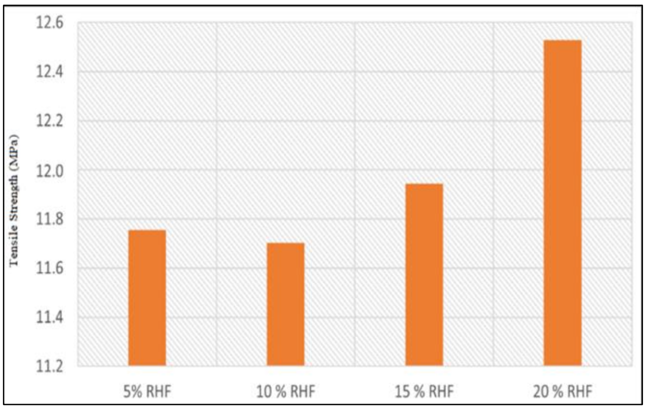
Figure 6(a) shows the sample with 20% RHF exhibited the highest maximum load at 139.00 N, followed by 10% RHF at 108.45 N. In contrast, the 15% RHF sample had the lowest maximum load of 94.33 N, even lower than the 5% RHF sample, which registered 105.25 N. The tensile properties of composites are influenced by various factors, including fiber strength, modulus, fiber length, orientation, interfacial bonding, and fiber content. However, it's worth noting that increasing fiber content doesn't always lead to a linear increase in load resistance. This phenomenon can be attributed to the effective aspect ratio decreasing as the reinforcement content increases, which can lead to phase separation and fiber aggregation. While fiber-to-fiber contact increases, fiber-matrix adhesion decreases with higher fiber-to-matrix ratios, resulting in a weaker interfacial bond and less efficient load transfer [27]. Figure 6(b) illustrates the stress-strain behavior of each sample with different RHF percentages. The 5% RHF sample exhibited the highest maximum strain at 182.84%, followed by 10% RHF at 143.23%. In contrast, the 15% RHF sample had a significant drop in maximum strain, recording only 115.31%, and the 20% RHF sample had 110.89%. This decrease in strain with increasing RHF content is because more ductile materials can stretch further before reaching plastic deformation, indicating their ability to withstand mechanical stress.

Figure 7(a) shows the relationship between tensile strength and RHF percentage for RHF/R-PET polymer composite samples. The sample with 10% RHF had the lowest tensile strength at 11.70 MPa. The 5% RHF sample's tensile strength was only slightly higher, at 11.76 MPa. The 15% RHF sample reached 12.53 MPa, and the highest tensile strength was recorded for the 20% RHF sample. Generally, increasing the percentage of RHF tends to increase the tensile strength of the sample. However, in some cases, phase separation and fiber aggregation can lead to weaker binding due to poor fiber-matrix contact. Figure 7(b) presents the Young's modulus of samples with different RHF percentages. The highest Young's modulus value was observed in the 20% RHF sample at 12.12 MPa, followed by the 15% RHF sample at 9.91 MPa. The 10% RHF sample had a lower modulus at 7.39 MPa, while the 5% RHF sample had the lowest modulus at 6.45 MPa. This pattern is attributed to the interaction between RHF and R-PET during mixing. As the fiber content increases, RHF may start to collect rather than disperse, reducing the wetting ability of R-PET on the fibers and ultimately increasing Young's modulus [28].

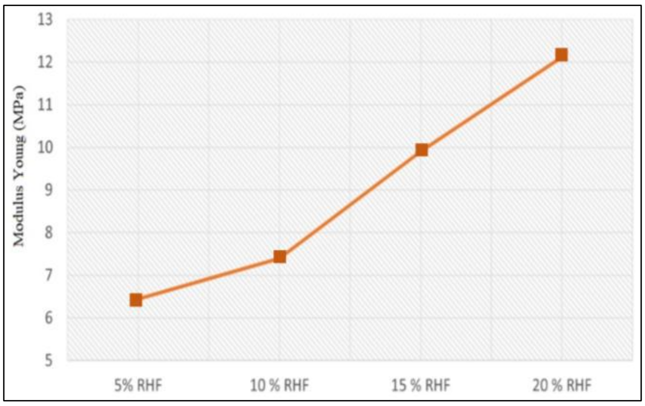


(a) (b)

Fig. 6. (a) Load vs. time; (b) stress vs. strain of tensile strength RHF/R-PET polymer composites



(a)



(b)

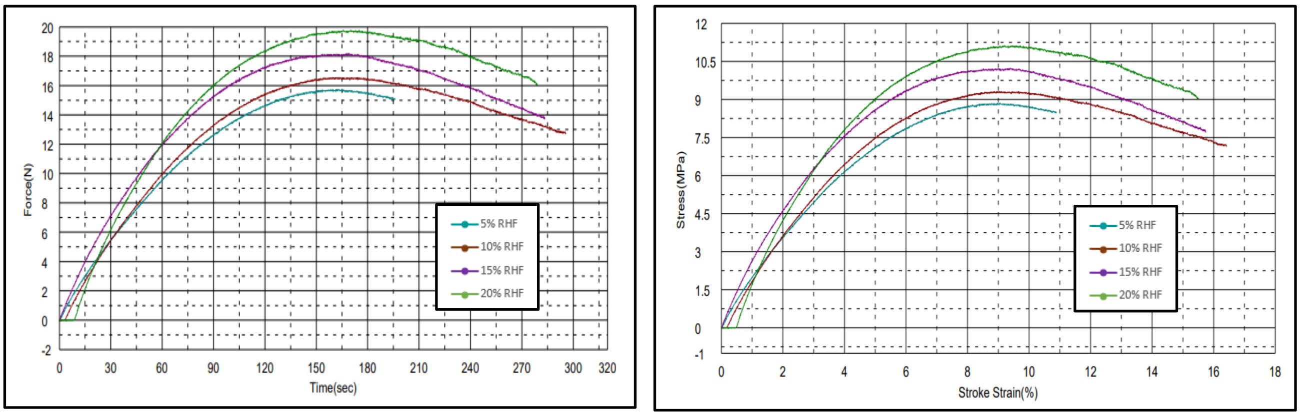
Fig. 7. (a) Tensile strength (b) Young's modulus of tensile strength RHF/R-PET polymer composites

Comparing these findings with prior research, Bukar *et al.,* studied coconut fiber (CF) reinforced LDPE composites with CF contents of 10%, 20%, and 30%, finding that the tensile strength increased from 10% to 20% RHF at 6.69 MPa and 8.69 MPa, respectively but decreased to 8.28 MPa for 30% CF. Increasing CF content beyond 20% may lead to reduced tensile strength due to poor bonding between CF and LDPE, consistent with this study's observations [29]. Furthermore, Hashim *et al.,* examined the tensile strength of wood waste-reinforced HDPE, with wood waste contents of 5%, 10%, 15%, and 20%, and found that tensile strength increased from 35 MPa to 43 MPa as wood waste content increased. This increase in strength may be attributed to wood waste's crystalline structure, which enhances load-bearing capacity. Additionally, chemical treatment of wood waste, removing impurities and roughening its surface, can contribute to the tensile strength increase with higher filler loading [30].

4.4 Bending Strength Analysis

Figure 8(a) shows the force-versus-time graph for various percentages of Rice Husk Fibre (RHF) in RHF/R-PET polymer composite samples. Notably, the sample with 20% RHF exhibited the highest maximum load, measuring 19.78 N. Following closely, the 15% RHF sample recorded a maximum load of 18.20 N, slightly lower than that of the 20% RHF sample. In comparison, the 10% RHF and 5% RHF samples had maximum loads of 16.58 N and 15.75 N, respectively. The time range varied for each ratio as the test was halted when the test specimen was about to slip from its bent position. Fiber-reinforced composite's strength depends on constituent characteristics and interface interactions. The interfacial zone between fibers and the matrix plays a critical role in load transfer and, consequently, affects the maximum load applied. Increasing the RHF percentage tends to reduce the shear force between the recycled Polyethylene Terephthalate (PET) while enhancing the bending strength of the composite, thus increasing load resistance [31].

Figure 8(b) presents the stress and strain values for each sample. The 20% RHF sample recorded the highest stress value (11.13 MPa) and strain percentage (9.46%), while the 5% RHF sample had the lowest stress value (8.86 MPa) and strain percentage (9.01%). The 15% RHF sample had a lower stress value (10.24 MPa) and strain percentage (9.38%) compared to the 20% RHF sample, followed by the 10% RHF sample with values of 9.35 MPa and 9.01%, respectively. The bending test resulted in plastic deformation, however, the specimen didn't tear; instead, it bent and nearly slipped from its original position, with the values for breaking stress and strain [32].

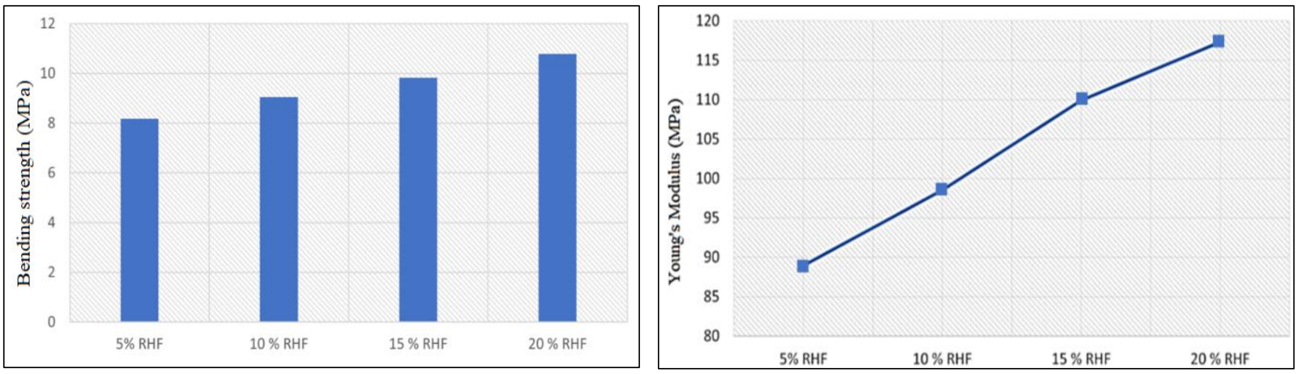


(a) (b)

Fig. 8. (a) Load vs. time; (b) stress vs. strain of bending strength RHF/R-PET polymer composites

Figure 9(a) demonstrates the relationship between bending strength and RHF percentage in RHF/R-PET polymer composite samples. The 5% RHF samples exhibited the lowest strength at 8.20 MPa, while the 20% RHF samples had the highest strength at 10.78 MPa. Samples with 15% RHF showed slightly lower strength (9.83 MPa) than those with 20% RHF, followed by 10% RHF (9.05 MPa). Increasing RHF loading generally improved the bending strength of RHF/R-PET polymer composites due to RHF's precision, surface adherence, and bonding to the R-PET matrix, enhancing the composite's ability to withstand bending forces [33]. Figure 9(b) provides Young's modulus values for different RHF sample percentages. The 5% RHF sample had a modulus value of 88.95 MPa, followed by the 10% RHF sample at 98.53 MPa. In contrast, the 20% RHF sample had the highest modulus value at 117.30 MPa, greater than the 15% RHF sample at 109.90 MPa. This indicates that higher RHF percentages lead to stiffer materials with reduced ductility. Thus, the 20% RHF/R-PET polymer composite is the stiffest and most suitable material [34].

Previous research by Jamal *et al.,* observed a constant increase in bending strength (35 MPa to 45 MPa) for bending strength analysis of HDPE plastic-reinforced wood waste content below 50%, supporting the findings of this study. However, bending strength began to decline as wood waste content exceeded 50% due to aggregation in the polymer matrix, leading to stress concentration and defects [35]. Kuri *et al.,* found a progressive rise in Young's Modulus with RHF content of up to 40% in RHF/Thermoplastic Waste (TW) composites. Similarly reported increasing bending strength values with increasing RHF content (5%, 10%, and 15%) in RHF/PS polymer composites. These studies support the increase in bending strength and Young's modulus values observed in this research [36].



(a) (b)

Fig. 9. (a) Bending strength result (b) Young’s modulus of bending strength RHF/R-PET polymer composites at different composition ratio

5. Conclusions

In conclusion, the 20% RHF/R-PET polymer composite sample exhibits optimal SEM microstructure image, retaining a substantial amount of fibers post-impact. Increased RHF content enhances adhesion between the matrix and polymer, leading to higher hardness and brittleness, ultimately enhancing mechanical strength. Apparent porosity values linearly increase with 20% RHF content, reaching 0.076%, accompanied by a density of 1.043 g/cm³. Density typically increases with rising fiber content until it reaches a threshold. Higher RHF content stiffens polymer chains, resulting in a more rigid and brittle composite. This increase in porosity arises from fiber-matrix interfacial regions and void formation due to elevated fiber content. For tensile strength, the 20% RHF sample demonstrates superior performance, achieving a tensile strength of 12.53 MPa and exerting a force of 138.90 N with a maximum stress of 14.8 N/mm². Additionally, it yields a higher Young's modulus value of 12.12 MPa. Higher RHF percentages generally lead to increased tensile strength, although potential phase separation and fiber aggregation may weaken the binding between fibers and the matrix. The relationship between bending strength reveals that the 20% RHF sample attains higher bending strength at 19.78 N, along with a maximum stress of 10.45 MPa. This improvement in bending strength is attributed to enhanced fiber-matrix bonding and increased load-bearing capacity associated with higher RHF percentages.

Acknowledgment
The research was supported by the GPPS Grant Vot. Q315 and Matching Grant Vot. H864. The author also acknowledges the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), and MyFlexitank Industries Sdn Bhd for the equipment and technical assistance. The authors are grateful for the fruitful discussions and input UTHM staff brought to the project.

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