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# Mechanical Characteristics Rice Husk Fiber (RHF) Blended Recycled Polyethylene (RPE) for RHF/RPE Polymer Composite

Iylia Izzati Jamal[1], Noraini Marsi[1,2,*], Anika Zafiah Mohd Rus[2], Aiman Hisyam Saiful Bahri[1], Asmadi Md-Said[2], Mohamad Mohshein Hashim[3] and Izzah Aqilah Ariffin[1]

1 Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Campus KM 1, Jln Panchor, 86400 Pagoh, Johor, Malaysia
2 Advanced Manufacturing and Material Centre (AMMC), Institute of Integrated Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor, Malaysia
3 Angkasa Kowaris Plastic Sdn Bhd, Lot 15796 Block A&B, Jalan Kebun Tambahan, Seksyen 32, 40460 Shah Alam, Selangor, Malaysia
4 My Flexitank Industries Sdn Bhd, Plot 3 & 4, Jalan PKNK 3, Kawasan Perindustrian LPK Fasa 3, 08000 Sungai Petani, Kedah, Malaysia

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**ABSTRACT**

This study investigates the mechanical characteristics of Rice Husk fibers (RHF) blended Recycled Polyethylene (RPE) to produce RHF/RPE polymer composites for building partition applications. The main objective is to formulate various composition ratios of RHF blended with RPE to fabricate optimum physical and mechanical properties to produce an RHF/RPE polymer composite. The significance of this research lies in developing a green polymer composite using natural resource materials such as RHF, which holds potential applications in Malaysia. Various ratios of RHF (0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight) were combined with RPE to create RHF/RPE polymer composites. The RHF fibers were processed into fine fibers measuring 0.5 ± 0.05 mm using a high-speed grinding machine operating at 18000 rpm. The process involved blending RHF with RPE using a Bra-blender machine with a pressure of 20 kPa and a temperature of 120℃. The results indicated the composition ratio of 0.4 wt./wt.% of RHF/RPE polymer composite demonstrated the optimum density (ASTM C20-00) at 715.74 cm2 and porosity at 1.02 g/cm2, highest tensile strength at 0.60 MPa at tensile strength (ASTM D638) with SEM microstructure analysis confirming well-reinforced bonding between RHF/RPE matrix. The bending test at 0.4 wt./wt.% achieved the highest bending strength at 27.17 MPa, with a maximum bending strain of 2.41%, and the impact test (ASTM D256) demonstrated the highest impact strength at 36.16 MPa with an impact modulus of 1.25 MPa. It can be concluded that the optimal composition for building partition applications is 0.4 wt./wt.% of RHF/RPE polymer composites.

## 1. Introduction

Polymer composites offer numerous advantages over traditional materials, including lightweight and superior mechanical properties such as tensile strength, flexural strength, and stiffness [1], making them well-suited for the construction industry, where polymer composite materials are used

* *Corresponding author.*
*E-mail address: mnoraini@uthm.edu.my*

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to create partition panels. Partition panels are essentially dividers or walls used to separate interior spaces within buildings [2]. The characteristics of partition panels, such as their lightweight, high strength-to-weight ratio, durability, good thermal and acoustic insulation, fire-resistance properties, and materials, are renewable resources [3].

Renewable resources refer to natural materials or substances that can be replenished or regenerated naturally over time. Examples of natural materials include rice husk fiber (RHF), bamboo, hemp, sugarcane bagasse, and wood [4]. Rice husk fiber (RHF) is gaining popularity as a renewable resource due to its abundance as an agricultural byproduct and its potential application in various industries. By introducing RHF, these composites can be further improved, rendering them more eco-friendly [4]. Generally, the use of RHF is advantageous due to its abundant availability as a by-product of the rapidly growing rice industry in Malaysia.

As a sustainable source of reinforcement, RHF rich in lignocellulosic biomass can effectively enhance the mechanical properties of the composites, contributing to their eco-friendly nature [5]. Based on the chemical analysis, the overall composition of the rice husk is mostly composed of organic matter (C, O) and Ca atoms [6]. It also contains trace amounts of silica, ash, and other organic materials. RH is hard, water-insoluble, woody, and has an abrasion-resistant silica-cellulose structure by nature. Because of its abrasive nature, rice husk has been utilised for numerous purposes, including abrasive blasting, to clean and prepare surfaces [7]. Additionally, unidirectional fiber alignment is explored as a means to optimise the composites' properties, with potential applications beyond the construction industry [1]. Besides, the use of renewable materials in manufacturing helps promote a circular economy where resources are reused, recycled, and regenerated to minimize waste and conserve natural resources, such as recycled polyethylene (RPE), is an environmentally friendly material, as it reduces the need for new products and helps divert plastic waste from landfills [8].

There are a few concerns, one of which is the incompatibility of the polymer matrix with the rice husk fiber. Because rice husk fiber is hydrophilic, it has weak interfacial adhesion with the polymer matrix, reducing the mechanical properties of the composite. Additionally, one of the drawbacks of the polymer composite is the reduced heat stability of the rice husk fiber [9]. The fiber may undergo thermal degradation as a result of the high-temperature processing needed to create polymer composites, which will reduce the fiber's mechanical properties. The third challenge is the rapid rate at which rice husk fiber absorbs liquid. The moisture content of the fiber may cause dimensional instability and a decrease in the mechanical properties of the composite [10].

Studies indicate that demand for polymer composites will likely continue to rise as industries seek materials that combine performance, affordability, and sustainability [11]. Technological developments in the composite production process, environmental consciousness, and ongoing research and development have led to the increasing usage of polymer composites, especially in the production of rice husk polymer composites. Natural fibers are used in construction materials, automotive interiors, and products that highlight environmental sustainability [12]. In the end, the choice between reinforcing with natural and synthetic fibers depends on the requirements of a particular application, considering factors like cost, performance characteristics and environmental impact goals. Long regarded as agricultural waste, rice husk has gained interest because of its possible use in a range of applications that promote environmentally friendly methods and resource conservation.

The escalating use of RPE has resulted in a pressing environmental concern regarding plastic waste disposal. To address this issue, recycling and reusing plastic waste as raw material for new products offer a promising solution [13]. By utilizing RHF and RPE waste materials to produce polymer composites, the research endeavours to mitigate solid waste and pollution linked to the growing construction industry in the region [14]. Integrating RHF waste and RPE into the polymer composites aids in reducing waste generation and prolonging the lifespan of plastic, contributing to environmental benefits [15]. This polymer composite can also lead to improved mechanical properties, making it well-suited for this specific application. However, polymer composite stability is also important in a material's capacity to sustain its overall performance, mechanical characteristics, and structural integrity over an extended period of time under varied external pressures and environmental circumstances. A polymer composite's mechanical attributes, such as its strength, stiffness, and toughness, need to be consistent throughout time [16]. The capacity of a composite to withstand loads, strains, and external forces without experiencing severe deformation, breaking, or failure is known as mechanical stability. The study thus seeks to promote the use of sustainable materials in polymer composites, contributing to a greener, more sustainable future that can perform well in all mechanical properties.

## 2. Literature Review

Rice husk is among the most abundant agricultural wastes in certain rice-producing regions. Worldwide, annual rice production reaches approximately 600 million tons, with rice husk constituting around 20% of this total, accounting for about 120 million tons each year, and this figure continues to grow annually. It produces rice husk ash which is of graver concern as its disposal is difficult. It is estimated that the production of rice husk worldwide is approximately 759.6 million tons in 2017 [17], of this 22% of this is husk with the amount of 167.10 million tonnes which give an enormous amount of virtually free of cost raw material if it can be brought to a good scientific use [18]. Table 1 summarises the few analyses that researchers have performed and published in related to rice husk.

Ismail *et al.,* [19] studied the mechanical properties of hybrid glass fiber/rice husk reinforced polymer composite. The study shows according to the testing findings, increasing RH fibers or decreasing glass fibers had minimal effect on the hybrid polymer composite's impact strength. Comparing these hybrid composites to other hybrid composites, their morphology showed less significant flaws between the fiber and matrix and fewer voids, which contributed to their strong adhesion interfacial and high strength. According to Hilal Olcay *et al.,* [20] enhancing the mechanical and acoustic properties of polymer composites using rice husk fiber and wood biomass. It is found that the inclusion of rice husk fiber increased the compressive strength of the composite material. The composite exhibited a compressive strength of approximately 35 MPa, indicating improved resistance to external compression forces. Regarding the Young's modulus, the addition of rice husk fiber also contributed to an enhanced in this property. The composite material exhibited a Young's modulus at 3 MPa, signifying its increased stiffness and ability to resist deformation under tension and compression. Furthermore, the study evaluated the modulus of rupture, which measures the maximum stress a material can withstand before failure in bending. The incorporation of rice husk fiber resulted in an improved modulus of rupture, with values reaching around 20 MPa, indicating enhanced resistance to bending stresses [21].

Ugochukwu *et al.,* [22] studied enhancing the mechanical properties of rice husk fiber blended straw fiber reinforced polymer composites. It is highlighted the effect of rice husk fiber content on the mechanical properties of polymer composites. The compressive strength was found to increase with an increasing percentage up to 30% of rice husk fiber, reaching a maximum value of 45 MPa. Additionally, the Young's modulus improved significantly by 25% compared the pure polymer matrix. Another authors, Dele-Afolabi *et al.,* [23] investigated the recent progress of rice husk reinforced polymer composites. Results showing that with the presence of alumina ceramics, can develop pore within the polymer composite that can help the polymer composite suitable for materials that have high thermal insulation. As evidenced, the relative density and total porosity are inversely related. While the relative density of the porous samples developed with different particle sizes of RH decreased with increased RH addition from 5 to 20 wt/wt%, the total porosity increased correspondingly. In this project, recycled polyethylene is blended with rice husk as the reinforcement material. The rice husk ratio composition was a key determinant of the mechanical and physical performance [24].

Sathiskumar *et al.,* [25] studied rice husk fiber-reinforced high-density polyethylene composites: effect of fiber and waste filler loading on mechanical and morphological properties. The study evaluated the mechanical and morphological properties of rice husk fiber-reinforced high-density polyethylene (HDPE) composites with varying fiber and waste filler loading. The study found that with increasing fiber loading, the tensile and flexural strengths of the composites improved significantly [25]. For instance, at a 40% rice husk fiber loading, the tensile strength increased by approximately 58% compared to the unfilled HDPE. Similarly, the flexural strength increased by approximately 105% at the same fiber loading. These improvements in strength were attributed to the strong interfacial adhesion between the rice husk fiber and the HDPE matrix [26]. In this study focuses on enhancing the physical mechanical properties of RHF/RPE polymer composites to explore innovative ways and increasing investing in research and development to harness the full potential renewable resources, aiming to create a more sustainable and eco-friendly future.

**Table 1**
The analyses that have been performed and published related to rice husk

| Matrix | Parametric Study | Results | References |
|---|---|---|---|
| Glass fiber | Hybrid | Tensile strength: 215.42MPa<br>Flexural strength: 275.51 MPa<br>Impact strength: 447.19J/m | Ismail (2020)[19] |
| Wood biomass | Matrix modification | Compressive strength: 35MPa<br>Young's modulus: 3 MPa<br>Bending stress: 20 MPa | Hilal Olcay (2021)[20] |
| Straw fiber | Matrix modification | Compressive strength: 45MPa<br>Young's modulus: improved 25% | Ugochukwu (2022)[22] |
| Alumina ceramic | Filler treatment | Pore: increasing as particle size increase<br>Tensile strength: 16.97MPa | Dele-Afolabi (2022)[23] |
| HDPE | Filler content | Tensile strength: increased 58%<br>Flexural strength: increased 105% | Sathiskumar (2022)[25] |

## 3. Methodology

The novelty of this research are the materials used to fabricate the sample are RHF and PET. Besides, the process of fabrication is using injection molding machine to produce 5 different composition ratios. The methodology presents the experimental approach used to prepare rice husk fiber (RHF) fibers blended recycled polyethylene (RPE) to produce RHF/RPE polymer composites samples for physical and mechanical testing. The methodology involved four phase processes in preparing the sample of RHF/RPE polymer composites. First phase involved the drying process, RHF was dried in a convection oven at 105°C for 48 hours. Second phase is grinding process, the sample is grinding using a Ballmill machine at 250 rpm for 10 minutes. Third phase is the sieving process of RHF was performed on the specimens using a siever machine set particle size of 900 µm, 1.0 amplitude, and 10-minute intervals for a total of 10 cycles. Fourth phase, mixing process of RHF blended RPE using a Brabender Machine to prepare the sample with different composition ratio weight by weight (wt/wt%) of RHF blended RPE tabulated in Table 2. The composition ratio of RHF/PET polymer composite referred to Fodzi *et al.,* [27]. As shown in Table 2, the ratio was chosen referring to previous research at which has been done on few ranges for each testing conducted in this research of RHF/PET polymer composites at various filler loadings. Throughout previous study, it shows that the composition ratios giving results needed for each testing. Utilising RH residues in biocomposites has several benefits. One of these is that it lowers the proportion of ingredients like resin polymers and certain additives that are generated from synthetic polymers. The kind of filler, matrix material, concentration, size, dispersion, and adhesion between the filler and matrix material all affect how composites behave.

**Table 2**
The composition ratio of RHF/RPE polymer composites

| Samples | Composition ratio (wt/wt %) | RHF (gram) | RPE (gram) | RHF/RPE polymer composite (gram) |
|---|---|---|---|---|
| A | 0.2% | 2.1 | 39.9 | 42.02 |
| B | 0.4% | 4.2 | 37.8 | 42.02 |
| C | 0.6% | 8.4 | 33.6 | 42.02 |
| D | 0.8% | 10.5 | 31.5 | 42.02 |
| E | 1.0% | 12.6 | 29.4 | 42.02 |

Before entering the injection molding machine, the samples need to be shredded using a crusher machine to achieve pellets that are smaller than 10 mm in size. Following this, the prepared samples undergo the injection molding process within the machine, with parameters set at 180°C, screw pressure of 3 bar (43.5 Psi), and a velocity of 55%. Injection moulding is a favoured manufacturing technique for producing plastic parts and components fast, accurately, and effectively. After injecting melted plastic into a mould cavity and letting it cool and harden, the completed item is ejected. The resultant final product or specimen is designated for conducting various tests including Density and Porosity testing (ASTMC20-00, dimensions: 15mm x 15mm x 10mm), Scanning Electron Microscopy (SEM) microstructure analysis, Tensile testing (ASTM D638 standards, dimensions: 73mm x 12mm x 2mm, with 45mm distance between shoulders and a 25mm reduced section) [28], Impact testing (ASTM D256 standards, specimen size: 75mm x 10mm x 4mm with a 45° V-notch) [29], and Bending testing (per ASTM D7264 standards, specimen size: 75mm x 10mm x 4mm) [30], as shows in Figure 1. The different composition ratio was determined based on a recent study involving polymer blends where other natural fiber was combined with polymer to form polymer composites [31]. Additionally, the utilization of recycled polyethylene (RPE) as a binder material for polymer composite at a specific percentage (wt/wt%) was taken into consideration [32]. Recycled Polyethylene (RPE) was selected as the polymer to be blended due to its presence within the polymer blend [33].

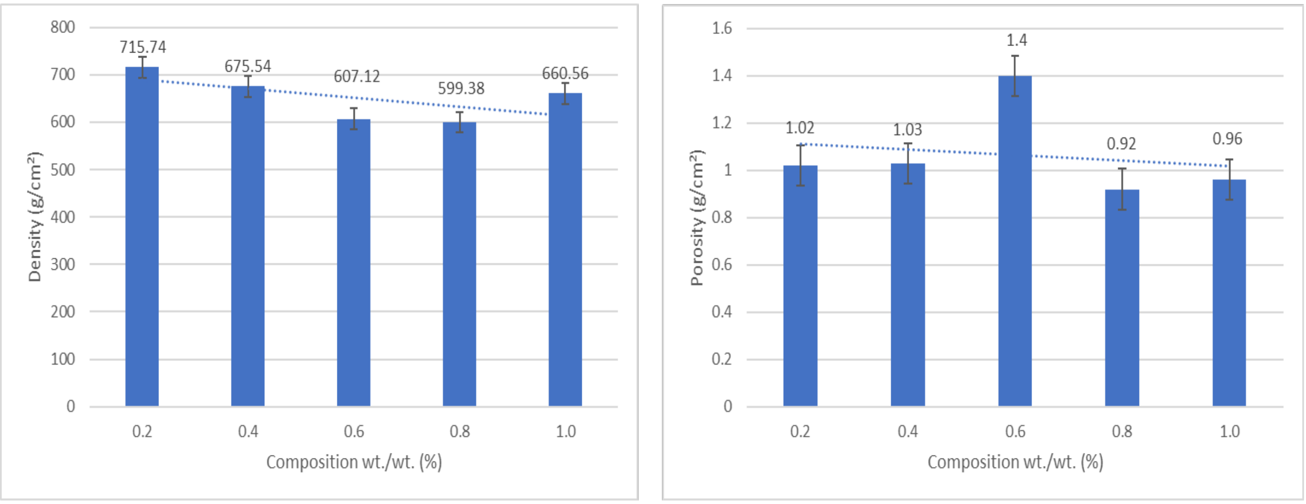
(a) (b) (c) (d)

**Fig. 1.** Sample of RHF/RPE polymer composites (a) Tensile test (b) Impact test (c) Bending test and (d) Density and Porosity test

## 4. Result and Discussion

### *4.1 Density and Porosity Test*

Figure 2 shows the density and porosity results at different composition ratio of RHF/RPE polymer composite. The results clearly indicate that the physical properties of the composite with 0.2% RHF display a higher density of 715.7 g/cm². The incorporation of 0.2 – 0.8% RHF fibers in the matrix reduces the sample density, resulting in a lightweight composite. It is support by SEM microstructure analysis in Figure 3(b) reveals that the matrix of the 0.4% RHF composite consists of pure RPE and RHF surfaces, which may enhance water absorption. This observation aligns with previous studies indicating a general increase in the density of RHF/RPE polymer composites with higher filler or compatibilizer loadings [34].




(a) (b)

**Fig. 2.** (a) Density and (b) Porosity result of different composition ratio of RHF/RPE polymer composite

As the composition ratios of RHF fiber increasing, it shows a decreasing trend of density from 0.2%-0.8% and started to increasing once the compositions reached 1.0%. Based on previous research obtained that the surface morphology of samples shows a rise in voids when the composition of reinforcing material or pore-forming agent is increased, which denotes the development of composites with higher porosity [35]. The lowest porosity recorded was at 0.8% which is 0.92 g/cm² followed by the second lowest 1.0% with value of porosity of 0.96 g/cm². The lower porosity of composites implies improved interfacial bonding and a reduction in micro-voids. This may be due to low interfacial bonding between the RHF and polymer composite mixture.

### *4.2 Scanning Electron Microscopy (SEM) microstructure analysis*

Figure 3 displays SEM images for specimens' surface morphology at magnifications of 200x for each under 100 µm resolutions. The morphological condition of the composites has a direct impact on their strength performances. On the RHF/RPE composite, the image in Figure 3 (b-d) of 0.4% to 0.8% RHF frequently reveals the existence of RHF fiber, which is made up of spot and ring-shaped fibers. Figure 3 shows the 200x image magnification of Scanning Electron Microscope (SEM) surface of bio composites from (a) to (e) RHF fibers blended RPE with better hardness, impact strength, flexural strength, and water resistance due to the high amount of polyurethane encapsulation with the fibers and improved adhesion between the polyurethane matrix and the fibers [36].

For 1.0% RHF specimens, the reduced mechanical characteristics are correlated with the poor fiber attachment to the matrix. Poor impregnation makes it simpler for the fiber to be taken out and lowers the composite's strength performance. It is clear from Figure 3 d-e that the fibers are firmly attached to the matrix. The fibers' cross-sectional fibrous morphologies were evenly intermingled throughout the surface and dispersed. This shows that the polymer and fiber have strong adherence. However, the void between the RHF and RPE is greater than 0.6% – 1.0% RHF, which results in a worse fiber RPE bonding and may reduce the composite's mechanical strength [37]. The visibility of RHF increases according to the RHF ratio, and RPE plastic waste is most visible with a lower RHF ratio. The weak connection between matrix and fiber, aggregation of RHF fibers, and insufficient encapsulation of the matrix over the RHF fibers are all factors that contribute to a material's low water resistance [38].

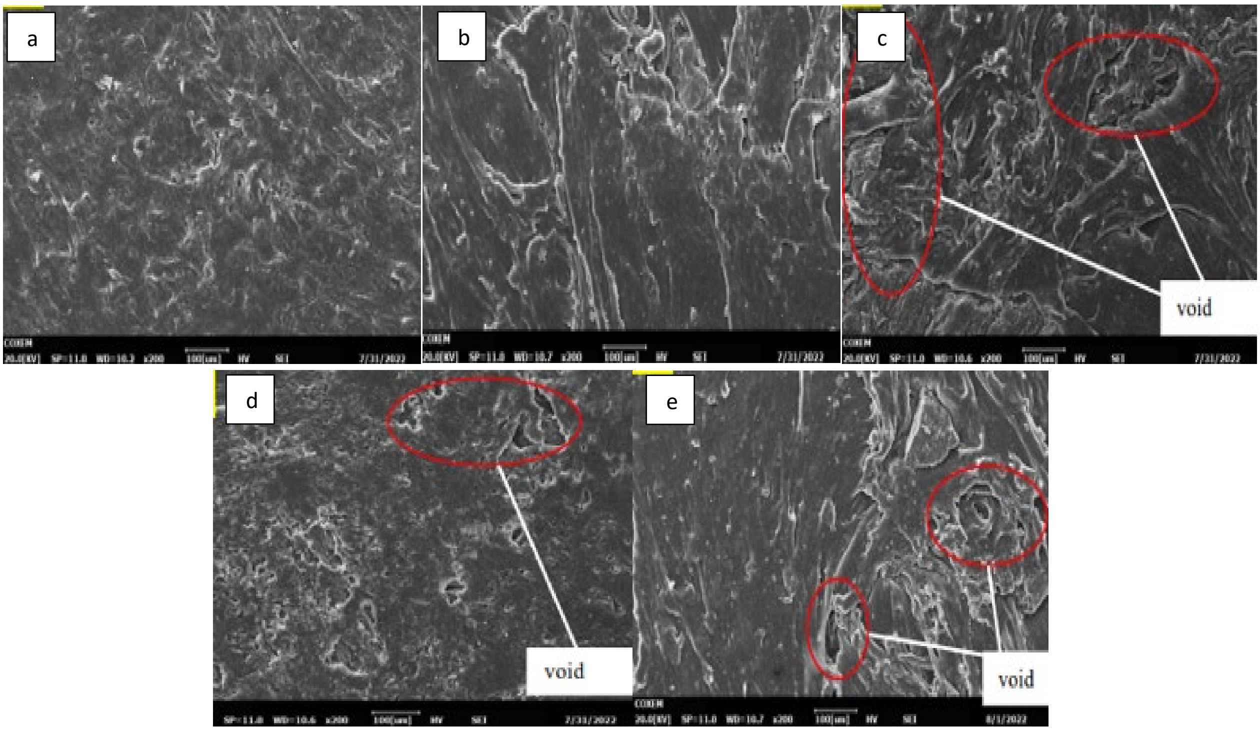
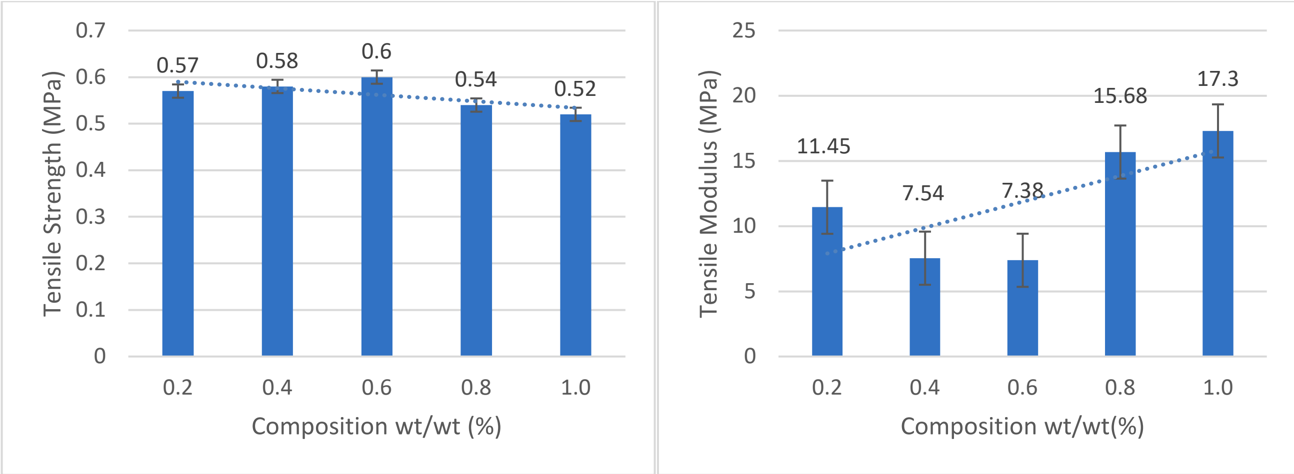


**Fig. 3.** SEM image of (a) 0.2% RHF (b) 0.4% RHF (c) 0.6% RHF (d) 0.8% RHF (e) 1.0% RHF

*4.3 Tensile Strength Test*

Figure 4 depicts the tensile stress graph for RHF/RPE polymer composites used in bumper car applications with various composition ratios of RHF fibers reinforced RPE plastic waste. With a composite RHF fibers ratio of 0.6% RHF, it exhibited the maximum tensile strength of 0.60 MPa, the lowest load tensile modulus of 7.38MPa. The tensile strength and tensile modulus for composite 0.2% RHF and 0.4% RHF are 0.57 MPa and 11.45 MPa, respectively, and 0.58 MPa and 7.54 MPa, respectively. Composite 0.8 % RHF was then put under a 0.54 MPa load with a 15.68 MPa tensile Modulus. This is corresponding to previous research that indicated adding fiber could not continuously increase the tensile strength [39]. The lowest tensile strength is finally found at a ratio of 1.0% for RHF fibers, which can withstand the lowest tensile strength at 0.52 MPa with a tensile modulus of 17.3 MPa. It is because, at higher percentage of fiber in the sample, the fiber-fiber contact increases but the fiber-matrix adhesion decreases, which leads to a weak interfacial bond of fiber-matrix and resulting in inefficient load transfer [40]. The decrease in mechanical characteristics can be attributed to the drop in the effectiveness of the fiber-matrix bond as the fiber content increases.

The collapse occurred quickly because insufficient interfacial bonding prevented effective load transmission [41].



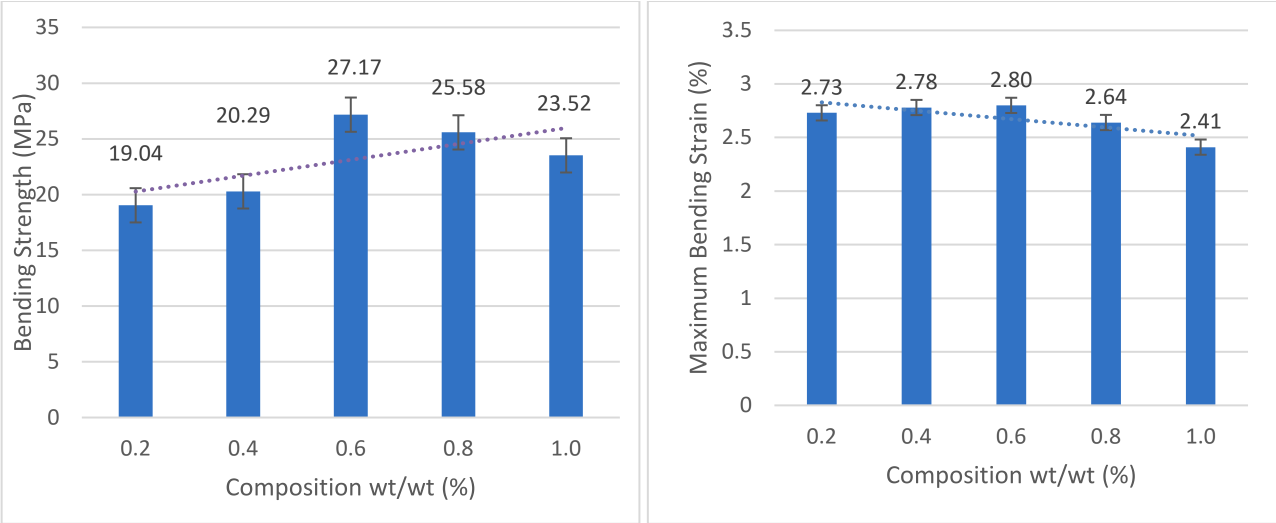

(a) (b)

**Fig. 4.** Results of (a)Tensile Strength and (b) Tensile modulus of RHF/RPE composite

A previous study on coir fiber reinforced polyester composites revealed that optimal composite strength required a substantially higher number of fibers in a sample than the epoxy sample alone [42]. Due of its fragility, epoxy is less able to absorb impact energy. Additionally, it is recognized that a higher fiber aspect ratio can transmit the load more effectively, as previously studies on crushed oil palm fiber reinforced polypropylene composites [43]. The study adopted the same stance and claimed that the filler's tensile strength increased along with its weight. A medium amount of filler loading yields the highest tensile strength due to a filler matrix bonding that is stronger than the majority of composites with less filler strength.

*4.4 Bending Test*

Figure 5 depicts the bending test at different composition ratio of RHF/RPE polymer composites. It is shows that RHF/RPE polymer composites containing 0.2, 0.4, 0.6, 0.8 and 1.0 wt/wt% of RHF fiber gives bending test of 19.04 MPa, 20.29 MPa, 27.17 MPa, 25.58 MPa, and 23.52 MPa, respectively. It showed that materials with 0.6% of RHF fiber had the highest bending strength (MPa) followed by 0.8% at the second highest. It is because, due to tensile modulus, the bending strength will increase as tensile modulus result because the strength of tensile in MPa are low. This is supported by previous studies that at volume composition greater than 0.8%, the fibers tend to aggregate in the composite which weakens the interfacial area and debonding tends to take place between the fibers and matrix of RHF by percent increased, the result for max bending strain (%) were decreased [44].

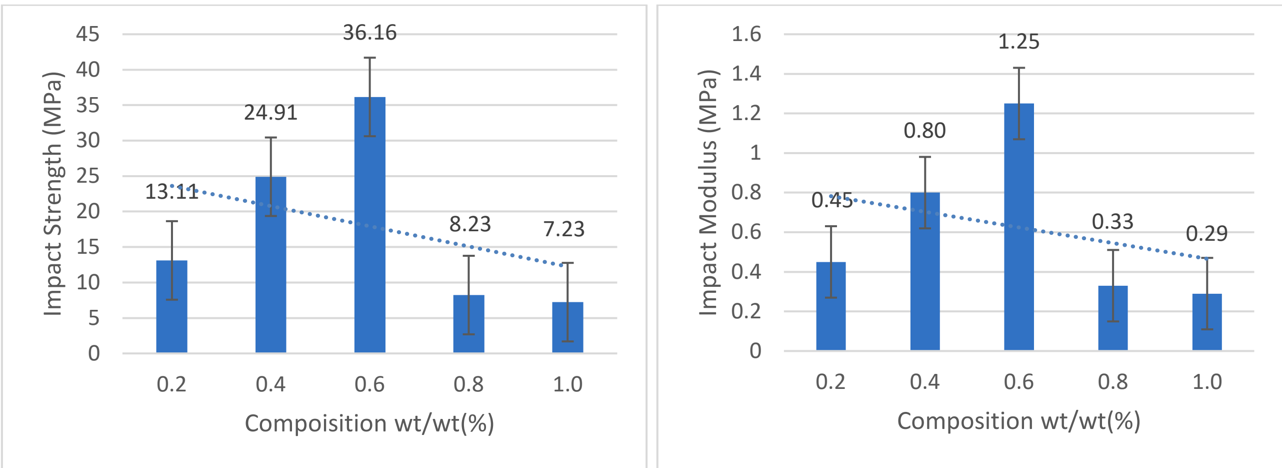



(a) (b)

**Fig. 5.** Results of (a)Bending strength and (b) Max bending strain of RHF/RPE composite

### *4.5 Impact Test*

Figure 6 depicts the sample impact strength when energy was applied to each sample in a different proportion, leading to sample breakage. The same 0.75 m² sample area applies to all of the samples. Sample A, which contains 0.2% of RHF fibers and has the highest density of 715.74 g/cm², had the highest impact strength of 36.16 MPa and required 1.25 MPa of energy to fracture. Then, after applying 0.80 MPa of energy and 0.4% of RHF fibers to Sample B, which had an impact strength of 24.91 MPa, Sample C received 0.45 MPa of energy and 13.11 MPa of impact strength. Then, the lowest impact strength is 7.23 MPa with 0.29 energy resulting in a 1.0% of RHF fibers on Sample E, and the second highest impact strength is 24.91 MPa with 0.80 MPa of energy to be broken on Sample B.




(a) (b)

**Fig. 6.** Impact strength and modulus of RHF/RPE composite

The ratio of RHF fibers in polymer composite samples that cracked at a given impact energy was used to determine the impact strength. The impact strength of each polymer composite sample was calculated by dividing the impact energy (J) by the area of the notch ($m^2$); a strong material has a higher impact strength. The material's resistance to high-speed fracture is indicated by its impact strength [45]. Therefore, the impact strength of a polymer composite increases as the RHF fiber ratio decreases. As the percentage of RHF fibers rises, the impact strength of the composites decreases, according to earlier study [46]. The obtained results, which showed that 0.2% of RHF fibers could sustain 1.25 of load while 1.0% of RHF could withstand 0.29 MPa, serve as evidence for this claim.

In previous research mentioned that the impact strength of the composites diminishes as the RHF fiber concentration increases [47]. It can be proved by the obtained result, where 0.6(wt/wt%) ratios of RHF fibers could withstand 1.25 MPa of load while 1.0 (wt/wt%) ratios of RHF could withstand 0.29 MPa. Impact strength gradually decreased with the increased percentage of fiber content at fiber size, 125 µm, and 250 µm in previous research on thermoplastic reinforced natural fiber and RHF composites. It found the highest tensile strain at break and lowest water absorption at 10% fiber content.

## 5. Conclusions

In conclusion, the research objectives have been achieved. The optimum composition ratio of RHF fibers is in 0.6 (wt/wt%) blended RPE for RHF/RPE polymer composites in deck panel application. The physical and mechanical properties have been analysed at different composition ratios of RHF fibers. The result experiment has compared to the actual material of panel which polypropylene material properties of deck panel. There were because sample had the highest density which is 675.54 g/cm$^2$ for density with 1.03 g/cm$^2$ average for porosity. Furthermore, with the ratio 0.6 (wt/wt%) had the highest tensile strength with 0.6 MPa that showed can withstand 7.38 MPa of tensile modulus. Moreover, sample with the ratio 0.6 (wt/wt%) had the strongest bonding of the structure from analyzing of Scanning Electron Microscopy (SEM). For bending test, sample B with 0.6 (wt/wt%) can stand with highest maximum bending strain with 2.80% with total 20.29 MPa of bending strength. However, for impact test, the ratio 0.4 (wt/wt%) which sample B showed the second highest with 24.91 MPa impact strength with 0.80 MPa of impact modulus. The physical and mechanical tests based on different ratio of RHF blended with RPE for deck panel application had been conducted and evaluated. The result and analysis clearly showed the best ratio to be produce deck panel application.

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