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ORIGINAL ARTICLE

Analysis Of Tensile Strength, Impact Strength And Microstructure of Rice Husk Rice Husk Fibre (RHF) Blended With Recycled Polyethylene Terephthalate (RPET) For RHF/RPET Polymer Composite

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The use of polymer composites, which are widely recognised for their ability to create sustainable materials from waste materials like rice husk, has grown. 150 million tons of rice husk as one of an agricultural waste, and 19-25 million ton plastic waste were dumped globally. This waste leads to environmental problems is not disposed of properly. This project focuses on utilization of rice husk fibre (RHF) blended with recycled polyethylene terephthalate (RPET) for RHF/RPET polymer composite. The main objective is to determine the physical and mechanical properties in different ratios of rice husk fiber (RHF) blended with recycled polyethylene terephthalate (RPET) to produce RHF/RPET polymer composite. The fabrication process includes grinding of RHF at particles size of 90 µm, mixing using brabender machine at temperature of 180°C for 15 minutes and crushing process into small particles size of 10 mm. The preparation was involving 10 samples of RHF/RPET polymer composite at different ratio RHF of 2-20 (wt/wt%) blended with RPET using injection molding machine at temperature of 180°C, screw pressure at 45 psi and the screw is operating 55-65% of its maximum speed capability. The results show 16 wt/wt% of RHF/RPET polymer composite gives higher tensile strength and, impact strength and energy absorbed at 21.01MPa, 36.72 kJ/m² and 3.04 % respectively. It is supported by physical properties SEM analysis at 16 wt/wt% gives good bonding structure between RHF and RPET elements. In conclusion, the optimum ratio of 16 wt/wt % has the potential to be implemented in deck panel application

1. Introduction

Nowadays, the usage of polymer composites has developed and is widely used in daily products and applications such as automotive components, construction materials, packaging materials as it is due to their low cost, light weight, high strength, and ease of production [1]. The demand for eco-friendly materials is rapidly increasing due to the concerns over environmental degradation caused by the excessive use of synthetic materials [2]. As the market grows in need of lightweight materials with high strength for particular purposes, composites reinforced with fibres of synthetic or natural materials are becoming increasingly important. The reinforcing material gives the composite strength, stiffness, and other desirable features [3].

Other types of polymers used with increasing demand in polymer composite market is recycled polyethylene. It contains a vital component needed in packaging that is used to make bags, films, and containers that meet a range of applications, from transportation solutions to food packaging[4]. Recycled Polyetehylene Terephthalate (RPET) forms timber, decking, and pipes, it reduces waste while providing durability comparable to pure polyethylene, which is beneficial to sustainability initiatives in the building industry [5]. In order to further lessen the environmental effect over their entire lifespan, polyethylene can be used as recycled plastic into parts like car bumpers. RPET is used in greenhouse coverings, mulch films, and irrigation tubes for agricultural applications since it helps with crop management and water saving [6]. With the numerous usages of RPET, it is undeniable that it can be one of the useful materials to contribute to the industry with few enhancements onto the materials.

Currently, it is concentrated on a strategy of self-sufficiency in rice and paddy cultivation, which is the nation's main staple food and food crop. For the creation of polymer composites, rice husk, an agricultural waste, is one of type of fibre that had frequently used as a natural fibre [7]. Typically, silica obtained from rice husk may be used to give distinct sets of physical and mechanical qualities. It can also be employed in the form of the husk itself [8].

Many applications rely on composite materials that include fillers, fibres, or particles inside the polymer matrix as reinforcing components to overcome these difficulties [9]. In comparison to pure polymer composites, these reinforced composites can provide better mechanical qualities, increased dimensional stability, and a wider range of application appropriateness[10].By optimizing these characteristics, the use of RHF/RPET polymer composite in a deck panel application may potentially be made and enhanced. This project research focuses on the utilization of rice husk fibre blended with recycled polyethylene terephthalate for RHF/RPET polymer composite can improve the use value of bioproducts while lowering the environmental issues. This study aims to analyse the mechanical and physical characteristics of polymer composites that are created by blending different ratios of recycled polyethylene terephthalate (RPET) and rice husk fibre (RHF). This research conducts a systematic analysis of the effects of varying ratios of RHF and RPET on the tensile strength, impact strength and microstructure analysis of the composite. The project aims to generate high-performance, sustainable materials from plastic and agricultural waste by thoroughly assessing these features and optimising mix ratios to attain the greatest potential performance attributes.

2. Literature review

A material known as a polymer composite is made up of a polymer and a reinforcing material also known as fibres that are commonly utilised as the reinforcing materials [11]. According to Yuhazri et al. (2020), a polymer composite is a material made up of two or more constituent materials, one of which is a polymer matrix, and the other is a reinforcing phase, and each of which has notably different physical or chemical properties [12]. These composites are made with specific properties in mind that go beyond those of any one of the constituent components. A study conducted by Saroj et al. (2021), fibre polymer composites are more corrosion resistant, lightweight, and strong in a large single piece than metallic materials. This improvement in polymer composites was particularly noticeable in mechanical properties like increased strength, stiffness, and durability [13].

Over the upcoming years, it is projected that the market for polymer composites will grow as research and development efforts continue to improve material performance, processing techniques, and economic feasibility [14]. The growth of the worldwide market for advanced polymer composites is predicted to exceed USD 18.63 billion by 2032 and in total 10.50 billion in sales value were registered and collected worldwide in 2022 [15]. Auto component production will increase due to the rising demand for vehicles and increased disposable income [16]. Polymer composites are being used in an increasing variety of industries, such as aerospace, automotive, construction, and medical, due to their excellent mechanical properties and reasonable cost [17]. Consequently, a number of companies have begun to consider innovative methods for producing and using these materials [18].

These composites are employed in the manufacturing of plastic pipes, storage containers, industrial flooring, and other products. Aircraft components represent the largest potential market for metal matrix composites [19]. These composites offer superior stiffness, durability, strength, and dimensional stability and are ductile by nature. Due to their ability to be produced with a broad range of properties, polymer composites find employment in a variety of sectors, such as sports equipment, automotive, aerospace, and construction [20]. Apart from that, the electrical and electronic industries employ polymer composite components in laptops, PCs, mobile phones, printers, fans, coolers, air conditioners, watches [21]. It could be able to do away with major problems like corrosion and fatigue in structural components by employing polymer composites; these problems result in the loss of materials and consequently resources [22]. Their lightweight, durability, and high strength-to-weight ratio make them an appealing alternative to traditional materials like metals and concrete.

The lightweight, high strength-to-weight ratio, corrosion resistance, and versatility of polymer composites make them highly desirable in a variety of industries [23]. This has led to a steady growth in the global market for polymer composites, which is anticipated to continue in the years to come. Polymer composites are in high demand due to a number of causes, such as their unique combination of properties, technological advancements, industry-wide sustainability trends, and regulatory requirements[24]. When creating polymer composites, it's critical to choose the most sustainable materials possible, such as RPET and RHF.

Plastic bottles and containers are commonly made from a kind of polymer called recycled polyethylene terephthalate, or RPET for short [25]. It is a kind of PET (polyethylene terephthalate) plastic that has been recycled. As part of the recycling procedures for chemical recycling waste material, the used PET bottles are collected, sorted, cleaned, and processed into RPET flakes or pellets [26]. Then, by melting and moulding these RPET pellets, new products including as bottles, containers, textile fibres, packaging materials, and even composite materials may be produced. Using RPET has several advantages, including financial and environmental ones. Considering the impact plastic waste has on the environment, using RPET materials is crucial since it prevents plastics from being burnt, ending up in landfills, or ending up as marine litter [27]. RPET is equally as good as virgin PET in terms of quality. According to Mahesh et al. (2023) the production process of RPET requires much less energy and produces 50% or less CO2 than that of ordinary PET [28].

As environmental issues gain greater public awareness, consumer demand for sustainable goods and packaging is growing. In response to consumer demand for eco-friendly options, companies across several industries are incorporating RPET into their product lines and packaging [29]. According to Joseph et al., (2023), the market size for recycled polyethylene terephthalate is predicted to grow from 2020 to 2030 [30]. The RPET market is expected to keep growing and is estimated to be valued USD 10.8 billion in 2023. The growth of the market may be attributed to the growing use of sustainable practices in food and beverage packaging. Throughout the course of the projection period, there will likely be an increase in demand for RPET because of expanding end-user activities towards a circular economy and increased acceptance of recycled plastics in the packaging, textile, and other end-use sectors [31].

RHF is categorised as a lignocellulosic material as most part composed of cellulose, hemicellulose, and lignin. The primary components are cellulose, a complex carbohydrate that provides structural strength, hemicellulose, a branching polymer that increases the material's overall flexibility, and lignin, a complex polymer that connects the cellulose and hemicellulose [32]. It also contains trace amounts of silica, ash, and other organic materials. RHF is hard, woody, insoluble in water, and has an abrasion resistant structure by nature. Due to its abrasive nature, RHF has been used to clean and prepare surfaces in a variety of applications, including abrasive blasting [33]. Utilising RHF in polymer composites reduces the environmental effect of composite manufacturing while providing a sustainable means of reinforcing materials. RHF has several benefits, including being renewable, biodegradable, durable due to its high silica content, thermally insulating properties, and use across multiple industries [34]. As a result, RHF is a material that can be applicate in sustainable and environmentally beneficial industrial operations.

Numerous research has used various types of matrix materials as polymer matrices to investigate how the tensile characteristics of RHF reinforced composites vary at various filler loadings [35]. Abhilash et al. (2023) conducted a study of the impact of rice husk (RH) particles on the mechanical and vibration damping properties of roto-molded polyethylene composites [36]. It was found that adding RH increased the tensile strength by up to 10% due to inadequate bonding between the reinforcement and matrix. The additional fibre content increases resulted in a drop in tensile strength. It is evident that, in comparison to the others, RH10 possesses the greatest strength. The mechanical characteristics of a hybrid glass fiber/rice husk reinforced polymer composite were investigated by Ismail et al. (2020) [37]. According to the research, hybridization has an impact on hybrid composites for RH glass fibre reinforced epoxy. The figure that was highest was 447.19 J/m for G25RH5. The results of the experiment showed that increasing the amount of RH fibres or decreasing the amount of glass fibre had no appreciable effect on the hybrid polymer composite's impact strength. Owing to the production method and potential interlaminar or interfacial adhesion between the fibre and matrix, a glass fibre hybrid composite with a lower RH was discovered. Nandiyanto et al.'s (2021), study about RH particle size in resin binders, discovered that smaller particles had better mechanical properties and improved density [38]. Dele-Afolabi et al. (2022) observed that with a rise in RH concentration, porosity reduced and mechanical properties improved in their study of RH with alumina ceramic fillers [39]. 10% RH enhanced the mechanical properties of linear low-density polyethylene (LLDPE) and its RH filler, according to research by Abhilash et al. (2023). In this work, we used recycled polyethylene (RPET) as a binder with RH filler. An ideal ratio of 16% RH produced greater density and reduced porosity, along with superior mechanical properties including tensile strength, flexural strength, and impact resistance.

3. Methodology

In the manufacturing process, 10 distinct composition ratios are produced using an injection moulding machine. The technique outlines the experimental procedure used to create samples of RHF/RPE polymer composites for mechanical and physical testing. RHF fibres are mixed with recycled polyethylene (RPE). Four step methods were used in the approach to create the RHF/RPE polymer composite sample. During the first stage, RHF was air-dried for 24 hours at room temperature and dried for an additional 12 hours at 70°C in an oven. Next as the RHF dried, it is ground using a Ballmill machine set to 250 rpm for ten minutes. The RHF next undergo sieving process using a Siemens machine with a particle size set at 900 μm, an amplitude of 1.0, and intervals of 10 minutes. Phase four involves mixing the RHF mixed RPE using a Brabender machine to create samples with varying composition ratios of weight by weight (wt/wt%), as shown in Table 1. The RHF/PET polymer composite composition ratio is mentioned in Fodzi et al. (2020) [40]. As indicated in Table 1, the ratio was selected based on prior studies that were carried out on a few ranges for each testing of RHF/PET polymer composites at different filler loadings.

Table 1. The composition ratio of RHF/RPET polymer composites

Sample	RHF (g)	RPET (g)	Composition of RPET (wt/wt%)	Composition of RHF (wt/wt%)	Total weight of the sample (g)
A	2.4	123.3	98	2	126.0
B	4.8	121.2	96	4	126.0
C	7.5	118.2	94	6	126.0
D	9.9	115.8	92	8	126.0
E	12.6	113.4	90	10	126.0
F	15.0	110.7	88	12	126.0
G	17.4	108.3	86	14	126.0
H	20.1	105.6	84	16	126.0
I	22.5	103.2	82	18	126.0
J	25.2	100.8	80	20	126.0

The samples must be crushed using a machine to shred them into pellets smaller than 10 mm before they can be put into the injection moulding process. After that, the prepared samples are injected into the machine using the following settings: 180°C, 45 Psi of screw pressure, and screw is operating in maximum speed capability 55-65% of velocity. A preferred manufacturing method for quickly, precisely, and economically creating plastic parts and components is injection moulding. The final product of samples is taken out from a mould after molten plastic is injected into the cavity and allowed to cool and solidify. Table. 2 illustrates the final product that used for the testing, such as Tensile testing (ASTM D638) standards, dimensions: 73mm x 12mm x 4mm, with 45mm distance between shoulders and a 25mm reduced section [41], Impact testing (ASTM D256) standards, specimen size: 75mm x 10mm x 4mm with a 45° V-notch [42], and Scanning Electron Microscopy (SEM) microstructure analysis [43].

Table. 2 The composition ratio of RHF/RPET polymer composites

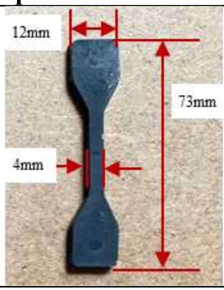
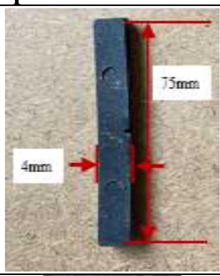
No.	Test	Standard	Specimen	Dimension
1	Tensile Strength	ASTM D3039: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials		• 73 mm x 12 mm x 4 mm, 40 mm distance between shounder, and 25 mm section is reduced

Table. 2 The composition ratio of RHF/RPET polymer composites (continue)

No.	Test	Standard	Specimen	Dimension
2	Impact Strength	ASTM-D7136: Standard Test Method for Measuring the Damage Resistance of a Fibre-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event		• 75 mm (length) x 10 mm (width) x 4 mm (thickness) • Slightly chipped at the middle of the samples
3	Scanning Electron Microscopy (SEM)	ASTM E766-14e1: Standard Practice for Calibrating the Magnification of a Scanning Electron Microscope		• Square-shaped specimens with 2 mm x 2 mm x 1 mm

4. Results and discussion

4.1. Tensile strength test

The results of the analytical tensile strength test performed on the mechanical characteristics of the produced RHF/RPET were shown in Figure 2. Tensile strength increasing trend until the RHF/RPET composition ratio reached 16 wt/wt%, at which point it began to decline until it reached 18 wt/wt% and 20 weight/wt wt/wt% composition ratios. The graph shows the ratio of 16 wt/wt% had the greatest tensile strength at 21.01 MPa, while the ratio of 14 wt/wt% had the second-highest tensile strength at 20.78 MPa. Additionally, it is evident that the lowest tensile strength of 15.15 MPa was attained at a weight-to-weight ratio of 20 wt/wt%. The maximal tensile strength is aligned with the SEM analysis, which indicates that the particles are most evenly distributed and linked within the matrix. Previous research has also demonstrated that the interfacial contact between the fibre and the polymer matrix plays a major role in the high tensile strength of low-density polyethylene composites [48]. As observed during the tensile test for the RH/glass fibre composite, the specimen showed elastic and plastic deformation as a result of the tension of the applied load, followed by normal deformation and the creation of a linear relationship between load and extension [49].

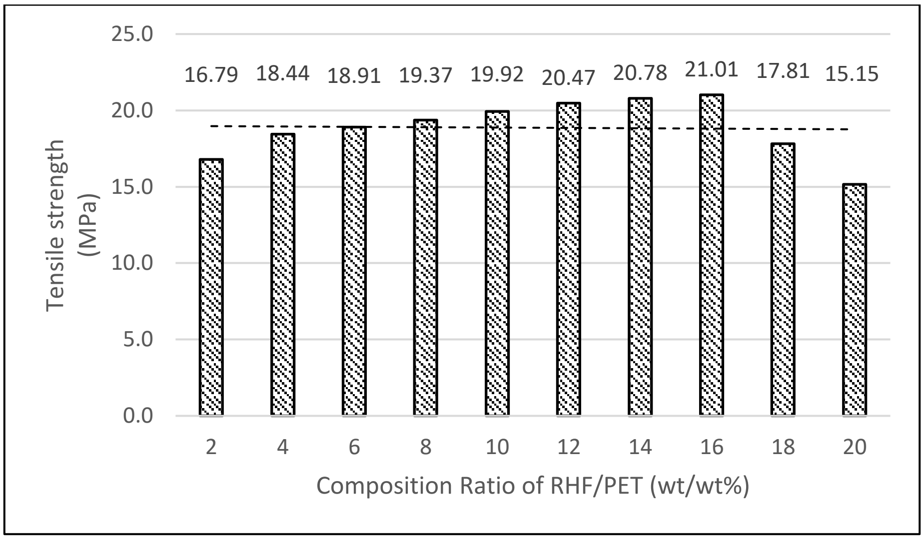


Fig. 2. Tensile strength of RHF/RPET in different composition ratio

The trend is declining to 17.81 MPa at 18 wt/wt% ratio and 15.15 MPa at 20 wt/wt% ratio as the composition reaches its maximum tensile strength, which is 16 wt/wt% ratio. This is consistent with earlier research that found adding fibre could not continuously boost tensile strength [50]. An excessive quantity of fibre tends to break down in the polymer and forms improper connections with the matrix. Furthermore, there is a chance that more fibres will be scattered to the splitting surface, which would weaken the bonds [51]. Due to the inner rice husk core distributes weight to the outer layers under tensile stress, a high interfacial adhesion is necessary for more effective stress transmission over the thickness of the reinforcing layers [52]. The efficiency of the fiber matrix bond decreases with increasing fibre concentration, which is associated with a decrease in mechanical characteristics. Inadequate interfacial bonding hindered effective load transmission, which led to the collapse quickly [53].

4.2. Impact strength test

Impact testing, which includes rice husk-polymer composites, is a crucial evaluation method for figuring out a material's ability to withstand sudden force or shock loading. Impact resistance of a composite is important in cases when the RHF/RPET has been exposed to dynamic loads or impacts. The impact resistance of rice husk-polymer composites is influenced by the quantity of RHF present in the matrix. RHF may function as a reinforcing filler to boost the composite's toughness, which in turn may contribute to a certain degree of increased impact resistance.

Figure 3 shows the effects of the RHF loadings on the impact strength of the RHF/RPET polymer composite, that the inclusion of rice husk fibre increased impact strength. As the amount of RHF filler increased, the composite's strength to impact increased as well. The filler's function as stress concentrators led to the composite's fracture during the application of a load. With a ratio of wt/wt% RHF/RPET polymer composite, the highest impact energy of 36.72 kJ/m² was attained. The second and third highest ratios were 18 wt/wt% with 35.05 kJ/m² and 20 wt/wt% with 32.73 kJ/m². When filler loadings are lower, the composite consisting of RHF and RPET showed poor interfacial bonding, which reduced impact energy. The lowest impact energy is found at the 2 wt/wt% ratio, which is 10.3 kJ/m².

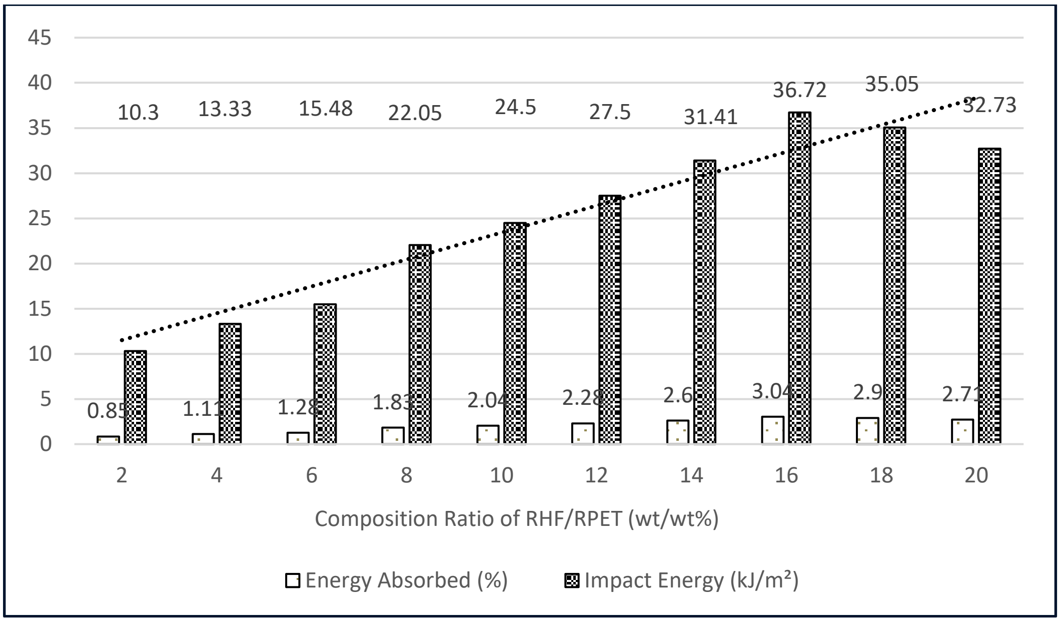


Fig. 3. Impact strength and energy absorb of RHF/RPET in different composition ratio

Lack of interfacial adhesion between the RHF and RPET may have contributed to the samples' unexpected failure upon impact. Due to the insufficient interfacial bonding, the filler and polymer matrix form micro-spaces upon impact, leading to many microcracks. A comparison analysis demonstrates that the impact strength of the polymer composite abruptly drops when the fibre content is raised to 20 wt/wt% [54]. Due to all the merging components, the composite effectively wastes more energy. According to a study by Homkhiew et al. (2022), there is inadequate interfacial bonding between the matrix polymer and filler at the point of impact, which leads to the formation of microcracks that spread quickly throughout the composite [55]. The sort and molecular structure of the polymer matrix also affect impact resistance. The interaction between the polymer and rice husk produces a synergistic effect that raises the overall toughness of the composite. It showed the reduced RH glass fibre hybrid composite, which may have been caused by the method of manufacture and the interfacial or interlaminar adhesion between the fibre and matrix [56].

4.3. Microstructure analysis by Scanning Electron Microscope (SEM)

Scanning Electron Microscopy (SEM) is a powerful instrument for analysing the microstructure of materials at high magnifications and resolutions. According to Radhakrishnan et al. (2023), SEM is a helpful instrument for comprehending the morphology, surface characteristics, and structural features of rice husk [57]. Rice husk surface forms may be seen at the microstructural level with SEM. It shows information about pores, fractures, surface flaws, and fibre arrangement. This information is necessary to comprehend the overall texture and surface topography of rice husk, which may influence its properties and applications. Figure 4 shows the microstructures of all samples with magnifications of x 2.0k and x 200. On the cross-sectional specimen surfaces, RHF particles, RPET, and void were denoted by the arrows. There are numerous apparent voids on the cross-sectional surface as well, which leads to a weaker polymer composite at the lower composition ratio of RHF.

Figure 4 shows a highly agglomerated mass with some voids was seen in SEM investigations at the early addition of RHF ratio, and it looked to be porous material. According to earlier study by Olcay et al. (2020), there were a few flaky particles on a smooth surface [58]. Figure 4 of (e)–(j) shows the positioning of the RHF inside the husk structure in detail. Figure 4 of (h), (i), and (j) demonstrate that the surface of the rice husk was rough and had many grooves, while the voids and pores vanished when the ratio of RHF increased. It is evident that the rough surface helps the fibre and matrix adhere to one another [59]. At Figure 4 of (i) and (j) of RHF addition, the fibres are observed to develop as clusters in the surfaces. This cluster formation is the main reason for the precipitous drop in mechanical strength for the 18 wt/wt% and 20 wt/wt% ratios. When the fibres form clusters, the matrix fibre bonding decreases because the fibres are bonded together. Consequently, throughout the composites' manufacturing process, the matrix material finds it difficult to appropriately accommodate the fibres. This explains the poorer reinforcing efficiency seen in composites with higher fibre concentrations [60].

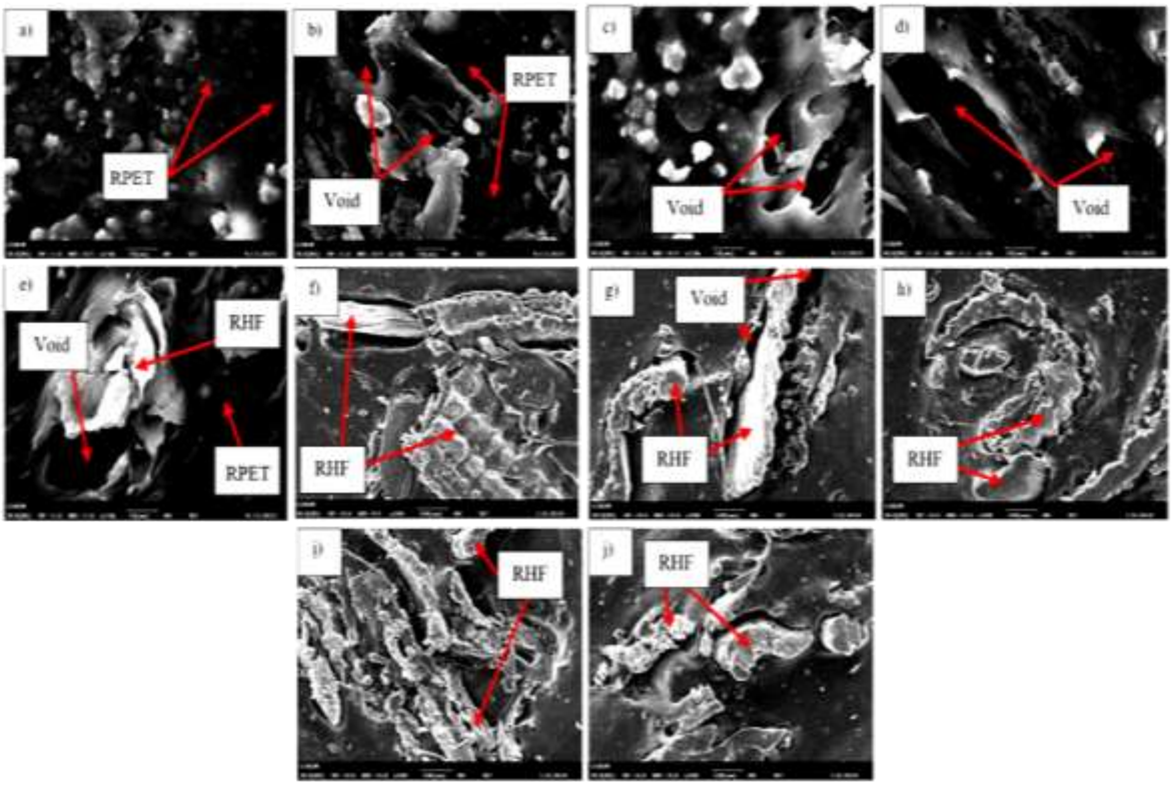


Fig. 4. SEM of RHF/RPET at different ratios wt/wt% (a) 2, (b) 4, (c) 6, (d) 8, (e) 10, (f) 12, (g) 14, (h) 16, (i) 18 and (j) 20

5. Conclusion

In conclusion, composites reinforced with fibre from rice husks are environmentally benign and sustainable. Nonetheless, the arising production challenges need to be fixed in order to improve their mechanical properties and increase their marketability. Based on the anticipated outcomes, it is highly likely that rice husk will be used to make bioplastic because of its excellent physical characteristics. The project's recorded 16 wt/wt% was the ideal composition to be used for deck panel application in terms of mechanical and physical qualities. Physical testing findings indicate that the ideal ratio for all samples in tensile testing and impact testing is 16 wt/wt%. SEM analysis reveals that the microstructure is well-dispersed at this composition ratio. Tensile strength reached a high of 163.42 MPa. Compared to Abhilash et al. (2023), where the greatest tensile strength recorded was 15.8 MPa, the findings reported in this study are significantly greater [36]. Meanwhile, this study recorded that 3.04% energy was absorbed and a maximum impact strength of 36.72 KJ/m. The impact strength findings exhibited a similar pattern to the tensile strength results, wherein the loading was raised due to the strengthening mechanism of the fibre. The application of hybrid reinforcements, surface modification, coupling agents, and processing parameter optimisation are some potential remedies for these issues. Further study is needed to improve the properties and streamline the production process of RHF/RPET polymer composites so that they may be used as a viable alternative to synthetic fiber-reinforced polymer composites.

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