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Enhancing Epoxy Composites: A Study on the Integration of Rice Husk and Coconut Fiber Reinforcements

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ABSTRACT

This study investigates the mechanical and structural properties of hybrid epoxy composites reinforced with rice husk (RH) and coconut fiber (CF), with a focus on sustainability and waste reduction. The research specifically examines the impact of Sodium Chloride (NaCl) treatment on these natural fibers, comparing the performance of both treated and untreated composites. Various composite formulations were subjected to rigorous tensile, flexural, hardness, and density testing, complemented by Scanning Electron Microscopy (SEM) analysis to observe microstructural characteristics. The findings reveal that NaCl-treated composites generally exhibit enhanced tensile strength, with the treated 80:10:10 sample achieving a tensile strength of 42.22 MPa. However, the treated samples demonstrated reductions in flexural strength and hardness compared to their untreated counterparts. Notably, the untreated 80:10:10 sample exhibited the highest tensile strength at 48.72 MPa, the highest flexural strength at 169.87 N/mm², and the highest hardness at 44.08 HV1. Density measurements remained consistent regardless of NaCl treatment, indicating minimal impact on composite density. SEM analysis highlighted microstructural defects, including voids, fiber pull-out, and poor adhesion, which adversely affected mechanical properties. In conclusion, while NaCl treatment can enhance the tensile properties of hybrid epoxy composites, further optimization is needed to improve other mechanical characteristics, contributing to more sustainable engineering practices.

Keywords: Epoxy; coconut fiber; rice husk; hybrid composite; NaCl treatment

INTRODUCTION

Composite materials are essential in materials engineering, integrating diverse components effectively. Natural fibers like Rice Husk (RH) and Coconut Fiber (CF) have become popular as composite reinforcements. However, the potential of Sodium Chloride (NaCl) treated fibers is underexplored. This research addresses this gap by examining the mechanical and structural properties of NaCl-treated RH and CF in epoxy composites. The research aims to reduce material waste and promote a circular economy that enhances the utilization of natural fibers. Incorporating insights from microwave treatment research, this study seeks to demonstrate the combined benefits of NaCl and microwave treatments for natural fibers in epoxy composites.

This study investigates the effects of NaCl treatment on the mechanical and structural properties of epoxy composites made of CF and RH. NaCl treatments are known to make natural fibers more wettable by resin, where it helps the epoxy wet the fibers and improves interfacial bonding. Additionally, NaCl causes slight surface roughening or swelling of cell walls that improves mechanical interlocking between the fiber and the matrix (Setyayunita et al. 2022). Verma et al. (2021) reported that NaCl can leach some soluble compounds, dust, and surface oils that may hinder good mechanical interlocking with the matrix. This is a gentler surface-cleaning approach compared with strong alkali. Suhot et al. (2021) explained that strong alkali is more commonly used to remove hemicellulose/lignin and increase adhesion, but NaCl is not as aggressive but can be useful and less harmful. Fewer chemical changes are observed while still improving adhesion/wettability.

Currently, no direct comparison exists for NaCl-treated RH and CF in hybrid epoxy composites. According to Siddiqui et al. (2019) and Neh (2020), Malaysia produces about 1.2 million tons of agro-industrial waste annually, including abundant rice husk and coconut fiber. Improperly managed, these wastes pose environmental risks. Traditional fiber drying methods are environmentally detrimental, necessitating greener alternatives. This research aims to reduce agro-industrial waste, promote a circular economy, and lower carbon footprints by utilizing natural fibers in the light of sustainable engineering practices. This material can serve as a viable material for sports equipment applications.

Using rigorous testing methods and Scanning Electron Microscopy (SEM) analysis, the objectives are to evaluate the tensile, flexural, hardness, and density properties of untreated and 5% NaCl-treated RH and CF hybrid epoxy composites, and to evaluate the structural properties of both treated and untreated hybrid epoxy composites using SEM.

Furthermore, this study examines the performance enhancement of NaCl-treated RH and CF in hybrid epoxy composites, using resin epoxy (RE) as the matrix. Fibers were treated with a 5% NaCl solution for one hour at room temperature and microwaved for 3 minutes at 700 watts. Various compositions (RE:80, CF:10, RH:10; RE:90, CF:5, RH:5; RE:98, CF:1, RH:1) will be tested for tensile, flexural, hardness, and density properties. Sixty samples will be tested to ensure accuracy, providing a comprehensive comparison of treated and untreated samples.

Subsequently, this study aims to redefine the application of natural fibers, specifically rice husk (RH) and coconut fiber (CF). By addressing significant knowledge gaps and aligning with sustainability goals, this study offers viable solutions to increase the utilization of agricultural waste. In addition, this study emphasizes the importance of promoting circular economy principles by transforming waste materials into valuable resources. Comprehensive testing methods which include tensile, flexural, hardness, and density tests, alongside Scanning Electron Microscopy (SEM) analysis, ensure a thorough evaluation of the mechanical and structural properties of treated and untreated composites.

These findings have the potential to revolutionize materials engineering by reducing environmental impact and lowering carbon footprints. All in all, the study aims to advance eco-friendly materials, inspire sustainable solutions across industries, and significantly contribute to materials engineering.

To understand the significance and context of this research, it is essential to review the current advancements and applications of natural fibers in composite materials. Composite materials have gained significant attention across various industries due to their unique properties. Composites, consisting of different components, have diverse applications. Natural fibers, being renewable, inexpensive, and environmentally friendly, are increasingly used as reinforcement in composites. This research focuses on rice husk (RH) and coconut fiber (CF) in hybrid epoxy composites, exploring previous studies and advancements in this field.

Karimah et al. (2021) noted that natural fibers, such as flax, hemp, jute, coir, sisal, and kenaf, have become essential in composite applications. In other studies, Azizatul et al. (2021) and Mani et al. (2020) mentioned that natural fiber's strength-to-weight ratio is particularly notable, making them superior to conventional materials like glass fiber. This property is crucial for industries like aerospace and automotive, where weight reduction is vital for fuel efficiency and performance.

Furthermore, natural fibers can be categorized into grasses and reeds, bast fibers, leaf fibers, seed fibers, wood and roots as highlighted by Karimah et al (2021) and Thapliyal et al. (2023). According to Girijappa et al. (2019) and Wresearch (2022), Malaysia has an abundance of natural fibers, with Indonesia producing significant quantities of cotton, ramie, abaca, and pineapple.

Rice Husk (RH), a byproduct of rice milling, is promising for composite reinforcement due to its silica-cellulose structure, providing strength and water resistance. As noted from Wan Mohtar et al. (2023), Malaysia produces about 0.77 million tons of RH annually, indicating its underutilization. Studies by Bisht et al. (2020) and Yunusa et al. (2023) show that RH improves the stiffness and tensile strength of composites.

Coconut Fiber (CF), derived from coconut shells, enhances composite mechanical properties as highlighted by Wan Mohtar et al. (2023) in his studies. In addition, studies by Obele et al. (2015) and Verma et al. (2015) mentioned that increasing CF content improves flexural strength, tensile strength, and hardness of composites.

Moreover, hybrid composites blend different fibers within a polymer matrix, optimizing their performance. According to Agarwal et al. (2019) and Amy Golden (2023), using resin epoxy (RE) as a matrix enhances the mechanical properties of composites. Hybrid composites as noted from Karim et al. (2018) and Shireesha et al. (2019) find applications in aeronautics, smart memory composites, thermoplastic applications, and civil construction. Shireesha et al. (2019) also noted that natural fibers in hybrid epoxy composites offer benefits like low density, biodegradability, affordability, recyclability, and eco-friendliness. They are used in automotive, building, sporting goods, and consumer electronics industries (Suriani et al. 2021).

Performance of natural fibers in composites depends on their cellulose, hemicellulose, lignin content, and other components (Karimah et al. 2021). Osmond et al. (2021) and Palanisamy et al. (2024) state that chemical treatments enhance fiber-matrix adhesion and reduce hydrophilicity. Research made by Abhishek et al. (2016), Chang Hui et al. (2020), Cholachagudda et al. (2013), Hameed et al. (2017), and Yogish et al. (2019) highlights the potential of treated RH and CF in hybrid epoxy composites, with improved mechanical properties.

Chemical treatments, such as NaCl, enhance the performance of natural fibers. NaCl-treated fibers show improved mechanical properties and surface adhesion (Setyayunita et al. 2021). Furthermore, studies by Bakri et al. (2018), Gilmore et al. (2023), Johar et al. (2022), Mohammed et al. (2018) and Renreng et al. (2021) noted that microwave treatment can enhance mechanical properties, reduce water absorption, and speeds up processing.

In summary, this study addresses the inadequate waste management strategies in Malaysia and supports the country's shift to align with sustainable development goals and circular economy as noted from Umeswara et al. (2021) and Ministry of Economy (2023). Research into the effects of NaCl and microwave treatment on RH and CF in hybrid epoxy composites is crucial. This exploration can lead to advancements in material design, improving the performance and sustainability of composites. Addressing these knowledge gaps could significantly contribute to the development of sustainable engineering solutions.

METHODOLOGY

MATERIALS AND PREPARATIONS

Various materials and preparation methods were utilized as follows. The resin epoxy used had a supplier's recommended ratio composition of 3 parts epoxy resin to 1 part hardener in by weight. The raw coconut fiber (CF) and rice husk (RH), shown in Figure 1, were obtained from agricultural waste in their original forms. The CF was then chopped with scissors to lengths under 2.5 cm. A 5% NaCl solution (Cenco Sains, Malaysia) was used to treat the RH and CF as shown in Figure 2. The untreated RH and CF were cleaned with distilled water to remove contaminants. The treated RH and CF were soaked in a 5% NaCl solution for 1 hour at room temperature, with a fiber to solution ratio of 1:20. Both treated and untreated RH and CF were sun-dried for at least 5 hours and microwaved for 3 minutes at 700 W with a frequency of 2.45 GHz using a domestic microwave oven (Panasonic NN-CD997S, Malaysia).

FIGURE 1. Raw (a) Coconut Fiber (CF) and (b) Rice Husk (RH)

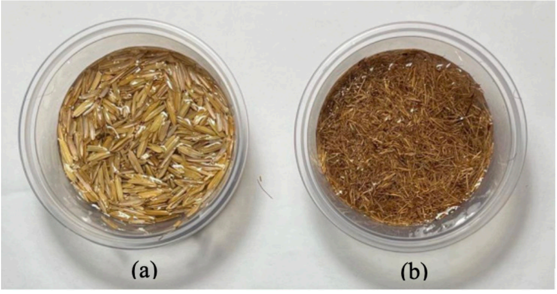

FIGURE 2. (a) RH and (b) CF soaked in 5% NaCl solution

COMPOSITE PREPARATION

In this study, the preparation of composite samples involved the following steps. First, the epoxy resin (Craftiviti, Malaysia) was mixed with both the untreated and NaCl-treated rice husk (RH) and coconut fiber (CF) until it was evenly distributed within the epoxy matrix. Next, the fiber-epoxy mixtures were poured into silicone molds. These molds conformed to ASTM D638 Type IV standards for dog bone-shaped samples used in tensile testing and ASTM D790 standards for rectangular-shaped samples used in flexural testing. The fiber content in weight percentages is detailed in Table 1. The compositions of the RH and CF for the samples were referenced from the parameters found in studies made by Johar and Ariff (2022) and Yogish (2019). Figure 3 shows the fabricated tensile and flexural samples for all the compositions of the RH-CF hybrid composite used.

TABLE 1. Compositions for the RH-CF hybrid composites

Composition	No. of Samples	
RE: RH: CF	Untreated (U)	5% NaCl Treated (T)
98:01:01	10	10
90:05:05	10	10
80:10:10	10	10

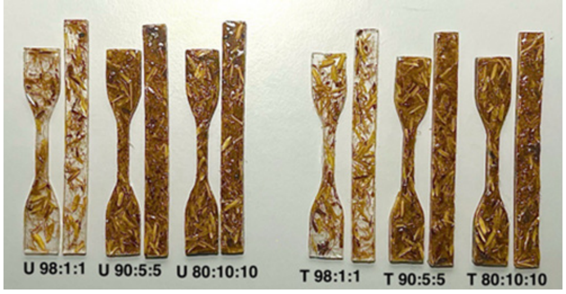

FIGURE 3. Fabricated samples for each composition

MECHANICAL TESTING

TENSILE TEST

Tensile tests were conducted using a universal testing machine (SHIMADZU -PFG5K, Japan) according to ASTM D638 standards. Dog-bone shaped specimens were prepared, and the tensile strength was measured at a crosshead speed of 5 mm/min.

FLEXURAL TEST

Flexural tests were performed using a three-point bending fixture on the universal testing machine (SHIMADZU-PFG5K, Japan), following ASTM D790 standards. Rectangular specimens were used, and the flexural strength was calculated from the load-displacement data.

DENSITY TEST

Density measurements were conducted using a densimeter (GK-300, Japan). Samples were weighed in air (A&D Analytical Balance HR-250AZ, Japan) and then in water, and the density was calculated based on the weight difference and the volume of water displaced.

HARDNESS TEST

Hardness tests were conducted using a Vickers hardness tester (Falcon 400 V, Netherlands) in accordance with ASTM E384 standards. A diamond indenter was used to make an impression on the surface of the composite samples, and the hardness was measured from the size of the indentation.

SCANNING ELECTRON MICROSCOPY

SEM analysis was performed using the SEM machine (JEOL-JSM IT-100, Japan) to observe the microstructural characteristics of the composites. Samples were gold-coated to enhance conductivity and examined under an SEM to assess fiber distribution, interface bonding, and the presence of any voids or defects.

RESULTS AND DISCUSSION

TENSILE STRENGTH

Figure 4 shows the stress-strain curve obtained from the tensile test. Pure epoxy shows typical thermoset behaviour where moderate stiffness is seen. It has the lowest tensile strength compared to the hybrid samples. It fails a long plastic deformation region. The T98:1:1 sample has very high stiffness indicated through the steep slope at the beginning. It appears to have reduced ductility compared to 80:10:10 samples likely due to the NaCl treatment and low fiber content creating strong adhesion but with less flexibility. The U98:1:1 is similar to T98:1:1 but slightly lower in strength. The untreated fillers are less effective than treated fillers at the same ratio. The NaCl treatment improves interfacial bonding. The 90:5:5 samples are stiffer than the pure epoxy but significantly lower than 80:5:5 samples. Increase in filler indicates a reduction in strength due to agglomeration, poor wetting and possibly higher void content. The T80:10:10 sample fails faster than the untreated U80:10:10 samples because higher content of the NaCl treated fibers resulted in weaker matrix-fiber interface. The untreated U80:10:10 sample which has the highest strength exhibits a long strain region before failure. It has a smooth, steady rise in slope with good interfacial bonding between fibers and matrix which results in the highest tensile strength.

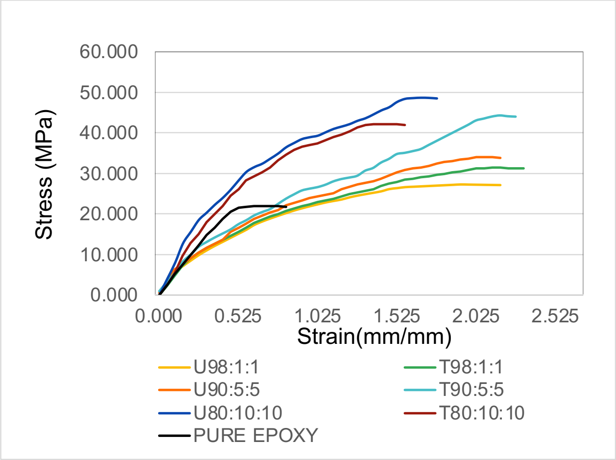

FIGURE 4. Tensile Test Stress vs Strain Curve

Figure 5 shows the bar chart that summarizes the tensile strength obtained for each sample. The measured tensile strength of the original epoxy resin (RE) sample was 22.01 MPa. Nevertheless, the combination of rice husk (RH) and coconut fiber (CF) into the epoxy resin resulted in a significant enhancement in the tensile strength of the U98:1:1 sample to 27 MPa, and U90:5:5 sample to 34 MPa, indicating a 22.7 % and 54.5 % improvement compared to the RE sample respectively. This justifies the ability of RH and CF to enhance the mechanical properties of epoxy resins. Moreover, a distinct pattern develops when comparing the tensile strengths of NaCl-treated and untreated materials. Samples with 1% (T98:1:1) and 5% (T90:5:5) fiber content treated with NaCl solution exhibit greater tensile strengths compared to their untreated counterparts. This aligns with findings from Setyayunita et al. (2021), which demonstrated that NaCl-treated fiber enhances the tensile strength of the hybrid epoxy composite. NaCl treatment improves tensile strength because it cleans the surface, slightly increases roughness, improves wettability, and thus enhances matrix-fiber bonding which results in a more efficient stress transfer.

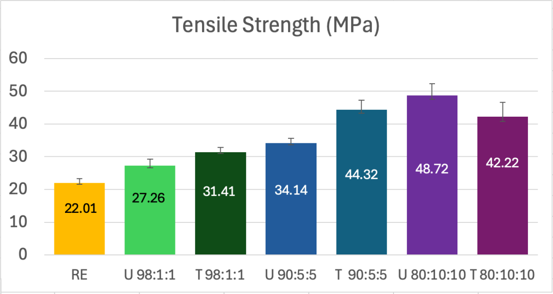

FIGURE 5. Tensile strength for each sample

However, the sample with 10% NaCl-treated RH and CF (T80:10:10) exhibits a 13.3% decrease in tensile strength compared to its untreated sample (U80:10:10) with the same proportion of reinforcing components. This is consistent with the results from Patel et al. (2023) who found similar outcomes at higher loading of kenaf fiber epoxy composites. The reduced tensile strength observed in the T 80:10:10 sample may plausibly arise from a combination of poor resin wetting, increased void content, and interphase weakening. Poor wetting leads to voids that act as stress concentrators, which is widely known to degrade strength in fiber-reinforced composites as reported in the findings of Thomason and Xypolias (2023). Moisture ingress, possibly exacerbated by elevated sodium content from NaCl treatment, can further weaken the fiber-matrix interface through plasticization and microcracking (Chaffey et al. 2025).

Additionally, fiber or filler agglomeration could locally amplify these defects, reducing effective load transfer and ultimately tensile performance. Nevertheless, a discernible pattern emerges across all samples. Independent of NaCl treatment, an increase in the proportion of reinforcing components results in enhanced tensile strength. The U80:10:10 sample exhibits the highest recorded tensile strength of 49 MPa, reflecting a 122.7 % increase relative to the RE sample. Overall, the results indicate that increasing hybrid filler content substantially enhances tensile performance, with certain treatment combinations yielding more than double the original strength.

FLEXURAL STRENGTH

Figure 6 shows the stress-strain curve obtained from the flexural test. This graph compares flexural behaviour of the RH-CF hybrid epoxy composites with the pure epoxy. The pure epoxy shows lowest flexural strength compared to the other hybrid samples. It has a stiffer initial slope indicating its brittle behaviour with almost no plastic region. The 98:1:1 and 90:5:5 show moderate increase over pure epoxy but less than the 80:10:10 composition. The 80:10:10 sample shows the largest peak stress and a long strain before failure, which indicates a higher flexural strength, toughness and enhanced ductility than the lower-fiber content and the pure epoxy. This is a result of better load sharing attributes by the larger content of fibers, higher reinforcement of volume fraction enabling more stress transfer from matrix to fibers. The presence of crack bridging reinforcements resulted in the delay time to failure. However, the NaCl treated fibers have decreased flexural strength when compared with the untreated fibers. Nevertheless, the treatment still improved interfacial bonding and hence, increased the flexural strength to slightly lower values from the samples with the untreated fibers.

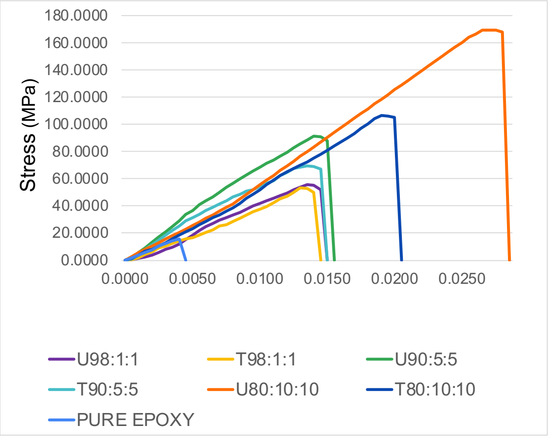

FIGURE 6. Flexural Test Stress vs Strain Curve

Figure 7 shows the bar chart that summarizes the flexural strength obtained for each sample. The pure epoxy resin (RE) sample had the lowest flexural strength, recorded at 15.68 N/mm². On the other hand, both NaCl-treated and untreated samples exhibited enhanced flexural strength at varying amounts of reinforcing components. A consistent pattern was observed, indicating that an increase in the proportion of reinforcing elements resulting in an enhancement of flexural strength. The highest flexural strength was observed in the 10% untreated RH and CF sample (U80:10:10), exhibiting a flexural strength of 169.87 N/mm², representing a 983% increase in tensile strength compared to the RE sample. This trend highlights the reinforcing effect of rice husk (RH) and coconut fiber (CF) within the epoxy matrix, as indicated by Yogish (2019), who asserts that RH and CF can enhance the composite's overall mechanical properties.

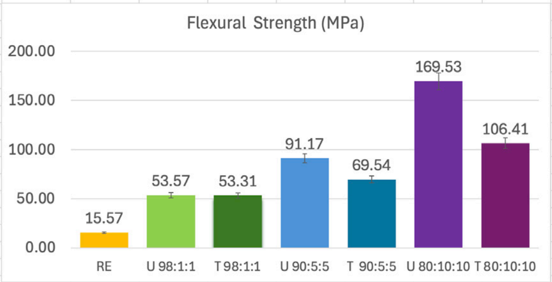

FIGURE 7. Flexural strength for all samples

However, the NaCl-treated samples exhibited a relatively decreased flexural strengths by 0.5 %, 23.7 % and 37.4 % for the T98:1:1, T90:5:5 and T80:10:10 samples respectively when compared to their untreated counterparts. This observation is in contrast with the findings from Setyayunita et al. (2021), which indicated an increase in flexural strength in samples containing fibers treated with NaCl. It is evident that the variance may be ascribed to the diverse types of fibers employed in the research. Setyayunita et al. (2021) utilised kenaf fiber derived from the stem of the Kenaf plant, which possesses unique structural properties compared to RH and CF. RH and CF fibers, conversely, originate from rice paddy and coconut tree fruit shells, possessing differing compositions and qualities compared to kenaf fiber. The disparities in fiber origin and structure could shed light on the variation in the measured flexural strength.

Nevertheless, results from Patel et al. (2023) revealed similar findings in the reduction of mechanical properties with higher loading of fibers which was due to poor resin wetting, increased voids, interphase weakening, and increased moisture. For the flexural strength, the matrix content is more dominant. In bending, the outer fibers carry compressive stress, while the core experiences shear. If resin continuity is disrupted with either voids, resin-rich or resin-poor regions, then the flexural properties will drop even more sharply than tensile. Ultimately, despite the reduction in flexural strength resulting from NaCl treatment, the treated samples greatly surpassed the RE sample in general.

DENSITY

Density measurements illustrated in Figure 8 showed consistency within the same composition, regardless of treatment. The density of the composites remained unaffected by the NaCl treatment, indicating that the treatment process primarily influences mechanical properties without altering the composite's density. However, as the fiber loading of CF and RH increases from 1, 5 and 10%, they substitute part of the heavier epoxy resin with lighter fibers which are lignocellulosic materials with lower densities, hence, reducing the overall composite density. This was also reported by Hasan et al. (2021) in his findings in his research in coconut coir fiber reinforced composites.

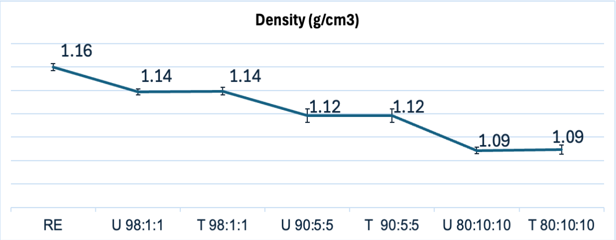

FIGURE 8. Density value for each sample

HARDNESS

Figure 9 shows the hardness results for the RE, untreated, and NaCl-treated samples. The RE sample had the lowest hardness value of 15.61 HV1. When RH and CF were added as reinforcing elements, the hardness values generally increased in comparison to the RE sample, demonstrating a positive reinforcing effect. Both untreated and treated hybrid composites showed minimal improvements for the lower fiber loadings (98:1:1 and 90:5:5). The untreated samples improved by 12% and 22% for the U98:1:1 and U90:5:5 respectively. The treated samples on the other hand appeared to have a smaller improved hardness and by 5% and 11% for the T98:1:1 and T90:5:5 respectively with hardness values ranging from 16.39 to 19.11 HV1. However, a significant increase of 180% in hardness is observed in the higher filler content (U80:10:10) over the RE sample. The highest hardness of 44.08 HV1 was obtained by the untreated hybrid composite (U80:10:10), whereas 41.79 HV1 was obtained by the NaCl-treated counterpart (T80:10:10).

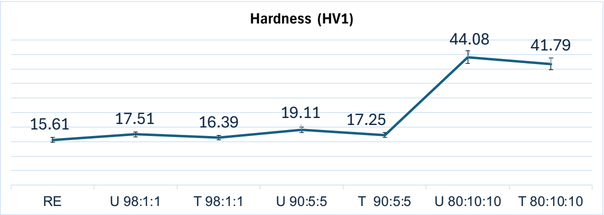

FIGURE 9. Hardness value for all samples

NaCl-treated composites generally showed slightly lower hardness than their untreated samples by 6%, 9% and 5% for the 98:1:1, 90:5:5 and 80:10:10 of RH and CF fiber loading. Changes in the properties of the fiber surface during treatment may be the cause of this decrease. These changes may decrease the hardness-causing interfacial bonding and localised compaction, even though they are advantageous for some mechanical characteristics like tensile strength. The homogeneous microstructure distribution of the RH and CF fibers within the epoxy matrix most likely contributed to the noticeable hardness improvement for 80:10:10 RH and CF. This implies that specific reinforcement effects in addition to overall density influence hardness.

Similar findings were reported, where hardness is determined by microstructural factors rather than density. For instance, while Gao and Huang (2022) found that surface compression treatments improved wood hardness regardless of bulk density, Karafi et al. (2023) showed that hardness increases in nanocrystalline tungsten were related to grain size rather than density. The results show that fiber distribution and composition are important factors in increasing hardness; the 80:10:10 RH–CF composition produced the greatest improvement by more than 130% when compared with the untreated samples. However, for the treated samples, the increase in hardness was more that 142% even though the effect was somewhat mitigated by the NaCl treatment by a small reduction in hardness by 5%.

SEM ANALYSIS

Using post-tensile test specimens, SEM analysis was performed to examine the microstructural characteristics of hybrid epoxy composite samples. Figure 10 shows the internal structures and fiber distribution of hybrid epoxy composites with different fiber contents using SEM images. The 98:1:1 untreated and treated fiber samples are shown in images (a) and (b), respectively. The epoxy matrix is mostly intact because the reinforcing elements are only irregularly scattered throughout it. Meanwhile, the 90:5:5 untreated and treated fiber samples are shown in images (c) and (d), respectively, which show a greater presence of reinforcing fibers that take up more matrix space. Additionally, the 80:10:10 untreated and treated fiber samples are shown in images (e) and (f), respectively, demonstrating a high fiber concentration that considerably lowers the resin epoxy volume.

Lastly, the pure resin epoxy resin (RE) sample is shown in image (g), which has a uniform and cohesive structure absent of notable porosity or reinforcing fibers. The comparison of these pictures shows that the distribution and internal structure of the composites are mostly influenced by the fiber content rather than the NaCl treatment. The microstructures of the NaCl-treated and control samples do not significantly differ from one another, as can be seen after closely examining the SEM images. Some fiber pullouts, voids and breaking of fiber are evident in general for all the images. It is challenging to draw definitive conclusions regarding the performance of each sample, such as its tensile and flexural properties, based solely on microstructural investigation because there are not any noticeable differences. Further analysis and testing are necessary to completely assess the impact of NaCl treatment on the microstructural properties, particularly the bonding of the matrix and the reinforcing elements, as well as the effect on the mechanical behaviour of the samples, even though the SEM images offer useful insights into the internal characteristics of the hybrid epoxy composites.

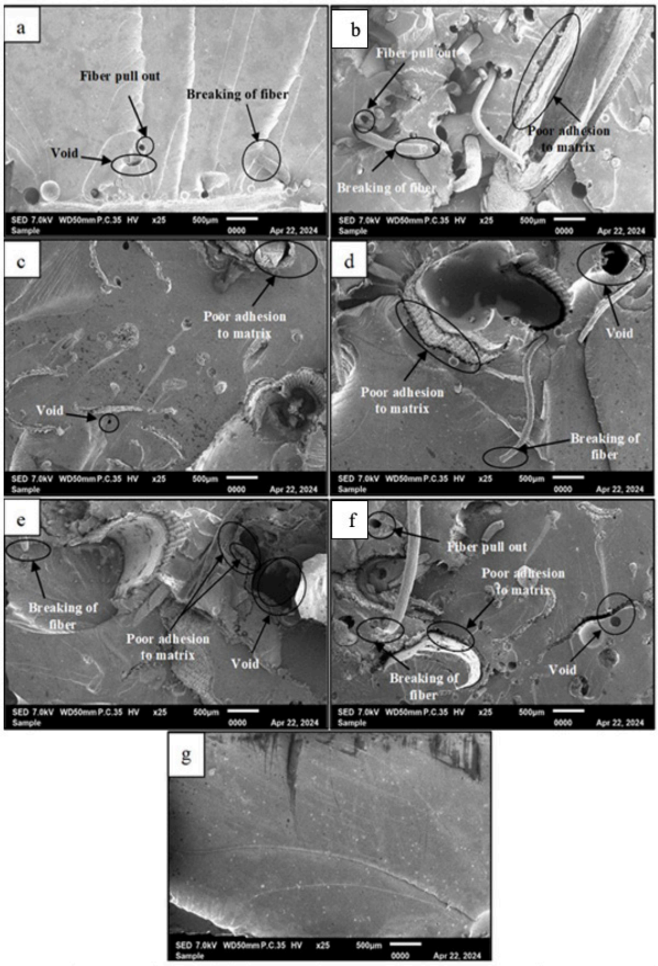

FIGURE 10. SEM images of the hybrid composite samples (a) U 98:1:1 (b) T 98:1:1 (c) U 90:5:5 (d) U 90:5:5 (e) T 90:5:5 (f) U 80:10:10 (g) Pure Epoxy (RE)

SUMMARY OF DISCUSSION

For the 98:1:1 and 90:5:5 hybrid samples, NaCl treatment improved both tensile and flexural strengths of the RH and CF hybrid epoxy composites. This improvement can be associated with the removal of surface impurities and slight fiber roughening, which have been widely reported by several researchers (Setyayunita et al. 2021; Setyayunita et al. 2022; Suhot et al. 2021) to enhance fiber–matrix adhesion by promoting improved wettability and mechanical interlocking. Similar observations have been made in natural fiber composites by Verma and Gope (2015), Bisht et al. (2020) and Hasan et al. (2021) where surface treatments increase interfacial bonding and stress-transfer efficiency.

However, for the 80:10:10 samples, the benefits of NaCl treatment were outweighed by negative factors. The higher reinforcement and filler content increased the viscosity of the resin mixture and reduced the available resin volume for complete wetting, a behaviour consistent with fiber–particle agglomeration and resin starvation reported in hybrid natural fiber composites by Cholachagudda et al. (2013), Chang Hui et al. (2020), and Johar and Ariff (2022). The presence of residual salts and moisture contributed to micro-void formation and stress concentrators, which various studies from Osmond et al. (2021), Renreng et al. (2021) and Patel et al. (2023) have identified as significant causes of interface weakening and premature failure.

During tensile loading, these interfacial defects facilitated early fiber pull-out and matrix cracking; failure patterns also observed in rice husk and coir-based epoxy composites with suboptimal bonding. Similar observations were reported by Abhishek and Gouda (2016), Yogish et al. (2019) and Hameed (2017). Under flexural loading, the same defects acted as crack initiation sites on the tensile surface of the specimen, reducing load-bearing capacity as previously documented in similar hybrid composites by Obele and Ishidi (2015) and Karim et al. (2018). As a result, both tensile and flexural strengths decreased at higher fiber and filler contents.

This behaviour reflects that although an optimum reinforcement content exists, excessive filler loading promotes interfacial defects and insufficient resin coverage, which dominate over any strengthening effects imparted by NaCl treatment as reported by Girijappa et al. (2019), Karimah et al. (2021) and Suriani et al. (2021). The NaCl treatment improves bonding, tensile, and flexural performance, but may reduce intrinsic rigidity and compaction of fibers, leading to slightly lower hardness; an effect also noted in treated natural fiber composites by Cesar dos Santos et al. (2018) and Setyayunita et al. (2022).

CONCLUSION

This study successfully met its primary objectives by evaluating the mechanical and structural properties of untreated and 5% NaCl-treated rice husk (RH) and coconut fiber (CF) hybrid epoxy composites. Increasing fiber content significantly enhanced the mechanical properties of both untreated and treated samples. For the untreated samples, the U80:10:10 sample exhibited the highest tensile strength (48.72 MPa), flexural strength (169.87 N/mm²), and hardness (44.08 HV1), demonstrating the reinforcing effectiveness of RH and CF in the epoxy matrix. Moreover, for the NaCl-treated composites, the T80:10:10 sample showed improved tensile strength (42.22 MPa) but possessed lower flexural strength and hardness compared to untreated samples. The density remained consistent across all samples, indicating that NaCl treatment does not affect the density characteristics.

In addition, the SEM analysis revealed that microstructural defects such as voids, fiber pull-out, poor adhesion, and fiber breakage were present in all samples, influencing their mechanical properties. Specifically, samples with 10% RH and CF exhibited the highest tensile strengths despite visible defects, highlighting that increased fiber content significantly enhances mechanical performance. The presence of voids and poor fiber-matrix adhesion were consistent across different fiber contents and treatments, but the tensile strength improved with higher fiber content, aligning with findings from Yogish (2019) suggesting that a fiber content of 20% would result in even better tensile strength. Ultimately, this research highlights the potential of RH and CF as sustainable reinforcing agents in epoxy composites, emphasizing the benefits of NaCl treatment for tensile properties. The study also underscores the importance of optimizing composite composition to mitigate the effects of microstructural defects and further enhance mechanical properties, suggesting areas for future research and development.

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DECLARATION OF COMPETING INTEREST

None.

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