# PROPERTIES OF REINFORCED POLYMER COMPOSITE PRODUCED FROM COCONUT FIBER[1]

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**Abstract.** This study aimed at the production of reinforced polymer composites from coconut fibers and plastics. Coir fiber (CF) sheets with dimensions of 200 × 200 × 12 mm (±3 mm) were used as the natural fiber, whereas a thermosetting plastic or an elastomer (unsaturated polyester [UPE] or silicon rubber [SIR]) was used as the binder in the matrix. Processing was performed using the vacuum infiltration method, wherein the liquid polymer was made to infiltrate the cellulose of the natural structure of the CFs and disperse within the CF matrix. The effect of production variables on thermal, sound, and flexural properties was evaluated. Material characterization tests revealed that the addition of UPE and SIR as reinforcing materials enhanced the thermal conductivity of the CFs. UPE improved the modulus of rupture of the CFs. The study further revealed that CF/SIR composites showed high ductility. Analysis of the sound absorption properties of the composites revealed that the noise reduction coefficient (NRC) of the CF/400 wt % SIR composite was the highest. Moreover, the CF/SIR composites showed higher sound absorption efficiency ($\alpha$) values at high frequencies than those of the CF/UPE composites. However, the polymers had no effect on the NRC of the neat CFs when added in a low concentration (200 wt%). This study shows that coconut husk waste can be used to produce reinforced polymer composites with desirable thermal conductivity and sound absorption characteristics.

***Keywords:*** Coconut coir fiber polymer, vacuum infiltration, composite properties.

## INTRODUCTION

Coconut coir fibers (CFs) are waste materials obtained from coconut husks. In general, coconut husks are used to produce charcoal, handicrafts, mosquito coils, and firewood. Brown CFs comprise lignin (45.84%), cellulose (43.44%), hemicellulose (0.025%), pectin, and other compounds (0.03%). CFs are low cost and can be used to make various products, such as doormats, sports mats, house floor brooms, spring bed mattresses, and car seats (Mir and Bawa 2018; Delarue 2017). In addition, the multiple layers and pores present in CFs allow them to absorb sound. Thus, they can be used to control the noise pollution from outdoor sources such as machines and other sound propagation systems, as noise pollution can have a negative effect on human life (Zulkarnain and Noret al 2010). Moreover, coconut waste can be used for bioenergy in the form of firewood as well as a fuel for small-scale electricity production, industrial heating, cooking, and household products (Obeng et al 2020). Finally, cement hollow blocks reinforced with CFs and coconut shells are lightweight and have higher average load-bearing capacity, stress, and compressive strength, and better thermal insulation properties than commercial concrete hollow blocks (Ganiron et al 2017).

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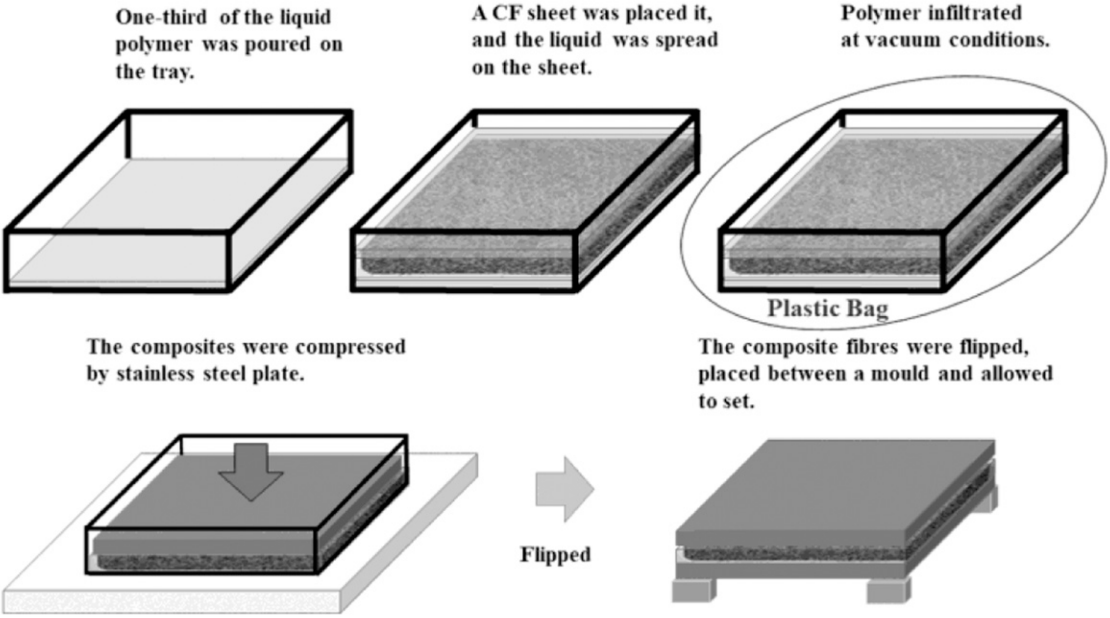

Figure 1. Schematic of the proposed procedure for fabricating natural fiber/polymer composites.

Polymers can be classified into three groups: thermoplastics, thermosetting polymers, and elastomers. Thermosetting polymers form a cross-linked structure during the curing process; however, they cannot be reshaped by heating. The choice of the thermosetting process used, such as compression molding, transfer molding, pultrusion, hand lay-up, and filament winding, depends on the thermosetting behavior of the polymer in question. The most commonly used polymers are epoxies, polyesters, phenols, and polyimides. Elastomers consist of natural or synthetic materials that exhibit large elastic elongations and can be either thermoplastic or thermosetting in nature. Synthetic elastomers are polymers synthesized from petroleum by-products, which have good thermal stability and high resistance to oils and oxidization. Silicon rubbers are widely applied in various industries, such as automotive, medical devices, insulators, and seals.

A literature review showed that the process of producing polymer composites reinforced with natural fibers, such as silicone rubber (SIR) reinforced with natural nanoparticles (pomegranate peel powder) and an ultrahigh molecular weight polyethylene fiber blend, used a mechanical mixer at a speed of 360 rounds/minute at a low pressure (approximately 10 bar). The mixture was then poured into a mold and allowed to set for 6 h (Salih et al 2019). A two-dimensional carbon fiber–reinforced polymer composite with desirable properties was prepared using preformed carbon fibers through molding heating, and infiltration under vacuum conditions. Hot compression molding results in uniform infiltration inside the composites (Ma et al 2020). Moreover, plant fiber/polyester and hybrid fiber/polyester composites, in which natural fibers such as hemp, jute, banana, sisal, coir, kenaf, bamboo, rice, oil palm, and flax were used as reinforcing materials within the polyester matrix, have been synthesized in the layup configuration through curing. These composites exhibit good fracture properties (Haghdan and Smith 2015).

The aim of this study was to increase the income of farmers in developing countries by producing new products from coconut husk waste. Liquid polymer infiltration was performed under vacuum conditions to prepare natural fiber/polymer composites using CF sheets as the matrix and unsaturated polyester (UPE) or silicone rubber

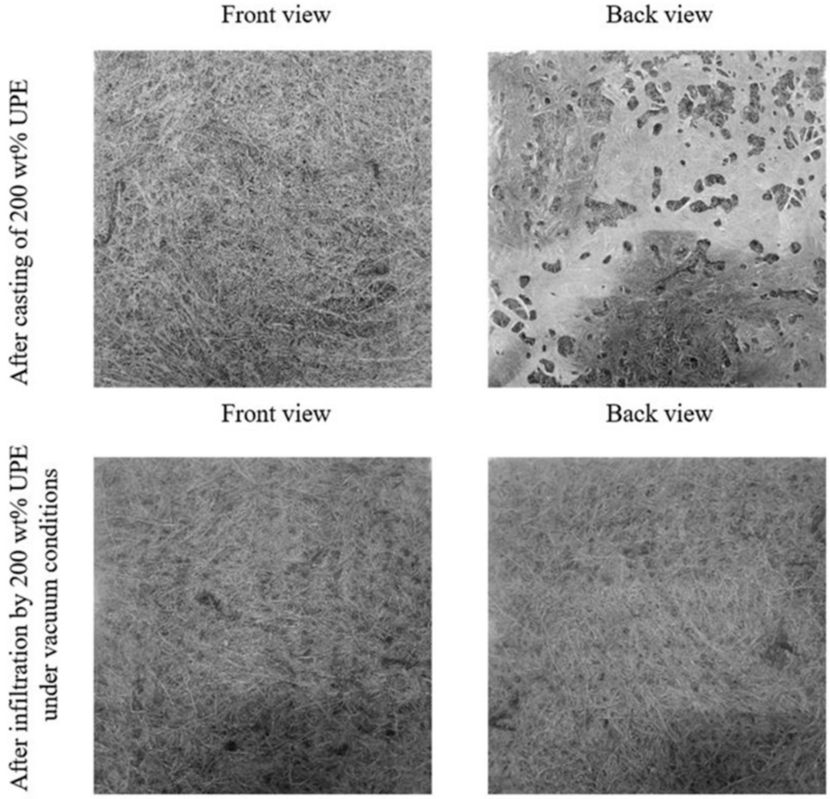

Figure 2. Comparison of coir fiber (CF)/unsaturated polyester (UPE) composites formed by simple casting and the infiltration method.

(SIR) as the reinforcing material. The thermal, mechanical, and sound absorption properties of the fabricated composites were evaluated and compared.

## MATERIALS AND METHODS

### Materials

***Coconut coir fiber matrix.*** The CFs were obtained from the husk of the coconut fruit, which is a waste material, after the extraction of the useful material, and has a density of 0.97-1.27 g/cm$^3$ and a thermal conductivity of 0.0382 W/m·K. CF sheets with a thickness of 12-15 mm were used. The sheets had a length of 200 mm and width of 200 mm.

***Reinforcing polymers.*** UPE (Rungart Co., Ltd., BKK, Thailand) with a density of 1.13 g/cm$^3$ and thermal conductivity of 0.2 W/m·K was used as thermoset plastic. The curing process was performed by adding methyl ethyl ketone peroxide (1 wt%) and cobalt octoate (0.2 wt%) under slow stirring, respectively. In addition, SIR (Rungart Co., Ltd., Thailand) with a density of 0.97-1.27 g/cm$^3$ and thermal conductivity of 0.2 W/m·K was used as the elastomer. During polymerization, the catalyst was embedded in a concentration of 2 wt%.

### Preparation of Natural Fiber/Polymer Composites

Figure 1 shows a schematic process used for forming the natural fiber composites by vacuum infiltration. The composites were prepared using molds made from a sheet (thickness of 2-5 mm) of stainless steel in the form of an open tray. The mold dimensions were 200 × 200 × 25.4 mm

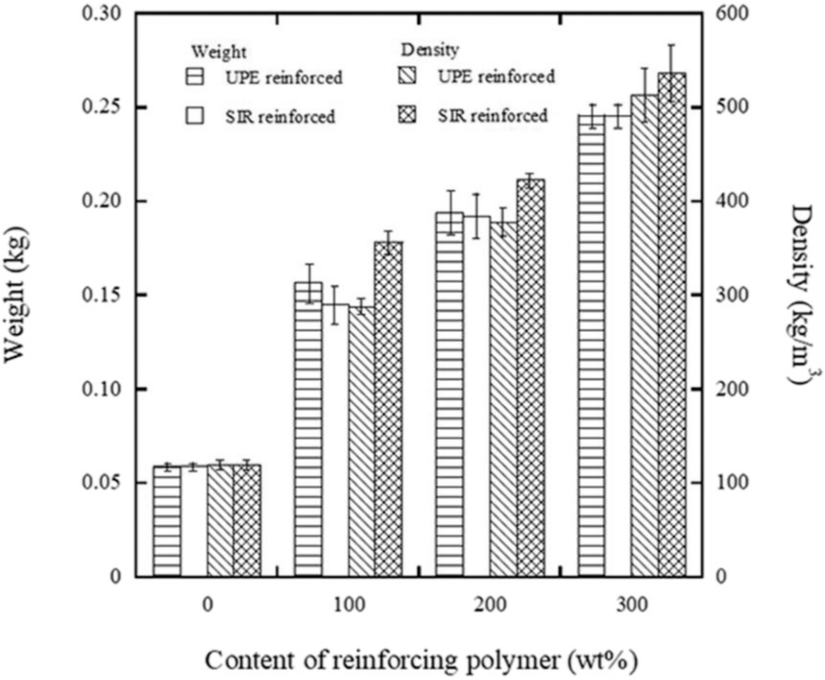

Figure 3. Weights and densities of various coir fiber (CF)/polymer composites.

(height). In step 1, UPE or SIR was added to the neat CFs in a concentration of 200, 300, or 400 wt % (mass of the CF sheets was 0.05 kg). In step 2, one-third of the liquid polymer was poured onto the tray. Thereafter, a CF sheet was placed on it, the liquid was spread on the sheet, and the bubbles present were brushed away. In step 3, using a plastic bag (polypropylene) as cover, suction was performed for 15-60 min with a vacuum pump to ensure that the polymer infiltrated the void spaces present in the CFs. In step 4, to ensure that the composite fibers exhibited a uniform shape, they were compressed using a stainless steel plate for 15-30 min. Finally, the composite fibers were flipped, placed between a stainless steel plate, and allowed to set. Infiltration under a vacuum ensured that the liquid polymer did not solidify at the bottom of the mold.

A comparison of CF/UPE composites formed by simple casting and the proposed infiltration method are shown in Fig 2. It was found that some of the UPE had precipitated on the backsides of the fibers of the CF/200 wt% UPE composite. However, the UPE had infiltrated the CFs, and the composite fibers filled the porous structure of the natural fibers. The weights and densities of the various composites are shown in Fig 3. These results confirmed that the addition of the polymers to the reinforced material resulted in increases in the weight and density of the neat CFs. Moreover, the morphology and surface revealed the infiltrated behavior of UPE and SIR in the CFs and are shown in Fig 4.

## Characterization Tests

The thermal conductivities (*K*-value) and insulation characteristics (*R*-value) of the composites were measured using a heat flowmeter designed specifically for insulating materials in accordance to ASTM C518 standard. Flexural tests were performed on the composites using the simple beam method with center-point loading (ASTM C293 standard) to determine their modulus of rupture (MOR) values. Impedance tube measurements were performed at low and high frequencies (50-6400 Hz) to determine the sound absorption

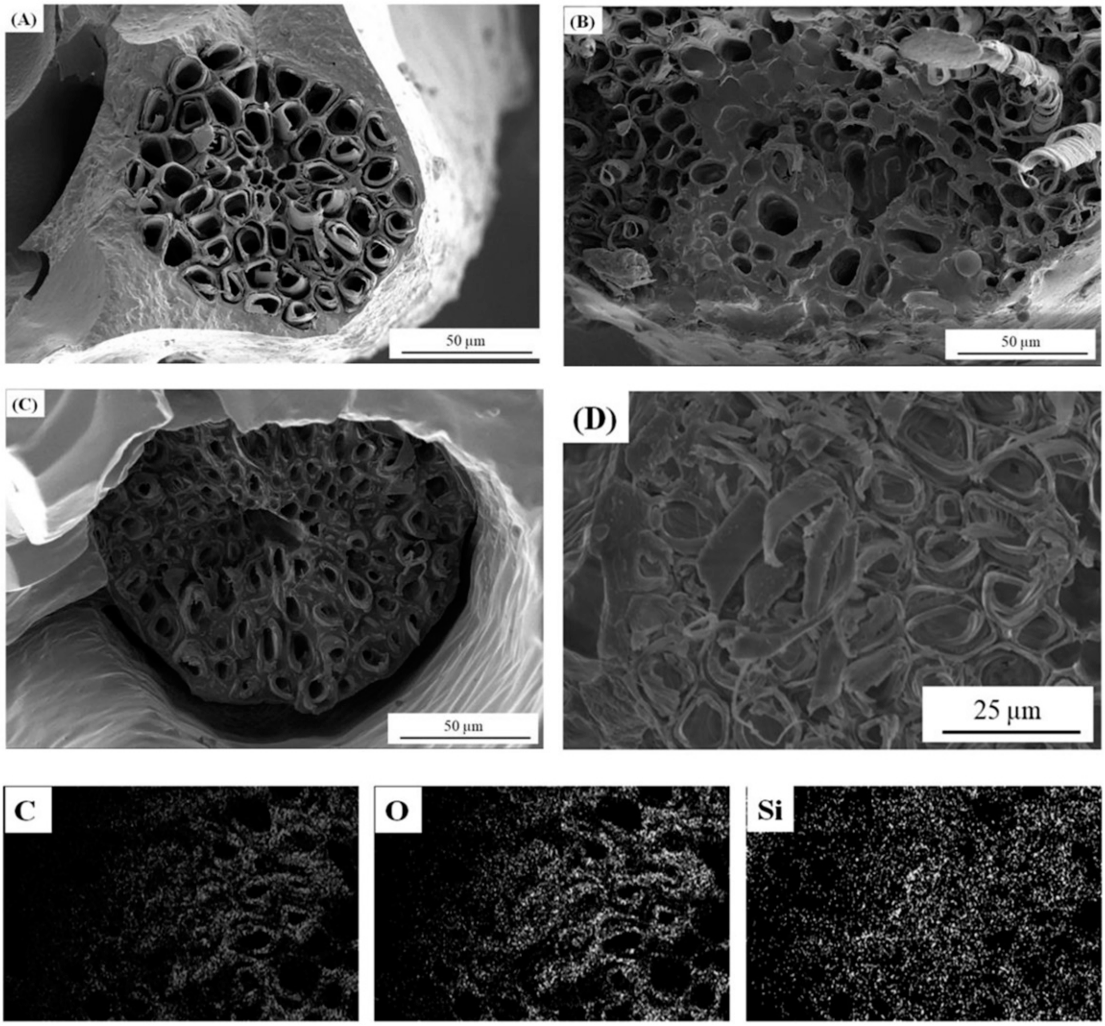

Figure 4. Morphology and surface properties of (A) coconut coir fibers, (B) coir fiber (CF)/300 wt% unsaturated polyester (UPE) composite, (C) CF/300 wt% SIR composite, and (D) EDX spectrum of CF/300 wt% SIR composite.

coefficient (α) and noise reduction coefficient (NRC) values of the composites as described by ISO 10534-2 standard. The diameters of the samples used for these tests were 30 and 100 mm. An average of five samples corresponding to each formulation were used for the tests.

## RESULTS AND DISCUSSION

### Thermal Properties

The results of the thermal conductivity (*K*-value) and insulation characteristic (*R*-value) measurements of the polymer-reinforced CF composites are shown in Fig 5. The thermal conductivities of the CF/UPE and CF/SIR composites depended on the amount of the polymer added. Furthermore, the thermal conductivities of the composites filled with SIR were higher than those of the composites filled with UPE. The highest *K*-value was observed at CF/400 wt% SIR composite (0.0683 W/m·K); this value was 78.80% greater than that of neat CFs. However, the results of the *R*-value (insulation characteristic) measurements indicated that the insulation

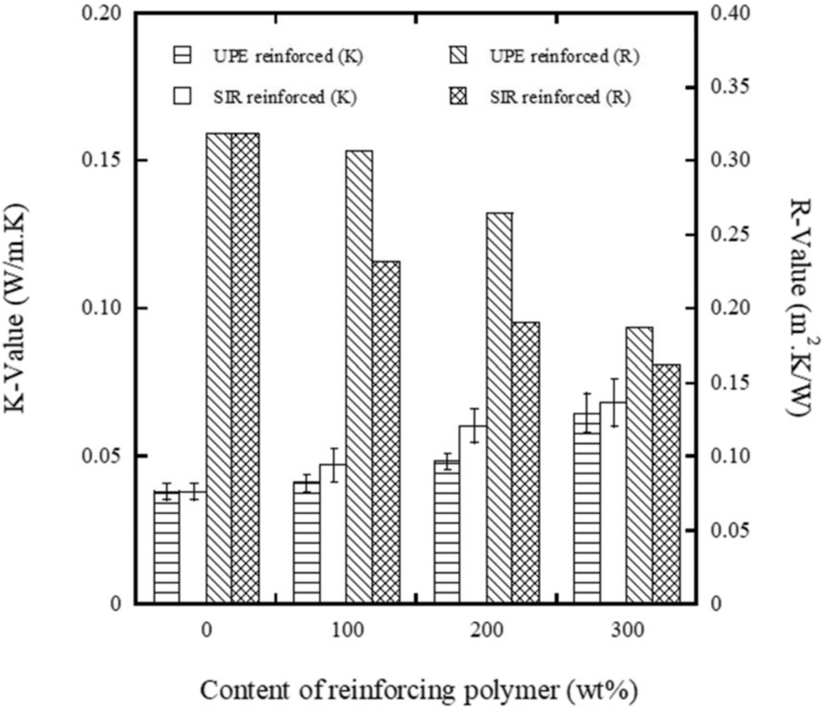

Figure 5. Thermal conductivity (K-value) and insulation (R-value) characteristics of coir fiber (CF)/polymer composites.

properties became poorer as the amount of the polymer added was increased. Furthermore, the UPE-filled composites showed better insulation properties than SIR-filled composites. The maximum *R*-value was observed in the case of the neat CFs.

Thus, the type and quantity of the polymer added had a strong influence on the thermal conductivity of the CF/polymer composites because UPE and SIR were better thermal conductors than neat CFs. Suffice to say that, the polymer infiltrated and was uniformly dispersed within the CF matrix, resulting in an increase in the thermal conduction pathways.

## Flexural Properties

Figure 6 shows the results of the flexural tests. The MOR tended to increase with an increase in the amount of UPE added. The highest MOR value was observed in the case of CF/400 wt% UPE (5.4317 MPa); this value was 28.37% greater than that of the neat CFs. On the other hand, although the MOR of the CF composites containing SIR increased after the addition of 200 and 300 wt% SIR, it was the lowest for the sample reinforced with 400 wt% SIR. Figure 7 shows the morphology of composites. It is likely that the CF/SIR composites are elastomers, and thus did not exhibit good flexural properties, in contrast to the CF/UPE composites; in this case, UPE had a positive effect on the flexural strength of the CFs.

## Noise Absorption Properties

Figure 8 shows the results of the sound absorption coefficient (α) measurements performed at low and high frequencies (50-6400 Hz). It can be seen that the absorption coefficient was higher than 0.5 in the case of the neat CFs (4435-6400 Hz), CF/300 wt% SIR (1300-2375 Hz), CF/400 wt% SIR (1880-3400 Hz), CF/400 wt% UPE (2700-4250 Hz), CF/200 wt% SIR (2700-6400 Hz), CF/300 wt% UPE (3000-6400 Hz),

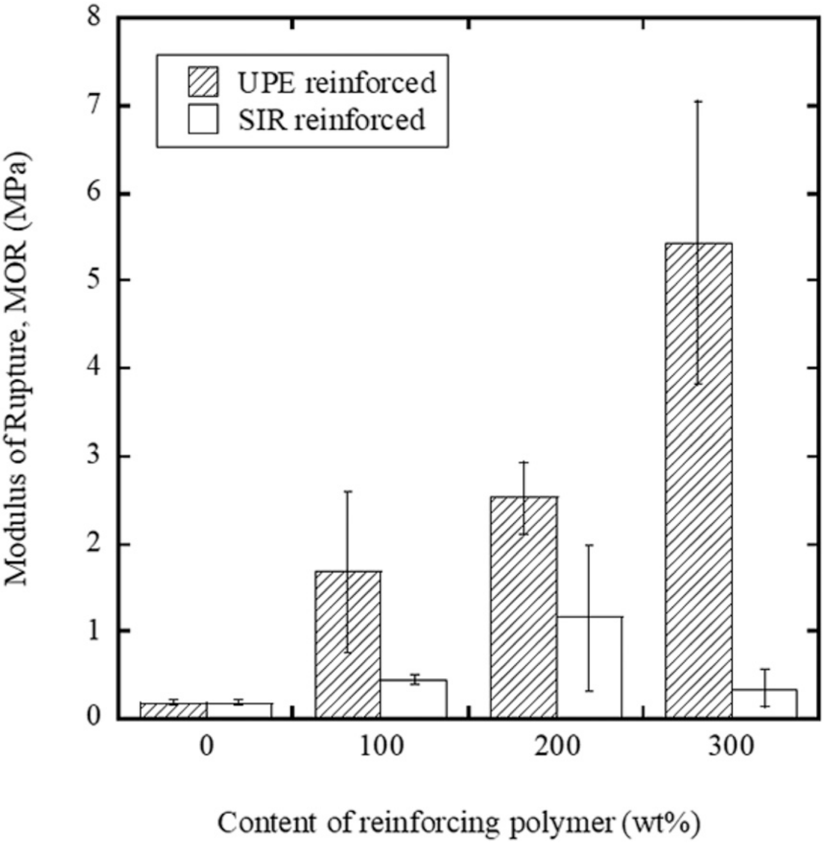

Figure 6. Modulus of rupture (MOR) values of various coir fiber (CF)/polymer composites.

and CF/200 wt% UPE (3000-6400 Hz). This means that the infiltration of the CFs by UPE and SIR resulted in an increase in their sound absorption coefficient at frequencies greater than 2000 Hz.

The NRC values displayed in Fig 9 indicate the ability of the fabricated composites to absorb sound as calculated as the average arithmetic value of their sound absorption coefficients at four frequencies (250, 500, 1000, and 2000 Hz). The composites containing 300 and 400 wt% SIR exhibited higher values than those of the neat CFs and the CF/200 wt% SIR composites. Further to this, the composites reinforced with 300 and 400 wt% UPE exhibited poorer sound absorption characteristics, probably because they tended to reflect the incident sound. Finally, the NRC values of the CF/200 wt% SIR and CF/200 wt% UPE composites were similar.

## CONCLUSIONS

The study shows that reinforced polymer composites can be manufactured using coconut fiber. The material properties of neat CFs as well as those of composites formed by the addition of polymers to them were assessed through thermal, flexural, and sound absorption tests. The addition of polymers to the CF matrix had a significant effect on its material properties. Increase in the polymer content caused increase in weight and density of the CF/polymer composites. The highest thermal conductivity was observed for CF/400 wt% SIR (0.0683 W/m.K), which was 78.80% greater than that of the neat

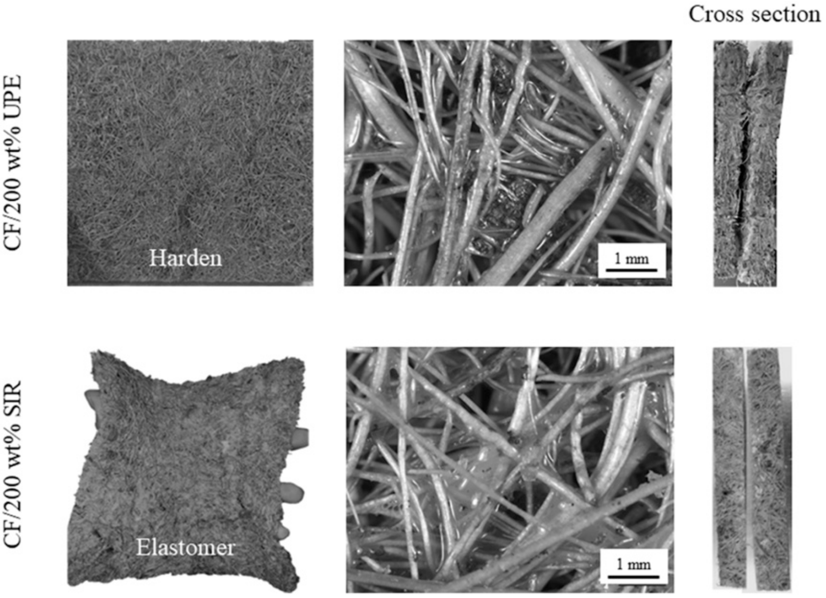

Figure 7. Morphologies of coir fiber (CF)/200 wt% unsaturated polyester (UPE) and CF/200 wt% SIR composites.

CFs. The second highest value was CF/400 wt% UPE (0.0648 W/m.K, 69.63% greater than that of the neat CFs). Thus, SIR polymer increased the thermal conductivity of the CFs. By contrast, the neat CFs were found to be a better insulator as than the CF/UPE and CF/SIR composites. UPE polymer affected the MOR of the neat CFs. The CF/SIR composites showed lower MOR values than those of the CF/UPE composites. UPE resulted in brittle CF composites, whereas SIR resulted in ductile CF composites.

The CF/polymer composites showed good sound absorption characteristics, and their sound absorption coefficient values were higher than 0.5 at high frequencies. Both CF/300 wt% SIR and CF/400 wt%

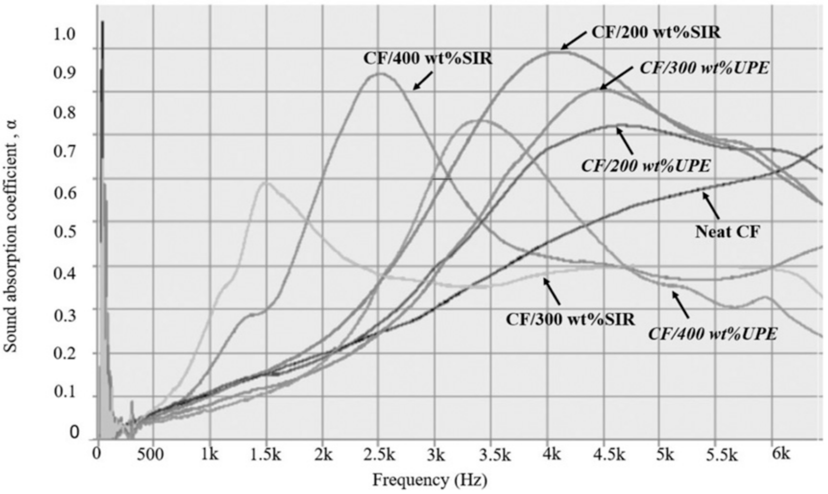

Figure 8. Sound absorption coefficient (α) values of various coir fiber/polymer composites.

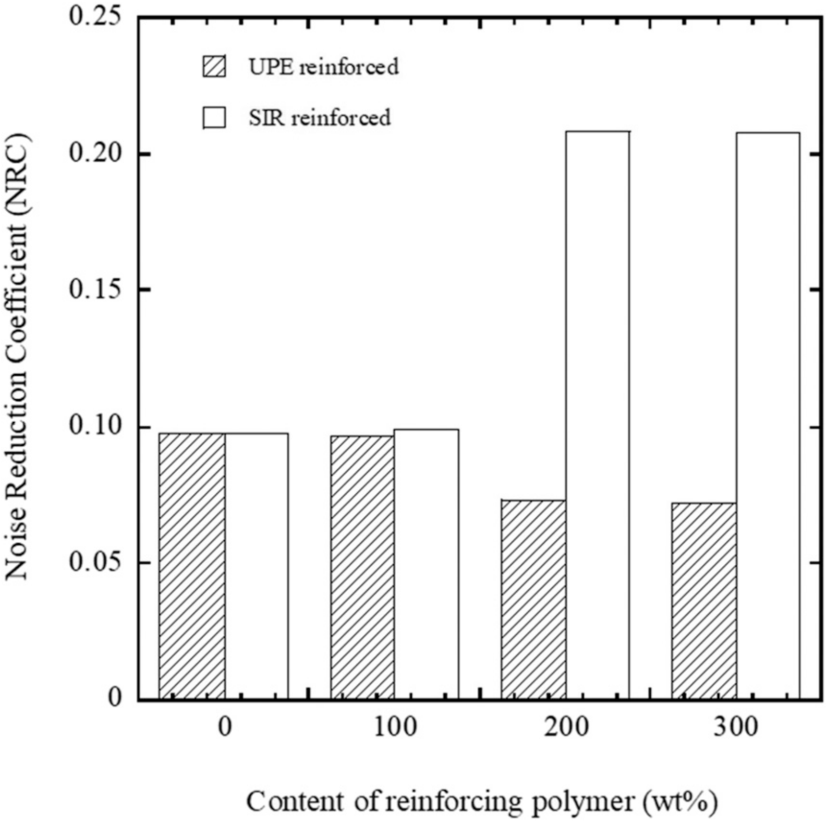

Figure 9. Noise reduction coefficient (NRC) values of various coir fiber/polymer composites.

SIR exhibited absorption coefficients greater than 0.5 for frequencies of up to 2000 Hz. Thus, the SIR-reinforced composites are suitable for use as sound absorption materials, whereas the UPE-reinforced composites are suitable as sound reflection materials.

This study shows that the manufactured coconut fiber–reinforced polymer composites exhibit desirable thermal conductivity (thermal conductors or insulators) and sound absorption (sound absorbers or reflectors) characteristics. Generally, the properties of the product depend on the type and amount of the reinforcing polymer added as well as the thickness of the CF sheets used.

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## REFERENCES

Delarue JA (2017) Tensile strength of coconut fiber waste as an organic fiber on concrete. Civil Environ Res 9(11):7-11.

Ganiron TU, Ucol-Ganiron NU, Ganiron T (2017) Recycling of waste coconut shells as substitute for aggregates in mix proportioning of concrete hollow blocks. World Sci News 77(2):107-123.

Haghdan S, Smith GD (2015) Natural fiber reinforced polyester composites: A literature review. J Reinf Plast Compos 34(14):1179-1190.

Ma Y, Wang J, Zhao Y, Wei X, Ju L, Chen Y (2020) A new vacuum pressure infiltration CFRP method and preparation experimental study of composite. Polymers (Basel) 12:419.

Mir IA, Bawa ER (2018) Utilization of waste coconut coir fiber in soil reinforcement. Int J Civil Eng Technol 9(9): 774-781.

Obeng GY, Amoah DY, Opoku R, Sekyere CKK, Adjei EA, Mensah E (2020) Coconut wastes as bioresource for sustainable energy: Quantifying wastes, calorific values and emissions in Ghana. Energies 13:2178.

Salih SI, Olewi JK, Al HM (2019) Investigation the properties of silicone rubber blend reinforced by natural nanoparticles and UHMWPE fiber. Int J Mech Eng Tech 10(1):164-178.

Zulkarnain RZ, Nor JM (2010) Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel. Am J Appl Sci 7(2):260-264.