Characterization of the density and mechanical properties of corn husk fiber reinforced polyester composites after exposure to ultraviolet light

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Abstract

The best properties of corn husk fiber (CHF)/polyester composites are still being investigated and developed for the expansion of applications of CHF composites. The focus of this study was to evaluate the physical properties, tensile strength, and flexural properties of CHF/polyester composites after exposure to ultraviolet (UV) light. The addition of CHF 15, 20, 30, 40, and 50% (volume fraction) was used as fillers and polyester resin as the binder. The composites were made by hot press technique. Density, tensile strength, and bending tests were carried out to evaluate the developed composites, and the fracture morphology was analyzed by scanning electron microscopy. The results reveal that after exposure to UV light, the density, tensile strength, and flexural strength of the composite decreased compared to the composite before UV exposure; because UV has caused the interface bond between the resin–CHFs to be less strong. Increasing the number of fibers causes the number of individual fibers to smaller and shrink in the composite due to the evaporation of the water content in the composite.

1. Introduction

Cornhusk fiber has a great potential to be developed as a filler for polymer composites because of its advantages such as lightweight, porous structure, tensile strength, and good thermal resistance. Researchers continue to develop the properties of corn husk fiber (CHF) (Yılmaz *et al* 2014, Sari *et al* 2018). Sari *et al* (2018) has reported that applying 0.5%–8% NaOH chemical treatment to the CHF surface has increased the tensile strength of CHF by about 77.7% and the thermal properties of the CHFs are getting better. Yılmaz *et al* (2014) have reported that CHF treated with 0.4% Pentopan® mono BG enzyme has a breaking tenacity of 9.44 cN tex^{-1}, and an initial modulus value of 282 cN tex^{-1}. The reinforcement of CHFs in polymer composites in terms of physical, mechanical, and thermal properties has also been investigated and reported by several researchers (Sari *et al* 2017a, Huda and Yang 2009, Pandecha *et al* 2015; Sari *et al* 2020a). Sari *et al* (2017a) reported that the reinforcement of polyester composite with a volume fraction of CHF from 20% to 60% was found to have a tensile strength of 17–25.73 MPa and a sound absorption coefficient of 0.99. Then, Pandecha *et al* (2015) reported that the thermal properties of CHF composites with urea formaldehyde resin as a matrix are technically and financially suitable as an insulation material rather than fiberglass composites. Further, meanwhile, Huda and Yang (2009) reported that except for tensile modulus, the mechanical properties of mechanically split cornhusks (MSH)–polypropylene (PP) are inferior to jute-PP composites.

The MSH–PP composites have 155% less modulus of elasticity, 51% less tensile strength, 11% less flexural strength, and 71% less impact resistance.

Most of the previous studies that have reported on CHF composites have focused on the mechanical properties and sound absorption of composites, however, there is very little research related to the effects of the external environment on the physical and mechanical properties of composites. Sari *et al* (2020b) has reported that the compressive and impact strength of composites after immersion in water for 24 h and 72 h is lower compared to composites without immersion. After being submerged in water for 24 h, the tensile strength and elastic modulus of the composites increase when the fiber volume fraction is 20%–30%. Furthermore, Sari and Suteja (2020) reported that increased CHF content in resin and a longer immersion time are prone to lower mechanical properties. The lowest water absorption (2.39%) was detected in 20% CHF/80% PE composite immersed for 6 d. However, to the best of our knowledge, information, or investigations related to the physical and mechanical properties of CHF composites after exposure to ultraviolet (UV) have not been reported. In designing polymer-based products for applications in the outdoor environment, we must know the performance of the resulting composites; this is because the sunlight, humidity, microbial growth, and others are known to reduce the properties of the polymer and composite materials (Lv *et al* 2015, Yang *et al* 2015, Ammar *et al* 2017, Ayu *et al* 2020, Asyraf *et al* 2020, Sabaruddin *et al* 2020, Abral *et al* 2021, Ilyas *et al* 2021b).

Therefore, this study aims to evaluate the density, tensile strength, and flexural strength of CHF composites after exposure to UV light. The effect of adding fiber content in composites is the focus of this study to quantify the properties of the density, tensile strength, and flexural properties of composites after exposure to UV and compared with composites before exposure to UV. The fracture morphology has also been characterized using scanning electronic microscopy (SEM).

2. Materials and methods

2.1. Materials

CHF has been extracted from corn husk waste that has been collected from Mawun Village, Central Lombok. Indonesia.

Polyester resin used as a binder has a flexural and tensile strength of 500 kg mm^{-2} and 8.8 kg mm^{-2}, a density of 1.9 g cm^{-3}, a melting temperature of 110 °C–200 °C and a viscosity of 6–8 (25 °C) (Sari *et al* 2017b, Sari *et al* 2020b).

Methyl–ethyl ketone peroxide catalyst has a molecular mass of 210.22 g mol^{-1}, water-solubility, 6.53 g l^{-1} at 20 °C, and vapor pressure, 0.01 mm Hg at 20 °C. The percentage of peroxide was 1% of polyester by mass.

2.2. Extraction of fibers

The collected corn husks are soaked in water for two weeks for the decomposition process and make it easier to extract fibers (Sari *et al* 2016). Bundles of CHFs were taken by combing the corn husks using a wooden brush, followed by drying under the hot sun until dry and then cutting 2 cm in length. The fiber diameter average of 0.133 ± 0.03 (mm). The photo of CHF is shown in figure 1.

2.3. Alkali treatment

In this process, CHFs are immersed in a sodium hydroxide solution with a concentration of 8% NaOH for 120 min. They were rinsed with distilled water four times and then dried under the hot sun to dry and stored in storage boxes, ready to be used as composite fillers. The chemical composition of CHF as display in the table 1.

2.4. Composites fabrication

Specimens were prepared using a hot press technique. Cornhusk fibers (fiber length of 2 cm) mixed with polyester resin are formed and pressed at a temperature of 107 °C with a pressure of 4 MPa for 4 min, and followed by cooling at room temperature with a pressure of 3 MPa (~64% relative humidity). Five types of composites were produced for each of the different types of tests including tensile strength, flexural strength, and SEM. Each specimen was labeled with the percentage of CHFs, as seen in table 2.

2.5. UV irradiation

The UV irradiation process is carried out according to the ASTM standard D4329-99. In this process, all composite specimens are placed on glass so that all parts of the specimen can be exposed to UV light. The artificially accelerated UV exposure cycle was carried out on the LUV-II accelerated weathering tester (Pushen, Shanghai) with an automatic spray system and heating equipment. All composite specimens were exposed to 60 W short wave UV light at 50 °C, and accelerated to last up to 1000 h.

Figure 1. CHF.

Table 1. The chemical of CHFs (Sari *et al* 2018).

CHF	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Raw	46.15	33.79	8.92
Treated 8% NaOH	62.87	13.62	5.55

Table 2. Nomenclature of composites.

Codes	
SFV20	Polyester composites with a volume fraction of CHF 20%.
SFV30	Polyester composites with a volume fraction of CHF 30%.
SFV40	Polyester composites with a volume fraction of CHF 40%.
SFV50	Polyester composites with a volume fraction of CHF 50%.
SFV60	Polyester composites with a volume fraction of CHF 60%.

2.6. Characterisation of composites

2.6.1. Density test

The density of the composites was checked using the mass and volume of the specimen. The density of the composites has been determined using a liquid displacement method based on the Archimedes principle. The composite volume is estimated based on the mass of volume transferred when the sample is immersed in distilled water. CHFs composite samples were weighed using an analytical weighing to the nearest 0.0001 g. The simple relationship used to evaluate the density (ρ) of composites is presented in equation (1) (Sari *et al* 2017a, Singh and Sharma 2020)

$$\rho\left(\mathrm{gcm}^{-3}\right) = \frac{\text{mass}}{\text{volume}}. \tag{1}$$

2.6.2. Mechanical test

The bending and tensile properties of the composites were carried out according to the test standards ASTMD-790 (ASTM D790-00) and ASTMD-3039 (ASTM D3039-01), respectively. The tensile and bending tests were carried out by the Instron 5500R testing machine at room temperature and the tensile speed of 0.5 mm min^{-1}.

2.7. SEM

The fracture surfaces of the composite samples were characterized using SEM with high-resolution field emission type s50. SEM is operated at an emission current of 47 μA and an accelerating voltage of 1–5 kV. The fracture surface of the specimen was coated with gold about 50 nm in thickness.

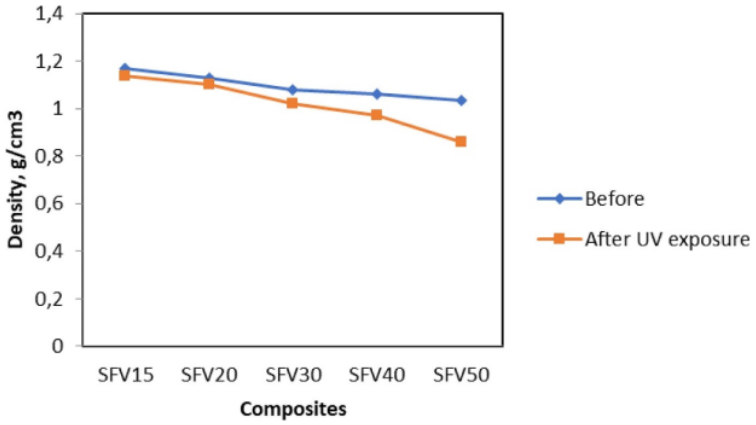

Figure 2. Density of composites before and after exposure to UV light.

Table 3. Porosity of CHFs before and after alkali treatment 8% NaOH (Sari *et al* 2016).

Panel of CHF	Thickness (t) (mm)	Density (kg m^{-3})	Porosity (ε)	Airflow resistivity (R) (Pa.s m^{-2})	Tortuosity (α_∞)
Raw	20	344 ± 0.01	0.88 ± 0.02	1375 ± 332	1.06 ± 0.01
Treated 8% NaOH	20	615 ± 0.08	0.77 ± 0.01	11 118 ± 462	1.15 ± 0.01

3. Result and discussion

3.1. Density analysis

Figure 2 shows the decreasing trend in the density value of the composites before and after UV exposure. The lowest density of the SFV50 composite was 1.035 (g cm^{-3}) than other composites in this study. The decrease in the density value is due to the addition of fibers in the resin. The difference in density values of CHFs ($\rho = 0.61$ g cm^{-3}) and resin ($\rho = 1.025$ g cm^{-3}) (Sari *et al* 2016, 2017a) may cause the density of the composites to decrease. The presence of many pores and lumens in CHF (Sari *et al* 2016) has been suggested to increase with the addition of fibers; this may be suspected to be the cause of the lower composite density. The values of porosity is listed in table 3.

Furthermore, the density of the composites decreased after exposure to UV light from 1.14 g cm^{-3} to 0.86 g cm^{-3} which may be associated with changes in mass and volume of the composites during the UV cycle process; because the small amount of water in the fibers evaporates during UV exposure, consequently the fiber mass in the composite decreases as the number of fibers increases and the resin is less able to protect the fibers from UV entering the fiber–resin interface through the resin pores, and finally the composite density decreases *slightly*.

Lyu *et al* (2019) have stated that UV radiation affects the degradation rate with wavelength, where a shorter wavelength can cause the yellow index (YI) to increase below 306, 326, and 354 nm, and slow down below 452 nm. The effects of wavelength were clear for YI growth and loss of UV absorber. The loss of UV absorbers increased with longer exposure times and higher light intensity resulted in a higher rate of UVA loss per time. Furthermore, the higher light intensity caused faster yellowing growth.

3.2. Tensile strength analysis

Figure 3(a) shows that before exposure to UV light, the tensile strength of the composites increased when the fiber content was increased from 15% to 30% and decreased when the fiber content was above 30%. An increase in the tensile strength value when the fiber content was raised 15% to 30% was reported by Sari *et al* (2020a) where the strength increased because the interface bond between the fiber-resin formed was quite strong. The strength decreased due to more number and the less strong binding of fibers by resin (Diyana *et al* 2021, Tarique *et al* 2021, Ilyas *et al* 2021b). This might also be the reason of the composites' tensile strength increment when the fiber content was increased from 15% to 30%.

Furthermore, figure 3(a) also shows that after exposure to UV, the tensile strength of the composites tended to decrease than before exposure to UV. It was due to the evaporation of certain amount of water in

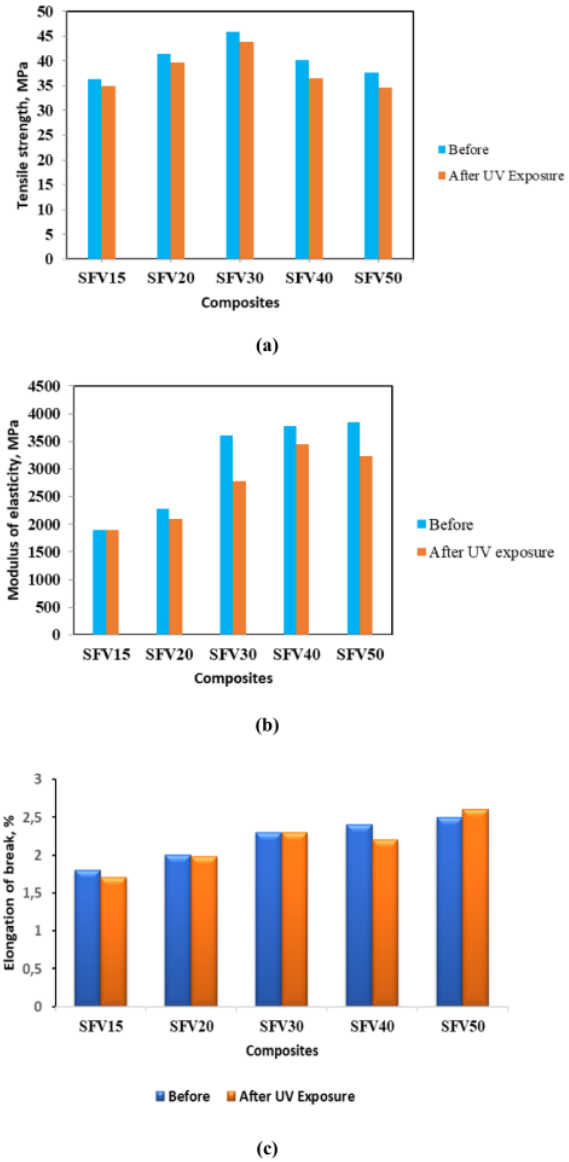

Figure 3. (a) Tensile strength, (b) modulus of elasticity, and (c) elongation of break of CHF composites before and after exposure to UV light.

the fibers and when the fibres was dried up, the interface bond between the corn husk–polyester fibers became less dense, resulting in low strength. This reason was also supported of the investigation by Sari *et al* (2020b) that reported the large amount of water absorbed by the composites can reduce the interface bond between CHF and PE, and was responsible for the damage. The swelling of the composite increased as the fiber content was increased from 20% to 60%. It might also explain the low strength observed in the studied composites. The elastic modulus of the composite before exposure to UV (see figure 3(b) was found to also increase with the increase in the number of CHFs. The highest modulus of elasticity was obtained from the SFV50 of 3850.37 MPa. This increase was presumably because the CHFs were arranged in polyester. In contrast, the modulus elasticity value of the composite was slightly decreased after exposure under UV with an increasing number of fibers; one might suspect that the composite had decreased in density because UV entered the composite through the fibers and caused a reduction in size. As a result, the fibers became small

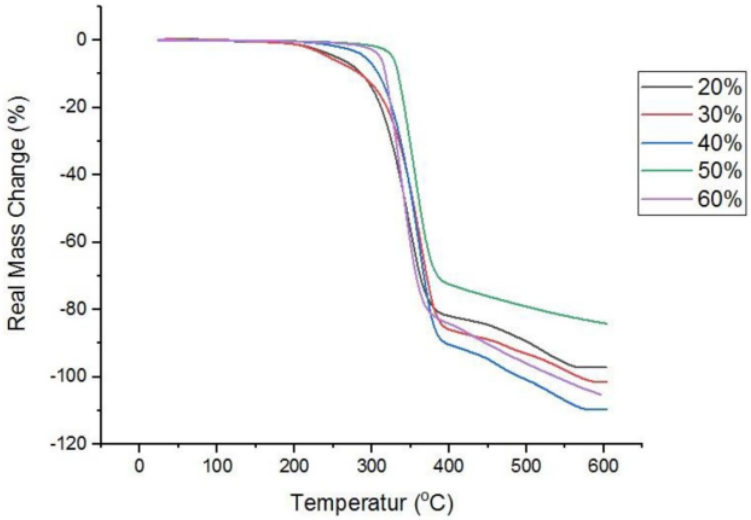

Figure 4. TGA Komposit Serat Kulit Jagung resin polyester.

due to the evaporation of water in the fibers, and consequently producing slight decrement in the resulting modulus of elasticity.

Luo *et al* 2017) stated that the internal strength is very dependent on the density as increased density means an increase in the internal bond strength and thus composite strength. When resins can form bonds with strong CHF, high composite densities can be obtained, conversely, when bonds are formed weak, composite densities are low. Furthermore, Sari *et al* (2020b) have stated that composites with CHF content from 20% to 60% when immersed in water with longer immersion times tend to decrease their mechanical properties; because the interface bond between CHF and PE is reduced; due to water absorption in the composite. Swelling of the composites was found to increase with increasing CHF content. The lowest water absorption was owned by the 20% CHF and 80% PE composites, namely 2.39%. For the composites studied, the matrix has the function of binding the fibers together and acting as a medium in which the externally applied stress is transmitted and distributed to the fibers. Only a fraction of the applied load is supported by the phase matrix. If the number of fibers in the matrix increases, it will limit the mobility of the matrix to wet the fibers completely, as a result, the strength of the adhesive bond between the fibers and the matrix is weak so that the mechanical strength of the composites is small. Conversely, the mobility matrix to wet the fibers is perfect if the number of fibers is small which results in tighter bond strength and high mechanical properties. The thermal stability of the prepared composites as shown in figure 4. The thermogravimetric analysis (TGA) curves in figure 4 can be divided into three stages. In stage 1 (30 °C–270 °C), majority of the mass loss can be attributed to the volatilization of water. The resin also decomposed in this stage. In stage 2 (270 °C–400 °C), CHFs decomposed. Majority of the mass loss occurred during this stage; therefore, the rate of mass loss was particularly rapid in this stage. Finally, material carbonization was the main source of mass loss in stage 3 (400 °C–600 °C).

3.3. Flexural strength analysis

The results of measuring the flexural strength of the composites in this study are shown in figure 5. After exposure to UV, the flexural strength of all composites was lower than that of the composites before exposure. The highest strength of the composite was obtained from the SFV40 specimen of 96.45 MPa. It may be because the stress distribution is evenly distributed to fracture without the fiber's pullout on the SFV40 than for the other composites studied. However, after exposure to UV light, fiber composites experience fiber pullout from the matrix because the interface bonds are less strong than those of the composites before exposure. The results in less bending and tensile properties compared to pre-exposure composites. Besides that, this decrease in flexural strength indicates that the composite after exposure to UV can withstand a lower stress concentration, thus the resulting flexural strength is low. For SFV50 specimens, the flexural strength decreased presumably because the increase in the amount of fiber content in the

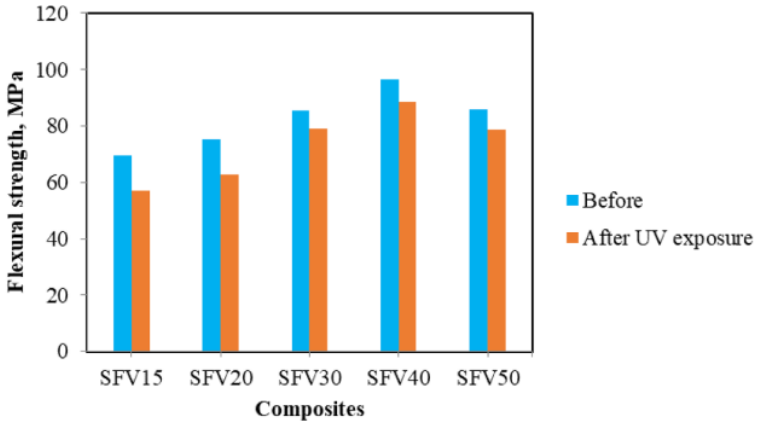

Figure 5. The bending strength of the composites before and after exposure to under ultra violet.

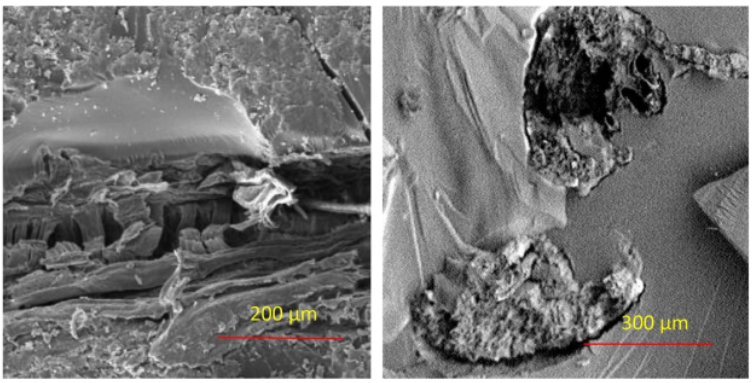

Figure 6. SEM images of SFV30 composites, (a) before. (b) after being exposed under UV.

composite had caused the water content in the composite to evaporate; consequently, the fiber-resin interface becomes weak and consequently the flexural strength is small.

The effect of UV radiation on materials can be seen through changes in the properties of the material, the material becomes brittle, cracks, or even severe erosion. As a result, the material loses its original mechanical properties in terms of tensile, flexural, and impact strength, which has the potential to cause faster service life (Andrady *et al* 1998, Karbhari *et al* 2001). This reason may also answer why the strength, tensile, flexural and impact of the composite studied were lower than before exposure to UV light.

When compared between figures 3(a) and 5, it can be seen that the value of the bending strength of the composite is greater than the tensile strength of the composite, this happens because most composites have a small or large defect in them which serves to concentrate the pressure locally, effectively causing local weakness. When a composite is bent, only the extreme fibers are subjected to the greatest stress, and if the fibers are free from defects, the flexural strength will be controlled by the strength of the intact 'fiber'. However, if the same material is subjected to a tensile force only then all the fibers in the material are at the same stress and failure will begin when the weakest fibers reach their limiting tensile stress. Therefore, the bending strength is generally higher than the tensile strength for the same material.

3.4. Morphological analysis by SEM

The fracture morphological analysis of the tensile test specimen represented by the SFV30 specimen before and after UV exposure is presented in figure 6. Before exposure to UV light the composite specimens showed that the interface bond between corn husk and polyester fibers was quite tight. This supports the reason why

the tensile strength of composites is stronger than composites after exposure to UV. CHF fracture can be seen in the fiber cross section as shown in figure 6(a). Conversely, after exposure to UV (see figure 5(b)), the fracture morphology of the composite showed a cavity between the fiber and resin interfaces confirming that UV had entered the interface and caused the fiber–resin interface to be less dense; it is presumed that UV has caused the residual water content in the fibers to evaporate and the fibers to shrink and eventually the interface bonds loosened, resulting in low strength.

4. Conclusion

The effect of UV light on the density and mechanics of the composites showed that after exposure to UV light, the density and mechanical properties of the composites decreased slightly compared to composites before exposure to UV light. The highest tensile and flexural strengths were obtained from composites before exposure to UV on SFV30 and SFV40 specimens of 45.81 MPa and 96.45 MPa respectively and after exposure the tensile and flexural strength values decreased by 0.44% and 0.95% respectively. -according to. These results indicate that the corn husk-polyester fiber composite is still able to withstand UV rays and is suitable for outdoor applications.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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