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Effect of fish scales on fabrication of polyester composite material reinforcements

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Abstract: Renewable resources are used to create useful, biologically sustainable materials. It has the potential to minimize waste while also challenging existing research and developments. Several researchers have concentrated their efforts on natural fiber composites. Natural fibers include plant, mineral, and animal fibers. In this project fish scales, a bio-waste, were used as a reinforcing agent in polyester/polystyrene for the fabrication of composite materials in the different weight fractions of 0, 6, 7, 9, and 11%, at a constant load of 1 N and temperature of 20 and 26°C. The hand layup technique was used to create the fabrication setup for composite materials. The creep behavior, modulus of elasticity, and stress were studied experimentally.

Keywords: composites, fish scale, polyester/polystyrene, reinforcement

1 Introduction

Continued technological development, consumer expectations, the increasing demand for global resources, and the need for environmental sustainability led to the development of these resources. During the past few decades, the compounds of bio-fibers have undergone remarkable development. As new compounds were created, these materials became increasingly sufficient, and their research and development processes have become intensive and their applications wider [1]. There is an increasing global interest in natural fibers as they cost less, are environmentally friendly, and as their structural

applications are increasing. Bio-fibers such as bird feathers and animal hair have recently drawn the attention of researchers. Fish are among the most abundant aquatic resources and their scales are considered waste. Available research on fish scales are relatively limited [2]. Recently, attention is being paid to composites based on natural fillers due to their many advantages [3–7]. Sathapathy et al. [8] created a composite utilizing small flakes of fish scales and incorporated it into the resin of epoxy. The wear, curing, and corrosion properties of the manufactured composites were investigated, and it was discovered that these composites had lower porosity, improvement in hardness, less tensile strength, and a lesser likelihood of bending than pure polymer. Borah et al. [9] used the hand layup technique for the fabrication of composites and polymer composites reinforced with three weight proportions of fish scales (5, 10, 15 wt%). It was found that composites reinforced with fish scales have engineering applications that improve wear properties. Majhool et al. [10] studied the fortification of epoxy resins with natural hydroxyapatite composites extracted from fish scales, to achieve biocompatibility of the composites as well as to improve their mechanical properties. Flexural and impact tests were investigated and it was found that the optimum filler ratio of natural hydroxyapatite was 10 wt%. This gives the highest ratio of impact and flexural strength when compared to pure epoxy composites. Harahap et al. [11] studied the effect of fish scale powder as a reinforcement of acrylic resin using flexural strength. The results showed that adding 5 and 10% of fish scale powder reduced the acrylic resins' flexural strength. Kumar et al. [12] studied the mechanical characterization of epoxy-based composites and hybrid bio-composite with epoxy resin (CY-230) reinforced with different weight ratios (wt%) of leftover powder (extracted from fish) and chicken feather fiber to enhance the physical and mechanical properties of epoxy composite. Nirmalraj et al. [13] designed and fabricated animal fibers, such as chicken feather and fish scales, and developed composites reinforced with random-oriented flakes obtained from chicken feather and fish scales, using the hand lay-up mechanism. The

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mechanical properties of the composites such as compression, strength, tensile strength, hardness, impact, and water absorption were studied.

In this article, the creep behavior of polystyrene (PS) composite materials reinforced with different weight fractions of fish scales is studied.

2 Experimental

The quality of the new composite materials depended mainly on the raw materials used as well as the processing techniques used to make them.

2.1 Fish scale

The fish scales (carp fish were obtained from local fish markets) were washed eight times with tap water to remove sticky dust, slippery coatings, and dissoluble surface impurities, and to remove the odor from the scales. The scales were dried by exposing them to sunlight for a period of 3 days to remove moisture permanently. After

that, the dried scales were collected and placed in the oven until they became crispy. Then scissors were used to obtain small flakes (approximately 1×6 – 10 mm) from the fish scales as shown in Figure 1. The flowchart in Figure 2 explains the preparation of fish scale flakes, which were used as a reinforcement to PS in several weight fractions.

Figure 1: Fish scales and fish flakes.

Figure 2: Preparation of fish scale flakes.

2.2 Fabrication of composite

The hand layup technique was used to create the fabrication setup for composite materials, which is a widely used technique to fabricate composites and reinforce products. PS granules were dissolved by adding chloroform and mixed with a magnetic stirrer. Then PS was added to the polyester (UP) (mechanical properties of the clear cured casting for UP are given in Table 1) and mixed for 3 h (the ratio of UP to PS is 92:8) [14]. After that, the corresponding hardener (K-6) was added to the mixture in the ratio (10:1) as recommended and mixed for 15 min. The dry flakes of fish scales that were prepared earlier were placed in the mold in the weight fractions of 0, 6, 7, 9, and 11% in the longitudinal direction of the sample. After that, the PS/UP resin mixture is poured over it and left in the mold for 48 h. The molds were placed inside an oven at 50°C for 1 h to eliminate moisture. Figure 3 shows creep samples inside the mold.

Table 1: Clear cured casting mechanical properties for UP

Properties	Test value	Method
Barcol hardness	40	ASTM (D2583)
Tensile strength in (MPa)	70	ISO (527-2)
Breaking elongation	4	ISO (527-2)
Temperature of heat distortion (°C)	78–82	ISO (75-2)
Bending strength (MPa)	110	ISO (178)

Figure 3: Creep samples inside the mold.

Figure 4: Creep testing instrument.

2.3 Creep test

After removing the samples from the mold, the appendages were removed as per the ASTM test methods of creep test (D2990). The creep test is mostly conducted using the creep testing instrument (WP600; Figure 4) at the different temperature ranges of 20 and 26°C during a static condition of load (1 N). The load is applied on the sample for 1 h, then it is lifted and readings are taken without it for another hour.

3 Results and discussion

Creep tests are needed to determine the (long-term) behavior of unidirectional composites; it is essential to provide (long-term) data to estimate the life of composites for design purposes. Five weight fractions of fish scales (0, 6, 7, 9, and 11%) were used as a reinforcement to UP/PS composites in this study at a constant load of 1 N and temperature of 20 and 26°C. The Maxwell approach was utilized to extract the stress and modulus of elasticity from the strain–time curve using curve-fitting techniques, as shown in Figure 5 (spring and dashpot in series) [15].

$$\sigma(t) = \sigma_0 e^{-\frac{\delta_1 \cdot t}{\eta_1}}, \quad (3.1)$$

$$\delta_1 = \frac{\sigma_0}{\varepsilon_1},$$

$$\eta_1 = \frac{\sigma_0}{\tan \beta},$$

Figure 5: Maxwell approach (spring and dashpot in series).

$$\varepsilon^- = \tan \beta = \frac{\Delta \varepsilon}{\Delta t} (1/s), \quad \text{where} \quad \varepsilon = \frac{\Delta L}{L}$$

$$E(t) = \frac{\sigma(t)}{\varepsilon(t)} = \frac{\delta_1 \cdot \eta_1}{\eta_1 + \delta t}, \quad (3.2)$$

$$E(t) = \frac{\sigma(t)}{\varepsilon(t)} = \frac{\delta_1 \cdot \eta_1}{\eta_1 + \delta t} \varepsilon(t) = \frac{\sigma}{\varepsilon_1} + \frac{\sigma}{\eta_1} t.$$

Figures 6 and 7 illustrate creep behavior (strain vs time) for PS reinforced with different weight fractions of fish scales at temperature of 20 and 26°C, respectively. These figures showed creep failure time and strain.

With the increasing fish scale percentage, the modulus of elasticity increased significantly (Figures 8 and 9). The scale, shape, and interfacial adhesion between the filler's surface and the matrix all play a role in the increase in elasticity. After this percentage, up to 7%, forces are weak. This is insufficient to form the necessary bond between the matrix and the filler. This may be attributed to a higher concentration of filler particles agglomerating. Therefore, the stress can easily be transferred between the reinforcement and the matrix polymer due to the weak bonds, as shown in Figures 10 and 11, for

Figure 6: Strain versus time for UP/PS reinforced by different fish flakes weight fractions at 20°C.

Figure 7: Strain versus time for UP/PS reinforced by different fish flakes weight fractions at 26°C.

Figure 8: Modulus of elasticity for UP/PS reinforced with fish flakes for different weight fractions at 20°C.

Figure 10: Stress versus time for UP/PS reinforced with fish flakes for different weight fractions at 20°C.

Figure 9: Modulus of elasticity for UP/PS reinforced with fish flakes for different weight fractions at 26°C.

Figure 11: Stress versus time for UP/PS reinforced with fish with different weight fractions at 26°C.

20 and 26°C, respectively. At a temperature of 26°C, it was noticed that all samples reinforced with fish scales failed at different times as shown in Figure 12. Hence UP materials have high ductility, as shown in Figure 7. At a weight fraction of 0%, it has the highest strain, then it decreases at 7% and increases at the rates of 9 and 11% due to the effect of increasing temperature, which led to an increase in the strain in a homogeneous amount. Figure 13 represents a comparison between the strain parameters (where ε_1 is the instantaneous extensions [Maxwell element],

and ε_2 is the creep Kelvin element that are shown in Figure 14) and the different weight fractions with temperature of 20 and 26°C. The significant effect of temperature on the strain parameters was observed in this figure, where the mixing rate of 0% recorded the highest strain parameters. Then these parameters decreased while the weight fraction increased until it reached 7%. Then it rose again at 11% when the percentage of fish scales was increased.

Figure 12: Samples that failed at 26°C.

Figure 14: Creep behavior of UP/PS at constant weight 1 N and 20°C.

Figure 13: Comparison between 20 and 26°C of UP/PS creep behavior at different weight fractions.

4 Conclusion

The aim of this study is to look into the effects of the creep behavior of fish scale reinforcement on PS composites. A summary of this study's conclusions is as follows.

1. The creep behavior of PS was enhanced and reinforced by the addition of appropriate percentages of fish scales.
2. Higher temperatures reduce PS's tensile strength and speed up creep failure.

3. PS reinforced with fish scales had a high modulus of elasticity percentage.
4. The highest strain was obtained with a 7% weight fraction at 26°C and at 800 s.
5. The weight fraction of 11% fish scales at 26°C had the better ratio due to the homogeneity of strain parameters (ϵ_1 , ϵ_2 , $\epsilon_{\max}$) and it has the highest stress and the lowest strain compared to other weight fractions.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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