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# Tensile Characteristics of Bio-Composite Material Reinforced with Corn Skin

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**Highlights:**

- Reinforcement type affects tensile strength.
- Better interfacial bonding between the reinforcement and the matrix, resulting in higher tensile stress and Young's modulus.
- Corn skin fibers (CSF) produced higher tensile strength compared to corn skin chips (CSC).
- Bio-composite reinforced by corn skin chips could be weak due to the non-homogeneous material structure.

**Abstract**. The main focus of the present work was to study corn skin as reinforcement of polyester bio-composite (CSPCs). The effect of reinforcement type, i.e. short fibers and discontinuous chips, on the tensile properties was studied. The corn skin materials were chemically treated with NaOH and added as reinforcement of polyester bio-composite using the hand lay-up fabrication method. Tensile tests were carried out according to ASTM D3039. The tensile strength characteristics of stress and modulus showed a different behavior between the two types of reinforcement due to a slight difference in specimen thickness, which affected the calculated stress and modulus values. Furthermore, from a physical properties point of view, the larger surface area of CSC compared to CSF, which still contains a lignin layer after the treatment with NaOH, could decrease the interfacial bonding between polyester as the matrix and CSC as the reinforcement. The tensile damage characteristics showed brittle behavior, propagataing perpendicular to the loading direction. Matrix cracking and interfacial debonding were identified as the main two damage modes of the CSF bio-composite and the CSC bio-composite, where the final failure was dominated by fiber pull out and chip fracture.

**Keywords***: bio-composite; brittle behavior; corn skin; NaOH treatment; tensile strength.*

## 1 Introduction

Reinforcements that come from nature as constituents of bio-composite materials are important because of their renewable and biodegrability behavior, apart from their good ratio of strength to weight of material. Maize (*Zea mays* L.; Poaceae family) is an angiosperm monocot plant that has skin or husk tissue as major agro-

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waste product. The use of this bio-waste and the need for natural reinforcements of bio-composite create new possibilities in this research field for the invention and characterization of new materials, addressing the issue of agro-waste recycling in developing countries. This is to ensure the suistainable development of a good quality environment in industry as well as in our daily lives [1].

Previous papers have investigated the use of corn-waste as reinforcement for polymer composites [2-14] as an agro-waste recycling technique. Rodriquez, *et al.* [2] investigated the ability of corn stalks as reinforcement fibers of composites through modeling and concluded that corn stalks can potentially be applied as reinforcement in polypropylene composites. Jagadeesh, *et al.* [3] studied the effect of corn husk as reinforcement (content and mesh size) on the mechanical properties of corn husk flour/pp bio-composite and found that their mechanical strength was significantly affected by filler content and particle size. Studies on the effect of corn husk concentration on composite properties has been conducted by previous authors [4-5], who found that the corn husk fiber concentration influenced the tensile properties and thermal stability of the composites. A similar study on the influence of corn husk fiber content on recylced-low density polyethylene (R-LDP) was done by Youssef, *et al.* [6], who found that the mechanical properties were enhanced by increasing the content of corn husk fiber. Furthermore, Omoyeni, *et al.* [7] investigated PE composites reinforced with corn husk, where the results showed that corn husk improved the composites' compressive strength. Other studies investigated the effect of matrix type variation in composites reinforced with corn fiber [8-9]. It was found that Maleic anhydride grafted polypropylene corn fiber composites obtained better mechanical properties compared to polypropylene composites. A study on hybrid composites reinforced with corn cab particles and e-glass fiber was conducted by Garadimani, *et al.* [10]. They concluded that the hybrid epoxy composites reinforced with corn cob particles and e-glass fibers had superior properties. Another study [11] investigated hybrid kenaf fiber-corn husk bio-composite and found that the aspect ratio of the reinforcements may be used to optimize the mechanical properties of hybrid bio-composite. In recent years, researchers have modified natural fibers through surface treatments to improve the interface bonding strength and mechanical strength of polymer composites [12-14]. They concluded that chemical treatments of the fiber surface can be successfully used to improve the mechanical properties of composites reinforced by natural fibers, including corn waste fibers.

This study primarily investigated the tensile characteristics of polyester reinforced with NaOH treated corn skin waste as bio-composite material. There were two aspects of comparison to determine the tensile strength. First, different forms of corn skin (fibers and chips) were evaluated. Second, the variation of length geometry was also investigated. In addition, macro observation of damage appearance was performed to determine the damage behavior of corn skin polyester composites under static tensile loading.

# 2 Experimental Procedure

## 2.1 Materials and Specimen Preparation

Corn skin was the main raw material used in this study. It was treated with 5% NaOH for 2 hours to remove impurities in the corn skin in order to enhance the bonding ability with the matrix. Then the corn skin was formed into fibers and chips as the two reinforcement types used in this study. Samples of each type with different lengths (3 cm, 5 cm, and 7 cm) were prepared. The chip type had a fixed width of 8 mm. The specimens were fabricated with the hand-lay up method to contain 30% of reinforcement volume. Polyester was used as the matrix throughout 200 mm x 25 mm x 4 mm of the specimen geometry, as shown in Figure 1.

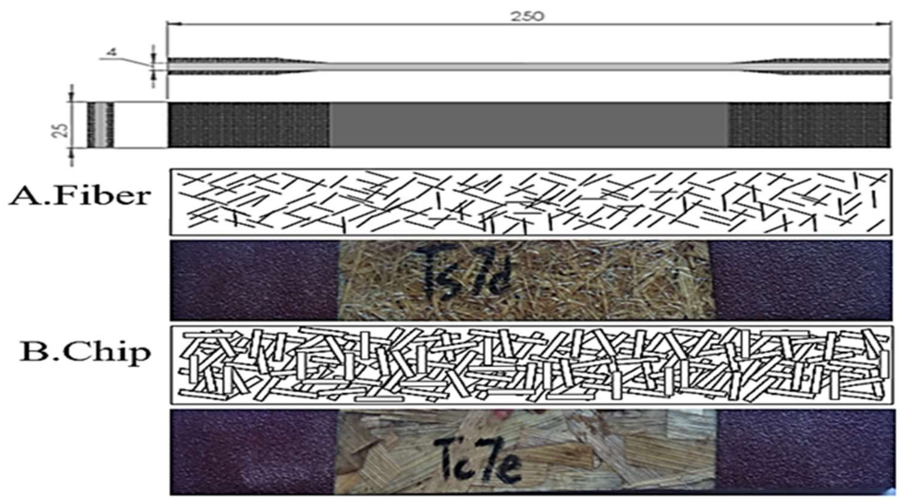



**Figure 1** Specimen of corn skin polyester bio-composite (CSPCs).

## 2.2 Test Configuration

The tensile characteristics of tensile stress-strain and Young's modulus were determined using a servo pulser testing machine, type EHF-EB20, with a load cell of 20 kN. All specimens were tested according to the ASTM D3039 standard, at a crosshead speed of 1 mm/min. Figure 2 shows the test configuration.

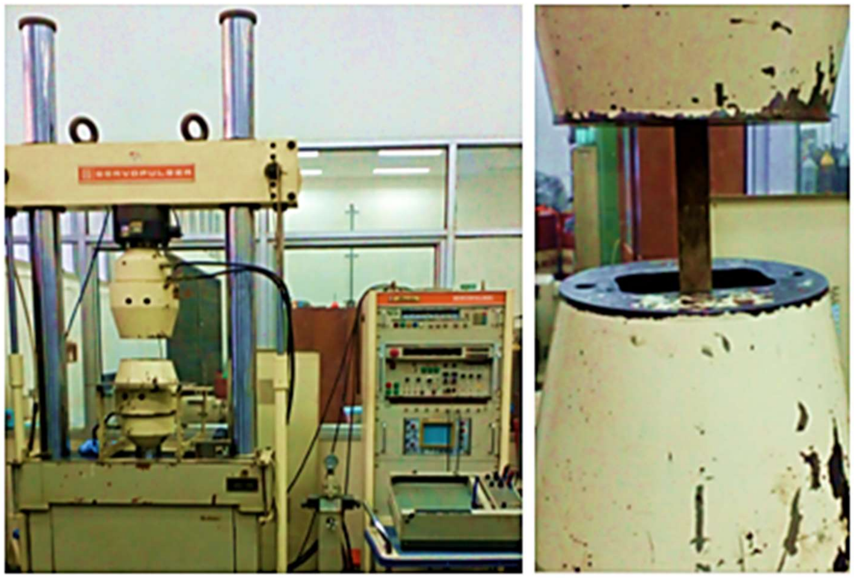


**Figure 2** Test configuration.

## 3 Results and Discussion

The results from the tensile tests of the CSPCs with different reinforcement types are shown in Figure 3. The tensile strength of the polyester reinforced by corn skin fibers (CSF) and corn skin chips (CSC) was different, as can be seen in Figure 3. That of CSF was 30% to 35% higher than that of CSC for all three length variations. As can also be seen in Figure 3, the linear relationship between stress and strain of the CSPCs showed the typical behavior of a brittle material, where there is no yield and plastic region.

Figure 4 presents the Young's modulus (E) for the CSPCs with CSF and CSC reinforcement. As explained by previous authors [15-19], the material state of composites reinforced by chips can be weak due to the non-homogeneousness of the material structure at meso scale, which has stress concentration at the end of the chip plate form. Another reasonable explanation for this behavior are possible fabrication defects in resin-rich areas from the hand lay-up process. Figure 5 shows an ilustration of a critical area in a non-homogeneous structure resulted by CSC reinforcement.

Furthermore, the NaOH treatment did not completely remove the lignin layer and impurities from the chip surface due to the larger area compared to the fiber surface, as indicated in Figure 6. This affects the interfacial bonding between the chip as reinforcement and the polyester as matrix and results in lower tensile stress and Young's modulus.

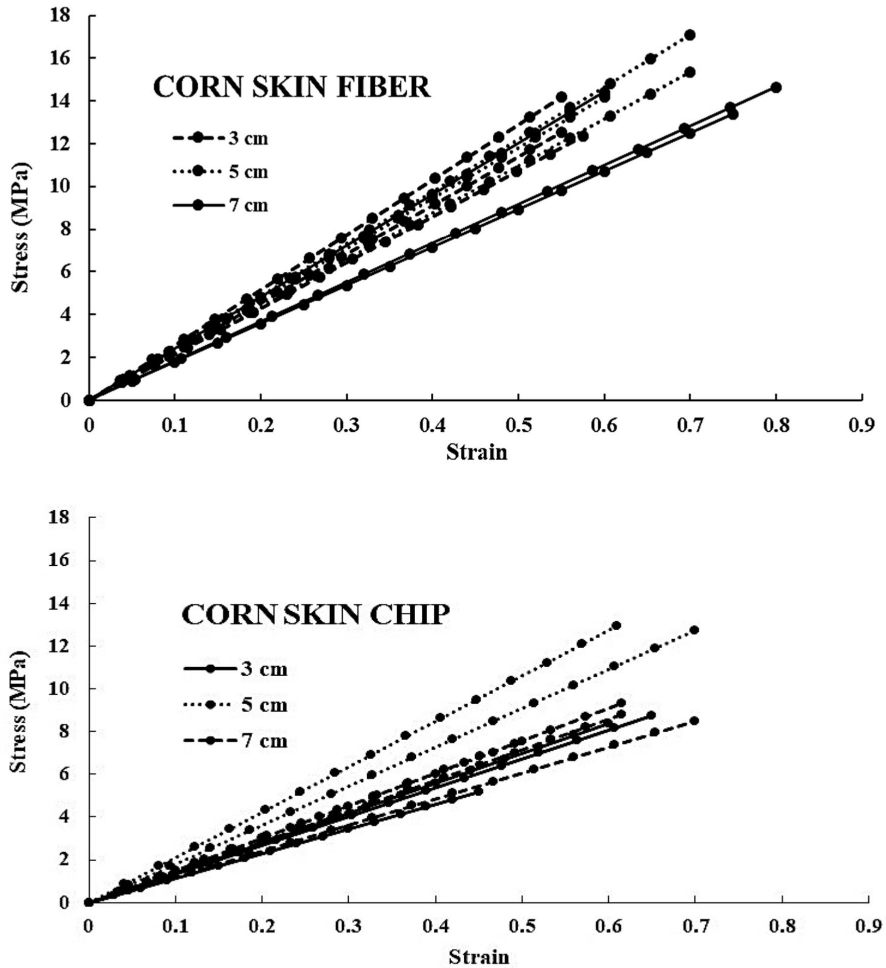



**Figure 3** Stress vs strain of CSPCs with different reinforcement types under tensile loading.

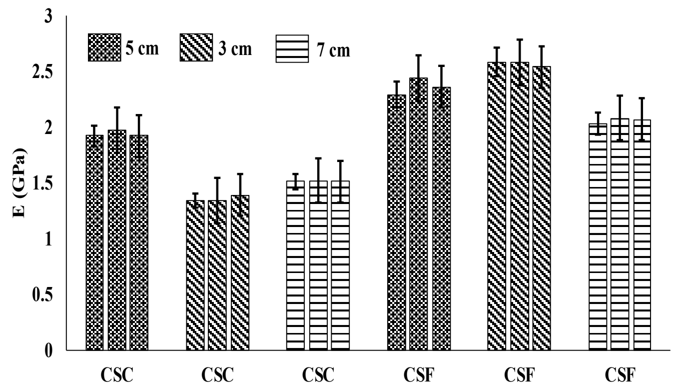



**Figure 4** Young's modulus (E) of CSPCs for different reinforcement types.

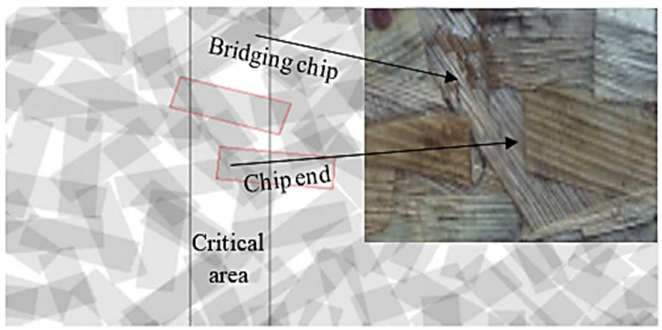



**Figure 5** Critical area of CSPCs.

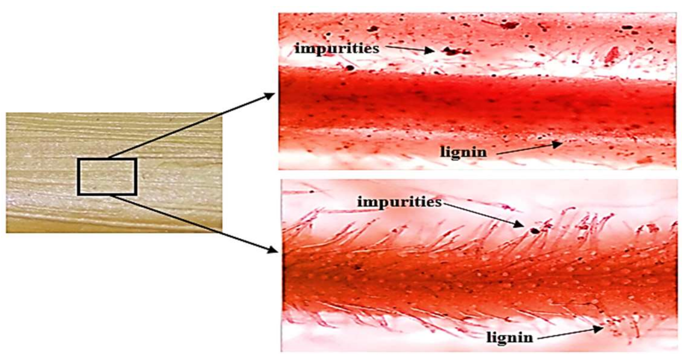
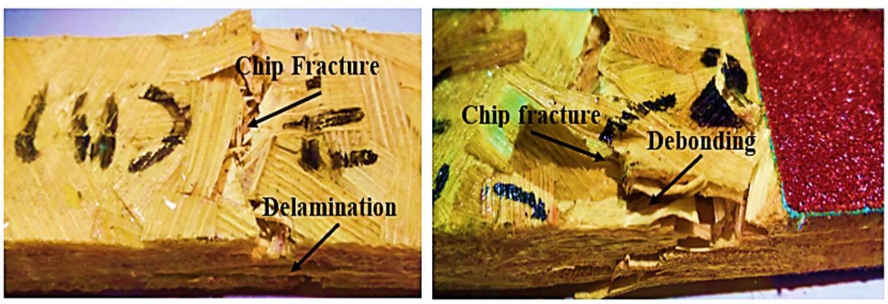


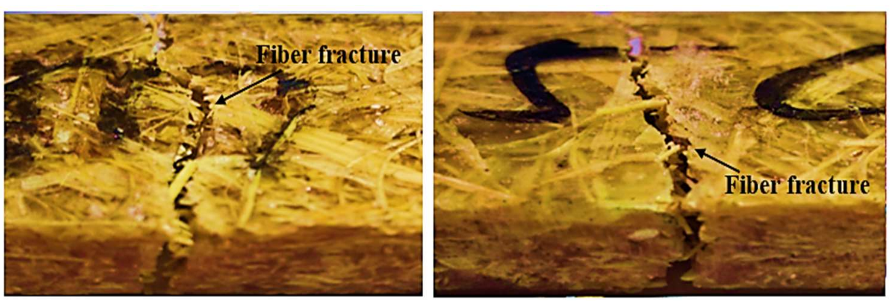

**Figure 6** NaOH treated CSC.

As a consequence, damage mechanisms were formed in CSC, dominated by interfacial debonding and delamination and propagating into chip fractures as final damage (Figure 7(a)). The damage mechanisms experienced by CSF were different compared to CSC, which showed better interfacial bonding of the reinforcement and the matrix so that the damage mechanisms were only initiated by matrix cracking and dominated by fiber fracture without showing any other damage that indicates weak interfacial bonding, as occurred in CSC (Figure 7(b)). This means that the transfer load from the tensile test on the polyester reinforced by CSF could continue to carry and generate higher stress. This phenomenon also produced higher stiffness, as indicated by the Young's modulus of the CSF compared to the polyester reinforced by CSC (Figure 4).

A tensile strength comparison of the CSPCs with different reinforcement lengths is shown in Figure 8.

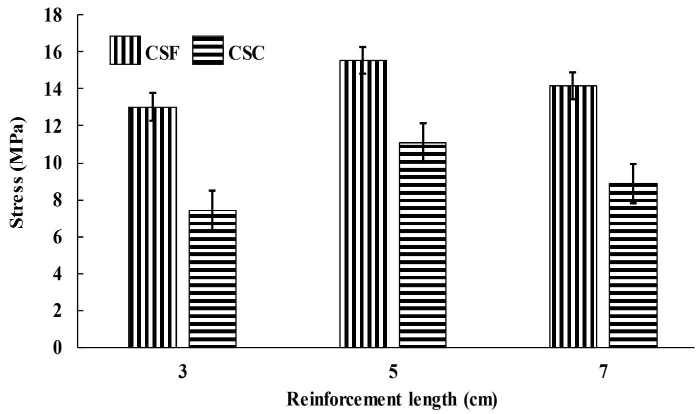



(a) Damage mechanisms of polyester reinforced by CSC

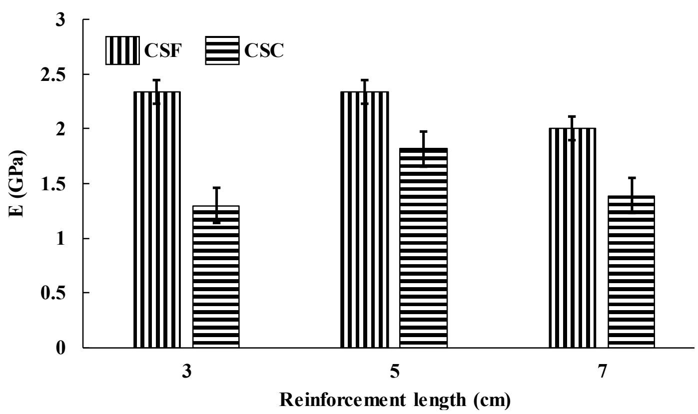



(b) Damage mechanisms of polyester reinforced by CSF

**Figure 7** Damage mechanisms of CSPCs.




(a) Stress comparison




(b) Young's modulus comparison

**Figure 8** Tensile strength of CSPCs with different reinforcement length.

It is well known that fiber length, volume fraction of fiber and matrix, distribution and fiber orientation are factors that affect the mechanical properties of fiber-reinforced polymer composites. When load is applied, shear stress occurs at the interface along the fiber. This means that the load transmitted to the fiber is a function of fiber length, direction and orientation of the fibers relative to each other and the compatibility between the fiber-matrix interfaces [20]. In general, fiber length and mechanical properties have the same increasing trend. The more the fiber length increases, the more the mechanical strength of fiber reinforced polymer composites increases, as expressed in the following equation:

$$\sigma_c = \sigma_f \, C \, F(L) V_f + \sigma_m \, (1 - V_f) \quad (1)$$

where $\sigma_c$ is the tensile stress of randomly oriented fiber composites, $V_f$ is the fiber volume fraction, $\sigma_f$ is the fiber tensile strength, $\sigma_m$ is the matrix tensile strength, C = 1/3 for random orientation, and F(L) is the function of fiber length. The effect of fiber length on composites reinforced by chips was investigated by Ferabolli, *et al.* [21]. They concluded that tensile strength is shown to increase with chip length, which is a similar trend to that in composites reinforced by fibers. However, for CSPCs, the optimal condition was a reinforcement length of 5 cm, as shown in Figure 8, which produced a higher tensile strength, varying between 10% and 30% for both stress and Young's modulus. Theoretically, a higher tensile strength should be produced with a reinforcement length of 7 cm for both types. The lower trend for a reinforcement length of 7 mm occured due to the fabricating process, specifically the presence of fabrication defects, such as resin-rich areas and weak interfacial bonding between reinforcement and matrix, as also noted by Raghavendra, *et al.* [22]. Figure 9 shows that there was a resin-rich area between the reinforcement and the matrix, which was probably due to imperfect distribution of the reinforcement and manual compression during specimen preparation by the hand lay-up method.


**Figure 9** Fabrication defect of resin-rich area

## 4 Conclusion

In this paper, different types of NaOH corn skin treatment were studied and evaluated to be used as the reinforcement phase in the manufacture of corn skin polyester bio-composite (CSPCs). The results indicate that the fiber-reinforced CSPCs performed better. Furthermore, the CSPCs based on both types of reinforcement, corn skin fiber (CSF) and corn skin chip (CSC), with 5 cm of reinforcement length had better ability to transfer the given tensile load and showed better tensile strength. Therefore, fiber-reinforcement with a fiber length of 5 cm was the optimal and most suitable among the CSPC treatments in terms of tensile properties, namely stress and Young's modulus. The damage mechanisms of the CSPCs showed brittle behavior. This was initiated by interfacial debonding in the CSPCs based on the fiber type of reinforcement and by matrix cracking in the CSPCs based on the chip type of reinforcement. To improve the performance of CSPCs, the corn skin fiber could be treated by other chemical treatments during the manufacture of CSPCs to increase interfacial bonding between reinforcement and matrix and apply other types of fabrication processes to avoid the presence of fabrication defects such as resin-rich areas.

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