Effect of Steam Pre-treatment of Bagasse as Fiber Reinforcement SCG Composite

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Abstract. Steam pre-treatment has been examined to sugarcane bagasse fibers (BF). Steam pressure plays an important role in the fibrillation process that is capable in dissolving fibers up to micron scale. Values of fiber diameter with steam pre-treatment (BFP) significantly decreased by 57%. Decrease of the size of fiber can increase the active area of bonding interaction between the fiber surface and the composite matrix. The investigation resulted in mechanical characteristics of unsaturated polyester composite matrix (UP) containing a filler of spent coffee grounds (SCG). When compared between UP-SCG-BF composites to UP-SCG-BF8, it has an increase in tensile strength and flexural strength by 53.57% respectively.

Keywords: steam pre-treatment, spent coffee grounds, fiber reinforced composite

1. Introduction

Coffee and white sugar are among the world's agro-commodities. High consumption levels for foods and beverages linearly produce large amounts of waste such as spent coffee grounds (SCG) derived from coffee beverages and fiber bagasse (BF) from the sugar production process. These are usually less utilized as an added value. In the composite mechanical properties, the addition of SCG filler to polypropylene matrix will decrease the tensile strength [1, 2]. The bending test has also shown the same results, flexural strength decreases with the addition of SCG [2, 3]. Those are due to uneven dispersion of particles, poor interfacial bonds that resulted in hydrophobic matrix properties, and lignocellulose materials that have hydrophilic properties. However, in those studies [1, 3], both (flexural and tensile strength) showed the addition of coffee grounds (SCG) would increase the impact strength.

Bagasse fibers are an organic waste generated in sugarcane processing factories, having the largest cellulose content of up to 43% [4]. The component plays an important role in boosting stem cell structure. They are renewable, decomposes rapidly, and non-toxic [5, 6]. Bagasse fiber has a tensile strength of 89.9 MPa with a modulus young of 4.526 GPa [3]. This could potentially make natural fibers as a composite reinforcement in panel applications and automotive parts [8, 9]. The steam explosion method is a well-known method of initial processing of lignocelluloses materials. In this method, the biomass pieces are treated by passing a high pressure saturated vapor, then the pressure is lowered rapidly so that the lignocelluloses material undergoes explosive decompression. Meanwhile, there is a transformation process of lignin followed by the degradation of hemicelluloses as well as an increased possibility of hydrolysis to cellulose. The steam explosion is initiated at a temperature of 160-260 °C (pressure 0.69-4.83 MPa) for several seconds to several minutes before the material is
placed at atmospheric pressure. The advantage of steam explosion is it uses minimum chemical processes besides water, there are minimum corrosion of equipment, and requires less energy than mechanical processes [10]. The weakness is it needs extra safety in human errors or machine failure to handle the high steam explosion. Pressure variation (bar), treatment temperature (°C), and operating time (s) of steam explosion treatment on lignocelluloses material can decrease material dimensions [11]. High temperature steam pressure on the raw fiber will release non-cellulose components and speed up the process of fibrillation [12]. The process in figure 1 is capable of damaging the fiber bonds to become smaller, increases the effective surface area contacts with the matrix, and gives good interface bonding [13]. The strength of the fibers increases with the increase of cellulose content and decrease the microfibrils spiral angle in fiber [14].

Lignocellulosic fibers are derived from plant fibers (renewable matter), one fiber is composed of several cells. In a cell is composed of microfibrils cellulose filaments connected with lignin amorphous layer and hemicelluloses [14]. The part of hemicelluloses and lignin are as a matrix separates each elementary nanofibril which is structured as a thread fibrillar known as the microfibrils [15]. After pretreatment using steam, then it is proceeded with a treatment of 1% sodium hydroxide solution in distilled water to improve the elimination of hemicelluloses content. In the concentrations it will match with the fibrillation process and the treatment that occurs on the surface, where it would increase the strength of bending of bagasse [7].

In the fiber-reinforced composite materials, fiber plays an important role as a load-bearer. The fiber surface is surrounded by an interface binding matrix and maintains a certain orientation and position. Simultaneously the matrix distributes loads among the fibers. In addition to fibers and matrix, there can be found fillers in composites. The fillers are commonly used on polymer matrix to reduce costs, it increases dimensional stability and gains certain characteristics [16].

**Figure 1.** Changes of fiber dimension to the duration of the steam pre-treatment process.

In this study, the researcher observed the effect of low-pressure steam pre-treatment using a variation of steam retention of time on the changes in the diameter of BF fiber and its influence on the mechanical properties of the composite UP-SCG-BF.

2. **Research methodology / Experimental Method**

The BF fibers were separated manually into pieces of fiber. Then washed several times with water to remove any juice and clean up the dirt, followed by drying at 80 °C for 3 h using the oven and crushing the fibers; sieved #20 mesh to separate the sponge and fiber parts. In the next stage, 40 g of BF fibers are placed in 500 ml of water in a pressure cooker. While the operating time varies from 2, 4, 6, and 8 h while maintaining a fixed temperature of 118 °C to maintain constant vapor pressure. Operating times are calculated when it has reached 0.18 MPa pressure. The dry fibers BF then are
immersed into a solution of Sodium hydroxide 10 g/ℓ with a comparison of fiber and solution of 0.4 vol%, and stirring is done manually at 90 °C for 1 h. The last stage is the fiber washed up in neutral conditions. Spent Coffee Grounds (SCG) particles were obtained from the kitchen of coffee shops. Then the SCG filler were ovendried at 80 °C for 3 h. Followed by crushing the clumps of SGC with size under mesh #80 sieve. Unsaturated Polyester (UP) used were Eternal 2504 APT. The composite manufacturing process was applied using hand-lay-up technique. The matrix UP by 60 vol% was mixed with 30 vol% of SGC particles and BF fibers 10 vol%. Stirred slowly, then added 1% methyl ethyl ketone peroxide as hardener. Air bubbles on the mixture of composite were trapped during the process of mixing and it reduced through a vacuum process at -0.9 MPa. Then proceed with the application of the mixture into composite mold, followed by a curing process at room temperature for 24 h. The manufacturing of the sample dimensions test was based on ASTM D3039 and ASTM D 790 standards.

3. Result and discussions
There is a defibrillation zone (see figure 3) which is the region where the steam pre-treatment process over 6 h in the BF fibers begins to decrease in diameter. In the increased steam pre-treatment duration up to 8 h, there was a noticeable decrease in average BF fiber diameter up to 2 times. At the duration of treatment 0-4 h, fibers did not change significantly in its diameter. Unlike the case for the duration of treatment 6-8 h, the small fibers are clearly visible. This suggests that the vapor pressure retained for a given duration is able to release most of the lignin and hemicelluloses, the activity exhibits a well-executed fibrillation process [12]. Loss of lignin and hemicelluloses, increased the gap among fibers and the final detachment, also eroded from the main part of BF fibers. This condition corresponds to the defibrillation process of BF fibers shown in figures 2a-2e.

![Figure 2](image-url)

Figure 2. (a) raw BF; steam pre-treatment (b) 2 h; (c) 4 h; (d) 6 h; (e) 8 h; and (f) Fiber breakage and pull out in UP-SGC-BF composite with 8 h pre-treatment duration.
There is a correlation between the duration of pre-treatment, fiber BF diameter with tensile strength. Changes in pre-treatment duration up to 8 h have reduced fiber diameter (μm) and also increased tensile strength of UP-SCG-BF composites by 25.7 MPa (see figure 4). The results of this test showed the improvement of mechanical properties UP-SCG-BF composite when compared with the tensile strength UP-SCG composite without BF fiber of 10.05 MPa.

![Figure 3. Effect of pre-treatment duration to changes the diameter of BF fiber.](image)

![Figure 4. Tensile Strength of UP-SCG-BF composite (MPa).](image)

The flexural strength of UP-SGC composite without BF fiber is 29.83 MPa. Then the strength of the UP-SCG-BF composite increased after the addition of pre-treatment BF fibers in the duration of 8 h (see figure 5). There was small reinforcement for treatment duration <6 h, but BF fibers in the defibrillation zone (duration >6 h) began to show strengthening in the function. This function was indicated by the increase in flexural strength of UP-SCG-BF composites up to 55.5 MPa. The decrease in fiber diameter BF has increased the active interaction area of the matrix interface [13]. Where fiber break is more visible than fiber pull out can be show in figure 2f.

The strength of the UP-SCG-BF composite before the defibrillation zone showed that the fibers play a small role as the UP-SCG-BF composite reinforcement. The flexural load can be effectively retained by many fiber surfaces. UP-SCG-BF composite strength on pre-treatment duration before defibrillation zone showed that fiber does not play a role as UP-SCG-BF composite reinforcement.
This is more due to the BF fiber diameter is almost uniform between the duration of pre-treatment 0, 2, and 4 h.

Based on Cao et al. report, the results of the flexural strength in this study is in line at ~ 60 MPa [7]. On the other hand, UP-SCG composites in the presence of BF fibers have proven that their mechanical properties have been improved, which, as experienced by some researchers [1-3] that the presence of SCG will decrease the mechanical strength.

4. Conclusion
The mechanical properties of UP-SCG composite can be improved through the addition of BF fibers. Low-pressure steam pre-treatment process has been able to decrease the BF fibers diameter with the minimum equipment and low-cost. Fiber defibrillation can occur with sufficient time when the process of temperature retention and constant pressure is applied. Increasing the amount of fibrillation causes the fiber diameter to decrease, so the active area as a composite reinforcing would also increases to withstand the external load.

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