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Mechanical Properties of Organic Polymer and Exfoliated Graphite Reinforced Bacteria Cellulose Paper

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***Abstract*—**Bacterial Cellulose (BC) is a structural organic compound produced in the anaerobic process. This material can be a useful eco-friendly substitute for commercial textiles that are used in industries today. BC is easily and sustainably produced and has the capabilities to be used as a replacement in textiles. However, BC is extremely fragile when it completely dries. This research was conducted to improve the mechanical properties of the BC by reinforcing with an organic polymer and exfoliated graphite (EG). The BC films were grown over a period of weeks in a green tea and kombucha solution at 30 °C, then cleaned and added to an enhancing solution. The enhancing solutions were a mixture of 2.5 wt% polymer and 2.5 wt% latex solution, a 5 wt% polymer solution, a 0.20 wt% graphite solution and were each allowed to sit in a furnace for 48 h at 50 °C. Tensile test samples were prepared and tested until fracture at a strain rate of 8 mm/min. From the research with the addition of a 5 wt% polymer solution, the flexibility of the BC has significantly improved with the maximum strain significantly larger than that of the base sample. The addition of EG has also increased the modulus of elasticity of the BC by about 25%.

***Keywords*—**Bacterial cellulose, exfoliated graphite, kombucha scoby, tensile test.

I. Introduction

BC presents itself as eco-friendly and sustainable. It is a natural cellulose produced by bacteria such as *Agrobacterium, Achromobacter, Rhodobacter* and *Acetobacter xylinum* [2]. BC is a strong and ultrapure form of cellulose produced naturally by several species of the *Acetobacteraceae*. Its high strength, purity, and biocompatibility make it of great interest to materials science; however, precise control of its biosynthesis has remained a challenge for biotechnology [4]. The blending of this natural polymer with a synthetic polymer can form a new class of materials with improved mechanical properties as well as bio capability compared with those of a single component. These are called biosynthetic polymeric materials or bio artificial materials. Materials based on biopolymers have been employed in numerous applications owing to their renewable eco-friendly nature and also their flexibility in processing conditions together with the competitive cost of their end products [1].

The production of the BC fabric can be maximized depending on the type of nitrogen and carbon sources using the culture medium. As an essential nutrient, the nitrogen sources promote the growth of microorganisms and cellular construct. Yeast extract, casing hydroxylate, ammonium sulfate, peptone, sodium glutamate, and tea substrate are common nitrogen sources used for BC production [2]. In addition to the BC production, enhancing materials can be added to the BC byproduct as a means of reinforcing its physical properties and strengthening the skin of the BC product.

Studies on reinforcing BC to improve their physical and mechanical properties are scant. Recently the effect of reinforcing BC using natural rubber has been reported [3]. The reinforcement yielded significant results that enhanced some of the mechanical properties of the material, more specifically the tensile strength and elongation at break. This paper reports methods of reinforcing BC using different fillers and the effects of these fillers on the physical and mechanical properties of BC.

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II. Materials and Methods

A. Green Tea BC Product Creation

Uncle Lee's organic green tea was used as the nitrogen source for the bacteria along with granulated white cane sugar. The tea was made using 4000 mL of distilled water that was heated to 100 °C. Once the water was boiled, the heat source was removed and 1 cup of white granulated cane sugar was added to the water and stirred until fully dissolved in the solution. 22 tea bags were then allowed to steep in this sugar-water solution for approximately 15 minutes. The green tea solution was then allowed to cool to room temperature and then placed into containers to hold approximately 2400 mL of the solution. Kombucha Scoby liquid of 450 mL was added to the solution and allowed to mix together. A kombucha Scoby starter sample was then added to the solution and the container was placed in an incubator to sit undisturbed for 4 weeks. Sets of 4 samples were created with the same concentrations and durations [5].

B. Strength Enhancement Preparation

A total of four conditions were prepared for each sample set. The conditions were a 5 wt% polymer solution, a mixture of 2.5 wt% latex and 2.5 wt% polymer solution, a 0.20 wt% EG solution, and a base solution of water for comparison. Each solution was mixed with distilled water in preparation for the BC material to be submerged in the contents. Table I summarizes the solutions and sample types created.

TABLE I
TESTING CONDITIONS

Sample ID:	Condition of sample	Solution contents
C41	2.5wt% latex/polymer	12 mL polymer, 14 mL latex, 460 mL Distilled water
C42	5wt% polymer	40 mL polymer, 450 mL distilled water
C43	EG	0.20 wt% (1.01 g) EG, 500 mL distilled water
C44	Base sample	500 mL distilled water

C. Cleansing BC Culture

The BC byproduct was collected after the specimen was allowed to form for approximately 27 weeks, due to the inability to collect the samples during that time. The sample was then cool-dipped into distilled water, changing water between each dipping to rinse the sample. This removed the smell and cleaned the sample from by product remnants. The sample was then submerged in 1wv% NaOH solution for 24 hrs. The samples were then rinsed again until the pH stabilized at approximately 7.0.

D. Combing Sample and Test Solution

The harvested BC was then cut into 4 sections and labeled to simplify the procedure. The sample sizes were approximately 150 mm by 125 mm, with average thicknesses of 62.5 mm. After cutting and respectively weighing each sample section, these samples were then submerged into the previously created solutions and placed in a furnace at 50 °C for 48 hr. After the 48 hr. period, the samples were collected and measured for changes.

E. Drying the Samples

The samples created are placed in a furnace between two Teflon sheet covered aluminum plates. After placing a weight of 5.0 kg on top of the material to add pressure and prevent warping, the samples were heated to 80 °. The material was then allowed to dry until the samples were only slightly moist. At this time the samples were then further cut into uniform test segments of 2 0mm wide and approximately 140 mm in length, creating 5 segments per sample set. These segments were then place back into the furnace to continue the drying process.

F. Tensile Test

Using the ASTM D882-12 standard, each of the test samples were loaded into a tensile testing system (Instron model 5944) The strain rate used was 8 mm/min and each sample were tested until failure. The gauge lengths of each sample were approximately 85 mm.

III. RESULTS

A. Physical Observations

Before Drying Process

Prior to the material enhancing and drying process, the BC was observed to be uniform in each of the test samples. From visual inspection, the growth of the bacteria was uniform and maintained an evenly distributed thickness of 62.5 mm for each of the samples. Figs. 1 A and B display the state of the samples prior to drying and treatment.

Fig. 1 (A) Complete sample raised to show uniform thickness, (B) sample segment that each test sample was made to have the same dimensions and shape

After the treatment of the samples in their respective solutions, the samples appeared to have been coated by the material they are soaked in. The most noticeable of the changes was in the EG sample C43 when compared to C44 of the base sample. The dimensions of each of the samples remained approximately the same though some of the changes are displayed in Table II.

TABLE II
THE AVERAGE LENGTHS FOR EACH OF THE SAMPLE TYPES

Sample ID	Length	Width	Thickness
C41 (Poly/latex)	81.84(+/- 3.56)	20.1(+/- 0.38)	0.466(+/- 0.16)
C42 (5% poly)	81.244(+/- 0.27)	19.36(+/- 1.93)	0.512(+/- 0.06)
C43 (Graphite)	84.932(+/- 0.57)	19.118(+/- 0.86)	0.354(+/- 0.06)
C44 (Base)	82.82(+/- 1.44)	18.9225(+/- 0.56)	0.3325(+/- 0.05)

After Drying Process

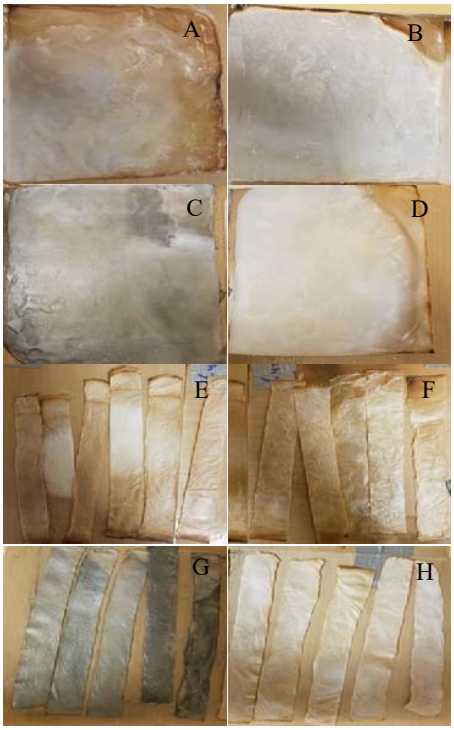

Fig. 2 (A)-(D) are dried C41, C42, C43, and C44 samples, (E)-(H) the tensile test specimens cut from C41, C42, C43, and C44 samples respectively

After the following drying process, the thickness of each of the samples changed dramatically as most of the water had evaporated. Some of the samples also had small warping in various locations. Figs. 2 A-H display the samples after the drying process and after the test strip creation process which further reduced the sample sizes to be tested. Table II consolidates the dimensions and mass of the samples tested. The average thickness reduction for each of the samples are 99.28%, 99.21%, 99.36%, 99.46% for the C41, C42, C43, and C44 samples respectively.

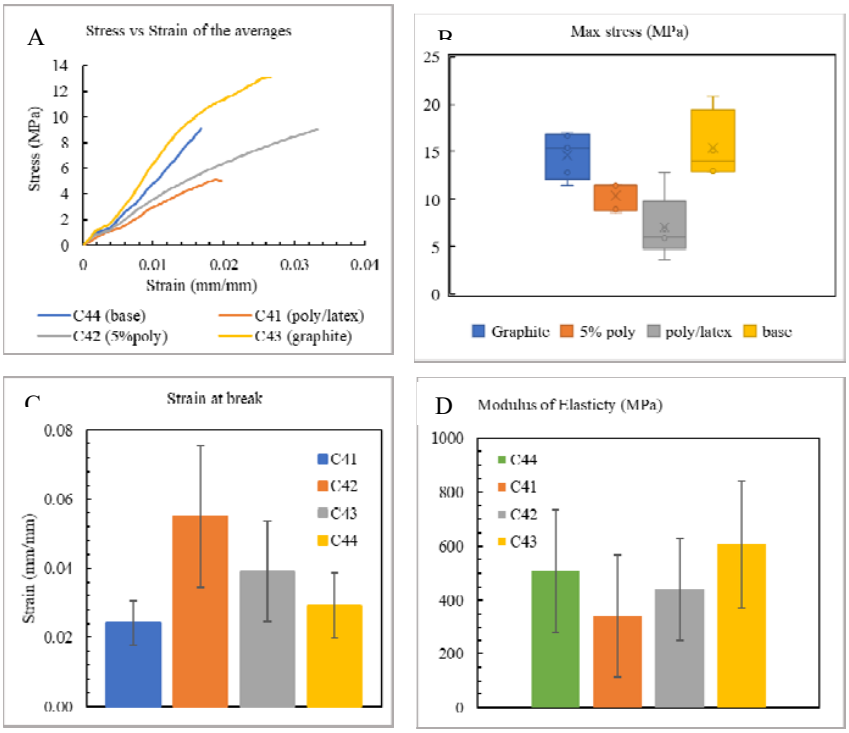

Fig. 3 (A) the stress stain plot for the averages of the samples; (B)-(D) the max stress, strain at break, and modulus of elasticity of the samples, respectively with the standard deviation

B. Tensile Test Results

From the tensile testing done as described in the earlier sections, a summary of the results has been created and displayed in Table III. The moduli of elasticity for each of the C41, C42, C43, and C44 samples are 339.4 MPa, 440.5 MPa, 608.05 MPa, and 507.4 MPa respectively. Fig. 3 A displays the modulus of elasticity with the respective standard deviation for each sample.

TABLE III
MAXIMUM STRESS, ELONGATION, AND STRESS AT BREAK COMPARED TO BASE C44 SAMPLE

Sample ID	Max stress (MPa)	Elongation %	stress at break (MPa)
C41 (Poly/latex)	7.040	2.43%	5.826
C42 (5% poly)	10.386	5.50%	9.304
C43 (Graphite)	14.643	3.91%	13.095
C44 (Base)	15.423	2.93%	13.711
	Percent difference		
Poly/latex	-54.36%	-16.92%	-57.51%
5% poly	-32.66%	87.99%	-32.14%
Graphite	-5.06%	33.64%	-4.49%

IV. DISCUSSION

The reduction in performance of the polymer and latex sample is significant with reductions in maximum load capacities, elongations and modulus of elasticity as compared to the base sample and other samples types. The 5w% polymer sample enhanced the samples' ability to flex and elongate as compared to the other samples tested but was not able to increase the maximum stress the sample could endure. The 0.20 wt% graphite sample performed past expectations with the least amount of mass and subsequently allowing the material to elongate more and increase the modulus of elasticity. It also could not increase the maximum stress endured but provided plenty of additional attributes.

Each of the test types had similar nature that can be seen in Fig. 3, where a plateau region occurs around the same stress and strain regions. In this region the stress does not increase for a few intervals and then proceeds to claim at a rate similar to the initial elastic deformation region. This may be attributed to the small warping within the material that occurred during the drying process straightened at this load and then the material continued to deform. However, further experiments will need to be conducted in order to confirm these results and eliminate the warping if possible, with better processing procedures.

V. Conclusions

In further test, the reduction of the warping in the material will be a priority as to determine the cause of the plateau region. Additionally, the further experimentation with the polymer and EG solutions will be used to determine if the addition or removal of these materials will amplify the results found during this study. With the increase in strength and flexibility of the BC material, being integrated into a textile design and tested for its endurance can become exceedingly feasible. This integration will be a way for the textile industry to use more sustainable and bio-friendly materials as substitutes for current industrial textiles.

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