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Bacterial Cellulose Yarns: Preserving Fiber Strength and Improving Performance

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Introduction. Cotton is one of the most popular cellulosic fibers, with 17 million bales produced in the U.S. in 2012 (National Cotton Council of America, 2013). However, cotton manufacturing requires large amounts of land, water, and pesticides every year, making cotton less than ideal for sustainability. Bacterial cellulose, on the other hand, requires no land or pesticides and less water to produce. This material is promising for textiles, but several limitations must be overcome. Currently, the cellulose is a nonwoven fiber web, which limits its performance with respect to strength; thus, we investigate the potential of bacterial cellulose yarns for weaving.
Literature Review. Bacterial cellulose is produced by a small acetic-acid bacterium, which produces a biodegradable, vegetable leather-like product (Iguchi, Yamanaka, & Budhiono, 2000). This material exhibits increased tensile strength and water absorbing capability (El-Saied et. al., 2008). Moreover, this textile is markedly distinct from traditional cellulosic fibers, as it lacks hemicellulose and lignin; that is, the material is composed solely of micro-cellulose fibrils produced and extruded by *Komagataeibacter xylinus* (Iguchi, Yamanaka, & Budhiono, 2000). Lacking hemicellulose and lignin, the cellulosic micro-fibrils interact extensively with one another via hydrogen bonds. Indeed, these interactions make for a highly crystalline, absorbent, and strong fiber-web (Hsieh, Yano, Nogi, & Eichhorn, 2008).

The three main methods of textile fabrication are woven, knitted, and nonwoven. Each of these fabric types has various uses and limitations. Comparisons between woven and nonwoven identical products are limited, but one we can look to comes from medicine. When woven versus nonwoven surgical gowns were investigated for tensile strength, woven gowns were found to be superior in strength (Pamuk, Abreu, & Öndoğan, 2008). Furthermore, woven textiles offer consumers better breathability and therefore better comfort properties (Kadolph, 2007). Such advantages prompted this exploration into bacterial cellulose properties for woven fabric.

Previous bacterial cellulose garments have focused on harvesting the nonwoven mats that grow on the surface of the media (Lee & Ghalachyan, 2015; Harmon, 2017). Attempts to make yarns from bacterial cellulose have been limited. Wet spinning regeneration has been tried, but resulted in a weaker, more expensive fiber (Gao, Q., Shen, X., & Lu, X. (2011). Thus, this process is not practical with respect to producing a woven bacterial cellulose material. Therefore, this project investigated one alternative way to produce bacterial cellulose yarns.
Experiment Methodology. In this experiment, ATCC bacterial strain 23768 was cultivated. Molasses mannitol media was used as it has been shown to dramatically increase cellulose production (Harmon, Thibault & Fairbourn, 2017). This bacterium was propagated for 1 week then transferred to larger growing containers. This bacterial broth was evenly distributed into containers. Media for these containers were autoclaved at 120 degree Celsius for 20 minutes before bacterial addition. Growing containers were incubated at 32 degrees Celsius for 21 days. Once the cellulose growth was complete, these mats were treated with a 1% NaOH solution for

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24 hours to purify the cellulose. These mats were rinsed with distilled water until a neutral pH was reached. Samples were placed in a 12 hour, 5% glycerol soak. Then, cellulose was rinsed again with distilled water. The cellulose was divided into thicker and thinner grown samples and cut into single ply yarns. All yarns were wrapped in double knit fabric and half were air dried at room temperature, while half were freeze dried at -32 to -42 degrees Fahrenheit, for 9 days.

Results. After the drying period, the strands were placed textile conditioning room for 24 hours before being tested. Prior to testing, strands were weighed, after their conditioning period, then tested for tensile strength using ASTM-D 882 in at least triplicate samples, from each drying method. The average weight of the thin yarns was nearly identical at .36 g for air dried and .35 g for freeze dried. There was a marked difference in the weights of the thick yarns, with the average for air dried yarns being 1.27 g and freeze dried 3.77 g. From the thin yarns, the average tensile strength for those air dried was 25.55 N while in the freeze condition, the average was 23.16 N. The extension average for air dried was 7.51 mm and for the freeze dried group, 10.14 mm. From the thick yarns, the average tensile strength for those air dried was 91.10 N while in the freeze condition, the average was 27.81 N. From the thick yarns, the average extension for those air dried was 10.82 mm while in the freeze condition, the average was 15.64 mm.

Conclusion. The strongest yarns were the thick air dried yarns. However, freeze drying appears to have a more beneficial effect on yarn extension, as both yarn types performed better than the air. These results indicate such yarns would be suitable for hand or slow mechanical weaving.

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