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Development of Bacterial Cellulose based sustainable non-woven

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ABSTRACT

Bacterial cellulose is one of thebio-based materials produced from the bacterium Acetobacter xylinumand it is considered that it has the potential to achieve zero waste sustainability. In this research, Bacterial Cellulose (BC) sheet was developed using Acetobacter xylinum strain in Mannitol medium and black tea was identified as a cost-effective alternate source and further production of BC is made in black tea. The developed BC sheet was evaluated for their morphological properties using a scanning electron microscope. The physical properties of BC sheet were evaluated using tensile strength, elongation, tearing strength, thickness, stiffness and crease recovery tests. The moisture management test was done to analyze the wetting time, wetting radius, spreading rate and absorption speed of the developed sheet. These results provide a higher perception into the potential applications of BC sheets in the apparel and textile industry.

KEYWORDS: *Bacterial Cellulose, Sustainability, Non-woven, Textile, Fashion*

INTRODUCTION

The textile and fashion industry which is the reason for 5.4% of the world's pollution is considered as the fifth most unsustainable industry preceded by electricity and heat, agriculture, road transportation, and oil and gas production [1]. The textile and fashion industry has a considerable impact on sustainability starting from the raw materials to finished goods. The waste generation occurs at every stage of manufacturing and sustainability stands as the need of the hour [2]. Whenever the impact of the fashion industry on the environment is taken into the study, the major role of polluting the environment is being played by the raw materials that are used in the industry. The raw materials used in the industry have a serious impact on the environment than the effects of processing. A huge amount of resources is being exploited in the process of obtaining raw materials for the fashion industry. The production of cotton requires a large amount of cultivation land and water. And the production of synthetic fibers relies on non-renewable resources and their extraction process involves the usage of high energy machinery [3]. Moreover, the level of impact of the materials in the disposal stage also relies on the raw material used. The problems with the available materials give rise to the exploration of sustainable bio-based materials like bacterial cellulose, mycelium,etc [4]. Researchers have explored the development of bio-based material called Bacterial Cellulose (BC) which is produced from the acetic acid bacterium *Acetobacter xylinum* and they found that it has the potential to achieve zero- waste sustainability in the textile industry. The development of Bacterial Cellulose is pioneered by a British fashion designer Suzanne Lee in her research project, called Biocouture, in a sustainable fashion. She developed a BC sheet and designed a jacket and kimono using conventional garment construction methods [5]. The Bacterial Cellulose is a sustainable non-woven textile material and it has a leather-like appearance [6]. The research aims to develop the BC sheet in a cost-effective manner using different sources and to commercialize its application in the textile and fashion industry. The aim also covers the analysis of the physical, chemical, and thermal characterization of the developedbacterial cellulose sheet along with the environmental impact and biodegradability for theapplication as a sustainable textile material.

MATERIALS AND METHODS

A. Material

Acetobacter xylinum ATCC 2526was sourced from National Chemical Laboratory (NCL), Pune, India. Mannitol, Peptone, Yeast extract, Sodium hydroxide and Acetic acid were purchased from Hi media chemicals, Mumbai and used without any purification. Black Tea and Sugar were brought from the local store in Coimbatore, India.

B. Preliminary production of Bacterial Cellulose (BC)

The inoculation medium is prepared by using 3.3g mannitol,0.3g Peptone,0.5g Yeast extract, mixed with 100ml of distilled water in a beaker and the medium is autoclaved at 121°C for 1 hour [7]. Then, it is taken out and allowed to cool till it reaches the room temperature. The bacterial is inoculated with the help of inoculation loop in the Laminar Air Flow Chamber and the beaker is kept in the shaker for 12 hours. After taking it out from the shaker, it is kept in the incubator for 14 days at the temperature of 21+/-2°C for the period of 14 days. After the period of 14 days, we can visualize the formation of Bacterial Cellulose. The formed cellulose sheet is used for the further production with different carbon sources.

C. Development of BC sheet

The culture medium was prepared using 60g sugar and 40g tea powder mixed with 1000ml water in a beaker and the medium was allowed to boil. The boiled tea was allowed to cool down in room temperature and filtered using a muslin cloth or filter paper and transferred into the wide glass bowl. After the addition of produced BC sheet from the *Acetobacter xylinum* in mannitol medium, the glass bowl was covered with a clean muslin cloth that was tightly held in place with rubber bands [8]. The glass bowl was kept in the dark place with room temperature (30 ± 3°C) where it is allowed to ferment for 10-12 days. During this period, Bacterial Cellulose (BC) sheet was seen floating in the culture medium.

The produced sheet was taken out and a small piece can be added to the next batch in a tray with 200ml of previous batch tea (Starter tea) and sealed with muslin cloth and kept for 12-15 days, it is not necessary to add a new BC sheet for next cellulose sheet production.

D. Purification of BC sheet

Alkali treatment and Neutralization

The produced BC sheet is washed in tap water and soaked in soap solution for 12 hours at room temperature. Then the sheet is taken out and it is washed in water to remove the soapy substance. Now, the sheet is treated with 0.1 M NaOH for 2 hours to eliminate the attached residues and bacterial cells. For neutralization, the water is heated and bought to 50°C and acetic acid is added till the pH value reaches 3. The treated BC sheet was kept at this acidic medium for 2 hours and it was taken out. The pH value was maintained at 4-7.

E. Drying of BC sheet

To squeeze the extra moisture content, the BC sheet was wrapped using muslin cloth and kept between two wooden blocks and the weight was added on the top and it is left for 12 hours. The squeezed BC sheet is taken out and it is dried at room temperature.

F. Material Characterization

Scanning Electron Microscopy (SEM)

The BC sheet is tested for scanning electron microscopy test to understand the shape and morphological structure of the bacterial cells present in the cellulose and on the fibrils of cellulose. This test is performed by placing the dehydrated BC sheet on a copper support covered with a layer of gold using iron sputter which is about 1nm thick for a period of 60 seconds [9].

G. Physical Characterization

Tensile strength and Elongation

Tensile strength test was carried out according to the standard ISO 13934. The sample size 12-inch x 2.5 inch is cut and mounted on the clamp of Unistretch 250 tensile tester and load has been applied, the cellulose sheet stretches to its maximum level and stops. It gives the breaking strength and elongation of the bacterial cellulose [9].

Figure 1. (a) BC sheet formed in a glass tank and (b) Dried BC film.

Tearing strength

The specimen size 100mm x 75mm is taken and initial cut 20mm has been made and the specimen is clamped in the tensile tester and the pendulum is released and reading is noted. This testing shows how much the bacterial cellulose sheet can resist the cut when in tension. The standard followed in testing is ASTM D 1424.

Abrasion resistance

The specimen size 1.5 inch in diameter is taken and weighed and fitted into the round disc and kept in the tester with load. After 3000 cycles, the specimen is taken out and weighed again. The weight loss shows how much the bacterial cellulose can resist the surface wear caused in contact with another material. The standard followed in testing is ASTM D 4966.

Thickness

The bacterial cellulose sheet to be tested in placed between the two circular disc and the upper disc is released so that it contacts with the BC sheet and the space between the two disc is displayed in the tester which is thickness of the sheet.

Stiffness and Crease recovery

According to the standard IS 6490, the specimen size 25mm x 200mm and the reading template is kept on the platform with BC sheet underneath and the reading template is moved forward until the specimen tip reaches the index line viewed in the mirror. The bending length is read off from the reading template opposite to the zero-line engraved in the tester. According to the standard IS 4681, the specimen size 15mm x 40mm is folded into equal half and placed between a disc for three minutes with 500g weight. It is removed and clamped on the instrument and allowed to recover from the crease. After one minute, the instrument dial is rotated to note the recovery angle. The recovery angle is used to calculate the crease recovery.

Moisture management test

According to AATCC test method 195–2009, Bacterial cellulose (BC) sheets were tested on moisture management tester (MMT)-SDL ATLAS M290. BC sheet was placed between upper and lower horizontal electrical sensor, each sensor has seven concentric pins to evaluate the liquid moisture management properties. A presetamount of test solution has been dropped on the upward facing BC sheet which helps in the measurement of electrical conductivity changes. The solution spreads in the top surface of the BC sheet and it transfer from the top surface to the bottom surface and spreads in the bottom surface. Changes in electrical resistance of BC sheet are recorded which can be used to fabric liquid moisture content changes that quantify dynamic liquid moisture transport behaviors in multiple directions of the sheet. Using the predetermined indices, grades of the liquid moisture management properties can be determined [10]. Moisture management testing has been done for bacterial cellulose sheet developed from tea.

Results and Discussion

H. Characterization of BC sheet

Analysis of SEM

The SEM image in Figure 2 shows that the developed BC sheet consists of denser cellulosic microfibril in it. From this result, it is confirmed that the sheet is made of cellulosic fibrils with an approximate diameter in nanometers. It also showed that the BC sheet consists of nano and micro-sized pores in its randomly oriented structure.

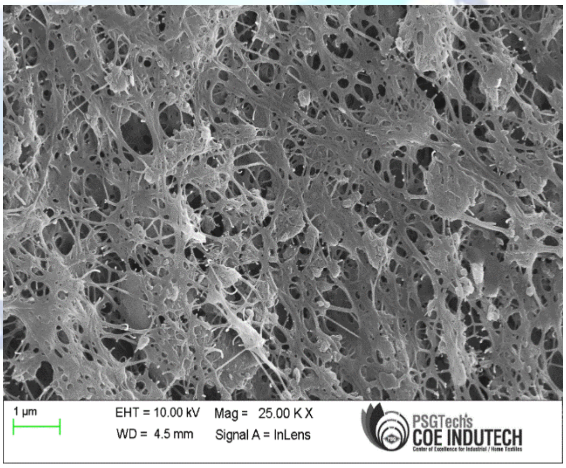

Figure 2. Surface morphology of BC sheet at 25000 X magnification

Analysis of physical properties

Mechanical properties

The mechanical properties including crease recovery, bending length, tearing strength abrasion resistance, elongation, tensile strength of the produced BC sheets are analysed. Table 1 summarises the mechanical properties of the BC sheets. The sheets are found to have good tensile properties. The tensile strength is 15.51 kg/cm whereas the acceptable tensile strength for the bottom wear as per ASTM D 5035 standard is 8.92 kg/cm. BC sheets have good abrasion resistance. The weight loss is such that it can be used for textile application. The other values also showed that the BC sheets are having the potential to be used in the textile and apparel applications.

Table 1 Mechanical Properties of BC sheets

1	Crease Recovery	127.80
2	Bending Length (cm)	5.36
3	Tearing Strength (g)	1152
4	Abrasion Resistance (wt.	3.92
5	loss%)	50.99
6	Elongation (mm)	15.51
7	Tensile Strength (kg/cm)	0.29
	Thickness (mm)	

The overall moisture management properties of the developed sample were analyzed and the results are summarized in Table 2.

Table 2 Moisture Management Properties

Parameters	BC sheet developed from tea	
	Top surface	Bottom surface
Wetting time(sec)	8.143	20.779
Absorption rate(%/sec)	36.1057	4.4416
Max Wetted radius(mm)	10.0	0
Spreading speed(mm/sec)	1.3899	0
One-way transport capability (%)	-1142.3317	
OMMC	0	

The Soil burial test is carried out for the developed BC sheet to check the degradability of the material and it is compared with the degradability of cotton fabric [11]. The results showed that the BC sheets have good bio-degradable properties.

Conclusion

The Bacterial Cellulose sheets were produced using a cost effective medium and the purification was done. The morphology of the developed sheet was analysed using Scanning Electron Microscope and the other mechanical properties that are essential for the use of BC in the textile and fashion applications were also analysed. The result of the soil burial test supports the degradability nature of the sheets so that it can reduce the landfill. It has also been found that the BC film has good handling properties and can be sewedand molded to the requiredshape, which can further be used for textile and fashion end-use.

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