The Role of Technology Towards a New Bacterial-Cellulose-based Material for Fashion Design

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***Abstract*—In the late 90s, the textile industry has given rise to organic textiles. Since then, the concern for environmental quality has grown in the research and development of new environmentally friendly products as an important factor for sustainable development and economically feasible for population. Bacterial cellulose (BC) is synthesized by bacteria belonging to the genera of bacteria- *Aceto*, in particular very efficient gram- negative bacteria, such as *Gluconobacter xylinu*. The purpose of this study is to evaluate the potential application of textile finishing processes in the bacterial cellulose (BC development in order to give it more suitable properties to be used as a material for fashion design. We decided to use the knowledge of textile processing along with the knowledge about biotechnology in order to transform the BC in a hydrophobic material. The results of BC contact angle test showed an increase of about 60° comparing with untreated BC, thereby achieving a hydrophobic material whose surface reaches a contact angle of 118°. The surface analysis was also performed in order to verify the morphology of hydrophobic BC and compared with the pure BC. This analysis was performed by scanning electron microscopy (SEM). Finally, we analyzed the crystallinity by X-ray diffraction, comparing the pure hydrophobic BC and BC to observe possible changes in the structure of BC.**

***Index Terms*—bacterial cellulose (BC), hydrophobicity, fashion design, sustainability**

I. INTRODUCTION

Sustainability is a critical issue for current and future generations. The fixed idea that natural resources are infinite and that the environment has the capacity to regenerate and compensate for all human action, is no longer acceptable. Consequently, sustainability issues will influence all organizational aspects of human life from the point of view of economic, political, social and environmental. The transformation of human behavior is due to the shift in thinking in relation to resources and unlimited capacity “unlimited world” for regeneration, becoming aware and checking the possibility of termination of resources [1]. It is in this sense that we have to change because these issues encompass all areas of culture, economy, technology and many more. Fortunately, nature and the environment are capable of self-regulation and can give the man a chance to recover [2].

Technology, where much of the production is based, is challenged, along with the culture and the economy, to give the tools and options for building new solutions to a concept of sustainable production [2].

Bacterial cellulose (BC) is the most abundant biopolymer on earth. This is synthesized by bacteria belonging to the genera of bacteria-Aceto, and BC producing bacteria such as Gluconobacter xylinus are more efficient [3].

BC is based on a structure efficiently obtained by a self-assembly forming a network of nanofibers, giving rise to a BC structure that causes a higher crystallinity, higher tensile strength and a large water retention capacity compared to vegetable cellulose, which translates into a very hydrophilic material [4].

In textile industry context, a hydrophobic cellulosic is required because it has a wide range of applications, not only in conventional applications, such as in functional applications like in clothing, waterproof textile stain resistant (oils), among others. The ideal cellulose fabrics for water repellency are the hydrophobic fiber surfaces because they resist to water, with some porosity which allows moisture transport for user comfort [5].

Efforts to reduce the hydrophilicity of the surface of modified cellulose involved different technologies with different efficacies and durability’s.

The aim of this study is to generate bacterial cellulose water repellent, or hydrophobic BC, to try to obtain a material with potential application in design, particularly in the textile industry. In addition, a study of incorporation of a softener was performed to improve BC flexibility.

To achieve this we used the knowledge and applications in the textile industry as well as biotechnology safeguarding the best sustainability issues, environmental concerns and costs, allowing the process to be easily implemented extensively in the textile industry.

II. EXPERIMENTAL

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A. Material

For the production of cellulose, Kombucha xate of BioFermenté, green tea, black tea and sucrose (commercial products) Glucose from RAR, Peptone from Sigma Aldrich, Yeast Extract from Sigma Aldrich, Disodium Phosphate (anhydrous) from Sigma Aldrich and Citric Acid from RAR, were used. For the purification step, sodium hydroxide (NaOH) from Sigma Aldrich and acetic acid (CH3CO2H) from Pronalab, were used.

Hydrophobic commercial products from DyStar textile finishing were gently given in order to obtain the hydrophobic cellulose, the softener agent is EVO Soft Pen and the hydrophobic finishing agent is EVO Wet Fest.

B. Preparation of Bacterial Cellulose Pellicles

BC was obtained through a craft production at the University of Beira Interior. The BC is produced in a fermenter comprising an infusion of tea made with 2500ml of distilled water, 4g of green tea, 4g of black tea and 225g of sucrose, boiling until the sugar dissolves [6]. In addition to the tea brewer, we used a liquid culture medium Schramm and Hestrin composed of 10g of glucose, 2.5g peptone, 2.5g yeast extract, 1.35g disodium phosphate (anhydrous) and 0.575g of citric acid in 500ml of distilled water, the medium is autoclaved at 121C °for 20 minutes [7], [8]. After both solutions reach an ambient temperature, they were mixed in a glass fermenter with 250ml of Kombucha xate.

The fermenter is maintained at an average temperature of 30oC for 7 days. After this period the film is removed and purified in a solution of 0.1N sodium hydroxide for thirty minutes at 80℃ to remove the film medium components that were impregnated. This treatment is repeated three times [9], and neutralization comprising 5% acetic acid was subsequently done and finally the film is washed with distilled water [8], thereby obtaining a transparent film.

C. Preparation of Bacterial Cellulose Hydrophobic

After drying at room temperature, the film was divided into 16 samples weighing 0.013g-0.014g. The samples were subjected to a preliminary purification by delipidation - BC grease cleaning in order to remove oils, fatty acids and lipids, so that these do not interfere with the setting of DyStar products (softener and hydrophobic finish). The assay was performed by adapting the standard IWTO 10-64, taking into account the characteristics of the film BC.

The extraction of fats BC film with dichloromethane was performed using a balloon and a soxhlet extractor for 2h, so that it works 3 times per hour. In the end, when dichloromethane is found in its entirety in the flask, samples were removed from the soxhlet extractor and dried at room temperature.

After delipidation, a study of incorporation of a softener was performed to improve BC flexibility. Thus proceeded to the placement of four samples in four baths softener with different concentrations to ascertain whether a significant difference existed at the touch/final texture of the film. These baths were composed of distilled water, acetic acid 60% and softener, 0.5ml/l. After 1h of treatment, samples were removed from the bath and drying was performed for 2 minutes in the oven at 40℃. Then we ascertain whether there are significant differences in the touch/texture of the film BC taking into account the different concentrations.

After the softener study, the hydrophobic finishing process, where we used two different methods in order to check whether there were changes in the material behavior, was performed. The first method employed was that is customarily used in the textile industry, 6 BC samples were placed in a bath of 0.5ml softener, and then placed in a bath with hydrophobic finishing agent. These hydrophobic finishing baths were composed of distilled water, acetic acid 60% and hydrophobic product with two concentrations 1.5ml/l and 6ml/l, to check whether there are significant changes in the wettability test. The second method is the opposite of the first, this means, the 6 samples were placed initially in a hydrophobic finishing bath and finally in a softener bath. We followed the same amounts mentioned above for the various finishing hydrophobic baths. The different samples were dried in an oven at 120oC for 1 minute.

The combination of both treatments are according with the proportions for each finishing agent described on Table I.

D. BC and BC Hydrophobic Characterization

The assay was performed contact angle Contact Angle System in Dataphysics OCHA 200 with water only in order to analyze the samples wettability of BC and BC hydrophobic.

In addition, the patterns of X-ray diffraction (XRD) were recorded on X-ray diffractometer (Rigaku, D/MAX III/C), in order to verify the crystallinity and microstructure of the samples.

Finally microscopic images were made of BC and hydrophobic BC, through SEM - Scanning electron microscopy - (HITACHI S-2700), to study their morphology. The surface and cross-section of the samples were first treated with gold to be observed in SEM.

III. Results and Discussion

A. Material Characterization

In this work, we prepared different samples of BC, subjected to a softener treatment along with different concentrations of hydrophobic finishing from DyStar. There were two groups of different samples with respect to hydrophobic bacterial cellulose (hydrophobic BC) since there were two different methods, one method starts with the fabric softener bath and then the hydrophobic finishing bath, the other begins with the hydrophobic finish bath and finally in the bath softener.

The different samples considered for analysis is presented in Table I, in order to simplify the reading of the results.

TABLE I. BACTERIAL CELLULOSE (BC) AND THE DIFFERENT HYDROPHOBIC BACTERIAL CELLULOSE SAMPLES (HYDROPHOBIC BC) ACCORDING TO THE CONCENTRATIONS USED.

Material	Method	Softener Quantity	Hydrophobic Product Quantity
Bacterial Cellulose (BC)	*Kombucha tea + Schramm and Hestrin medium*	-	-
		Softener Quantity	**Hydrophobic Product Quantity**
Hydrophobic Bacterial Cellulose (Hydrophobic BC)	*Softener bath + Hydrophobic finishing bath*	0,5 ml 0,5ml	1,5ml 6ml
		Hydrophobic Product Quantity	**Softener Quantity**
	Hydrophobic finishing bath + Softener bath	1,5ml 6ml	0,5ml 0,5ml

B. Contact Angle

The contact angle test was performed on Dataphysics Contact Angle System OCHA 200 (Fig. 1a), in order to verify the results of the hydrophobic treatment (DyStar), and check which of the quantities introduced best suits the goals.

The samples were all cut to the same size with the help of a guillotine and then placed on the display, in a linear and homogeneous form, and a droplet (5 μ l) was subsequently deposited and a film instantly started to record the drop behavior (Fig. 1b) and absorption after 10s, in order to give information about the wettability of the samples. All results were transferred into computer so as to obtain numerical results of the absorption.

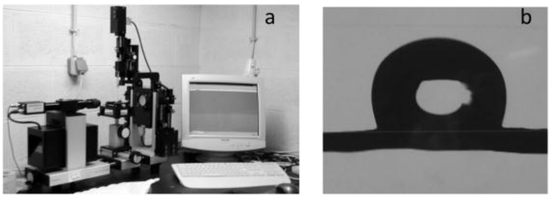

Figure 1. The equipment used for measuring contact angles (a). Image obtained by filming the device, the placement of the drop on the hydrophobic BC (b).

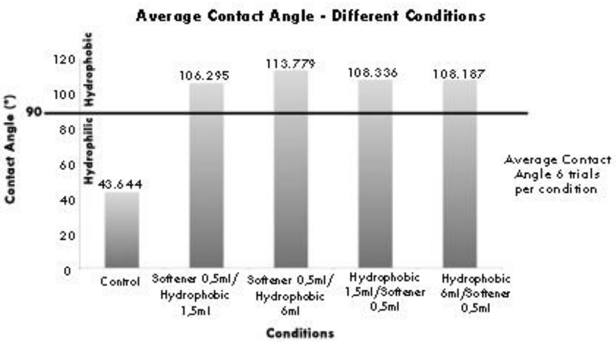

Figure 2. Average contact angle of BC and hydrophobic BC, taking into account the different conditions.

Six trials were performed for each condition, which allowed us to verify the homogeneity of the sample and its hydrophbicity. The use of two different methods, namely the use of initial softener and then the hydrophobic finishing, and on the other hand the use of hydrophobic finishing and finally aimed softener was done to check if there was any change of behavior of the material, knowing that in the textile industry the method is the use of softener and then the hydrophobic finishing. Likewise, the modifications of the material as the touch and texture were not significant regarding the behavior of the material.

In contrast, the average of all the tests concerning the contact angle showed a different behavior and the results can be seen in Fig. 2, so that it can be checked the most advantageous condition in accordance with the purpose of this work in achieving a hydrophobic material.

According to the method used in the textile industry, the use of softener and finally the hydrophobic finishing proved that achieves best results when referring to the hydrophobicity of BC. At the higher concentration of the hydrophobic finishing agent BC becomes more hydrophobic. However, it is possible to verify that any application abled to achieve a more hydrophobic BC, in comparison with pure BC.

C. X-ray Diffractometry (XRD)

The X-ray diffraction was used to study the crystallinity and microstructure of the samples from pure BC and hydrophobic BC. The spectra shown in Fig. 3 regarding to BC obtained before and after treatment, showed the peaks corresponding to the typical profile of amorphous cellulose I [10].

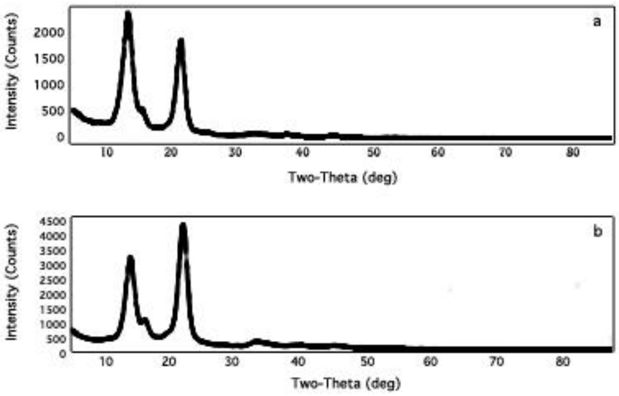

Figure 3. Images of Bacterial Cellulose XRD (a) and Hydrophobic Bacterial Cellulose (b)

However, compared to the XRD profiles of vegetable cellulose [11] those peaks show differences in intensity. This difference may indicate the difference of the processes of biosynthesis. Examining the plant cellulose, is usually synthesized by terminal clusters, whereas bacterial cellulose produced by bacteria of the family Gluconobacter is synthesized in linear terminals. The plant cellulose does not have a preferential plane, which means it has different levels, unlike bacterial cellulose having a preferential plane, where the cellulose molecules are oriented parallel to the plane, identified as tendency guidance “uniplane” [10], [11]. The peak is sharper for hydrophobic BC than for pure BC, and then the average value of the crystallinity index (CI) of the hydrophobic BC is slightly larger than that of the BC film.

The treatment does not alter the hydrophobic BC amorphous structure, compared to the BC peaks, which are sharper in the hydrophobic BC, which translates into an indication of the higher degree of crystallinity in the structure of the treated sample. The similar increase of crystallinity was detected by other authors [12] for samples of film treated by combining the effects of pressure and temperature, whereas the decrease of the porosity in the film leads to overall higher crystallinity.

D. SEM Image Observation

Fig. 4 shows the SEM images of BC and hydrophobic BC. As it can be seen from the figure, BC nanofibrils can be observed on the surface in a multilayered structure, thus verifying a structure of well-organized three-dimensional network.

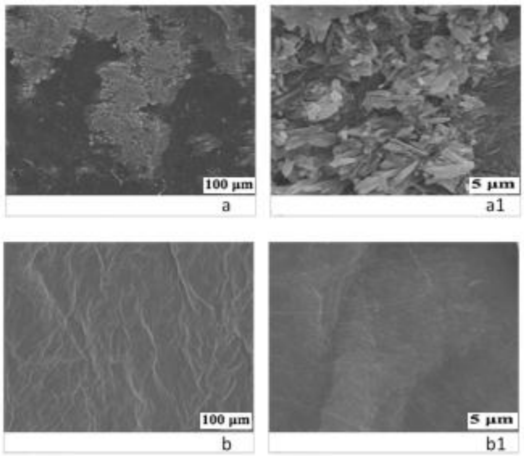

Figure 4. SEM images of Bacterial Cellulose (a) and Hydrophobic Bacterial Cellulose (b).

The biosynthesis of cellulose is characterized by growth in a single direction of crystallization, which verifies that the molecules are linear glucose, connected by β (1 → 4) glycosidic connection. The combination of glycosidic chains form microfibrils oriented with intramolecular hydrogen bonds [13]. The growth mechanism during bacterial activity determines the morphology of the final film.

After the hydrophobic treatment, the surface morphology of BC was changed. Hydrophobic BC unable the observation of nanofibrils as BC, and this change is due to the hydrophobic coating layer deposited on the treated BC forming a thick layer. With this coating layer the BC pores were sealed making it a hydrophobic layer.

IV. Conclusion

The hydrophobic BC was prepared by immersing the film in a solution of BC softener solution followed by a hydrophobic finishing. The test of the contact angle achieved in this way proves hydrophobic BC and that is possible to obtain hydrophobic BC with minimal quantities of hydrophobic finishing agents.

With these results we can see that besides the added value to make BC a hydrophobic material it can be also obtained a more homogeneous surface morphology with a more uniform fiber surface.

According to these results, it is expected that the hydrophobic BC may find interesting applications in design, such as the application of textile material in clothing, flooring and other interior design materials.

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