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Jute fabric in the development of a smart thermochromic textile

Tecido de juta no desenvolvimento de um têxtil inteligente termocrômico

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Ana Paula Hiller
ORCID: https://orcid.org/0000-0002-6645-5126
Federal University of Santa Catarina, Brazil
E-mail: hiller.anap@gmail.com
André Luiz Marquardt
ORCID: https://orcid.org/0000-0002-9605-4665
Federal University of Santa Catarina, Brazil
E-mail: andremarquardt007@gmail.com
Andrea Cristiane Krause Bierhalz
ORCID: https://orcid.org/0000-0002-7133-1590
Federal University of Santa Catarina, Brazil
E-mail: andrea.krause@ufsc.br
Fernanda Steffens
ORCID: https://orcid.org/0000-0003-3402-3641
Federal University of Santa Catarina, Brazil
E-mail: fernanda.steffens@ufsc.br

Abstract
In recent years, the market has shown a growing interest in adding value to textile materials through the search for natural processes that are less harmful to the environment. In this context, the use of natural fibers from plants provides very attractive properties, such as biodegradability, UV protection, acoustic insulation, among others. In this way, the purpose of this work was to functionalize a fabric from jute fiber with a thermochromic agent, making it a material with an intelligent property, being able to react thermally to the environment in which it is inserted. Through the analysis of reflectance spectrophotometry, the L*, a* and b* coordinates of the targeted and functionalized tissues were observed. When the ΔE of the samples functionalized at 4 different points was analyzed, good homogeneity of the thermochromic agent in the tissue was verified. The aging effect of the thermochromic agent was evaluated on the tissue for 1, 15 and 30 days after functionalization, where a slight increase in the b* value was observed, which indicates a certain loss of blue coloration in the sample. It was verified, therefore, that the functionalized jute fabric presented satisfactory results, allowing its use in other areas of application, mainly when referring to the interaction with the environment in which it is inserted.
Keywords: Chromic agent. Functionalization. Natural fiber.

Resumo
Nos últimos anos, o mercado vem manifestando um interesse crescente em agregar valor aos materiais têxteis através da busca por processos naturais e menos prejudiciais ao meio ambiente. Neste contexto, a utilização de fibras naturais a partir de plantas permite conferir propriedades muito atraentes, como biodegradabilidade, proteção UV, isolamento acústico, entre outros. Desta forma, a proposta deste trabalho foi funcionalizar um tecido proveniente da fibra de juta com agente termocrômico, tornando-o um material com propriedade inteligente, sendo capaz de reagir termicamente ao meio em que é inserido. Através das análises de espectrofotometria de reflectância

foram observadas as coordenadas L*, a* e b* dos tecidos alvejados e funcionalizados. Quando analisado o ΔE das amostras funcionalizadas em 4 pontos distintos, verificou-se boa homogeneidade do agente termocrômico no tecido. O efeito *aging* do agente termocrômico foi avaliado no tecido para 1, 15 e 30 dias após a funcionalização, onde foi observado um ligeiro aumento do valor de b*, o que indica certa perda da coloração azul na amostra. Verificou-se, portanto, que o tecido de juta funcionalizado apresentou resultados satisfatórios, possibilitando sua utilização em outras áreas de aplicação, principalmente quando refere a interação com o meio o qual está inserido.
Palavras-chave: Agente crômico. Funcionalização. Fibras naturais.

Nomenclature

a* Red/green axis
b* Yellow/blue axis
L* Luminosity
Δa Color difference on the red/green axis
Δb Color difference on the yellow/blue axis
ΔL Color difference on the brightness axis
ΔE Delta E – Color Difference

1. Introduction

The textile industry expresses its dissatisfaction due to the stagnation of its production process regarding the products it makes available on the market. Increasingly, the search for the development of fibrous materials with high benefit has become fundamental, seeking to develop simpler and more direct responses to processes and products in this sector.

Based on this conception, processes have been applied to textiles in order to functionalize them, to increase different properties in these materials and thus meet a greater demand from consumers with different specifications and preferences (Revaiah; Kotresh; Kandasubramanian, 2020). Smart textiles are getting attention in this field, and they can be defined as textiles that can sense and react to environmental conditions or stimuli, from mechanical, thermal, magnetic, chemical, electrical, or other sources. They are able to sense and respond to external conditions (stimuli) in a predetermined way (Syduzzaman et al., 2015).

There are countless reasons to produce functional activities in textile materials, highlighting: the search for comfort, protection and safety, durability of extra effects, and the facilitation of care during use. It is possible to apply the final product in various sectors of the economy, such as design and architecture, civil construction, automotive, naval and aerospace industries, and also in health, sports, fashion, among others (Revaiah; Kotresh; Kandasubramanian, 2020).

When addressing social benefits, fibrous materials are associated with growing regions that produce these fibers, which may be residues of some agricultural crops, thus justifying the possibility of obtaining additional economic benefits for the communities that work in their crops (Adekomaya; Jamiru; Sadiku, 2016).

With this, the objective of this work is to functionalize the jute fabric with a thermochromic agent, in order to analyze the transfer of this effect to the fabric as well as its durability, bringing, as a consequence, new functionalities and application possibilities for the jute fabric.

2. Methods and materials

For the development of the smart textile, jute taffeta rapport fabric was used, weight 190 g/m², with 3 threads/cm in the warp direction and 2 threads/cm in the weft direction, supplied by the company CASTANHAL COMPANHIA TÊXTIL. The functionalizing agent for dyeing was Chromicolor AQ Ink, BRASCHEMICAL brand, Fast Blue color.

The samples went through the processes of dyeing and reductive washing. Next, measurements were performed in the spectrophotometer. All tests were performed at the Federal University of Santa Catarina (UFSC) in the Department of Textile Engineering, in the Postgraduate Program in Textile Engineering, Campus Blumenau.

2.1 Preparation of jute for application of thermochromic agent

First, 10 samples of jute fabric, each weighing 10 g, were bleached using the HT-IR DYER equipment from TEXCONTROL, model TC 2200, with infrared heating (IR). The bleaching was made with the objective of transforming the colored impurities into colorless particles, producing a whiter material.

For the bleaching process, a 1 L solution was prepared with concentrations of 1 % industrial sodium hydroxide 50 %, 1 % hydrogen peroxide (H_2O_2), 4 % COLOR QUÍMICA brand detergent (Color emulg EMG 441) and 4 % calcium and magnesium dispersing agent, COLORSPERCE DSP 1098.

The fabric to bath ratio was 1:20. The samples and the solution were placed individually in the dyepot and the process started at room temperature, around 23 ºC, heating up to 80 ºC with a heating ramp of 3 ºC/min. After reaching 80 °C, the process was held at that temperature for 30 minutes and then cooled to 40 °C. At the end of the process, the samples were washed with deionized water, in order to remove residual detergent and NaOH, until a neutral pH was obtained. Afterwards, they were placed in an oven for drying.

After finishing the bleaching process, the cationizing agent was applied, where 5 % of poly(diallyldimethylammonium chloride) (PDDA-CL) was used on the mass of the material, totaling 0.5 g of the agent. The samples were placed individually in dyepot and the cationization process started at room temperature, heating up to 70 °C with a heating ramp of 3 °C/min. Upon reaching 70 °C, the samples remained at that temperature for one hour and after this period were removed from the equipment.

2.2 Functionalization

The jute fabric, after going through the bleaching process, went to the dye bath. This process took place using the so-called pad-dry and pad-bath methods, which are continuous dyeing systems using a foulard bath, consisting of a chassis containing two compression rollers. In the pad-dry process, the fabric is hot-dried at a temperature of 80 ºC after dyeing, while in the pad-bath the substrate dries at room temperature. Both forms were tested, showing no significant change in the dyeing of the samples. Therefore, it was decided to use the samples submitted to the pad-bath. For functionalization, a concentration of 50 g of agent for a 1 L solution was used. The dye was deposited on the pad, which was adjusted to a pressure of 4 bar, at a speed of 4 m/min. The samples passed through the pad twice to obtain a greater impregnation of the thermochromic pigment in the fabric.

2.3 Functionalization

The samples previously bleached and dyed were then measured in the DATACOLOR spectrophotometer equipment (model 500) in order to analyze the uniformity of the application and the effect of the thermochromic agent on the jute fabric. The D65 illuminant was used, which represents daylight, 10° observer and 6 mm aperture. To evaluate the uniformity of dyeing, related to the absence of stains and the quality of the product, color measurements were performed on three functionalized samples at four different points.

CIELAB color parameters L*, a* and b* were measured. L* represents lightness, which varies between 0 (ideal black) and 100 (ideal white); the coordinate a* represents the color red (+ a*) and green (- a*); the b* coordinate represents the color yellow (+ b*) and blue (- b*) (ANAND, 2016).

From these parameters it is possible to obtain the color difference that can be indicated by means of a single value, the Delta E (ΔE), which represents the geometric distance between two points in the color space, thus obtaining the value of the difference of color among the analyzed samples. The higher the ΔE value, the greater the color difference. Through the analysis of color in the functionalized fabrics, it was also possible to verify the uniformity of the dyeing, performing the reading in 4 points and analyzing the ΔE in the same sample. The color variation was calculated according to Equation 1, where ΔE represents the color difference, ΔL the color difference of the L* coordinate, Δa the color difference of the a* coordinate and Δb the color difference of the b* coordinate.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

To verify the change in the color of the jute fabric, the tests were performed in an environment with a temperature between 22.8ºC~23.8°C, one day after functionalization. The stimulus in the samples occurred through the following way: heat application by means of a hair dryer, at a temperature of 60 °C and a distance of 5 cm from the samples.

To obtain the values of each coordinate, analyzes were performed in triplicate for each sample. Then, the average of the results obtained was performed.

Figure 1 shows a demonstration of the steps to develop this work.

Figure 1 – Work development stages.

3. Results and discussion

First, the colorimetric characteristics of the samples were evaluated. The solution presented in the research aimed at to enable new applications of jute fabric, combined with innovation, in the development of smart textiles.

3.1 Preparation and functionalization of the jute fabric

The jute fabric was previously bleached and cationized. After it was functionalized. The bleaching result can be seen in Figure 2.

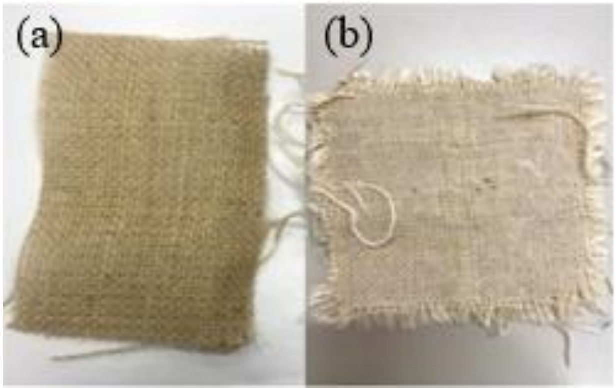

Figure 2 – Comparison between samples without (a) and with bleaching (b).

The result of cationization in the samples and the influence that the process generated on the jute pigmentation can be seen in Figure 3.

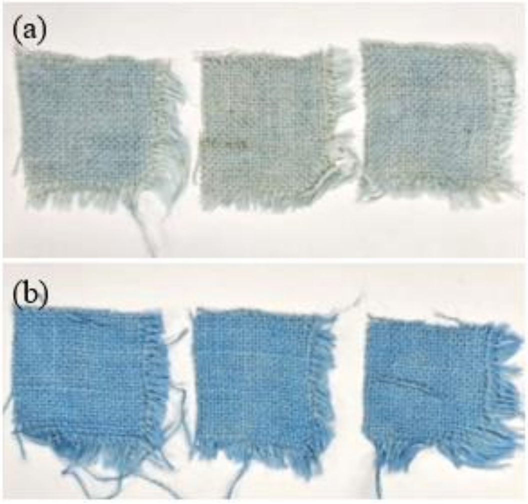

Figure 3 – Comparison of samples without (a) and with (b) cationizing agent.

The purpose of incorporating cationic groups in cellulose is not only to eliminate the repulsion between dye and fiber, but also to create an ionic attraction, in order to increase the efficiency of the dyeing process. After observing Figure 4, it is possible to conclude that the cationization of the fiber favors the thermochromic fixation, which is probably due to the ionic chemical interactions between anionic functional groups of thermochromic and the cationized groups of cellulose in jute. Figure 4 illustrates the fabric that, after bleaching, went to the functionalization stage with the thermochromic agent.

Figure 4 – Functionalized jute fabric.

Visually, it can be seen from Figure 4 that the dyeing showed good quality and uniformity of the fabric.

3.2 Coloristic changes

From the analysis of the color of the functionalized fabric, the transfer of the effect of the thermochromic agent can be evaluated. For the functionalized jute fabric, the period of heat application and observation of the total color change in the sample was 7 seconds.

Table 1 shows the mean readings per quadrant as well as the ΔE values for each functionalized fabric sample.

Table 1 – Color reading by quadrants.

Sample 1	**L***	**a***	**b***	**ΔE**
Average	53.90	-11.60	-21.63	**0.26**
Sample 2	**CIE L***	**CIE a***	**CIE b***	**ΔE**
Average	52.90	-11.56	-21.66	**0.22**
Sample 3	**CIE L***	**CIE a***	**CIE b***	**ΔE**
Average	52.25	-11.66	-22.53	**0.31**

All readings performed on the functionalized samples showed ΔE below 1, in relation to the average of the sample itself, that is, they indicated that the visual variation was not perceptible.

In Table 2, the L*, a* and b* coordinates for in natura, bleached and cationized, and functionalized tissues were compared. As a standard for calculating the ΔE, the values referring to the jute fabric in natura were used, in order to also observe the action of bleaching and cationization in the samples.

Table 2 - Colorimetric coordinates of fabrics.

Sample	**L***	**a***	**b***	**ΔE**
Natural fabric	68.09	2.98	16.39	**-**
Bleached and cationized fabric	80.08	2.59	16.32	**11.99**
Functionalized fabric	53.09	-11.63	-21.94	**43.67**

Analyzing Table 2, it can be seen that the values found indicate that bleaching the jute brought about a great change in the color of the fabric, which made it possible for the thermochromic agent to stand out more when applied to the samples. Also, the dyeing color of the jute fabric showed great changes in its color, indicating that the functionalizing agent was uniformly applied to the fabric, where the total difference in color is due to the change in the three coordinates, especially in the coordinate b*, which the more negative, indicates that the color is bluer.

4. Conclusion

From the development of this work, it was possible to demonstrate the possibility of using jute fabric for the development of textiles with smart properties, capable of thermally reacting to the environment in which it is inserted.

The results for verifying the color characteristics of the samples appreciated for the functionalized jute fabrics, all the readings in the spectrophotometer showed ΔE below 1, that is, the exposures after dyeing present uniform colors. Still, the functionalized fabrics showed good visual results, according to spectrophotometry

Therefore, after the analyzes carried out, it was possible to verify the transfer of the thermochromic functionalizing agent to the jute fabric, allowing the development of a fabric with smart characteristics using a new application aspect for the jute fiber. Based on the results presented, this work provides new information on the development of smart thermochromic materials, enabling the use and application of natural substrates for applications, which until then have not been widely explored. Consequently, a greater (re)use of jute fabric is possible, directing its use to a greater diversity of areas such as engineering, architecture and design.

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