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# SUSTAINABLE AND MULTIFUNCTIONAL NATURAL FIBER-BASED ELECTRIC WIRE SHEATHS FOR SMART TEXTILES

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## ABSTRACT

Envisioning the development of sustainable products for improvement of daily life quality, a cable-like composite using natural fibers was developed to be potentially used in smart textiles. Natural fibers such as jute and hemp were used along with Bekinox®VN yarn. Bekinox®VN is a stainless steel conductive yarn often used in intelligent textiles within a wide range of applications such as antistatic, power and signal transfer, thermal conductivity or even as a heat resistant sewing yarn. Furthermore, applying a chitosan coating on the surface of the sheath will confer antibacterial properties, thus preventing the colonization and proliferation of bacteria, as well as natural fiber degradation. The chitosan coating was applied by a pad dry method. Tests were performed to evaluate the mechanical, electrical and antimicrobial properties. The results displayed that the best tensile strength was obtained for hemp fabric followed by cable composite. The antimicrobial properties were improved with the coating of chitosan and demonstrating excellent results against Gram-positive and Gram-negative bacteria. Although chitosan reduces the mechanical strength of the sheath, it confers antibacterial activity, which not only will preserve the fiber in the structure but will also protect human skin against possible cross-contaminations.

## KEYWORDS

Natural fibers; conductive yarn; chitosan; antimicrobial; electronic textiles.

## INTRODUCTION

Stepping towards sustainability encourages replacing synthetic fibers with natural fibers in several applications [1]. Fibrous structures owing to their flexibility, lightweight, and capability to form various shapes can find several applications such as in military, sports, automotive, aerospace, and wearable electronics, due to their ability to conduct electricity. Natural fibers such as jute and hemp are promising reinforcements in composites. They are abundantly available, biodegradable, recyclable with higher strengths, low extensibility, and good sound and heat insulation properties. Furthermore, they display good mechanical properties due to their low microfibrillar angle and high cellulose content. However, they have high resistance and absent electrical conductivity which hinders their application in smart textiles [2]. Hence, one of the strategies to reduce resistance is to functionalize with metallic elements [1]. Conductive yarns are mixed with natural fibers to reduce electrical resistance. These yarns can be used to produce a conductive textile that potentially viabilizes applications in wearable electronic devices [2,3]. Natural cellulosic fibers are likely to be affected or deteriorated by microorganisms colonization and activity, thus compromising the quality of the fibers [2]. To overcome this issue, antimicrobial polysaccharides, such as chitosan, can be used as coating agents and applied with different techniques, namely by dipping and padding [4]. Chitosan is derived from chitin, which is commonly available in nature, renewable, biodegradable, biocompatible, antimicrobial, and possesses good mechanical and thermal properties. It can improve the antibacterial properties of natural fibers by killing the microorganisms through the electrostatic interaction between the positive and negative charges of the chitosan and microorganisms respectively [4].

This study envisaged the production of an antimicrobial conductive composite, using a 100% stainless steel yarn and jute fibers, as conductive and insulator materials respectively, enclosed in a hemp fabric (cable-like structure) as a substitute of plastic or synthetic fibers for sheaths. It was then functionalized with chitosan to provide antimicrobial activity. This natural fiber-based sheath may be applied in a plethora of wearable electronic devices.

## MATERIALS AND METHODS

### Materials

Raw jute fibers and plain hemp fabric 125 g $m^{-2}$ were obtained in local market. 100% stainless steel, 250 Tex Bekinox®VN multifilament yarn (reference VN 12/1x275/100Z/316 L) was obtained from Bekaert, Belgium. High molecular weight chitosan and glacial acetic acid were both obtained from Sigma Aldrich.

### Composite preparation

Raw jute fibers were combined with Bekinox®VN yarn and enclosed into the hemp fabric by sewing, forming a cable-like structure. The obtained structure was then functionalized, with a chitosan solution at 3% wt and acetic acid at 1% v/v, by padding (Roaches Padder, 4 m $min^{-1}$ at 2 bar) and then dried at 60 ºC for 1 h.

### Conductivity measurement Standard Test (EN 16812:2016 (E))

The resistance of the Bekinox®VN yarn was measured according to the standard EN 16812:2016 (E), using a "four electrode – four-wire" method. This method is used to measure linear resistance. Furthermore, it is more advantageous than the two-wire method since the four-wire eliminates the inherent resistance of the connecting cables, thus requiring fewer measurements and calculations. The following test equipment was used for the test setup: an electric power source, a voltage meter, contact electrodes (copper), a portable dynamometer for yarns (to ensure adequate tension), a calibrated ruler for measuring the distance between electrodes and an insulating surface on which the sample is placed while measuring. The distance between electrodes was set to 50 cm.

### Tensile Strength Standard Test (ASTM D5035-11 (2019))

The maximum force and elongation were evaluated according to the principle of the standard ASTM D5035-11 (2019). The width of the sample was fixed at 10 mm and a length that allows an initial distance between the clamps of the universal tensile equipment (Hounsfield 100 KS, Salfords, UK) of 100 mm was set out in grips and subjected to tensile force. Three replicas were performed for each group of samples at constant speed of 25 mm $min^{-1}$.

### Antibacterial evaluation

The antibacterial activity was assessed through an adaptation of AATCC 100 TM 100 as described in [5]. Briefly, 3 $cm^2$ of hemp (control) and the developed composite were inoculated with *Staphylococcus aureus* ATCC 6538 or *Escherichia coli* ATCC 25922. The concentration of each inoculum was $1 \times 10^7$ CFU $mL^{-1}$. After 1 h at 24 °C, were immersed in a solution of 100-fold the volume of the inoculum and were vortexed at maximum speed for at least 1 min. Subsequently, each sample was serial diluted and inoculated in TSA and incubated for at least 14 h at 37 °C. CFU $mL^{-1}$ log reduction was estimated after CFU quantification.

## RESULTS AND DISCUSSION

The prepared composite was evaluated for electric wire resistance, tensile strength and antimicrobial activity. Electrical resistance was measured in the Bekinox®VN yarn per se and when it was incorporated in the composite. When a power of 14 V was applied, the Bekinox®VN yarn and the cable-like composite displayed tensions of 48.2 mV and 55.5 mV, respectively. As the direct current was maintained at 3.00 mA, the determined resistance of 16.01 Ω and 18.45 Ω, was achieved for Bekinox®VN yarn and the cable-like composite, respectively. The tensile strength of four different groups of samples, was assessed: cable composite; cable composite without Bekinox®VN yarn; hemp with chitosan; and hemp (Figure 1).

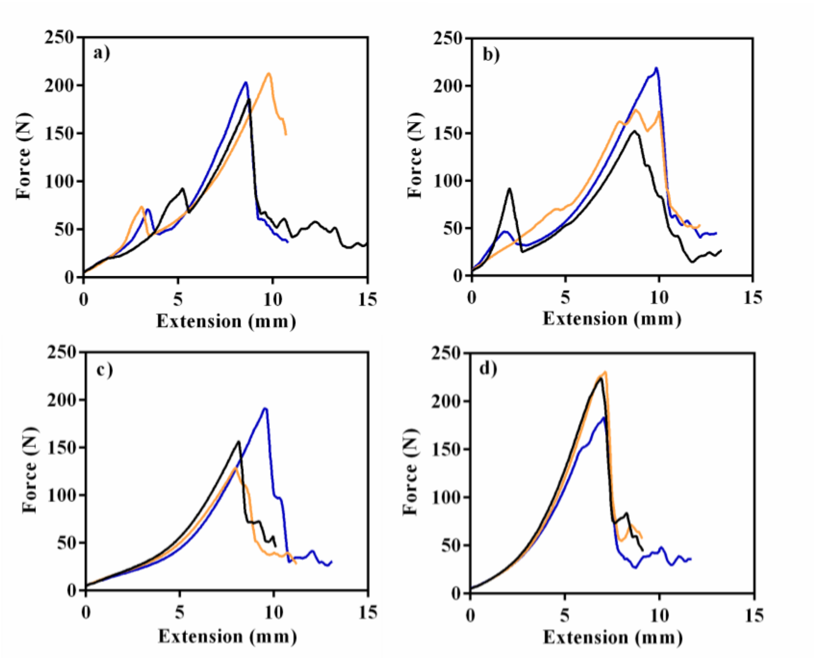


**Figure 1. Tensile strength measurements (n=3) of a) cable composite (200.6±13.37 N), b) cable composite without Bekinox®VN yarn (182.4±34.05 N), c) hemp + chitosan (158.8±31.09 N) and d) hemp (212.4±25.87 N).**

Of these four groups of samples, hemp presented the best tensile strength, followed by the cable composite, cable composite without Bekinox®VN and finally, hemp coated with chitosan. These results show that chitosan is reducing the tensile strength by 5.5% when compared to hemp. When the conductive yarn is removed the tensile strength reduces an additional 9%. Chitosan coating clearly diminished the mechanical properties of the composite, probably due to the increase in stiffness. However, the samples containing chitosan denoted excellent antibacterial activity against both tested bacteria (Figure 2). The cable-like structure displayed disinfection properties against *E. coli*, with log reduction above 3 (99.9%). As for *S. aureus*, the cable-like structure denoted sterilization properties, since the log reduction was above 6 (99.9999%) [6]. Hemp fabric displayed a similar, non-relevant, inhibitory activity against the tested Gram-negative and Gram-positive bacteria.

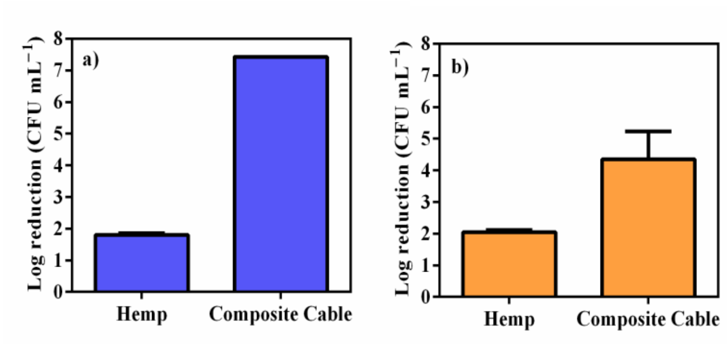


**Figure 2. Antimicrobial activity of composite cable against a) *S. aureus* and b) *E. coli.***

## CONCLUSION

The developed cable-like composite did not increase the resistance and displayed a relevant antibacterial activity. Being mainly composed of natural and sustainable materials it may be considered as proof of concept that sustainability may go hand in hand with functionality and active properties. Antimicrobial properties have gained a pivotal role during the current COVID-19 pandemic, and all efforts to prevent microbial transmission are considered extremely important.

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