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Moisture Absorption and Desorption in Flax and Hemp Fibres and Yarns

Abstract
The aim of this paper is to present research work about the mode in which the water sorption-desorption process is influenced by the type of spinning yarns (dry or wet) and by the type of roving treatment (boiling or bleaching) in the case of flax and hemp yarns. The hygroscopic properties of fibres, yarns and woven fabrics from flax and hemp boiled or bleached were investigated at different relative humidities. The saturation limit of moisture absorption of the fibres varies depending on the source as well as pre-treatment of the sample. The effect of water quantity absorbed on the electrical resistance of the fibres and yarns and on the mechanical properties was examined.

Key words: *fibre, yarn, electrical resistance, mechanical properties, hygroscopicity.*

Introduction

Recently research efforts from the flax and hemp industry have been directed towards obtaining materials that have environmental protection through to the end of their life cycle. In this context, the tendency is to substitute the glass fibres or carbon fibres in the structure of the composite with natural fibres, which are biodegradable and lower in energy consumption, [1 - 3]. The presence of natural fibres in the structure of the composites under the action of environmental factors can influence their mechanical and electrical properties.

Textile hygroscopicity has great importance for textile and non-textile users as it affects processing and performance [4 - 11]. The electrical resistance of textiles is one of the physical characteristics influenced by the hygroscopicity [12, 13, 20].

The moisture absorption capacity of textile fibres has a direct impact on the size of the fabric and comfort level. Flax and hemp fibres, composed mainly from cellulose, possess OH groups, the active chemical groups important for the absorption of water particles [14 - 17]. The transfer of specific properties of fibres and yarns to woven fabric behaviour is a complex process which is dependent on many factors. Thus fibre hygroscopicity has a direct impact on the amount of water in yarns and in weaves, as well as on their main physical and mechanical characteristics. Maintaining for a longer duration the normal behaviour of flax and hemp products used in high humidity environments requires detailed knowledge of the complex phenomenon of the sorption-desorption of water and its influence on the product's characteristics. The mechanical properties of flax and hemp yarns and fibres are comparable to those of glass fibre due to their high degree of specific rigidity. On the other hand, the mechanical properties of wet fibres and yarns such as fibre strength, elongation, elasticity, and modulus of elasticity are influenced by the processing and use mode of the final products.

The objective of this paper is to study the mode in which the water sorption-desorption process is influenced by the type of spinning (dry or wet) and by the type of roving treatment (boiling or bleaching) of flax and hemp yarns. Also the electrical resistance of fibres and yarns at the wet and dry state and the mechanical properties after wetting and drying at room temperature were evaluated.

Experimental

Materials and methods

Flax and hemp woven fabrics, fibres and yarns used in this study were obtained from the local market (Spinning Mill, Falticeni-Romania). The two types of fibres have similar microstructures [19]. The main aspects that are different are the ratio of amorphous and semi crystalline cellulose and the microfibrillar angle, defined as the angle that the micro fibrils form with the longitudinal axis of the cell [4 - 7, 18, 19, 21]. These two parameters and chemical compositions (***Table 1***) explain the difference in physical and mechanical properties between the two types of fibres.

The values of chemical components of fibres (***Table 1***) depend on the conditions of plant growth. The linear density of the elementary fibres are (0.20 - 0.33) tex for hemp fibres and (0.125 - 0.285) tex for flax fibres.

Table 1. *Chemical composition and some physical properties of hemp and flax fibres.*

Type of fibres	Cellulose, %	Hemicellulose, %	Lignin, %	Pectine, %	Density, g·cm^{-3}	Crystallinity degree, %	Microfibrillar angle *Φ*, °
Hemp fibres	52 - 58	15 - 18	3 - 6	4 - 10	1.43 - 1.48	8 - 79	4 - 12
Flax fibres	71 - 76	13 - 17	0.6 - 5	3 - 4	1.43 - 1.54	47 - 88	12°52' - raw roving in dry state; 17°34' - raw roving in wet state; 6°67' - bleached fibres in dry state; 16°09' - bleached fibres in wet state.

Before testing, the flax and hemp fibres, yarns and woven fabrics were conditioned in standard conditions for 48 hours [22].

The effect of water absorption on the test samples from fibres, roving, yarns and woven fabrics was investigated in accordance with the standard method presented in SR ISO 6741-1/1998, [23]. Hemp fibres were extracted from hemp tow type II and flax fibres from raw roving. The degree of compactness of flax and hemp fibres during the sorption-desorption process was comparable. Measurements were made under the same air conditions of temperature and humidity. At the beginning, all of the samples were conditioned in standard conditions for 48 hours and then cooled to room temperature before weighing. Water absorption tests were conducted by immersing the samples in a de-ionised water bath at 25 °C for different time durations: 5, 10, 15, 20, 25 and 30 minutes. The desorption process was monitored at ambient temperature until equilibrium. The samples were weighed every five minutes until the quantities of water absorbed and transferred were equal and constant. Before the tensile testing, excess moisture was removed with sheets of absorbent paper.

The tensile strength before and after water immersion of the flax fibres from raw roving and for yarns was measured according to ISO 2062 on a TINIUS OLSEN H5 K-T yarn tester (UK) by automatic registering of the force–extension curve. For serial testing in the wet state, the yarns were stressed after 30 minutes moistening and the fibres after 10 minutes. In the dry state ten measures were made. For the first five measurements the samples were conditioned in standard conditions before testing and for the second five the samples were tested after one hour of moistening and drying at room temperature at constant weight. The electrical resistance of fibres and yarns in the wet and dry state was measured with a Digital Multimeter DUW.

Results and discussion

The coding of samples of fibres and yarns submitted to analysis are presented in ***Table 2***.

The percentage of water absorption into the hemp and flax fibres, yarns and woven fabrics was calculated from the weight difference between the samples immersed in water and the dry samples using the following equation:

$$\Delta M(t) = \frac{m_t - m_0}{m_0} \cdot 100$$

where $\Delta M(t)$ is the moisture uptake, and m_0 & m_t are the mass of the specimen before and after drying, respectively.

The maximum water absorption degree for hemp fibres was obtained after an interval of being stationary in water for 25 minutes, see ***Figure 1***. Flax fibres reached the maximum water absorption degree after 20 minutes of wetting. In the first 15 minutes, water molecules accumulated on the surface of fibres entered into the amorphous zones of each fibre. After 20 minutes, the water penetrated into the entire volume of the sample. The water sorption capacity of flax and hemp fibres depends on the ratio of cellulose polarity and water polarity. Hydroxyl groups inside the molecular chain of cellulose determine the polarity of polymer. The hydrated water is composed of water molecules which are linked through hydrogen bonds to the hydroxyl groups of cellulose fibres. After 20 minutes of wetting, the diameter of flax fibres increase by about 30%. In the case of hemp fibres the growth of the diameter is about 40%. The swelling effect during moisture absorption in flax and hemp fibres may be explained by the non crystalline zones, by the presence of polar groups and by the crystallite dimensions, [12]. The maximum water degree absorption coincides with the saturation of hydroxyl groups situated on the macromolecular chain of cellulose.

The high value of water degree absorption of flax fibres, 280%, in comparison with 250% for hemp fibres, may be attributed to the higher cellulose content of flax fibres in comparison with the cellulose content of hemp fibres.

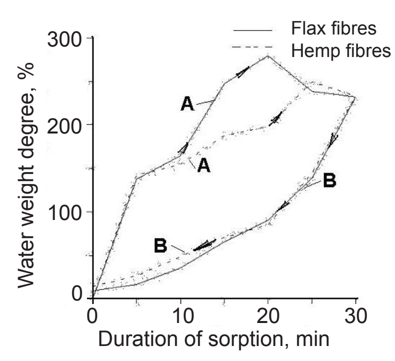

Figure 1. *Sorption – desorption curves of hemp and flax fibres at 21 °C ambient temperature and 40% relative humidity: A - sorption, B - desorption.*

During the desorption process, water molecules indirectly linked are the first which are vaporised and then water directly connected to the fibres is gradually removed. For flax fibres, the sorption-desporption equilibrium was reached within 40 minutes of drying at 21 °C ambient temperature and 40% relative humidity. The desorption is slower to a limited state of equilibrium (see ***Figure 1***). Hemp fibres lost 40% of the moisture content, water swelling linked indirectly to the fibre, during the first 5 minutes of drying in air at 21 °C ambient temperature and 40% relative humidity. Then after each interval of 5 minutes of drying, the decrease was 15 - 20% of the water content of the hemp fibres. The entire water absorbed by hemp fibres is removed by drying at ambient temperature in 40 - 45 minutes, when it reaches sorption-desorption equilibrium.

Dry and wet spun yarns obtained from raw, boiled and bleached roving were studied to prove how the fabrication technology of yarns influences their hygroscopicity. The yarns that have high compactness reach sorption-desorption equilibrium at ambient temperature more slowly than fibres. Hence for flax and

Table 2. *Samples' coding of fibres and yarns.*

Types of fibres and yarns analysed	Sources of fibres, or type of spinning yarn and roving finishing	Coding is similar to average linear density, T_{tex}
Flax fibres	Fibres extracted from raw roving with 555 tex linear density	2
Hemp fibres	Hemp tow type II.	6
Flax yarns	Dry spinning yarn from raw roving	69
	Wet spinning yarn from boiled roving	104
	Wet spinning yarn from bleached roving	72
		24
Hemp yarns	Wet spinning yarn from raw roving	73
	Wet spinning yarn from boiled roving	91
	Wet spinning yarn from bleached roving	53

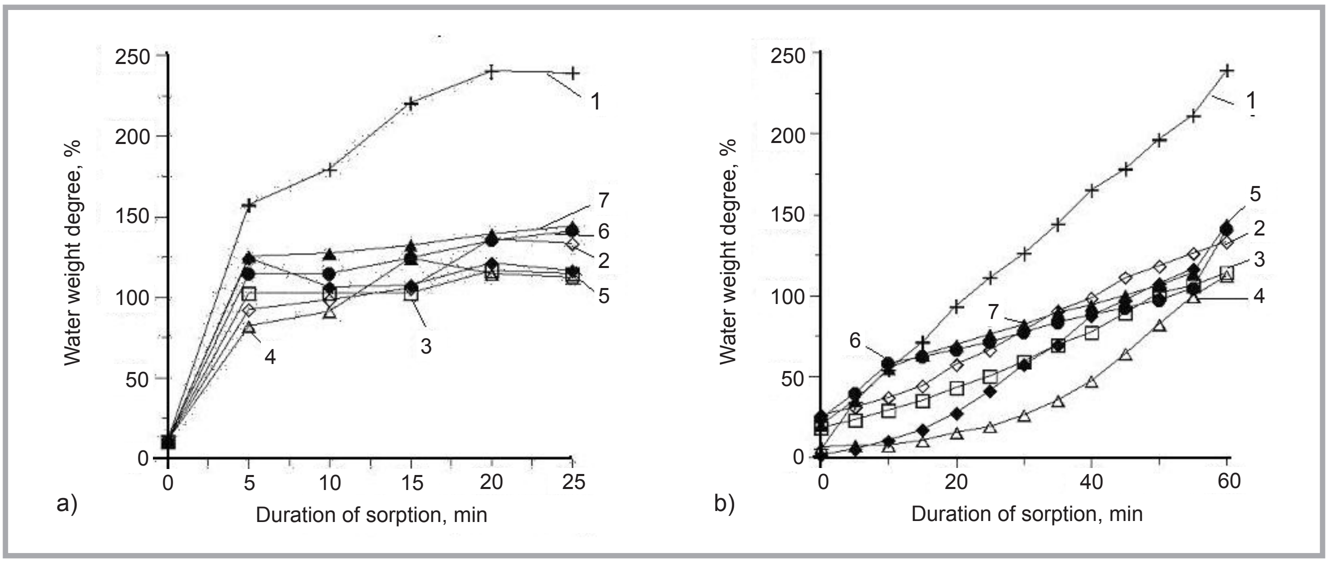

Figure 2. *Sorption (a) and desorption (b) curves of flax yarns (curves 1 - 4) and hemp yarns (curves 5 - 7): curve 1 - yarn 69 tex, dry spun from flax raw roving; curve 2 - yarn 104 tex, wet spun from flax boiled roving; curve 3 - yarn 72 tex, wet spun from flax bleached roving; curve 4 - yarn 24 tex, wet spun from flax bleached roving; curve 5 - yarn 73 tex, wet spun from hemp raw roving; curve 6 - yarn 91 tex, wet spun from boiled roving; curve 7 - yarn 53 tex, wet spun from bleached roving.*

hemp yarns the duration of desorption is 60 - 65 minutes and the maximum sorption is reached at 20 - 25 minutes, see ***Figure 2***. The values of water degree absorption for flax and hemp yarns according to yarn fabrication technology are presented in ***Figure 2***. Analysis of these curves allows the following comments:

The maximum degree of water absorption, for almost all yarns, is reached after 20 minutes, excepting for thin yarn 24 tex wet spun from bleached flax roving, which reaches the hydration peak after 15 minutes. Flax yarn of 69 tex linear density obtained by dry spinning from raw roving, with high porosity, absorbs a larger quantity of water in comparison with wet spiun yarns, with a structure of no porosity, see ***Figure 2***. This means that natural pigments and non cellulosic substances remaining on the fibres influence yarn hygroscopicity significantly.

Flax yarn 24 tex from bleached roving has the maximum degree of water absorption, about 20% greater compared with flax yarn 72 tex. This fact can be a consequence of a more intensive process of bleaching for flax roving in the case of yarn 24 tex. Flax yarn 69 tex from raw roving absorbs a higher quantity of water in comparison with the other yarns (***Figure 2.a***) thanks to higher porosity obtained by dry spinning.

All hemp yarns studied have a compact structure, which means a structure without porosity because of the wet spinning. Hemp yarn 73 tex from raw roving reaches the maximum degree of water absorption after 20 minutes, while hemp yarns of 91 tex and 53 tex from boiled roving and bleached roving reach the maximum after 25 minutes. Hemp yarns obtained from boiled or bleached roving absorb about 20% more water than that obtained from raw roving, which may be attributed to the higher cellulose content of boiled and bleached yarns in comparison with that obtained from raw roving.

For the desorption of water from yarns performed at ambient temperature, equilibrium was reached in the case of all flax yarns and for the 73 tex hemp yarn wet spun from raw roving, after more than 60 minutes, see ***Figure 2.b***. Hemp yarns of 91 tex and 53 tex lose the water quickly. This phenomenon may be based on the increased number of water molecules linked inside of the boiled and bleached fibres, which have a higher content of cellulose than the raw fibres. The low speed of yarn desorption at room temperature may be attributed to the high compactness of the yarns and of the water molecules directly connected to fibres.

Table 3. *Structural characteristics of the woven fabrics investigated.*

Characteristics		Woven fabric from hemp	Woven fabric from bleached flax
Linear density of yarns from woven fabric, tex	Warp	348	50
	Weft	480	50
Technological density of woven fabric, yarns /10 cm	Warp	50	170
	Weft	60	170
Fabric weight, g/m^2		541	173

The sorption of water from the woven fabrics with the structural characteristics presented in ***Table 3*** is a function of the wetting time.

As can be seen from ***Figure 3***, the hemp woven fabric reaches the maximum water content after 10 minutes and bleached flax woven fabric after 5 minutes wetting. Greater thickness and lower technological density have a positive influence on the water sorption process.

The degree of water absorption for woven fabrics compared with the yarns that compose them is presented in ***Figures 4*** and ***5***.

It can be seen that in both cases component yarns from the weft and warp have registered a high degree of water absorption in comparison with woven fabrics. The weft yarn which has a lower twist has a higher water weight degree.

The high hygroscopicity of flax and hemp fibres and yarns strongly influences their electrical resistance. Thus the physical characteristic for flax and hemp fibres and yarns in the dry and wet state was

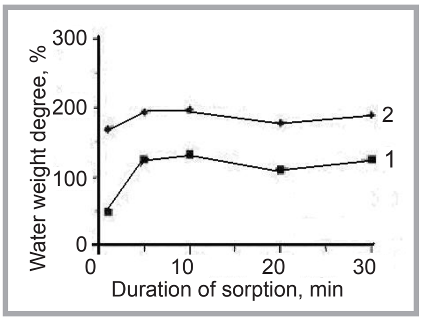

Figure 3. *Water weight degree of the woven fabrics depending on the wetting time: curve 1 – woven fabric from 100% bleached flax, curve 2- woven fabric from 100% hemp.*

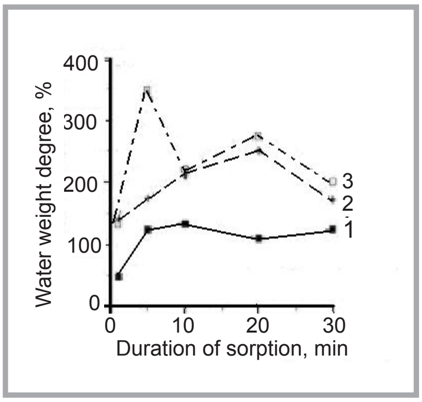

Figure 4. *Water weight degree of 100% flax woven fabric compared with the water weight degree of component yarns from weft and warp, depending on the wetting time: 1 - woven fabric, 2 - warp yarn, 3 - weft yarn.*

measured. The electrical resistance of flax and hemp fibres and yarns in the dry state, is greater than 20 megaohm/cm. After ten minutes wetting, the electrical resistance of flax and hemp fibres and yarns decreases about ten times, see ***Table 4***.

Because of the decreases in the electrical resistance of flax and hemp fibres and yarns in the wet state, textiles products from these natural fibres are not recommended for electrical insulation materials

The high hygroscopicity of flax and hemp yarns strongly influences their mechanical characteristics. Thus the behaviour of flax and hemp yarns at breaking strength was monitored in the dry and wet state.

Before starting the test, the yarns were prepared in standard conditions [22]. ***Figure 6*** present the force-extension curves of yarns tested in the dry and wet states. The initial length of the samples tested was 500 mm.

For flax yarn 104 tex obtained from boiled roving, the increase in tensile breaking strength in the wet state is about 32% in comparison with the resistance obtained in the dry state (***Figure 6.a***).

Flax yarn moistened and then dried at room temperature shows for the tensile breaking strength values comparable to those obtained for the yarn tested in the dry state. It indicates that immersion and drying at room temperature in this case have no effect on the tensile breaking strength. Flax yarn 72 tex wet spun from bleached roving presents about a 7% increase in tensile breaking strength, in comparison with the value obtained in the dry state.

After wetting and drying at room temperature, the yarn has values for the tensile breaking strength comparable to those obtained for the yarn tested in a dry state (***Figure 6.b***). As can be seen

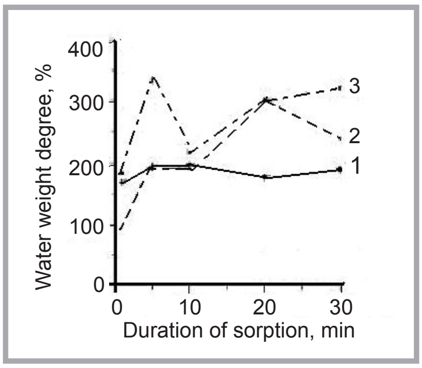

Figure 5. *Water weight degree of 100% hemp woven fabric compared with the water weight degree of component yarns from weft and warp, depending on the wetting time: 1 - woven fabric, 2 - warp yarn, 3 - weft yarn.*

Table 4. *Values of the electrical resistance of flax and hemp fibres and yarns measured after 10 minutes wetting.*

Types of fibres and yarns analysed	Electrical resistance, MΩ/cm
Flax fibres, 2 tex	0.6/1 1.0/2 1.4/3 1.5/4
Hemp fibres, 6 tex	0.65/1 0.80/2 1.00/3
Flax yarns 69 tex from raw roving	1.0/1 1.2/2 1.5/3 1.9/4
Flax yarns 72 tex from bleached roving	1.2/1 1.6/2 1.8/3 2.0/4

in ***Table 5*** (see page 30), regardless of the roving treatments, the wet tensile strength increases from 8 to 109% in comparison with the dry tensile strength. The fact that the tenacity in the dry state has relatively equal values for boiled or

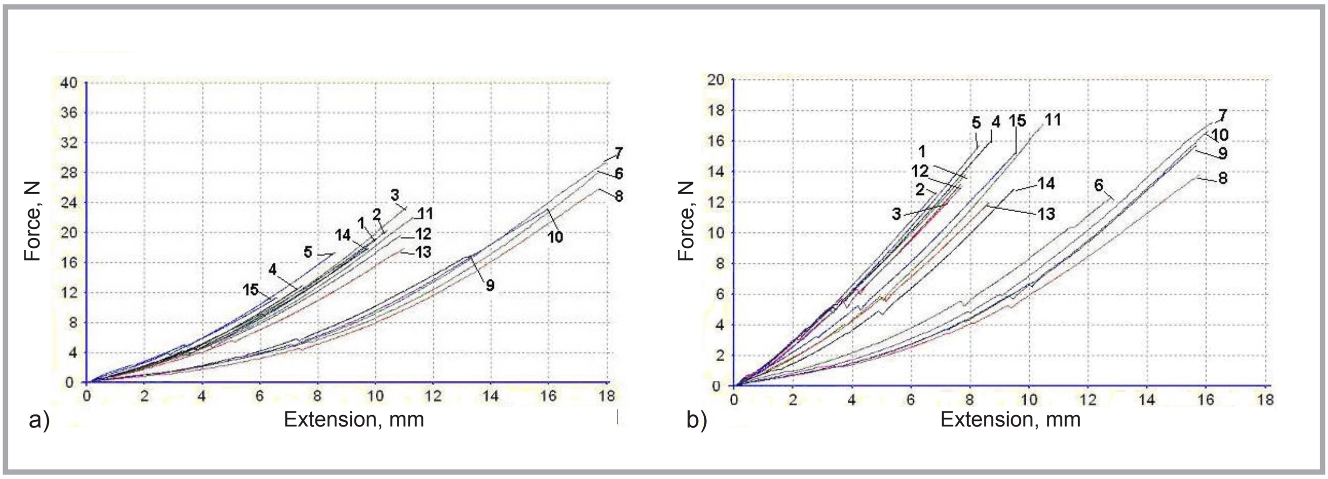

Figure 6. *Force-extension curves of flax yarn 104 tex (a) and 72 tex (b) produced by wet spinning from boiled, respectively from bleached roving, tested in the dry state, curves:1 - 5, in the wet state after 30 minutes wetting, curves: 6 - 10 and after drying at room temperature at constant weight, curves: 11 - 15.*

Table 5. Tenacity of the flax and hemp yarns studied.

Type of yarn analysed	Yarn state in breaking time	Breaking force (mean value for five measurments), N	Tenacity, cN/tex
Flax yarn 104 tex (Nm 9.6) produced by wet spinning from boiled roving	dry yarn	21.4	21.2
	wet yarn after 10 min. wetting	23.3	18.9
Flax yarn 72 tex (Nm 13.8) produced by wet spinning from bleached roving	dry yarn	13.2	20.9
	wet yarn after 10 min. wetting	19.5	18.0
Hemp yarn 73 tex (Nm 13.6) produced by wet spinning from raw roving	dry yarn	10.8	14.2
	wet yarn after 10 min. wetting	11.7	17.5
Hemp yarn 91 tex (Nm 11) produced by wet spinning from boiled roving	dry yarn	10.5	11.2
	wet yarn after 10 min. wetting	21.9	22.1
Hemp yarn 53 tex (Nm 19) produced by wet spinning from bleached roving	dry yarn	5.2	11.2
	wet yarn after 10 min. wetting	7.9	16.0

bleached yarns suggests that these treatments did not affect the macromolecular structure of the fibres.

On the other hand it can be observed that the specific resistance of the flax yarns tested in the wet state decreases by 10-13% in comparison with that in a dry state, see ***Table 5***, which may be due to flax yarn's hygroscopicity, which has a value up to 102%, followed by increases in the linear density of yarns which exceed the increase in breaking strength. The yarns presented in ***Table 4*** have a compact structure without porosity because they are produced by wet spinning. The compactness of these yarns is not influenced by the effect of twist.

Conclusions

Flax yarns obtained by dry spinning from raw roving with high porosity absorb a larger quantity of water in comparison with wet spun yarns with a compact structure. This means that natural pigments and non cellulosic substances remaining on fibres in the case of yarns obtained by dry spinning influence the yarn hygroscopicity significantly.

The degree of water absorption for flax and hemp yarns depends on the duration of moisture, on the finishing treatment applied to roving before spinning (boiling or bleaching) and on the type of spinning (dry or wet).

Flax and hemp yarns wet spun from boiled or bleached roving absorb more water than those obtained from raw roving, which may be attributed to the higher cellulose content of boiled and bleached yarns.

The speed of water sorption is different for yarns obtained by wet spinning from boiled roving and from bleached roving. The low speed of water desorption at room temperature for boiled and bleached yarns may be attributed to the high compactness of these yarns.

Flax and hemp yarns showed an increase in tensile strength in the wet state in comparison with that in the dry state, as a consequence of water absorption in fibres.

For flax yarns obtained from boiled roving and from bleached roving, wetting and then drying at room temperature have no effect on the tensile breaking strength.

The electrical resistance of flax and hemp fibres and yarns decreases by about ten times in the wet state after ten minutes wetting.

Moisture retaining and absorption properties can be disadvantageous to the dimensional stability of the composite as well as to the electrical resistance.

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