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The influence of the content of hemicelluloses on moisture sorption and effective relative dielectric permeability of alkali modified jute woven fabrics

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In this investigation, the influence of alkali modification conditions on the chemical composition, *i.e.* content of hemicelluloses, moisture sorption and effective relative dielectric permeability of jute woven fabric were studied. In that purpose, jute woven fabric has been alkali modified with NaOH solution (1 %, 5 % and 17.5 %) at room temperature for different periods of time (5 and 30 min). Compared to the unmodified, the alkali modified fabrics have lower hemicelluloses content and higher moisture sorption. With decreasing the content of hemicelluloses, and increasing the moisture sorption, values of effective relative dielectric permeability of investigated jute woven fabrics increased.

Key words: *jute woven fabric, alkali modification, hemicelluloses, moisture sorption, effective relative dielectric permeability*

Introduction

Jute (*Corchorus capsularis* and *Corchorus olitorius*) is one of the best known and most extensively used textile fiber, with the exception of cotton. According to the International Jute Study Group, traditionally jute has been used to manufacture packaging materials such as hessian, sacking, ropes, twines, carpet backing cloth, *etc*. The major breakthrough in the uses of jute came when the industries of automobile, pulp, paper as well as the furniture and bedding started to use jute fibers in order to manufacture ‘non-wovens’ and other technical textiles and composites[1,2].

Jute fibers have three principal chemical constituents, namely: α-cellulose, hemicelluloses, and lignin. α-cellulose forms the bulk of the ultimate cell walls with the molecular chains lying broadly parallel to the direction of the fiber axis. The hemicelluloses consist of polysaccharides of comparatively low molecular weight built up from hexoses, pentoses and uronic acid residues. The third major constituent, lignin, is a high molecular weight polyphenolic polymer with a three-dimensional network, which, like hemicelluloses varies in composition from one type of plant material to another [3,4].

Jute fibers have been subjected to various types of chemical modifications to improve their suitability as textile materials and reinforcing materials in composites. The available literature[5,6] reveals that alkali modification removes one of jute fiber’s cementing materials, hemicelluloses, depending on the concentration of used alkali, time and temperature of treatment, liquor ratio, and so on. Many researchers investigated the influence of alkali modification on structural and mechanical properties[7-11] of jute fibers. According to the literature survey, most of the previous works on dielectric properties have been conducted on jute based composites[12-14]. The results of our investigation should provide useful additional information on the influence of alkali treatment conditions on effective relative dielectric permeability and relationship between content of hemicelluloses, moisture sorption and effective relative dielectric permeability of jute fabrics. The importance of determining the effective relative dielectric permeability of jute fabrics lies in the fact that this dielectric parameter, which describes the polarization in the material, is an indirect indicator of the tendency of fibrous materials to generate static electricity[15].

Materials and methods

Materials

A commercially produced raw jute plain woven fabric with the chemical composition: 1.88 % water soluble components, 1.92 % fats and waxes, 0.84 % pectin, 13.48 % lignin, 21.76 % hemicelluloses and 60.09 % α-cellulose was used in this investigation as experimental material. All used chemical agents obtained from commercial sources were of analytical grade and used without further purification.

According to the procedure described in literature[16], raw jute fabric was subjected to alkali modifications in order to partially remove hemicelluloses and keep the lignin content unchanged. Jute woven fabric was treated with 1 % and 17.5 % NaOH solution, 1:50 liquid ratio, at room temperature for 30 min and with 5 % and 17.5 % NaOH solution, 1:50 liquid ratio, at room temperature for 5 min. Alkali treatments were followed by neutralization with 1 % acetic acid, than, jute fabrics were rinsed with 0.5% $NaHCO_3$, washed and dried at room temperature for 72 h. In all, four alkali modified samples (H30/1, H5/5, H5/17.5, and H30/17.5) and unmodified sample (C) were prepared for investigation, Table 1.

Methods

Jute woven fabrics were characterised regarding their chemical composition and subjected to alkali modifications in order to form a knowledge-base for how different content of hemicelluloses and different moisture sorption affects the effectrive relaive dielectric permeability.

The weight loss, as a consequence of partial removal of hemicelluloses after different chemical modifications of jute woven fabrics, was determined by direct gravimetric method. The chemical composition of jute fabrics was determined according to the scheme of Soutar and Bryden[16] by successive removal of non-cellulosic components. After that, α-cellulose remains as a solid residue.

Moisture sorption was calculated as a weight percentage of absolutely dry material, according to thermo gravimetric method using – Infrared Moisture Analyzer MA35.

Effective relative dielectric permeability was determined at room temperature, 22 ^{o}C and 30 % relative humidity. Investigation of effective relative dielectric permeability was carried out by using the Precise LCR Hameg 8118 at three different frequency of 30 Hz, 300Hz and 30 kHz. The instrument was coupled to a LD-3 Rigid Dielectric Cell 3-terminal (guarded) in which the samples in form of thin disks (63.5 mm in diameter) was placed. The spacing of the electrodes was equal to the thickness of the sample. The susceptance B (S) and susceptance of an empty cell, B_0 (S), were obtained directly from the bridge from which the effective relative dielectric permeability (ε'_m) was calculated according to the following equation:

$$\varepsilon'_m = \frac{B}{B_0} \quad (1)$$

ε'_m refers to the fiber-air-moisture system.

Results and discussion

The influence of different alkali modifications on the weight loss and chemical composition of jute woven fabrics

The sample codes and explanations of unmodified and alkali modified jute woven fabrics together with the weight loss and chemical composition after different alkali modifications are given in Table 1.

The effects of alkali modification conditions on the chemical composition of jute woven fabrics are generally characterized by the weight loss. In all cases of jute fabric modifications, it is evident that loss in weight increased proportionally to the increase of the modification time and concentration of NaOH, Table 1. The highest weight loss (12.07%) occurred when jute woven fabric was treated with 17.5% NaOH for 30 min (sample H30/17.5). This is in agreement with the literature data[5,6,11,17].

Table 1. *Weight loss and chemical composition of unmodified and alkali modified jute woven fabrics*

Sample code	Explanation	Weight loss, %	Content of Hemi-celluloses, %	Content of lignin, %	Moisture sorption, %
C	Control, unmodified	/	21.76	13.48	8.26
H30/1	1% NaOH, 30 min	5.87	17.87	13.68	8.65
H5/5	5% NaOH, 5 min	7.67	16.28	12.64	8.69
H5/17.5	17.5% NaOH, 5 min	9.98	13.85	13.11	9.01
H30/17.5	17.5% NaOH, 30 min	12.07	11.97	13.27	9.38

The obtained results clearly showed that partial removal of hemicelluloses can be achieved by modification of jute woven fabric with NaOH. Many researchers came to the same results for different bast fibers: jute[5,6], hemp[18-20] and flax[21,22]. There was an evident tendency that the content of hemicelluloses decreased with increasing the concentration of NaOH, Table 1. During 30 min modification of jute fabric with 1 % NaOH (sample H30/1), the content of hemicelluloses decreased for 17.9%, while in the case of treatment with 17.5 % NaOH during the same time (sample H30/17.5), content of hemicelluloses decreased for 45.0%, compared to the unmodified fabric. During 5 min modification of jute woven fabric with 5% NaOH (sample H5/5), the content of hemicelluloses decreased for 25.2 %, while in the case of treatment with 17.5 % NaOH during the same time (sample H5/17.5), content of hemicelluloses decreased for 36.4%, compared to the unmodified fabric. These results are comparable with the results obtained for jute and other bast fibers reported in the literature[6,20,22]. On the basis of the presented results, it is evident that both concentrations of NaOH, as well as the duration of modification, have influence on the content of hemicelluloses. In the case of chemical modification with 17.5 % NaOH, with increasing the modification time from 5 min (sample H5/17.5) to 30 min (H30/17.5), content of hemicelluloses decreased for 13.6 %, Table 1. Certain content of residues of hemicelluloses after alkali modifications could be explained by existing the strong hydrogen bonds between hemicelluloses and cellulose fibrils[20,22]. Also, it is clear that after chemical modifications with

NaOH, lignin content remains almost unchanged. This occurs as a result of presence of strong carbon-carbon linkages and other chemical groups (aromatic) in the lignin which contributed to its limited degradation or fragmentation[20,23,24].

The influence of different chemical modifications on the moisture sorption of jute woven fabrics

Due to the presence of free hydroxyl groups in jute amorphous regions and at the crystallite's surfaces, the moisture sorption of jute fibers is high (8.26 % for unmodified jute fabric). Moisture sorption values provide information on the extent of areas accessible to water vapor within the fiber[2]. The obtained data (Table 1) showed that hemicelluloses removal increased the moisture sorption of jute woven fabrics compared to the unmodified fabric.

With decreasing the hemicelluloses content for about 18, 25, 36 and 45 % for H30/1, H5/5, H5/17.5 and H30/17.5, moisture sorption values increased for 4.7, 5.2, 9.1 and 13.6 %, respectively. Due to the penetration of NaOH and fiber swelling, many hydrogen bonds are broken and it is expected that the number of available hydroxyl groups is increased[25]. Also, chemical modification with NaOH causes some disorientation of fibrils and changed the amorphous and crystallinity region ratio, in favor to amorphous one[18,20]. This increase in the portion of amorphous part is directly related to the moisture sorption. There is small difference (about 4 %) between moisture sorption values of jute fabrics modified with 17,5% NaOH (sample H5/17.5 and H30/17.5). High coefficient of negative linear correlation (r = -0.98) between content of hemicelluloses and moisture sorption prove that content of hemicelluloses has significant influence on the moisture sorption.

The influence of different alkali modifications on effective relative dielectric permeability of jute woven fabrics

Jute woven fabric is a non-homogenous material with a very complex structure. Because of that, dielectric behavior of jute fabrics in real conditions of use depends on various factors such as chemical composition, moisture content and external influences (frequency, temperature, air humidity, etc.)[19].

Figure 1. shows influence of frequency and content of hemicelluloses on the effective relative dielectric permeability (ε'_m) of alkali modified jute woven fabrics. It may be noted that increasing of frequency caused decreasing value of ε'_m. When frequency increased, polarizability decreases as dipoles cannot follow the changes of the applied electric field[15]. Control sample has lower values of ε'_m than alkali modified samples. Further, from results shown in Figure 1 it is evident that with decreasing the content of hemicelluloses, values of ε'_m increased significantly at lower frequency. It may be noted that increasing of frequency caused decreasing of ε'_m for all samples and that reduction is more intense for the samples with the lowest content of hemicelluloses. When content of hemicelluloses decreased for about 18, 25, 36 and 45 % for H30/1, H5/5, H5/17.5 and H30/17.5, the ε'_m increased for about 60, 66.5, 110.5 and 153% (at 30 Hz), 20, 24, 53.5 and 7 2 % (at 300 Hz) and 2, 3, 23 and 28 % (at 30000 Hz) in comparison with unmodified, respecively. High coefficients of negative linear correlation (r = -(0.89-0.99)) between content of hemicelluloses and ε'_m at different frequences prove that content of hemicelluloses has significant effect on the effective relative dielectric permeability of alkali modified jute woven fabrics. As we mentioned earlier, the duration of alkali modification and concentration of NaOH have influence on the content of hemicelluloses and consequently on the values of ε'_m.

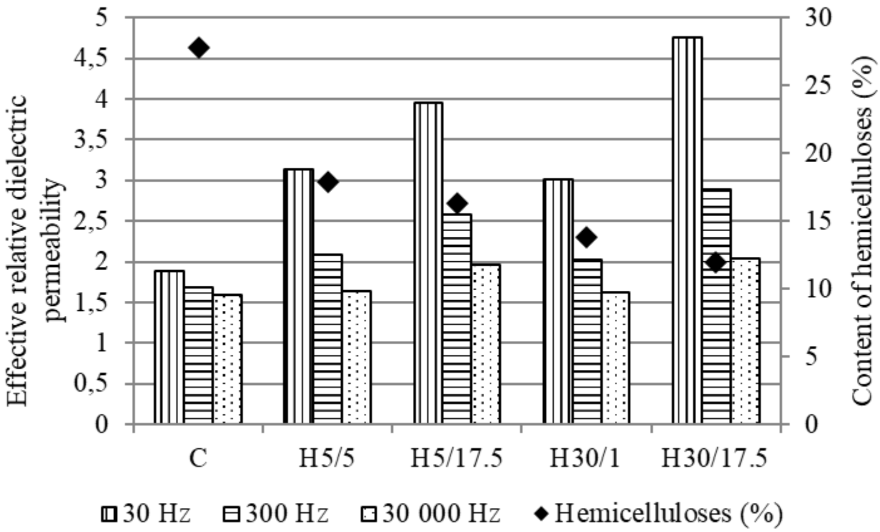

Figure 1. *Influence of content of hemicelluloses on the effective relative dielectric permeability of alkali modified jute woven fabrics*

Alkali modifications with NaOH increased the moisture sorption of the fibers due to the increase in the probability for the interaction between polar –OH groups of jute fibers and water molecules. In untreated fabric, the cellulosic hydroxyl –OH groups were relatively unreactive, since they formed strong hydrogen bonds. Alkali modifications of jute fibers destroyed the hydrogen bonds and it is expected that the number of available hydroxyl groups is increased. Thus, alkali modified fabrics showed a considerable increase in effective relative dielectric permeability compared to unmodified fabric, Figure 2.

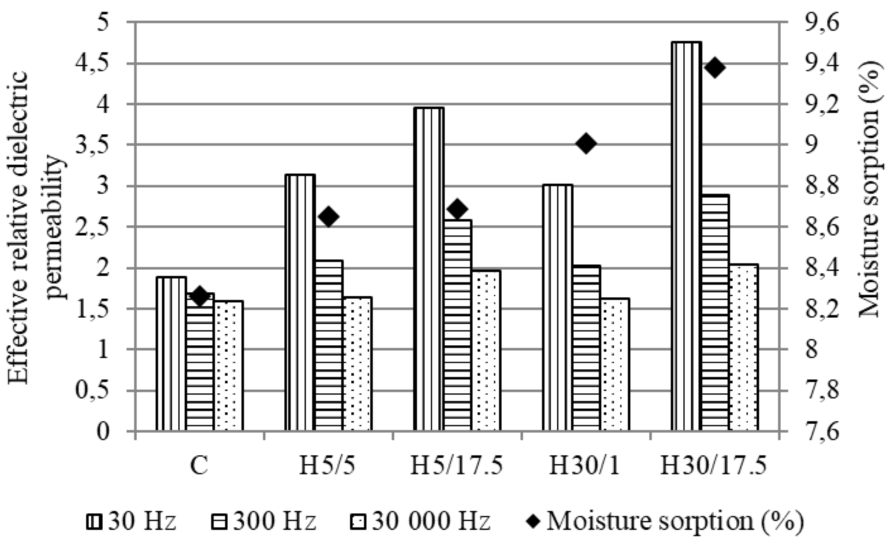

Figure 2. *Influence of moisture sorption on the effective relative dielectric permeability of alkali modified jute woven fabrics*

With increasing the moisture sorption, ε'_m increased. There is a high coefficients of linear correlation (r = 0.92-0.99) between content of moisture sorption and ε'_m at different frequences. The same connection between the frequency and moisture content was obtained for cellulose-based fabric[15]. By comparing the results showed in figures 1 and 2, it can be noticed that when frequency increase the highest reduction in the value of ε'_m has sample with the lowest content of hemicelluloses and the highest value of moisture.

Conclusion

In order to partially remove hemicelluloses, jute woven fabric was alkali modified with NaOH solutions of different concentrations during the different period of time. The obtained results showed that with increasing the concentration of NaOH and duration of modification, content of hemicelluloses decreased. With decreasing the content of hemicelluloses, the moisture sorption increased. The values of effective relative dielectric permeability are directly related to the content of hemicelluloses and moisture sorption, i.e. with decreasing the content of hemicelluloses and increasing the moisture sorption, values of effective relative dielectric permeability increased. Also, when frequency increased, the value of effective relative dielectric permeability decreased.

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Uticaj sadržaja hemiceluloza na sorpciju vlage i efektivnu relativnu dielektričnu propustljivost alkalno modifikovane tkanine od jute

U ovom radu je proučavan uticaj alkalnog modifikovanja na hemijski sastav, tj. sadržaj hemiceluloza, sorpciju vlage i na efektivnu relativnu dielektričnu propustljivost tkanina od jute. U tom cilju, tkanina od jute je modifikovana sa NaOH (1%, 5% i 17,5%) na sobnoj temperaturi u toku različitog vremena (5 i 30 min). U odnosu na nemodifikovanu, alkalno modifikovane tkanine imaju niži sadržaj hemiceluloza i povećanu sorpciju vlage. Sa sniženjem sadržaja hemiceluloza, i povećanjem sorpcije vlage, rastu vrednosti efektivne relativne dielektrične propustljivosti ispitivanih tkanina.

Ključne reči: *tkanina od jute, alkalna modifikacija, hemiceluloze, sorpcija vlage, efektivna relativna dielektrična propustljivost*

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