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Impact of plasma treatment on acoustic properties of natural cellulose materials

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Abstract Low-temperature plasma is widely used in many surface treatment technologies for modifications of the physical properties of different polymeric materials. In the present work, we have examined the modification of acoustical properties of natural cellulose materials (cotton, hemp) by the radio-frequency argon plasma. We have observed an increase of the sound absorption coefficient due to the plasma treatment for certain range of applied powers. An analysis of elementary processes which

happened during plasma–material interaction was conducted. Additional analyses related to material characterizations were performed in order to resolve structural and chemical changes of plasma treated materials. The micro-mechanical modification of treated materials, which happened upon the retrieved structural and chemical changes, was related to the modification of its acoustical properties in order to explain the observed effect.

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Graphic abstract

Keywords Cotton · Hemp · Radio-frequency argon plasma · Plasma treatment · Acoustic properties

Introduction

Various plasma polymeric material modification technologies are based on plasma discharges in different gases. Due to plasma treatment, numerous chemical and physical changes occur in the exposed materials, whereby the treated materials change their physical and chemical properties. Frequently used gas in plasma discharges is argon, which plays a very important role in a large number of plasma–material modifications (Vidaurre et al. 2002; Slepíčka et al. 2013). The pure argon plasma is suitable in the cases when the prevention of oxidation processes during plasma treatments is needed (Grace and Gerenser 2003). For the plasma treatments, beside commonly used direct current (DC) plasma discharges, the plasma induced by radio-frequent (RF) electric field is used, as well. It has been shown that the processing of plasma-surface modifications in RF plasmas can be effectively performed at much lower pressures

compared to DC plasmas, resulting in lowering the gas and energy consumptions (Baldwin et al. 1998).

Cellulose is known as the most frequently used natural polymeric material. The natural cellulose fibers usually obtained from both cotton flowers and bast fiber stalks (flax, hemp, jute), are used as the basic commodity for the production of textile products. The fabrics produced from natural cellulose fibers are primarily used in the clothing industry, but there are many other applications, especially in the automotive industry and in the construction and building industry. Natural cellulose fibers and their products, either in the form of conventional or industrial textiles can be very effective in sound absorption thanks to their intrinsic porosity. Nowadays they play an important role in creating an acoustically pleasant environment (room acoustics, automotive acoustics, industrial noise control) (Beradi and Iannace 2015). Natural fibers have received much attention for acoustical uses due to their renewable sourcing, biodegradability, recyclability and very low toxicity (Asdrubali et al. 2012). Their competitiveness has also come from their good mechanical properties and low density, as well as from their environmentally-friendly and cost-effective production (Arenas and Crocker 2010). As a consequence, a number of investigations dealt with the

sound absorption properties of natural fiber assemblies and fabrics. One of the most widespread ways of using natural fibers is for thermo-acoustic function in the form of fiber wool or web in building and automotive sectors, and therefore, quite a lot of studies were devoted to the acoustic absorption properties of raw natural fibers assemblies (Nick et al. 2002; Yang et al. 2010; Arenas and Crocker 2010; Oldham et al. 2011; Fouladi et al. 2011; Xiang et al. 2013; Beradi and Iannace 2015, 2017; Beradi et al. 2017). New composites in which glass fibers were replaced by natural fibers (biocomposites) appeared in the last decade of the twentieth century to be used as building materials, automotive parts, in special sporting equipment and aerospace industry (Marsh 2003). Since the satisfactory acoustic behavior is one of their essential performances, a range of investigations of sound absorption properties of various fiber-reinforced composites have been conducted over the years (Zulkifh et al. 2008; Buksnowitz et al. 2010; Fatima and Mohanty 2011; Krucinska et al. 2015; Echeverria et al. 2019). In addition to composite materials in which fibers are mixed with other fibrous or non-fibrous components, common textile materials are in use for a variety of purposes in residential and occupational environments such as upholstery materials, wall coverings, window coverings etc. Natural fiber based nonwovens are widely used thanks to their lightweight, formability (easily conforms to various shapes) and flexibility (Vasile and Van Langenhove 2004). Extensive research have been done on sound absorption properties of such nonwovens, some of which are referred in the manuscript (Parikh et al. 2006; Thilagavathi et al. 2010; Kucuk and Korkmaz 2012; Rwawiire et al. 2017; Islam and Alam 2018). Limited research has been conducted in the case of woven (Shoshani and Rosenhouse 1990, 2012, 2013; Tang et al. 2018) and knitted fabrics (Dias and Monaragala 2006; Dias et al. 2007; Honarvar et al. 2010; Stankovic et al. 2016), although they can have an important role in the design of sound absorptive materials when aesthetically pleasing appearance is needed (interior decorations).

In addition to experimental investigations, a number of research works have addressed the sound absorption modeling, both theoretical and empirical, of fiber assemblies or products. Although full theoretical sound absorption modeling is out of scope of this study, we refer to several works (Zwikker and

Kosten 1949; Biot 1962; Attenborough 1982; Dahl et al. 1990; Shoshani and Yakubov 1999; Yang et al. 2010; Honarvar et al. 2010). In 1970, Delany and Bazley (1970) introduced the first empirical model for fibrous absorbent material with a fiber diameter between 1 and 10 μm . They proposed simple power-law relations obtained by best-fitting a large amount of experimental data. Garai and Pompoli (2005) revised the Delany–Bazley model by best fitting the measured values of the relevant physical parameters for a set of polymer fibers with diameter ranging from 18 to 48 μm . Oldham et al. (2011) found in their investigation that these two models predicted quite well the acoustical properties of fibrous absorbers with fiber diameter up to approximately 60 μm . As reported elsewhere (Wang and Torng 2001; Rwawiire et al. 2017), the Delany–Bazley model is inadequate for very low and very high frequencies. However, in Fouladi's investigation (2011) the model was a good approximation for overall broadband trend of acoustical behavior. Besides Garai and Pompeli, other authors revised the Delany–Bazley model by providing the coefficients other than those originally proposed by Delany and Bazley (Miki 1990; Arenas et al. 2014; Beradi and Iannace 2017), but their model has been still widely used to describe acoustical characteristics of fibrous materials.

The aim of this work was to investigate the possible changes of the acoustical properties of natural cellulose materials caused by the plasma treatment. Surprisingly little research dealt with the effect of environmentally benign plasma treatment on acoustical properties of natural cellulose materials. In fact, to the best of authors' knowledge, the only published paper dealing with the influence of plasma treatment on sound absorption properties of textile materials proved the positive effect of plasma treatment on jute and kenaf (and polyester) nonwovens (Youngjoo and Gilsoo 2010). To achieve the modification of the materials, we used the RF plasma reactor with the argon as the working gas. The pre and post plasma treatment analyses of acoustical properties were done and confirmed the expected changes. Additional analyses related to the structural and chemical characterization of the materials were conducted in order to understand better the obtained effect. An adequate analysis of elementary processes during the plasma treatment which could lead to observed structural and chemical changes was performed. We also discussed

the potential micro-mechanical changes of cellulose materials which could happen during the plasma treatment and which could consequently lead to the observed changes of their acoustical properties. These changes were confirmed by the Delany–Bazley model used for predicting the sound absorption coefficient for the untreated and plasma treated fabrics.

Experimental

Materials

Textile fabrics can have various forms depending on the fiber packing formats. In nonwoven fabrics, fibers are randomly oriented in the layers which are bonded together by mechanical, chemical or thermal treatments. In woven or knitted fabrics, fibers have the configuration of parallel fiber bundle which are directionally oriented with an angle relative to yarn axis coming from the twist (which give cohesion to the yarn). To include both kinds of fiber packing format, the natural cellulose materials used in our investigations were a mixture of cotton and hemp 50%/50% in a form of knitted fabrics or cotton fiber assemblies. The basic characteristics of the material used in the form of rib (1:1) knitted fabrics are: stitch density: $64\text{--}72\text{ cm}^{-2}$; thickness: 2.36–2.50 mm; surface density (areal density): $950\text{--}1000\text{ g/m}^2$ and bulk density: $0.38\text{--}0.42\text{ g/cm}^3$. The basic characteristics of the fiber assemblies are: thickness: 2.45–2.55 mm and bulk density: $0.095\text{--}0.15\text{ g/cm}^3$. These fiber assemblies consisted of the fiber layers compressed to have a thickness similar to that of the knitted fabrics and to form the nonwoven-like structure but without bonding treatment. In such a way, cohesion in the fiber assemblies was arisen from the friction between the fibers such as in insulation fiber wool.

Plasma processing

The method used for the modification of the natural cellulose materials was the plasma treatment in the RF capacitively coupled plasma (CCP) reactor filled by the argon gas. The plasma reactor was placed in the cylindrical stainless steel chamber. In order to control gas or gas mixture purity, a vacuum system equipped with gas mass flow controllers was used. The Ar gas was introduced in the previously evacuated plasmas

chamber by a vacuum pump, with controlled mass flow of the gas. The high voltage RF generator was connected to the central electrode of the chamber, while the ground was connected to the outer body of the chamber. The standard 13.56 MHz frequency was applied for RF discharges. The argon gas was fed through mass flow controller at gas flow of 2 sccm. The pressure of the argon gas during our plasma treatments was about 1 Torr, which is within the approximately evaluated range of 1–100 mbar estimated as an optimum for achieving maximal plasma penetration effects (Poll et al. 2001). The applied powers used during plasma discharges were in the range from 40 to 100 W. The treated samples of materials were set in plasma reactor by using specially designed feedthrough connector and the treatments lasted for 20 min (this was an estimated optimum). In order to measure and control plasma conditions, the optical emission spectroscopy (OES) was employed.

Characterizations

Sound absorption measurement

The measurements of the sound absorption coefficient (SAC) of the examined materials were performed before and after the plasma treatments. We used a standard two-microphone impedance tube which has been designed as per the ISO 10534-2:1998 standard (Acoustics-Determination of sound absorption coefficient and impedance in impedance tubes-Part 2: Transfer-function method). The diameter of the tube (29 mm) was set up for measuring SAC in the high frequency range (up to 5000 Hz). According to ISO 10534 standard, for each examined material the SAC measurements were performed for three samples with repetition of at least three times for each of them, and their average was calculated. In consideration of the fact that the structure of the fiber assemblies or the knitted fabrics, and constituent yarns, would be changed by any finishing treatment (physico-mechanical or chemical), the investigation of their sound absorption ability before plasma treatment was conducted in the grey state.

SEM/EDAX analysis

The examined materials were inspected using a JEOL JSM 840-A Scanning Electron Microscope (SEM)

equipped with an Oxford Instruments INCA Penta FET $\times$ 3 Energy-Dispersive X-ray spectroscopy (EDX) micro analyzer. The SEM/EDX analyses were performed before the plasma treatment (pristine samples), a few hours and 7 days upon the plasma treatment.

XPS analysis

XPS analysis was performed using a SPECS instrument for surface characterization is described in detail elsewhere (Kljajević et al. 2017). Shortly, photoelectron emission was excited by monochromatic Al K α line with photon energy of 1486.67 eV. Detailed spectra of the main photoelectron lines were taken in the fixed analyzer transmission mode with a pass energy of 20 eV (FAT 20), an energy step of 0.1 eV and a dwell time of 2 s. Charging compensation was performed using an electron flood gun and the binding energy axis was adjusted according to the position of the nitrogen N 1s line. The composition analysis was performed according to the characteristic photoelectron line intensities after background removal, using the atomic sensitivity factors provided by the manufacturer. The photoelectron lines were fitted to peaks with accompanying software package.

Experimental results

Changes in the SAC upon plasma modification

The SAC spectra, in the frequency range 0–4800 Hz, for both types of samples (knitted fabrics and fiber assemblies) are shown in Fig. 1a, b, respectively. In both figures it can be seen SAC spectra for both untreated and the plasma treated samples. As can be seen from the figures, the knitted fabrics are characterized by higher SAC in the whole frequency range. This can be explained by higher bulk density range of the knitted samples than that of the fiber assemblies. With an increase in the number of fibers per unit volume the energy loss increases due to an increase in surface friction (Seddeq 2009). Plasma treatment results in an increase in SAC for almost the whole frequency range. In other words, the plasma treatment of the natural cellulose fibrous materials increases their ability to absorb mechanical sound energy. In Fig. 1a the SAC coefficient for the knitted samples

treated under different applied power is shown. It can be seen that an increase in the SAC is especially pronounced for the medium values of the applied power of RF plasma. In Fig. 1b beside the measured SAC spectra, the theoretically proposed spectra are also shown in order to compare them, which would be discussed in the next section.

It is well known that the plasma treatment of the materials is usually followed by the relaxation processes, i.e. the effect of the treatment may be significantly impacted by the aging. For example, the plasma treatment often results in hydrophilization of the surfaces, and the hydrophilicity of the surface may be stable for at least 24 h (Zemljič et al. 2009). In order to check out if there are any changes in the acoustical properties of the plasma treated materials upon the time, we repeated the SAC measurements 7 days, 3 and 9 months upon the plasma treatment, respectively. We did not detect any changes in SAC spectra, which is the solid evidence that the plasma treatment permanently changed the acoustical properties of the materials.

In order to explain the causes of the material modification, we firstly excluded the thermal effects as a reason of the modification, because the increase in the temperature of the samples during plasma exposition was less than 25 °C. In an attempt to explain the elementary processes, which happened during plasma–material interaction, and which are pivotal to modification of the treated material, we conducted the additional analyses. Further, we assumed that the pivotal role in the modification of polymeric materials by the inert gases plasma plays the interactions of free electrons and active species (ions, excited and metastable atoms) with polymeric molecules (Arefi-Khonsari and Tatoulian 2008). Such interactions cause the bond-breakage in the fiber polymer macromolecules producing the free radical parts in polymer chains. Free electrons in the argon plasma can perform such bond-breakage, especially at higher energies, due to an increase of cross sections for the processes which can break carbon–hydrogen, carbon–oxygen and carbon–carbon bonds. Cross sections for electron-induced breakage of carbon–hydrogen and carbon–carbon bonds were measured for small molecules by many authors (Grill et al. 1993; Zheng and Srivastava 1996; Tian and Vidal 1998; Feil et al. 2006; Szyman-ska et al. 2014). Cross sections for breakage carbon–oxygen and carbon hydroxyl bonds were measured for

Fig. 1 Sound absorption coefficient for untreated and plasma treated samples: **a** samples made in a form of knitted fabrics for different plasma power applied. **b** Samples made in a form of

small molecules by Freund et al. (1990) and by Rejoub et al. (2003). These cross section data can serve for estimating of the rates of electron-induced bond-breaking processes in the case of polymer macromolecules with these bonds in their chains. The second mechanism which leads to polymer modification is induced by ion bombardment of the treated materials by ions generated in the argon plasma (Slepička et al. 2013). The rates for ionization of argon atoms and estimations of their density in plasma can be calculated by using methods which are already developed for the cases of nitrogen and carbon-monoxide plasmas (Popović et al. 2014; Aoneas et al. 2017). The excited argon atoms can also take part in the bond-breaking processes in polymer macromolecules. The excited atoms emit visible or ultraviolet (VUV) radiation during their relaxation processes, which can be absorbed by polymer molecules. Energy obtained in the absorption processes can lead to the bond-breaking processes in polymeric molecules. The excited atoms in metastable states can also cause the bond-breaking processes by the non-radiative mechanisms of energy transfer. The rates for excitation of argon atoms can be calculated by the methods already developed for the nitrogen and carbon-monoxide plasmas (Ristić et al. 2017, 2018).

According to the discussion above, at medium and high applied powers a great portion of excited argon atoms and ions are created in the plasma bulk. They interact with polymeric molecules in the plasma

fiber assemblies and proposed theoretical results based on Delany–Bazley model for two different values of the fiber diameter

sheath and cause the bond-breaking processes between atoms in polymeric molecules (Slepička et al. 2013). At the same time, high energy electrons, populating the high-energy tail of electron energy distribution (the method for the calculation is given in Popović et al. 2014; Aoneas et al. 2017; Ristić et al. 2017, 2018) in plasma discharges have enough energy to take part in the energy transfer processes and to cause bond-breaking processes in polymer molecules, as well. All these bond-breaking processes make polymer macromolecules unstable, with plenty radical groups. The radical parts of polymer macromolecules, which consist commonly of carbon atoms, can either links with oxygen in oxidation processes or recombine their bonds.

SEM analysis of macro-structural changes

Additional analyses related to structural and chemical properties of the plasma treated cellulose materials were conducted. We employed a scanning electron microscope (SEM) technique to investigate the macro-structural changes of treated materials (Fig. 2a, b). One could easily notice the difference between the SEM micrographs of the untreated and plasma treated samples (Fig. 2a, b).

The sample of untreated cotton/hemp knitted fabric has an organized orientation of fibers while such organization for the plasma treated sample is compromised. Alongside, in the case of plasma treated

Fig. 2 SEM micrographs of the **a** untreated, **b** plasma treated samples of material obtained by SEM

sample, there are clearly visible damages in the structure of the fibers. The fibers' surface becomes rougher due to the plasma treatment, i.e. impact of plasma bombardment and etching. The similar conclusions for surface modification of cellulosic fibers after the plasma treatment have been already reported by many authors (Xiangyu et al. 2006; Zhou et al. 2012; Ventura et al. 2016). In addition, the effect of the changes in the nanotopography of fibers induced by plasma treatments were reported (Calvimontes et al. 2011; Vasiljević et al. 2013). Here should be pointed out that the SEM analysis reported in this paper provides only the rough estimation of the surface modification of treated materials.

XPS and EDAX characterizations

To investigate further the impact of the plasma treatment on the natural cellulose fibrous materials, we analyzed the change of the chemical composition caused by the plasma treatment. We employed the X-ray photoelectron spectroscopy (XPS) and the energy-dispersive X-ray spectroscopy (EDAX) to determine the chemical composition of the surface of cellulose fibers. Figure 3a–c shows the results of XPS analysis in the range 0–1000 eV of the untreated samples, the samples immediately after and 3 days upon the plasma treatment, respectively. Upon the plasma treatment, the samples were exposed to the normal atmospheric condition. As it was expected, the

Fig. 3 XPS analyses of **a** untreated (pristine) sample, **b** sample analyzed immediately upon the plasma treatment, **c** sample analyzed 3 days upon the plasma treatment

pronounced XPS peaks belong to oxygen and carbon (534.7 eV and 286.7 eV, respectively). It could be noticed that the carbon–oxygen ratio changes due to the plasma treatment, i.e. the amount of oxygen decreases. The share of oxygen in the pristine samples is about 37% while the share of carbon is about 63%. Immediately after the plasma treatment the share of oxygen decreases to 23%, while the share of carbon increases to 77%. The similar effect of decreasing the oxygen concentration on fiber surface of the treated cellulose material by the argon plasma has been observed by Sahin (2008). As the plasma treated samples are exposed to the normal atmospheric

condition, the amount of oxygen increases, overcoming the values for the pristine sample and its share is 45%, while the share of carbon is 50% and, additionally, the nitrogen is present (403.1 eV) with the share of 5%. The changing in carbon–oxygen ratio was additionally confirmed by the EDX analyses, which was conducted independently for the same samples. The effect of plasma treatment on the samples can be more precisely explained by the analysis of high resolution spectra for the pristine sample and the samples immediately after and 3 days upon the plasma treatment.

In Fig. 4a–c it can be seen the results of the deconvolution of the C1s XPS peak spectra observed for the untreated (pristine) sample (Fig. 4a), and for the samples which spectra were observed immediately upon the plasma treatment (Fig. 4b) and 3 days after the plasma treatment (Fig. 4c), which in the meantime were exposed to the normal atmosphere. Due to the breakage of C–O and C–C links in cellulose macromolecules during the plasma treatment, the O–C–O and C–C–O peaks decrease in relation to the corresponding peaks for the pristine sample, which can be observed by comparing Fig. 4a, b. The same effect of the bond-breakage should lead to a decrease in C–OH peak, but the part of broken O–C–O links becomes the insatiate C–O links which resulted in an increase in the C–OH peak. Figure 4b shows the appearance of the pure C peak, which is also a consequence of the bond-breaking effect. In such way, the carbon atoms became the radicals, tending to bond the oxygen. Therefore, the oxygen from the atmosphere tend to be bonded to replace the detached OH groups and to satiate radical carbon atoms at broken C–C bonds and at broken O–C–O bond, which exists as insatiate O–C* radical bonds. The radical parts of polymer chains are unstable and such free radicals tend to be fast reduced under atmospheric conditions (Sabharwal et al. 1993). That is why, during the post-plasma oxidation process, the amount of oxygen increases until the broken carbon bonds are satiated (Zemljč et al. 2009). The effect of post oxidation can be seen at C1s XPS peak spectra in Fig. 4c), where we can recognize new peaks which belong to O–C=O, HC=O and O–CO–O bonds. This effect has been already observed and it is concluded that the Ar plasma treatments initiate reactions mainly associated with the cleavage of C–C links of pyranosidic rings, followed by ex situ post plasma oxidation which lead to the formation of O–

Fig. 4 C1s region for **a** untreated (pristine) sample, **b** sample immediately upon the plasma treatment, **c** sample 3 days upon the plasma treatment, with the peak fitting components

C=O, HC=O and O–CO–O groups, as reported in Hua et al. (1997). The effect of increasing the amount of oxygen due to the plasma treatment has been already

confirmed by XPS analyses and reported by numerous authors (Wong et al. 1999; Kolarova et al. 2013; Vosmanska et al. 2014).

In Fig. 4c one can see the additional peaks which correspond to $C=N$ and $C\equiv N$ bonds. The share of nitrogen in spectra is only 5%, and its presence is a consequence of the activation of cellulose chains by argon plasma and the satiation processes of free radicals during the post treatment oxidation. In addition, a relative decrease in the central peak can be noticed. This peak belongs mainly to $C-OH$ link, but also to the intermediate $O-C^*$ and $C-O-C$ links between the adjacent macromolecules. The intermediate $O-C^*$ links satiate during post-oxidation process and become commonly $O-C-O$. $C-OH$ links are reestablished during post-oxidation processes and its number roughly remains the same as before treatment. The number of $C-O-C$ links which point to the links between the adjacent cellulose macromolecules decreases.

In the light of the presented XPS results, the previously mentioned irreversibility of an increase in the SAC of the cellulose materials due to the plasma treatment can be easily understand. Namely, the pivotal processes which take place at the surface of the sample during the plasma treatment (such as the breakage in the cellulose chains, the cleavage of $C1-C2$ linkages and breakage of the links between the adjacent macromolecules) are the irreversible ones. Both of these two effects lead to a decrease in the fiber stiffness, i.e. the fibers become more elastic for transversal oscillations. This is in accordance with the results reported by Yuan et al. (2004), which confirmed an increase in viscoelastic dissipation in plasma treated cellulose fibers. At the micro-mechanical level, an increase in fiber elasticity causes the amplitudes of the oscillations to become larger during the sound excitement and as a result, the amount of sound mechanical energy which they absorb is larger. It leads to an increase in the SAC as a consequence of the plasma treatments.

As a consequence of the noticed effect of breaking the links between the adjacent macromolecules, the packing density of cellulose chains in fibrils (in the fiber's surface layer) is reduced leading inevitably to an increase in the fiber diameter. The average diameter of the cotton fiber in the assemblies was 10 μm and the diameter of the cotton and hemp fibers in the rib knitted fabrics was ranged between 10 and 20 μm . An

increase in fiber diameter after the plasma treatment was not uniform but it was approximately 15%. To confirm this, we compared the experimentally obtained SAC spectra of the cotton fibrous assemblies with the theoretical ones, which were obtained by applying Delany–Bazley model for predicting the acoustical characteristics of fibrous absorbent materials (Delany and Bazley 1970). The results of applying the Delany–Bazley model for two different values of the fiber's diameter are presented in Fig. 1b. The first one is the diameter of the untreated sample, and another one is the estimated diameter (about 15% higher) of the plasma treated sample. It is clear that there is a good matching in the trend between the experimentally measured SAC spectra of untreated (pristine) sample and spectra obtained theoretically from the Delany–Bazley model. In the case of plasma treated sample, the experimentally measured spectrum agrees very well with SAC spectrum obtained by using the Delany–Bazley model for supposed 15% larger fibers' diameters. On the other hand, in accordance with the Delany–Bazley model, the increase in the diameter of the fiber causes the increase in the SAC. This obtained agreement supports our assumption that one of the reasons for an increase in the SAC after plasma treatment could be the larger diameter of fibers, which is the consequence of the bond-breaking processes between the adjacent cellulose macromolecules.

At the macroscopic level, an increase in the fiber diameter leads to an increase in the yarn diameter, due to which the size of the pores in the fabrics and assemblies is slightly reduced. Although this pore size reduction is probably not very pronounced from macroscopic point of view, we believe that this can additionally improve the sound absorption by an increase in the frictional resistance between the fibers and air. Bearing in mind that the cellulose knitted fabrics tested in this investigation are designed for clothing and home textile use, the obtained values of their SAC are to be expected (Honarvar et al. 2010; Yang et al. 2010; Rwawiire et al. 2017; Islam and Alam 2018). From that point of view, the effect of an increase in sound absorption by the plasma treatment of the fabrics is promising. We believe that the capacity of the plasma treatment for improving SAC will be even higher for cellulose fibrous materials designed for technical use (sound absorbing materials). The real challenge for scientists and engineers is

to achieve the adequate technological and economic aspects of the plasma treatment of cellulose fibrous materials.

Conclusion

The modification of the acoustical properties of natural cellulose fibrous materials by the low-pressure radio-frequency argon plasma has been investigated. It has been clearly shown that the sound absorption coefficient of natural cellulose fibrous materials, both with directionally and randomly oriented fibers, was irreversibly increased due to the plasma treatment. In order to enlighten the mechanism of plasma modification of the acoustical properties, the analysis of the pivotal processes in the plasma–cellulose interaction was supported by detailed SEM/EDX and XPS analyses. The modification of the acoustical properties of the natural cellulose materials was related to their structural micro-mechanical changes, such as a decrease in the fibers' stiffness and an increase in their diameter. Further research will include different plasmas and their effect on sound absorption properties of technical textiles (higher thickness range, specific structure).

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