*Agronomy Research* **15**(S1), 1242–1250, 2017

# Influence of sisal fibres on tribological properties of epoxy composite systems

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**Abstract.** Composite are materials, which synergically combine properties of the matrix and fillers. An interaction of polymers – resins – with biological kind of fillers can optimize their mechanical properties in the same way as synthetic fillers. Biological fillers have many advantages, which include low price and satisfying mechanical properties. Significant disadvantages are different properties of fibers – for example, fibre diameter and strength – which are caused by the biological essence of this material. The design of new composite materials based on natural renewable resources is essential for an environment and is also attractive from an economic point of view. This paper describes the hardness and resistance to abrasive wear of epoxy resins filled with unordered short sisal fibers (3, 6 and 9 mm). Scanning electron microscopy was used to assess the fibers and interaction between fibers and epoxy resin.

**Key words:** Abrasive wear, Agave Sisalana, electron microscopy.

## INTRODUCTION

Composite materials can be described as materials that combine two or more phases. These phases are interdependent and can create a synergistic effect (Muller, 2015). Among the most widely used composite materials include composites with the filler in fiber form (Muller, 2011; Valasek & Muller, 2013; Ruggiero et al., 2015; Muller, 2016).

The materials which contain one or both phases from natural materials are increasingly expanding at present (Ruggiero et al., 2016). Natural materials so very often replace conventionally used synthetic materials. This substitution has many advantages, but also disadvantages. The benefits may include low cost of natural fillers, low density, as well as availability. The most significant disadvantage is their very natural character when individual features may differ from each other depending on a growth rate, an area of the growth and other environmental conditions. Among the natural fibers, which often substitute synthetic ones include not only the fibers of coconut, oil palm fibers, banana fibers, but also fibers of sisal (Abdul Khalil et al., 2012; Valasek, 2016).

Sisal fibers are extracted from the plant Agave Sisalana; it is a multi-year xerophyte plant from the family Asparagaceae. This plant grows mostly in tropical and subtropical areas. The sisal fibers are obtained from the leaves of the plants.

Sisal fibers are commonly used in composite systems where they optimize basic mechanical characteristics. Hari Om Maurya et al. (2015) for example show that the presence of short sisal fibers (5, 10, 15 and 20 mm) in an epoxy resin led to improvements in flexural strength and impact strength, but the strength properties did not increase – tensile strength. To improve the interfacial interaction between the sisal fibers and the matrix, it is possible to use alkali treatment, benzoyl peroxide treatment or treatment with maleic anhydride, (Mohit Sood et al., 2015). According to the conclusions of Badrinath & Senthilvelan (2014), the composite systems based on sisal fibers and epoxy have a greater tendency to absorb water than composites with banana fibers, but they also indicate that the composites with sisal fibers in comparison with banana fibers reached a higher flexural strength.

The aim of this paper is to describe two-body abrasion of short-fiber undirected composite systems with fibers of sisal and epoxy matrix. Tribological characteristics are complemented by necessary information about the composite system, i.e., hardness, density, and porosity. Sisal fibers were modified before application of alkali and to optimize interfacial interactions. The partial objective of this paper is to describe the impact of this treatment on sisal fibers. Electron microscopy was used to assess a wear area and to describe the morphology of the fibers. The experimentally obtained data were statistically analyzed.

## MATERIALS AND METHODS

### Matrix

The epoxy resin based on bisphenol A and F suitable for lamination was used in this experiment. This resin very readily wets the synthetic as well as organic materials. Cycloaliphatic amines with high reactivity towards the resin were used as a hardener. The resin was cured according to the manufacturer' technological instructions; the resin-curing was conducted at a higher temperature of 50 °C to increase the resistance of the resin. When curing at elevated temperatures, it may lead to increase the stability of the resin. Resulting concentration corresponded by its volume percentages to 2.5–10 vol.%

### Filler

The filler used was fibers from the leaves of Agave sisalana – sisal fibers. The fibers were chemically modified with 6% aqueous solution of NaOH. After removal from the bath, the fibers were washed with distilled water and were then cut into a required fiber length 3 mm, 6 mm and 9 mm. Essential characteristics of sisal fibers are shown in Table 1. The length of fibers (3–9 mm) was chosen with regard to the description of the changes which are induced by increasing of the fiber length.

**Table 1.** Mechanical properties of sisal fibres (Mieck et al., 1994; Boopalan et al., 2012)

| Cellulose [%] | Hemi cellulose [%] | Lignin [%] | Density [g cm$^{-3}$] | Tensile strength [MPa] | Young´s modulus [GPa] |
|---|---|---|---|---|---|
| 67–78 | 10.0–14.2 | 8.0–11.0 | 1.45 | 468–640 | 9.4–22.0 |

**Experimental program**

The porosity of the composite system was determined as the difference between the theoretical and real density – expressed as a percentage.

Hardness was tested according to ČSN EN ISO 2039-1 (Plastics – Determination of hardness – Part 2: Rockwell hardness), the ball with a diameter of 5 mm was used, load force was 961 N.

The two-body abrasion was tested on a rotating cylindrical drum device with the abrasive cloth of the different grain size (P120 $Al_2O_3$ grains) according to the standard ČSN 62 1466 (Units used in the field of rubber technology), see Fig. 1. The testing specimen is in contact with the abrasive cloth, and it covers the distance of 60 m. During one drum turn of 360°, it is provoked the testing specimen left above the abrasive cloth surface. Consequent impact of the testing specimen simulates the concussion. The pressure force is 10 N. The mean of the testing specimens was 15.5 ± 0.1 mm and their height was 20.0 ± 0.1 mm. The mass decreases were measured on analytic scales weighing on 0.1 mg.

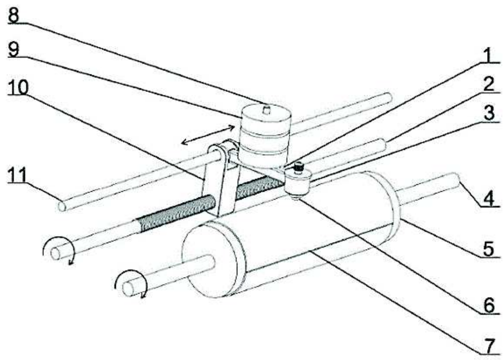


**Figure 1.** Schema of equipment for two-body abrasive wear testing: 1 – arm, 2 – motion screw, 3 – head, 4 – shaft, 5 – roller, 6 – test sample, 7 – abrasive cloth, 8 – weight holder, 9 – weight, 10 – sliding matrix, 11 – guide rod.

Electron microscopy assessed fiber morphology, interfacial interactions and the influence of chemical treatment of the surface on fiber morphology.

## RESULTS DISCUSSION

Fiber morphology was evaluated on the electron microscope before preparing the composition systems. Fig. 2 (left) shows the fibers before mechanical mixing with used matrix; the right figure shows the structure of sisal fiber and the interaction with the epoxy resin itself.

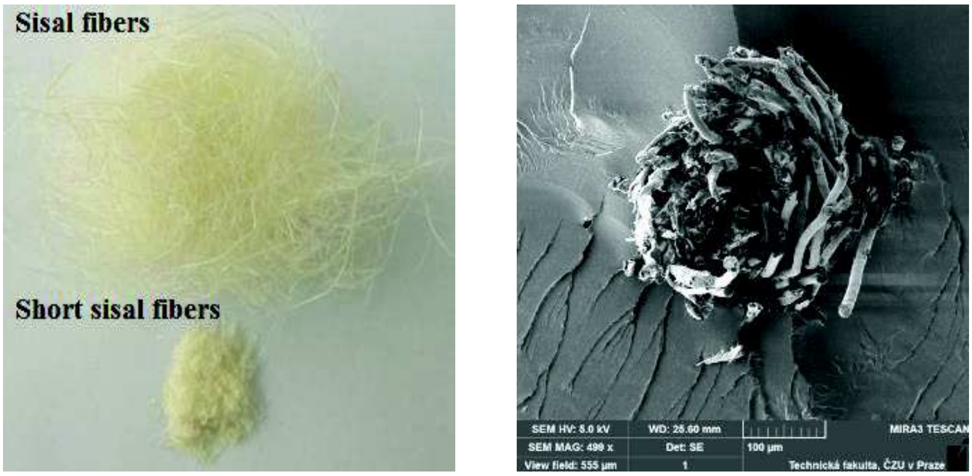


**Figure 2.** Sisal fiber (left), sisal fiber structure in interaction with the epoxy resin Mag. 499 x (right).

Microscopy determined the real dimensions of fibers (diameter and length) before the application of fibers in an epoxy matrix. The fiber diameter corresponded to 126 ± 42 μm, the original fiber length for 3, 6 and 9 mm shows the following histogram Fig. 3: 3 mm correspond to an average length of 3,053 μm, 6 mm correspond to 5,858 μm and 9 mm correspond to 9,116 μm.

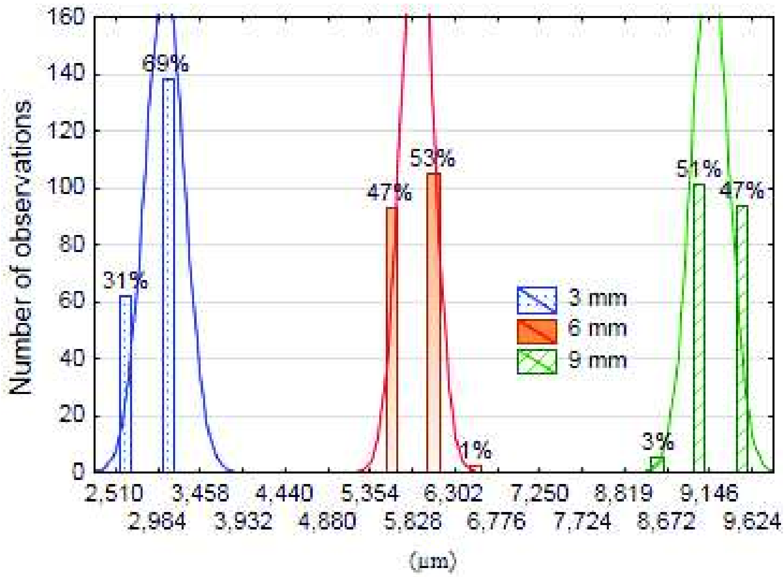


**Figure 3.** Histogram – real length of sisal fibers.

Performed chemical treatment of fibers surface with 6% NaOH solution leads to removal of surface structures from the fiber surface. The presence of undesirable surface features on the surface has the effect the smoothness of the untreated surface. This fact was proven by electron microscopy, which is presented in Fig. 4.

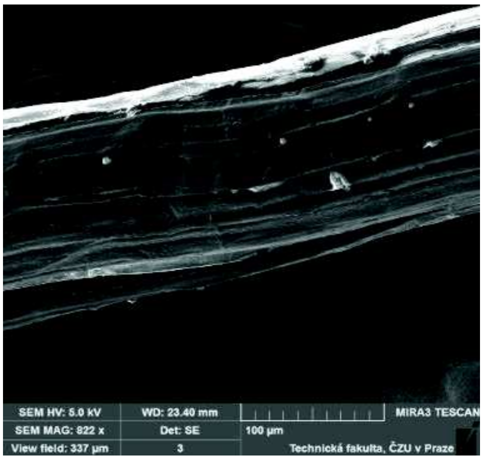


**Figure 4.** Sisal fiber surface before surface treatment (Mag. 822 x).

Removal of the waxy layers on the surface with chemical treatment of NaOH leads to the removal of smoothness caused by this layer, and the fiber becomes more rugged – its roughness increases. Such treatment process is in accordance with the conclusions of Mohit Sood et al. (2015) who state that apart from the cleaning of the fibers itself it also increases the roughness of the fiber. This treatment is then reflected on the interfacial interactions between the fibers and the matrix. Orue et al. (2016) state that the alkali-treated surface has a cavity, which causes better mechanical properties of composite systems than the systems with untreated fibers.

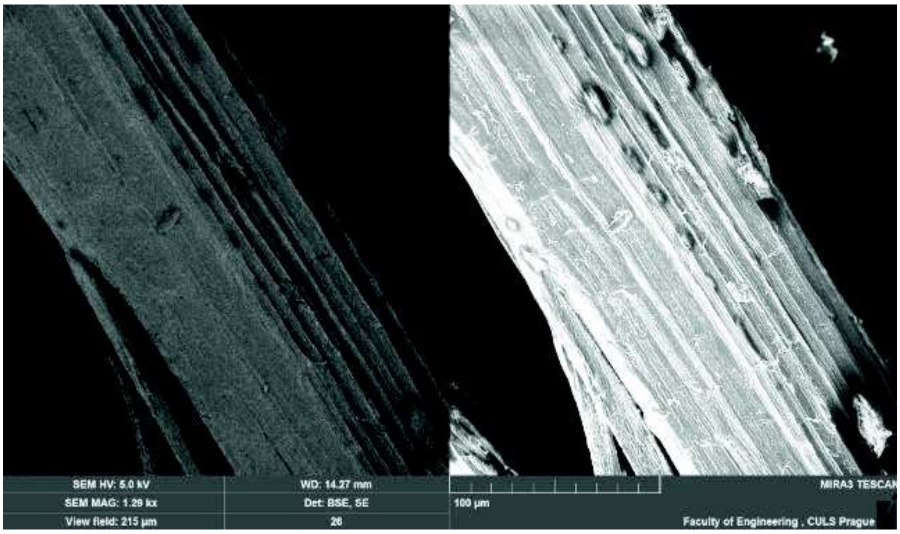


**Figure 5.** Surface of sisal fiber after chemical treatment with solution of NaOH (Mag. 1.29 kx): BSE, SE.

Essential characteristics of the composite systems are summarized in Table 2, which shows the theoretical density of the composite systems that was calculated based on the density of the resin (manufacturer's declared value 1.15 g cm$^{-3}$) and an average density of sisal fibers: i.e. 1.45 g cm$^{-3}$. High values of porosity may result in the initiation of cracks. The porosity can be reduced by vacuum technique – e.g. vacuum infusion.

**Table 2.** Density and porosity of composite systems

| Properties | vol. % of sisal fibers | | | | |
|---|---|---|---|---|---|
| | 0% | 2.5% | 5.0% | 7.5% | 10.0% |
| Theoretical density [g cm$^{-3}$] | 1.15 | 1.16 | 1.17 | 1.17 | 1.18 |
| Porosity [%] | - | 5.6 | 4.3 | 8.0 | 9.2 |

Hardness was assessed as an important characteristic that can be in direct correlation with resistance to abrasive wear. Due to the nature of the composite system was as indenter chosen a ball with diameter 5 mm. An inclusion of fibers of sisal has led to a decrease in hardness values of the composite system. The measured values together with their variances are shown in Fig. 6.

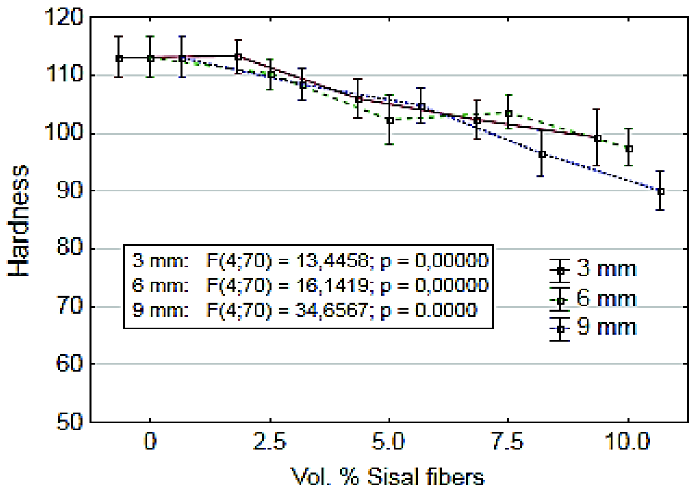


**Figure 6.** Hardness of composite systems with sisal fiber and after surface treatment with NaOH (ČSN EN 2039).

Resins without sisal fibers reached the hardness 113.11 ± 6.23. This hardness decreased with the inclusions of fibers to a value of 90.16 ± 5.78 (9 mm/10.0%).

Abrasion resistance, i.e. two-body abrasion, was evaluated through weight loss, which was with the help of theoretical density of composite systems converted to volume losses. The following graph (Fig. 7) displays the abrasive wear for the observed period of the proportion of sisal fiber in the matrix.

The inclusion of sisal fibers did not significantly affect the resistance to two-body abrasion. The volume loss of unfilled resins reached 0.5181 cm$^3$, and there was the highest volume loss from this value in the composite 9 mm/10.0%, the loss was 0.0121 cm$^3$. There was a decrease in volume loss in some composites; Composite

6 mm/7.5% reached the most significant decrease, the loss was 0.0450 cm$^3$. The coefficient of variation of measurement did not exceed 10%.

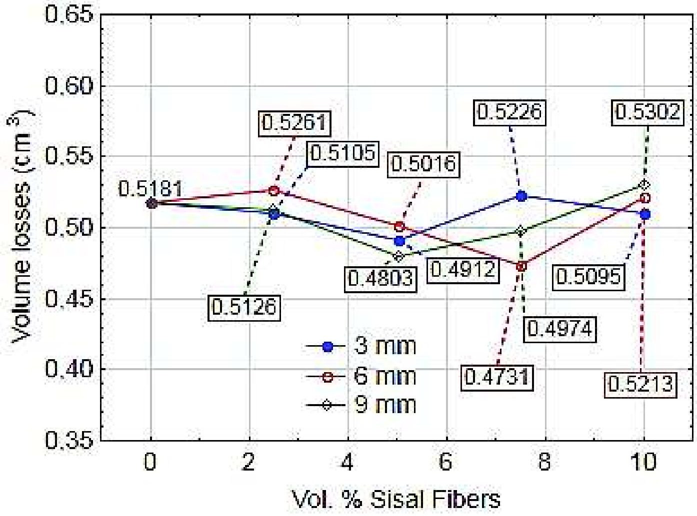


**Figure 7.** Volume losses – two-body abrasion (ČSN 62 1466).

Surfaces exposed to the two-body abrasion were evaluated with the electron microscope, see Fig. 8.

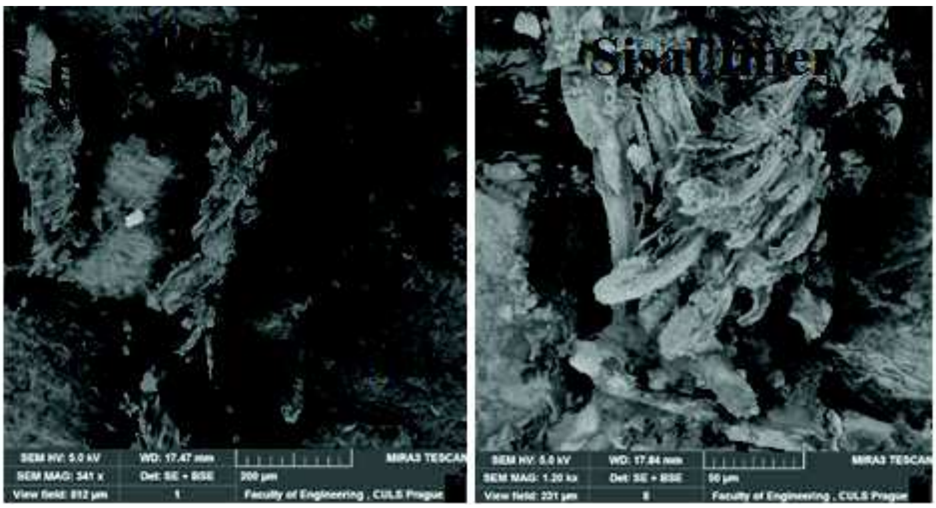


**Figure 8.** Worn out area of composite systems: Mag. 341 x (left), Mag. 1.20 x (right).

Niu et al. (2005) reported that sisal fibers affect the wear resistance of matrices, the authors demonstrated that sisal fibers might increase the resistance of polymers, the authors achieved the most significant increase in a composite with 15% of sisal fibers. These findings were not completely confirmed, some concentration of sisal fibers slightly increased the wear resistance, but there was also a decrease in wear resistance.

This might be due to the technological process of composite preparation, where the pressing was not used, the fibers were tentative, and the vacuum was not applied. They used technologically undemanding preparation, where the composite systems showed an increase in porosity. Wei et al. (2007) indicate that the surface treatment of sisal fibers with alkali positively affect the durability of the resulting composite system without surface treatment. It is therefore concluded that the treatment of fibers to optimize their surface was an adequate treatment for increasing the wear resistance. Dwivedi et al. (2010) also state that the abrasive wear of composites with sisal fiber depends on, besides other things, the fiber arrangement and just random arrangement could affect the disparate trend of volume losses depending on the concentrations of sisal fibers in the matrix. The composite systems based on biological fillers as sisal/epoxy are of high potential. Fibers composite on epoxy/sisal basis can be used for boards and a surface layers in industry and construction, these materials have significant design benefits in terms of appearance.

## CONCLUSIONS

The article describes the hardness and wear resistance of epoxy resin filled with short disordered sisal fibers treated with 6% NaOH solution. The results of the experimental program can be summarized in the following points:

- Surface treatment of the sisal fibers led to the removal of surface layers of fiber and increased the surface segmentation.
- Hardness of the composite systems decreased with the inclusion of treated sisal fibers, namely by 12.3% (3 mm/10.0%), 13.8 (6 mm/10.0%) and by 20.3% (9 mm/10.0%).
- Wear of the individual phases during a two-body abrasion were the same, without significant pulling of fibers from the matrix.
- Increase of the volume losses (two-body abrasion, grit P120) reached 2%, the maximum decrease was 9%.

ACKNOWLEDGEMENTS. This paper has been made with the assistance of the grant CULS – IGA TF.

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