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Study on impact strength of sisal fibers reinforced epoxy composites using experimental methods

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Abstract. Among the advantages of composite materials is their ability to exploit the properties of partial phases that creates the composite. Common materials used as matrix materials include polymeric composites. The properties of these matrices can be optimized by using synthetic or also natural fibers. Natural fibers are inexpensive, ranks among renewable resources and when respecting their biological nature, they can replace synthetic fibers in many applications. This paper describes the impact strength of epoxy resins filled with unordered short sisal fibers with a length of 2–6 mm. From the experimental results it is evident that the presence of fibers of sisal examined as epoxy resins, increases the impact strength, up to 143%. SEM (scanning electron microscopy) was used to assess the failure of mechanism of these composites.

Key words: Agave Sisalana, fiber composite, mechanical properties, porosity.

INTRODUCTION

Composite materials are materials that use the synergy effect of its individual components. Composites with fiber reinforcement are among the frequently used materials that play an indispensable role in a wide range of industrial applications. As the matrix fiber but also particles composites may be used polymer materials, such as epoxy resin, which have excellent mechanical properties (Valasek & Muller, 2013a, Muller, 2014; Ruggiero et al., 2015a).

Still increasing interest in environmentalism, increasing fears concerning the greenhouse effect instigated various industrial fields – for instance building industry, motoring and packaging industry, to find the sustainable materials which can substitute common synthetic polymer fibers (Silva et al., 2008). Sustainable substitute can be natural fibers, which are accessible, inexpensive and it is possible to consider them as a sustainable source (Mizera et al., 2015). Environmentally friendly may also be composites filled with waste, these primarily particles composites can optimize some mechanical properties like hardness, abrasive wear etc. (Valasek & Muller, 2013b, Valasek & Muller, 2012, Ruggiero et al., 2015b). Sisal fibers are in the area of composite systems according to Li et al. (2000) very perspective due to its low price, low density, and high specific strength and due to module of elasticity. Stated are also the absence of health risk in case of utilizing these fibers, easy accessibility and renewability. Besides advantages of natural materials it is essential to concern also their limits – thus is primarily natural substance of these materials, where for example the constant mechanical properties do not have to be maintained. Boopalan et al. (2012) indicates as a disadvantage the soaking of fibers, thereby reducing the mechanical properties in interaction with the polymer matrix.

Impact strength described in this paper ranks among important mechanical characteristic of composite systems. As it is stated by Chandramohan & Bharanichandar (2013) for optimization of impact strength can be used natural fibers of banana (Musa Sepientum), Roselle (Hibiscus Sabdariffa) but also sisal (Agave Sisalana) or their combination. For improving the impact strength of composite materials can be used short fibers, but significant improvement of epoxy matrices filled with long oriented fibers is described by Monteiro et al. (2014). Similar increase of impact strength of polymer matrix by inclusion of sisal fibers is also described by Li et al. (2015).

The aim of this experiment is to identify the change of impact strength of epoxy resins caused by the presence of short unorganized sisal fibres – confirm the hypothesis about positive influence of fibers presence on the impact strength of resins and primarily quantify the magnitude of this change. To confirm this hypothesis the common statistical surveys, i.e. ANOVA and T-test were used.

MATERIALS AND METHODS

Preparation of test samples

Matrix of composites was formed by two epoxy resins Glue Epox Rapid and Glue Epox Rapid F (these resins differ in viscosity).

The sisal fibers are extracted from the leaves of Agave Sisalana, which is mainly grown in tropical and subtropical zone – the untreated sisal fibers were used in this experiment. Country of origin: China. The fibers are obtained from the leaves of plants, each sheet weighing up to 1.5 kg and contains up to 7% fibers (see Fig. 1).

Figure 1. Fibers in the sheet of agave Sisalana plant.

The length of the fibers ranged from 80 to 100 mm. The length of the fibers was cut into short fibers having a length of 2 mm, 4 mm and 6 mm. The length of fibers after cutting did not correspond to determined length (2 mm, 4 mm and 6 mm) in all cases, therefore their concrete length was defined with stereoscopic microscope, where the real length was measured. By using this procedure, the value 1.9 ± 0.4 mm was determined for 2 mm, value 4.0 ± 0.5 mm for 4 mm, and the real length corresponded to 6.1 ± 0.5 mm length for 6 mm. Fundamental mechanical properties of these fibers shows Table 1.

Table 1. Mechanical properties of sisal fibers (Mieck et al., 1994)

Density (g cm^{-3})	Tensile strength (MPa)	Young´s modulus (GPa)	Elongation at break (%)
1.45	468–640	9.4–22.0	3–7

The preparation of composites was performed by mechanical mixing of short sisal fibers and the epoxy resins. The testing samples were consequently cast to the moulds prepared from two component silicon rubber. Concentration of the filler in the matrix was expressed with volume percentages, fiber systems with 1%, 2.5%, 5% and 10% were prepared. Casted testing samples were subjected to density control, where the deviation of real and theoretical density was measured – porosity and also the impact strength was evaluated.

The impact strength was evaluated based on the norm CSN 64 0611 (Determination of the impact resistance of rigid plastics by means of Dynstat apparatus). In these destructive tests, the Dynstat device nr. 283 stated impact strength a_n, which expresses kinetic energy the hammer needed to crush the tested object without notches in relation to the surface of its diagonal cut, as expressed by the following formula (1):

$$a_n = \frac{A_n}{b \cdot h} \tag{1}$$

where: a_n – impact strength (kJ m^{-2}); A_n – energy required to shift the specimen (kJ); b – width of the test specimen (m); h – thickness of the test specimen (m).

RESULTS DISCUSSION

Among significant properties determining the qualitative indicator of composite systems ranks the porosity. Fig. 2 compares the porosity of casted fiber systems based on comparison of real and theoretical density. Theoretical density was calculated according to volume concentration of fibers in the epoxy resin, namely based on density of resin stated by the manufacturer 1.15 g cm^{-3} and density of sisal fibers 1.45 g cm^{-3}.

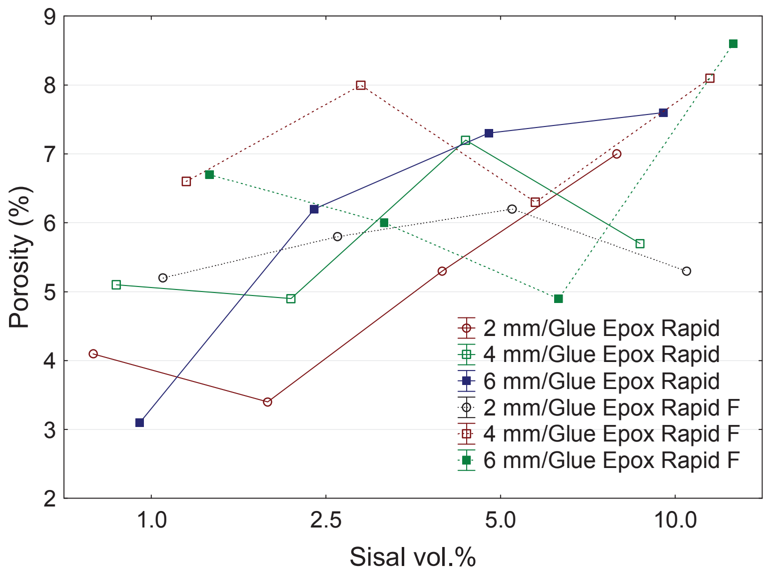

Figure 2. Porosity of Epoxy/Sisal composites.

As apparent from Fig. 3 the presence of sisal fibers in the resin Glue Epox Rapid significantly increased the values of impact strength. From the progress of the curves it is evident, that the increasing concentration has unequivocal effect on the increase of values of impact strength. With increasing length of fiber was not confirmed the effect on increase of impact strength of these cast composite systems. Impact strength of unfilled resin Glue Epox Rapid reached the value 3.24 ± 1.11 kJ m^{-2}. Significant values of dispersion were recorded when measuring the impact strength. The coefficient of variation of measurement was up to 39%. This fact can be attribute to increased porosity of cast composite systems as well as to disorder of fibers in the matrix. The highest value of impact strength 7.97 ± 2.30 kJ m^{-2} was measured in the system with fiber length 2 mm and concentration 10%.

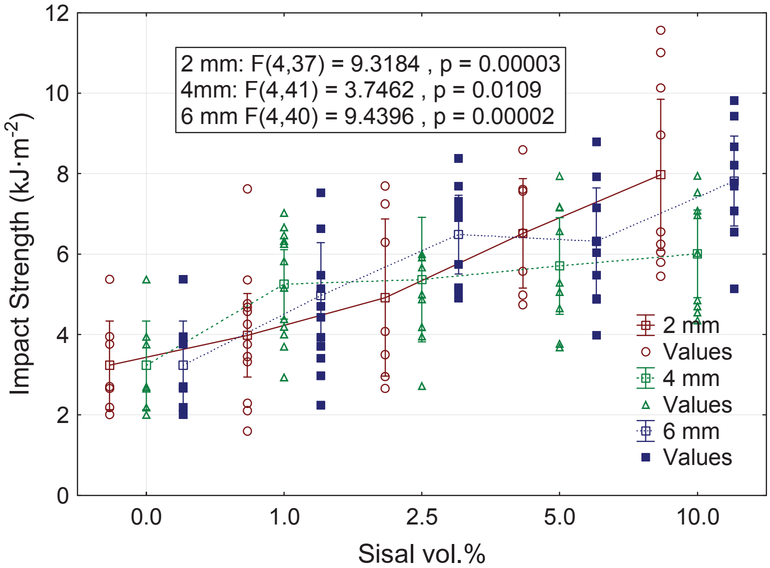

Figure 3. Impact strength of composites with matrix Glue Epox Rapid.

Average impact strength of resin Glue Epox Rapid F reached the value 3.67 ± 1.01 kJ m^{-2}. Presence of sisal fibers analogously as for other assessed resin increased impact strength proportionally with the increasing concentration of fibers in the matrix. The highest value was reached at fiber length 6 mm and concentration 10%, that was 8.91 ± 1.37 kJ m^{-2} (see Fig. 4 the results of ANOVA analysis). During measurement were recorded high coefficients of variation, which reached up to 30%.

From the Fig. 3 and Fig. 4 follows, that is possible to describe the dependence between increase of impact strength and increase of sisal fibers as a linear dependence, see equation in Table 2.

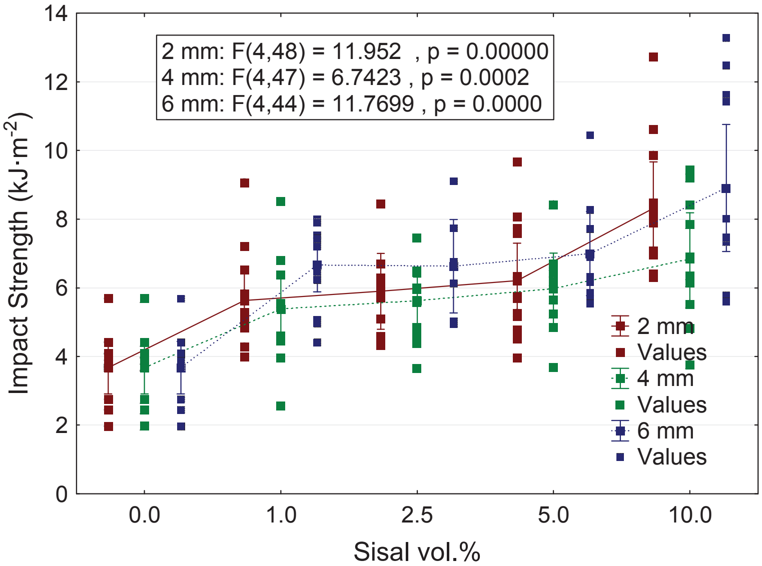

Figure 4. Impact strength of composites with matrix Glue Epox Rapid F.

Table 2. Description of increase of impact strength – linear trends

Composite	2 mm		4 mm		6 mm	
	equation	R^2	equation	R^2	equation	R^2
Glue Epox Rapid	$y = 0.7864x + 3.24$	0.84	$y = 0.6191x + 3.24$	0.76	$y = 0.88x + 3.24$	0.89
Glue Epox Rapid F	$y = 0.8004x + 3.67$	0.84	$y = 0.6256x + 3.67$	0.88	$y = 0.9884x + 3.67$	0.82

Electron microscopy confirmed sufficient wetting of fibers with resins, see fracture areas Fig. 5. From the Fig. 5 it is obvious fibers plucking during matrix failure and the presence of air bubbles, which were demonstrated by porosity as well.

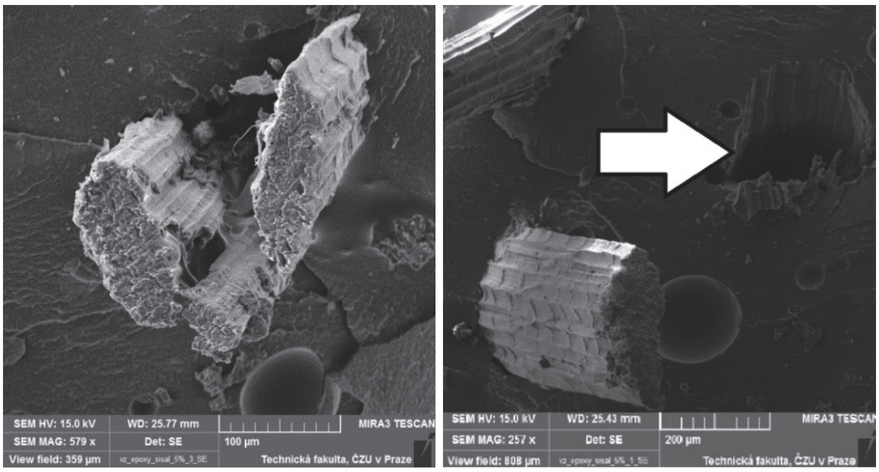

Figure 5. Fracture areas of sisal composites systems (SEM).

CONCLUSIONS

From the point of view of the coefficients of variation, which occurred at both unfilled resin and composite systems, it is necessary to analyze the measured data with statistical surveys in such way, that it was possible to statistically prove the influence of fiber inclusion on values of impact strength. To confirm the hypothesis about statistical significant effect of inclusion on the examined mechanical characteristic was chosen T-test in the level of significance $\alpha = 0.95$. If $p < 0.05$ the increase of impact strength is statistically proven, see Table 3 ($\mu 1 \neq \mu 2$), which compares low fiber concentrations with unfilled resin, that is up to moment of demonstrable increase of impact strength.

Table 3. T-test comparison of unfilled resin with low concentrations

H: $\mu 1 \neq \mu 2$	Glue Epox Rapid			Glue Epox Rapid F		
($p < 0.05$)	2 mm	4 mm	6 mm	2 mm	4 mm	6 mm
0 :1%	0.30	0.00	0.06	0.00	0.00	0.00
0 : 2.5%	0.09	-	0.00	-	-	-
0 : 5%	0.00	-	-	-	-	-

Statistical survey proved that for resin Glue Epox Rapid is possible to state the statistical increase of impact strength from 5% (2 mm) and from 2.5% (6 mm). In all other cases the increase occurs already from the lowest concentration of sisal fibers in the matrix, i.e. 1%.

The results confirm conclusions of Ashok Kumar et al. (2010), who describes the increase of impact strength for composites with epoxy matrix and fibers length 1 cm, 2 cm and 3 cm. Author recorded the highest mechanical properties for composites with fiber length 2 cm, while the experiment described in this paper unequivocally do not determine optimal fiber length from the lengths 2, 4 and 6 mm. The experiment confirmed also the conclusions about increase of impact strength of resins with sisal fibers, which were formulated by Li e al. (2015).

It is possible to agree with conclusions of Dharmalingam et al. (2015), who states, that the composite materials with sisal fibers have higher impact strength and it is possible to combine them with synthetic fibers, which could be object for further experiments in the area of evaluation of impact strength of short Sisal/Epoxy systems.

Adding the short sisal fibers has as the result the unequivocal improvement of absorption the energy of composites. Experimental values were loaded with big coefficients of variation. Impact strength did not evince demonstrable dependence on the fiber length. Increase of values of impact strength, achieved by inclusion of sisal fibers, reached up to 143% for Glue Epox Rapid F and 142% for Glue Epox Rapid.

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