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Mechanical behaviour of polymeric composite with fibres of false banana (Ensete ventricosum)

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Abstract. This study was focused on the analysis of the deformation characteristics of the polymer composite with continuous phase in the form of two-part epoxies and discontinuous phase (reinforcing particles) in the form of fibres of false banana (Ensete ventricosum). The aim of the experiment was to describe the mechanical behaviour of polymeric composite reinforced by fibres of false banana under tensile loading and to determine the modulus of elasticity and deformation energy. The fibres of Ensete ventricosum, originally from Ethiopian region Hawasa, were used in this experiment. Reinforcing fibres were prepared in sizes of lengths 1–2, 2–3, 3–5, 5–6, 7–8, 9–10, 15, 20, 25, 30, and 35 mm with randomly fibres arrangement in matrix. The fibres with length of 1–2, 2–3, 3–5, 5–6, 7–8 and 9–10 mm were used in short fibres composites and fibres with length of 10, 15, 20, 25, 30 and 35 mm in long fibres composites. The composite material was created with 2 wt.% of the filler. The modulus of elasticity of the short-fibre composite material was increased of 28 ± 12% by adding Enset fibres as the filler. The modulus of elasticity of the long-fibre composite material was increased of 46 ± 14%. The influence of the fibre length on the value of the volume deformation energy was not proved.

Key words: agriculture, deformation energy, tensile strength.

INTRODUCTION

Currently worldwide environmental and economic interests stimulate research in designing new materials whose substantial portion is based on natural renewable resources in order to avoid further pressure on the environment (Alves et al., 2010). A constantly increasing trend of using organic fibre as a reinforcement in composite materials based on epoxy resin has been seen in recent years. The organic fibre can be a suitable substitute of synthetic fibres because they are available in a fibre form at low costs (Aseer et al., 2013). They reach relatively high specific strength and a rigidity owing to their low density. Replacing of the synthetic fibres by the organic ones has a lot of advantages which can be rationalized also by means of an ecological equlibrium. Plastic composite materials reinforced with natural fibres become more significant in constructional applications. E.g organic fibre from a coir, kenaf, oil palm and a jute have suitable mechanical properties which are used in various industrial applications (Hpsa et al., 2001; Lu et al., 2003; Sharifah & Martin, 2004; Harun et al., 2008; Mominul Haque et al., 2009). However, they also have some disadvantages owing to their low plasticity (Keller, 2003). This can be removed by connecting the natural fibre with the natural or the synthetic polymer when a light composite material with required mechanical properties is gained. One of the suitable plants with great potential for the production of natural fibres is Ensete (Ensete ventricosum) also known as false banana (Tsehaye & Kebebew, 2006). The Ensete doesn't produce edible fruits and it is not categorized as usual banana plants (genera Musa). It is a perennial herbaceous plant that grows in Ethiopia and it is primarily intended for human consumption and animal feeding (Vincent et al., 2013; Herak et al., 2014). Over centuries the Ensete fibres have been extracted from the leaves of this plant as major material for the weaving, ropes and cord production, as well as for baskets production (Diriba et al., 2013; Yirmaga 2013). Composite material reinforced with Ensete fibres could be used for the production of parts for automotive industry. The aim of this experiment is to describe mechanical properties of the composite material reinforced with the fibres of the plant false banana Ensete ventricosum and determine a volume deformation energy.

MATERIALS AND METHODS

Preparation of test samples

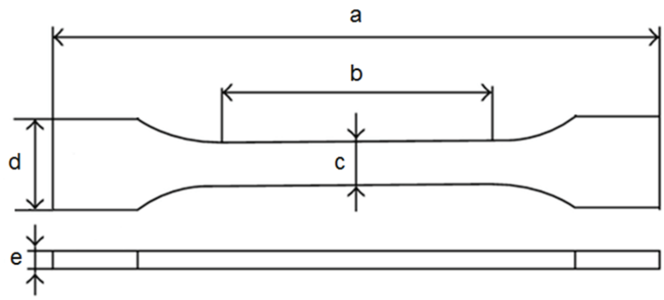
The fibres from the plant Ensete ventricosum originated from Etiopia (region Hawasa) were used for a production of test samples of the composite material. A humidity of the fibres 8.7 ± 0.74% (d.b.) was set by a standard method in a drying equipment according to (ASAE S410.1 DEC97, 1998). Samples of 100 g mass from a batch of Ensete fibres were randomly selected for the moisture content determination. The mass of each samples was determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). The true fibre density 710 ± 45 kg m^{-3} was determined gravimetrically (Blahovec, 2008) This means that the mass of individual samples from a batch of fibres, randomly selected and measured using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany), was divided by the volume of sample. The volume of the individual sample was determined by weighing the sample in toluene and applying the principle of buoyancy (Kim et al., 2012). The results obtained were expressed as mean of three replicates.

A maximum tensile stress 537 ± 77 MPa according to (ASTM D3379-75) was set at the sample of the fibres. Further, the fibre mean 0.1887 ± 0.0464 mm was set by means of a picture analysis by an optical microscope (Zeiss Jenavert, Carl Zeiss, Jena, Germany). Gained results were expressed as an average value of twenty replicates.

Ensete fibres were used as the filler from which fractions of a length of the fibres for short-fibre composites: 1–2 mm, 2–3 mm, 3–5 mm, 5–6 mm, 7–8 mm and 9–10 mm were created. The length of the fibres for long-fibre composites were chosen following: 10 mm, 15 mm, 20 mm, 25 mm, 30 mm and 35 mm.

The epoxy resin GlueEpox Rapid was used as a matrix. It is a two-component resin prepared from a bisphenol A and epichlorhydrin. This epoxy resin is suitable as a casting material. It serves as the matrix at the production of composites (Müller, 2014; Valášek, 2014). The composite material was created by mixing of the matrix and the filler in a ratio 50:1 (2%). This material was used for the preparation of test specimens (Fig. 1) according to the standard (ČSN EN ISO 3167, 2004). The composite systems containing

100 g of the resin GlueEpox Rapid and 2 g of the reinforcement in the form of the fibres Ensete were tested within the research. Moulds for casting of the test specimens were produced from a material Lukapren N. Dimensions of the test specimen are present in Fig. 1.



Dimension (mm)

a	b	c	d	e
150	80	10	25	4

Figure 1. Test sample – Tensile strength (ČSN EN ISO 3167, 2004).

Laboratory tests

To determine the relationship between tension force and deformation, a device (Labortech, MPTest 5.050, Czech Republic) was used to record the course of deformation function. The tensile test was performed according to (ČSN EN ISO 527-2, 2012). A deformation speed at the tensile test was 6 mm.min^{-1}. Set values of tensile forces were transformed by means of an equation 1 to the tensile stress and deformations were transformed by means of an equation 2 to the relative deformation.

$$\sigma = \frac{F}{S} \tag{1}$$

where: σ – tensile stress in sample, MPa; F – tensile force, N; S – appropriate cross section area of sample, mm^2,

$$\varepsilon = \frac{x}{L_0} \tag{2}$$

where: ε – strain, -; x – elongation of sample, mm; L_0 – gauge length, mm.

The elongation of the sample was determined from crosshead displacement. Modulus of elasticity was determined as a slope of line which was specified by fitting stress strain curve. The slope of fitted line was calculated by Marquardt Levenberg algorithm (Lourakis, 2005; Marquardt, 1963) using computer program Mathcad 14 (MathCAD 14, PTC Software, Needham, MA, USA), (Pritchard, 1998).

The volume deformation energy was set as an area below a curve 'stress – strain' from zero to a maximum value of the deformation according to an equation 3.

$$\lambda = \sum_{n=0}^{n=i-1}\left[\left(\frac{\sigma_{n+1}+\sigma_n}{2}\right)\cdot\left(\varepsilon_{n+1}-\varepsilon_n\right)\right] \tag{3}$$

where: α – volume energy, J m^{-3}; i – indicates the additional amount of strain in which the stress was determined (step of measurement – 0.001 mm), -; σ_n – tension stress at appropriate strain, MPa; σ_{n+1} – tension stress at the sequential strain, MPa; ε_n – strain, -; ε_{n+1} – sequential strain, -.

RESULTS AND DISCUSSION

The specimen of the composite material was analysed by means of the optical microscope. A disposition of the fibres in the composite material and their size is visible in Fig. 2.

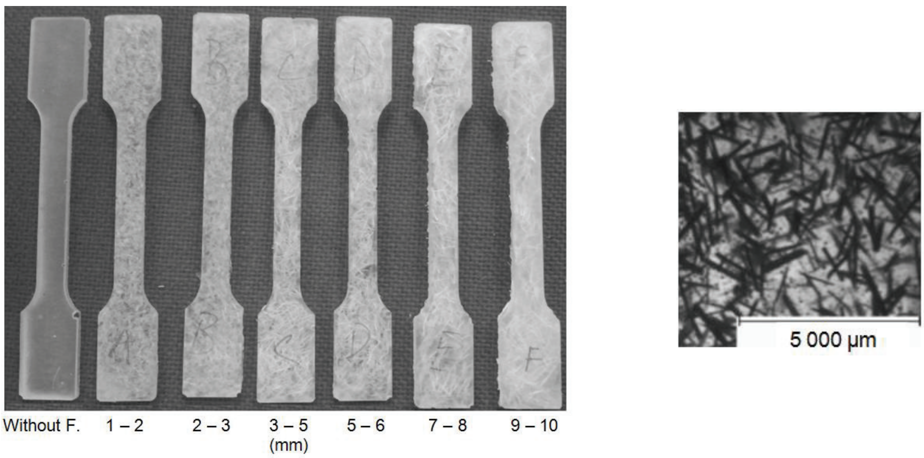


Figure 2. Specimens of composite material with Ensete fibres and disposition of fibres in matrix.

Modulus of elasticity of the short-fibre composite material with Ensete fibres is presented in Fig. 3. The modulus of elasticity increased by adding various lengths of the fibres comparing with the specimen of the epoxy resin without the fibres where the modulus of elasticity 2.173 ± 0.132 GPa was reached. The highest modulus of elasticity 3.217 ± 0.326 GPa was reached at the short-fibre composites at the specimen with the length of the fibres 10 mm. The polymeric materials are generally of relatively low values of the modulus of elasticity. The elasticity modulus is increased when crosslinking of the structure by means of e.g. natural Ensete fibres. The modulus of elasticity is increased also by adding of the natural fibres from a flax and jute into the epoxy matrix of the composite material (Ku et al., 2011; Arrakhiz et al., 2013). This quality was also certified at the fibres of the false banana Ensete ventricosum (Fig. 3).

At first, a two-choice F – test was used for a statistical comparison of particular measured values for an analysis of an agreement of variance. After verifying the agreement of variance. T-test of a significance of differences of two chosen means was subsequently used. Resultant parameters of T-test are stated in Table 1. Particular measured values for different lengths of the fibres were compared with the set of data of the epoxy resin without the fibres. It is visible from the Fig. 3 that the modulus of elasticity was increased at all short-fibre composite materials reinforced with Enset fibres which is evident also from the coefficients of T-test stated in Table 1. Measured deformation energy at the short-fibre composites is presented in Fig. 4. Similar trend is also at polymeric particle composites when small concentration of particles with sizes in the order of units and tens of micrometers leads only to mild improving of cohesive properties, that means the strength (Valášek et al., 2014). The statistical evaluation of the volume deformation energy is presented in Table 1.

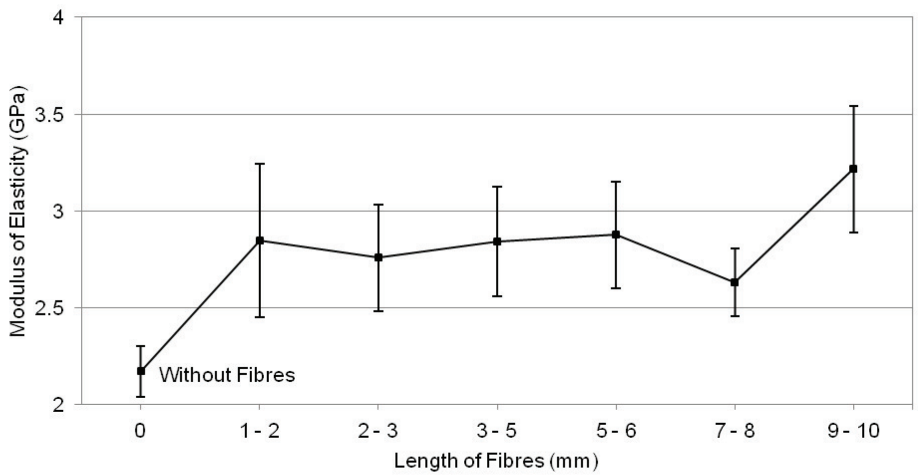


Figure 3. Dependence of modulus of elasticity on length of used fibres in short-fibre composite material.

Table 1. T-test Modul of elasticity and Volume Energy for short-fibre composites. Statistical comparison with pure specimen of epoxy resin without fibres

T-test	Modul of Elasticity			Volume Energy		
Length of F. (mm)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)
1–2	2.929	2.306	0.019	5.507	2.306	0.001
2–3	3.446	2.364	0.011	1.374	2.364	0.211
3–5	3.859	2.364	0.006	2.393	2.306	0.044
5–6	4.284	2.306	0.003	1.377	2.364	0.202
7–8	3.988	2.306	0.004	2.249	2.364	0.059
9–10	5.433	2.306	0.001	1.949	2.306	0.087

T-test H_0: $\mu_1 = \mu_2$ (p>0,05)

It is obvious from the Table 1 that the statistically significant change of the volume deformation energy did not occur by adding of Ensete fibres in stated ratio. Thus, the influence of the length of Ensete fibres in the composite material on the value of the volume deformation energy was not proved.

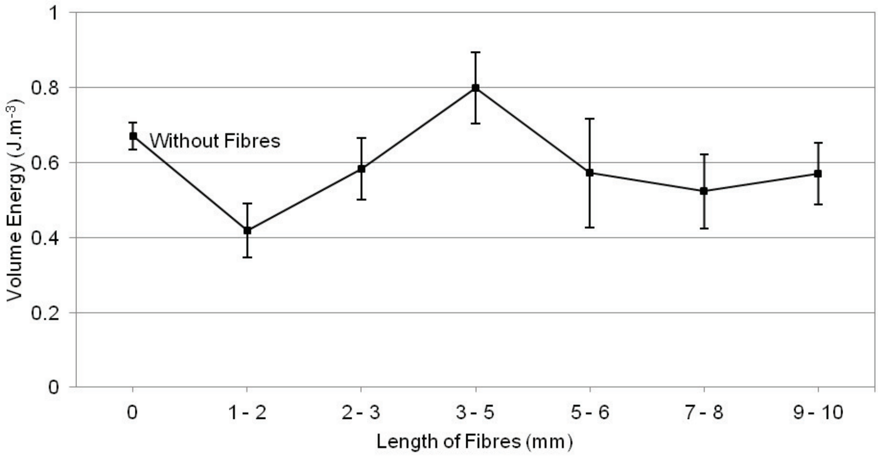


Figure 4. Dependence of volume deformation energy on length of used fibres in short-fibre composite material.

Modulus of elasticity at the long-fibre composites is presented in Fig. 5. The highest modulus of elasticity 3.341 ± 0.452 GPa was reached at the composite with the length of the fibre 35 mm. Particular specimens of composites were compared with the epoxy resin without the fibres where the modulus of elasticity was set as 2.268 ± 0.128 GPa. The two-choice F – test for the analysis of the agreement of variance was again used at first for the statistical comparison of particular measured values. After verifying the agreement of variance, T-test of the significance of differences of two chosen means was subsequently used. Resultant parameters of T-test for long-fibre composites are stated in Table 2. The modus of elasticity at the long-fibre composite materials was increased by adding of reinforcing fibres which is shown by the coefficients of T-test presented in Table 2.

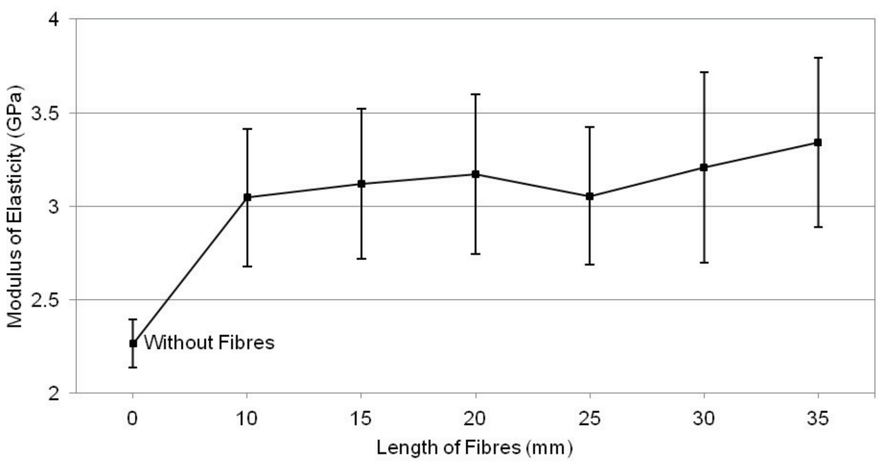


Figure 5. Dependence of modulus of elasticity on length of used fibres in long-fibre composite material.

Table 2. T–test Tensile Strength and Volume Energy for long-fibre composites. Statistical comparison with pure specimen of epoxy resin without fibres

T-test	Modul of Elasticity			Volume Energy		
Length of F. (mm)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)
10	3.989	2.306	0.004	0.193	2.364	0.852
15	4.056	2.306	0.004	0.090	2.306	0.931
20	3.962	2.364	0.005	0.157	2.364	0.160
25	4.052	2.306	0.004	0.372	2.262	0.718
30	3.574	2.306	0.007	0.464	2.306	0.655
35	4.482	2.364	0.002	0.275	2.228	0.789

T-test H_0: $\mu_1 = \mu_2$ ($p > 0,05$)

Measured volume deformation energy at the long-fibre composites is presented in Fig. 6. The statistical evaluation of the deformation energy at the long-fibre composites is stated in Table 2. The statistically significant change of the deformation energy did not occur at the long-fibre composites by adding of Ensete fibres in stated ratio which is certified also by the coefficients of T-test stated in Table 2.

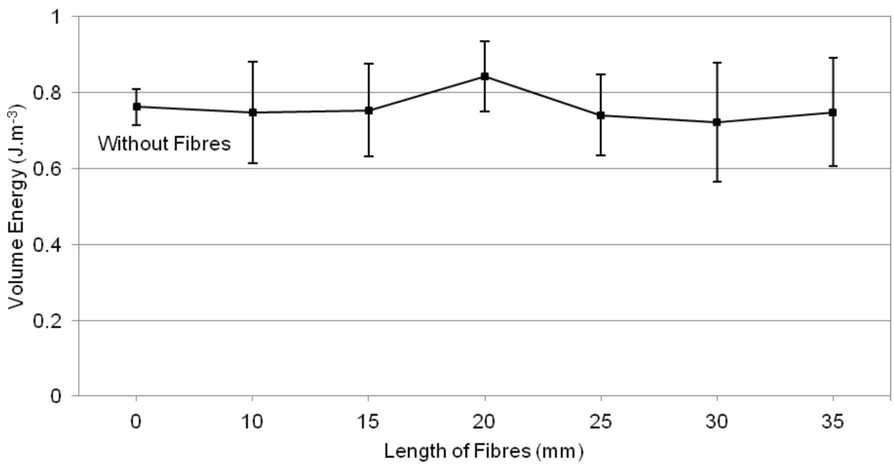


Figure 6. Dependence of volume deformation energy on length of used fibres in long-fibre composite material.

Ensete fibres are of suitable mechanical properties and that is why they can have a great potential for utilization in the composite materials. Adding of various types of fillers into the composite materials can modify their mechanical properties. (Valášek et al., 2014). One of possible treatments for improving of the mechanical properties of the composite materials reinforced with natural fibres is a chemical treatment of the fibres. A hydrogen bond in a structure of a net of the fibres is removed by using sodium hydroxide (NaOH) and a surface energy and a roughness of the fibre surface are increased (Lee et al., 2009).

The application of tested composite system is in the area of cementing and hollow reinforcements in constructions of bonds. The reason is a rise of the construction rigidity. Further, for eliminating of a penetration of degradation mediums (fertilizers) and humidity at agricultural machines. Used typ of matrix is of increased resistance to the influence of liquid contaminants (Müller, 2013).

CONCLUSIONS

The aim of this study was to set the mechanical properties of the composite materials prepared from the fibres of the plant false banana Ensete Ventricosum. It was ascertained following:

- Untreated Ensete fibres added as the filler into the composite materials increase the modulus of elasticity. The matrix reached the modulus of elasticity 2.173 ± 0.132 GPa. The modulus of elasticity was increased at the composite materials with the length of the fibres in the interval 1–2 to 7–8 mm comparing to the matrix without the fibres of 28 ± 12%. The modulus of elasticity was increased at the composite materials with the length of the fibres in the interval 9–10 to 35 mm of 45 ± 14%. The marginal values of the modulus occur at the material (composite) without fibres and of the composite with the length of the fibres 8–9 mm.
- The influence of the length of the fibres on the change of the deformation energy was not proved. The matrix reached the volume deformation energy 0.721 ± 0.054 J m^{-3}. The average value of the deformation energy was reached 0.582 ± 0.098 J m^{-3} at the composite materials with the length of the fibres in the interval 1–2 to 7–8 mm. The average value of the deformation energy was reached 0.759 ± 0.125 J m^{-3} at the composite materials with the length of the fibres in the interval 9–10 to 35 mm.

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