Mechanical properties of sisal fibre-reinforced soybean oil-based polyurethane biocomposites

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Abstract: This paper presents mechanical properties of polyurethane biocomposites reinforced with short sisal fibres. The biopolyurethane matrix was obtained by prepolymer method. The isocyanate (MDI) was reacted with a mixture of modified soybean oil with synthetic polyols (50:50 wt. %). Low molecular bioglycol – 1,3 biopropanediol was used as the chain extender of the polyurethane prepolymer. The fillers were added in different amounts: 5, 10 and 15% by mass. Tensile test was performed and hardness, abrasion resistance and elasticity were determined according to the standards. It was found that sisal fibre addition influences mechanical parameters of the biocomposites. Increasing the amount of fillers in the polyurethane matrix leads to higher tensile strength (TSb) and hardness. Elasticity and abrasion resistance of the biocomposites decreased when a higher proportion of sisal fibre was added.

1. Introduction

Sisal fibre is obtained from the leaves of the plant *Agave sisalana* and is produced in the tropical regions such as Mexico, Brazil, Tanzania, Kenya, Madagascar and China. Sisal is mainly used in the manufacturing of natural ropes, twine, sacking, carpet making, and textile materials like nets, mats and automobile floor mats. Sisal fibre can be used as a reinforcement fibre in production of composites (Sibani et al., 2012). Properties of the fibre depend on the nature of the plant, locality in which it is grown, age of the plant and the extraction methods used. Sisal is an important leaf fibre and it is very strong. It is one of the most extensively cultivated hard fibres in the world and it accounts for half of the total production of textile fibres. It could be natural but this is information from publication. This is due to the ease of cultivation of sisal plants, which have short renewing times, and are fairly easy to grow in all kinds of environments. Sisal fibre has high cellulose content (70%) and density (about 1.450 g/cm$^{-3}$). A good sisal plant yields approximately 200 leaves, with a mass composition of 4% fibre, 0.75% cuticle, 8% other dry matter and 87.25% moisture. Thus a normal leaf weighing about 600 g yields about 4% by weight of fibre, with each leaf containing about 1,000 fibres. The fibre is extracted from the leaves either by retting, by scraping,
by retting followed by scraping or by mechanical means using decorticators. The
diameter of the fibre varies from 100 mm to 300 mm. The characteristics of the sisal
fibres depend on the properties of the individual constituents, the fibrillar structure
and the lamellae matrix. Each fibre is composed of numerous elongated fusiform
fibre cells that taper towards each end. The fibre cells are linked together by middle
lamellae, which consist of hemicellulose, lignin and pectin. In cross-section, each
individual sisal fibre is built of about 100 fibre cells. The number of cells in cross-
section of a sisal fibre ranges from 260 to 584 depending on the diameter of the fibre.
The use of sisal fibres in polymer composites is increasing, due to the low production
costs of composites and amenability of these fibres to winding, laminating and other
fabrication processes. Manufacture of these composites is fairly easy and the cost
of production quite low (Joseph et al., 1999). Sisal fibres have moisture content
ranging from 5 to 20%, due to the hydrophilic characteristic of the cellulosic fibres.
This characteristic affects the mechanical properties of the composites because high
moisture content can lead to poor processability and result in porous products during
processing of the composites. The fibre surface structure can be modified by chemical
and thermal treatments, in order to enhance the bond strength between the fibre and
the matrix and to reduce water absorption of natural fibres. Thermal or hydrothermal
treatment processing should not be conducted at temperatures about 120°C because
processing above this temperature leads to increasing brittleness, reduces the strength
and changes other fibre properties (Milanese et al., 2011).

Sisal fibre can be used as a reinforcement in polyurethane composites. Thus
obtained material shows properties similar to unidirectional fibre-reinforced rubber.
Seed oil-based polyurethane composites have good thermal and mechanical properties
(Bakare et al., 2010). To prepare self-reinforced sisal composites, sisal fibres are
cleaned, treated with NaOH solution, and then benzylated with benzyl chloride. In
this way, the skin layers of the fibres are converted into thermoplastic material while
the core of the fibre cells remains unchanged. Self-reinforced all-plant fibre composites
of sisal can be prepared under conditions of hot pressing. In these, plasticised sisal
serves as the matrix and the unplasticised cores of the fibres as the reinforcement.
Structural characteristics, melt flow and mechanical properties of modified sisal and
their composite sheets were analysed by Lu. It was found that the balance between the
melt processability with the reinforcing effect of the modified sisal fibres in benzylation
process was required (Lu et al., 2004).

The current study investigated the possibility of using different amounts of sisal
fibre in a soybean oil modified polyurethane matrix. Mechanical properties of these
material were determined and compared with samples without sisal fibre.

2. Experimental Section

The biocomposites were produced using short sisalfibre. A biopolurethane matrix was
obtained by prepolymer method. Prepolymer was synthesized from
4,4’-diphenylmethane diisocyanate (MDI - BorsodChem, Hungary) and a polyol mix-
ture (50 % by mass of commercial polyether (Poly(tetramethylene ether) glycol,
PTMG), Mn 2000 (BASF PolyTHF® 2000, Germany) and 50% by mass of hy-
droxylated soybean oils (natural component) earlier modified by low molecular bi-
glycol. The reaction was carried out over 1 hour at 80°C. In the second step of the
process, the prepolymer chains were extended by 1,3 – biopropanodiol. DABCO - 1,4-diazabicyclo[2.2.2] oktan was used as the catalyst. The synthesized prepolymer were filled by 5, 10 and 15% by mass of sisal fibers per the polyurethane system (matrix). Thus obtained biocomposites were moulded and cured at 100°C for 24 hours.

3. Measurements

**Tensile test** (tensile strength, elongation at break) was performed using a Zwick Z020 tensile-testing machine according to EN ISO Standard 527-1:1996 and 527-2:1996. Dumbbell shaped samples with normalized dimensions were tested. The test was executed at a rate of 50 mm per minute. Measurements of the mechanical properties were carried out at room temperature.

**Abrasion resistance** was tested with a Schopper-Scholbach instrument. The abrasion resistance was calculated according to the following formula:

\[
1V = \frac{(m_1 - m_2) \cdot 0.2}{\rho \cdot \Delta m_w} [cm^3]
\]

where:
- \( m_1 \) – weight of the sample before the test (g);
- \( m_2 \) – weight of the sample after the test (g);
- 0.2 – the required mass loss of the standard sample (g);
- \( \rho \) – the density of the analyzed material (g/cm³);
- \( \Delta m_w \) – the arithmetic mean of the mass loss of three standard samples (g).

**Hardness** was measured according to the PN-EN ISO 868:2005 standard. Samples in the shape of a circle (56x6 mm size) were placed on a flat surface and then 10 measurements were taken for each sample with a Shore A durometer perpendicularly applied for 3 seconds.

**Elasticity** as the rebound resilience was determined according to the PN-C-04255:1997 standard. The test was carried out with a Schob pendulum. Rebound resilience is determined by a freely falling pendulum hammer that is dropped from a given height, impacts a sample and imparts to it a certain amount of energy. The test result is shown on the pendulum’s scale. In this test, the same circle-shaped samples as in the hardness analysis were used. For every sample, 10 measurements were made.

4. Result and discussion

The values of mechanical parameters determined in the tests were presented in Table 1. The tensile strength (TSb) ranged from 10.33 MPa (reference sample) to 8.47 MPa for biocomposite sample containing 5 wt% of sisal fiber in the matrix. The higher value of TSb, about 9.5 MPa, was obtained for the samples with the highest amount of sisal fibre (PU15). Overall, the addition of raw sisal fibre didn’t have a significant impact on the hardness of materials. The addition of 5% of sisal fibre caused a slight decrease of this parameter.

Elongation at break (Eb) decreased with increased content of sisal fibre; from 217% for the reference samples (REF) to 17% for the biocomposites with the highest amount of sisal fibre.

Rebound resilience (ε) also decreased. The lowest abrasion resistance was found in the samples with the highest content of sisal fibre (PU15). This could have been caused by not enough adhesion between the filler and the polymer matrix.
Tab. 1. The value of measurement parameters of biocomposites

<table>
<thead>
<tr>
<th></th>
<th>Tensile strength (TSₜ)</th>
<th>Elongation at break (Eₜ)</th>
<th>Hardness (H)</th>
<th>Rebound resilience (ε)</th>
<th>Abrasion resistance (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>10.33</td>
<td>217</td>
<td>90.8</td>
<td>23</td>
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</tr>
<tr>
<td>PU5</td>
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<td>87</td>
<td>89.3</td>
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<tr>
<td>PU10</td>
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<td>32</td>
<td>92.4</td>
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<td>0.05</td>
</tr>
<tr>
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<td>16</td>
<td>92.6</td>
<td>17</td>
<td>0.08</td>
</tr>
</tbody>
</table>

5. Conclusions

Hardness and abrasion resistance increased in the samples of tested biocomposites as the amount of sisal fibre added increased. Elongation at break and rebound resilience, however, decreased with increasing sisal fibre content. These results suggest that chemical modification of sisal fibre to enhance adhesion between matrix and sisal fibre might be necessary.

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