MATERIAL PROPERTIES EVALUATION OF POLYMER COMPOSITES BASED ON EXPERIMENTAL DATA AND NUMERICAL ANALYSIS

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Abstract: The paper presents results of advanced approach for material evaluation of polymer composites. The homogenization procedure based CT observation and numerical approach is presented. The standard macro test is simulated numerically. The results for wood based composite are presented.

Keyword: X-ray computer tomography, numerical homogenization, wood based composite, finite element.

1. Introduction

Nowadays the microscale X-ray computed tomography (CT) is perspective tool for investigation the structure of new advanced materials. Visualization and material segmentation of the materials allows to obtained data for numerical homogenization. Based on appropriate material model the adequate boundary value problem can be define and solved.


The basic idea of proposed technique is illustrated on following figure.

3. Investigation methods

Following methods are used:
A. Micro-CT Imaging and homogenization
B. Instrumented indentation test method [1]
C. Ultrasonic and vibration test
D. FEM simulation
A. Micro-CT Imaging and homogenization

B. Instrumented indentation test method (IIT)

Details about the indentation testing procedure may be found in [2]. Below is a schematic presentation of the basic procedure for performing and analysing nanoindentation IIT results.

C. Dynamic elastic modulus by ultrasound and forced flexural vibration test

Determination of the dynamic elastic moduli by ultrasound is based on the relation between ultrasonic longitudinal (C_l) and shear (C_t) waves, density (ρ) and Young’s modulus (E) [3]:

\[ E = \rho C_l^2 \left( \frac{3C_l^2 - 4C_t^2}{C_l^2 - C_t^2} \right) \]

The density is obtained by the method of hydrostatic weight. Ultrasonic wave velocities are determined by impulse direct method by measuring of the time of wave propagation. Ultrasonic longitudinal waves are excited by piezoelectric transducer with a central frequency of 3.5 MHz. The velocity of shear ultrasonic waves are measured by shear wave transducer at 3.5 MHz. The accuracy of determination of velocities is about 2%. The results of velocities are averaged on the specimen length.

The relation between cantilever beam resonance and Young’s modulus was found by analytical modeling [4,5] and obtained by solving the vibration equation of a beam with one fixed end. In our work we use a model of a beam with the additional mass at the free end. Considering the effective mass of a cantilever m_{eff} and the stiffness k, the first resonance frequency is as follows:

\[ f_i = \frac{1}{2\pi} \sqrt{\frac{k}{m_{eff}}} \]

If we consider the additional mass at the free end of the beam (m_{eff}), the total mass will be expressed as

\[ M = m_{eff} + m \]

The fundamental natural frequency of a beam is obtained by

\[ f_i = \frac{1}{2\pi} \sqrt{\frac{3EI}{L^3 M}} \]

Elastic modulus is determined by equation

\[ E = \frac{4\pi^2 f_i^2 L^3 M}{3I} \]

The scheme of the forced vibration test is shown in the figure below. For inducing the vibration, a small magnet with mass (m_m) is adhered to the end of the cantilever samples. As a pickup transducer a piezoelectric transducer is used. The resonance of the samples is registered by oscilloscope when the vibrational amplitude of the specimen reached maximum. The values of vibration frequencies of the samples are shown in the Table. The relative accuracy of estimated modulus is less than 5%.

D. FEM simulation

The finite element simulation of the vibration tests gives results in a very good agreement regarding the deformations with the experimental ones. The results of the modal analysis and the comparison with the experiment are presented in the table below:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Frequency vibration test</th>
<th>Frequency FE modal analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>42</td>
<td>42.8</td>
</tr>
<tr>
<td>WP10 wt%</td>
<td>46.5</td>
<td>45</td>
</tr>
<tr>
<td>WP20 wt%</td>
<td>51</td>
<td>47.2</td>
</tr>
</tbody>
</table>

4. Results and discussion
Investigation the micro-structure of composite materials (wood-polymer) by means of micro-CT imaging and extracting RVE.

The elastic modules obtained via homogenization based on micro-CT image, nanoindentation tests, tensile tests and vibration tests show different patterns when evaluating the influence of the amount of the filler (wood particles). The homogenization technique and the vibration tests give a steadily increasing elastic modules with increasing the filler content, while tensile tests and the IIT reveal a drop in the elastic modulus for the samples with 10% wood content.

The proposed approach allows to investigate material properties of new composite materials.

Challenges
Homogenization based on CT-reconstructed RVE:
- unknown mechanical properties of the ingredients;
- effect of interphases and interfaces;
- constitutive model (linear elastic model).

Indentation test:
- preparation of the samples;
- surface roughness;
- scattered data;
- constitutive model (linear elastic model).

Tensile test:
- foot correction;
- strain rate dependence

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5. References