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The influence of carbon nanotubes on the mechanical properties of nanocomposites

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ABSTRACT

Purpose: The paper presents a simply method of preparation of polymer matrix nanocomposite reinforced with carbon nanotubes and their influence on the mechanical properties.

Design/methodology/approach: A series of polymer matrix nanocomposite materials at filler weight fractions 5%, 10%, 15%, 20%, 30% and 40% both in the absence and in the presence of multiwalled carbon nanotubes (MWCNTs) at a 0.1% wt. were prepared. The specimens were tested at 3 point-bending and tension using an universal testing machine.

Findings: The paper presents the way of preparation of nanocomposite materials. The components were carefully measured and mixed in vacuum. The carbon nanotubes were homogenized using ultrasonicator. After that the mixture was injected into the moulds and heated in the temperature of 50°C by 24h.

Practical implications: Polymer composites reinforced with carbon nanotubes are considered to be an important group of materials for many engineering applications. MWCNTs (used as reinforcement in nanocomposites) have greater mechanical strength and endurance and a greater modulus of elasticity comparing to carbon fibers. Polymer nanocomposites reinforced with carbon nanotubes have been used at the production of chemical sensors, materials using emission field phenomenon, media converters, electrical appliances, supercapacitors.

Originality/value: Paper presents new polymer matric nanocomposites with high Young's modulus. Polymer nanocomposites reinforced with carbon nanotubes are characterized by dimensional stability, high stiffness, toughness, heat resistance, low combustibility, reduction of the transmission of liquids and gases, the lower density, low thermal expansion coefficient, and increased electrical conductivity.

Keywords: Nanocomposites; Polymers; Polymer matrix nanocomposites; Multiwalled carbon nanotubes

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PROPERTIES

1. Introduction

Polymer composites reinforced with carbon nanotubes are considered to be an important group of materials for many engineering applications [1-3]. The terms nanomaterial and nanocomposite are thought to be new fields in materials science, they have actually been used for centuries and always have been existed in nature. However, it is only recently that the means to characterize and control structure at the nanoscale have stimulated rational investigation and exploitation. Nanocomposites show much better properties than a convencional composites with the same chemical and phase composition [1-4].

This is due to the addition of nanofillers. A small amount of nanofillers already allows to obtain the advantageous properties of engineering materials. Carbon nanotubes used as reinforcement in nanocomposites have greater: mechanical strength, modulus of elasticity and endurance comparing to carbon fibers. At the same time carbon nanotubes are less fragile and have a lower density. Because of carbon nanotubes polymer composites are good electricity conductors. In addition, carbon nanotubes have been used in the production of chemical sensors, materials using emission phenomenon field, media converters, electrical appliances, supercapacitors [2,4,5].

Carbon nanotubes have generated huge activity in many areas of science and engineering due to their unprecedented physical and chemical properties. There is no material which offers the combination of such superlative mechanical, thermal and electronic properties attributed to them. These properties make nanotubes ideal, not only for a wide range of applications but as a test bed for fundamental science. In particular, this combination of properties makes them ideal candidates as advanced filler materials in composites [5,6].

Polymer nanocomposites reinforced with carbon nanotubes are characterized by dimensional stability, high stiffness, toughness, heat resistance, low combustibility, reduction of the transmission of liquids and gases, the lower density, thermal expansion coefficient, and increased electrical conductivity [7,8].

The paper presents method for the preparation of nanocomposite polymer matrix reinforced with carbon nanotubes and their influence on the mechanical properties (determined by flexural modulus, strain and bending stress) [9-11].

The new nanotechnology should consider tree main criteria [12-14]:

- the examined structure should have at least one dimension less than 100 nm;
- during the producing process the chemical and physical properties should be able to be controlled;
- it must be possible to build the larger objects in the future.

2. Experimental procedure

The material used for the research was composites and nanocomposites samples made of epoxy resin Epidian 5 amount by weight 5%, 10%, 20%, 30%, 40% with hardener Z-1 and 0.1 wt.% multiwalled carbon nanotubes (MWCNTs). The scanning electron microscome image of the nanotubes is shown in Fig. 1. All the components, both in the case of polymer material and nanocomposites were formed for 2 and 5 minutes each, taking into account parameters like: time, temperature and constant stirring speed.

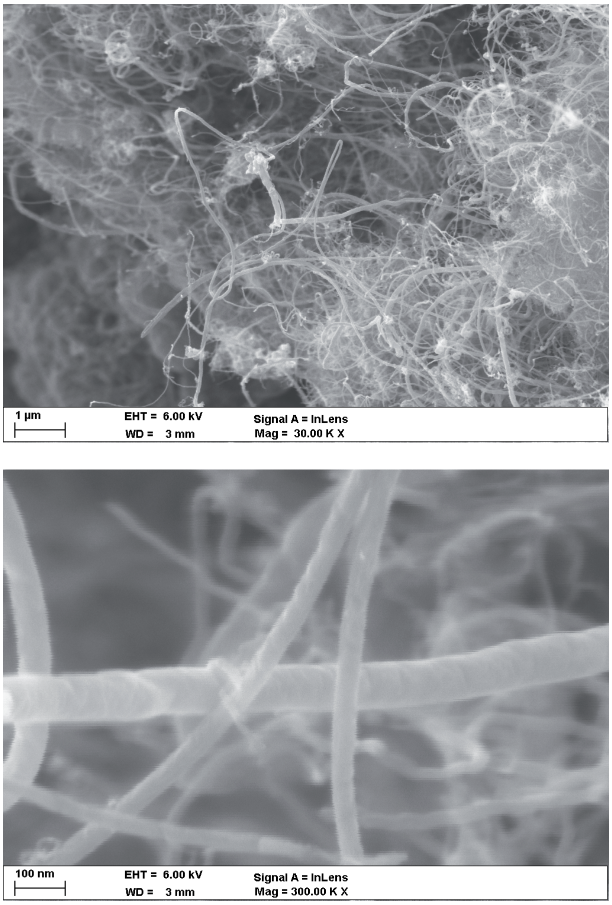

Fig. 1. SEM image of MWCNTs used as the nanocomposite reinfoncment

The preparation process of the polymer nanocomposite consiste the following steps (Fig. 2):

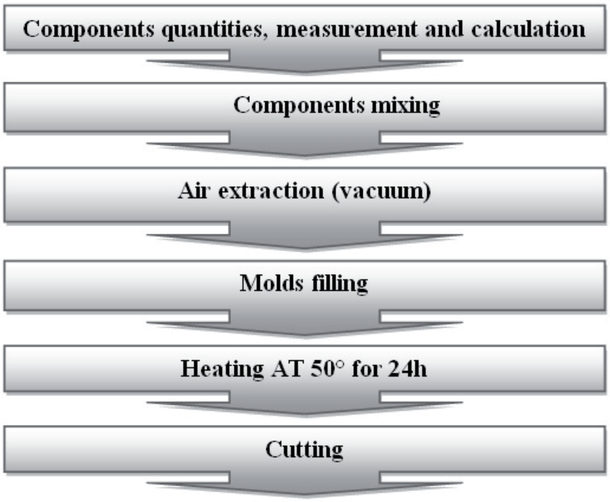

Fig. 2. Preparation of nanocomposite polymer matrix reinforced with carbon nanotubes

As a first step (before starting the manufacturing process) the amount of all components were carefully measured.

The moulds were prepared by applying a non-stick coating to release agent (wax) in order to be able to unmold the specimens easily after hardening. Then the hardener, the resin and multiwalled carbon nanotubes were mixed in vacuum for five minutes in order to remove the air that is entrapped in the mixture. During the mixing the chemical reaction of polymerization process occurred.

Dispersion of MWNT in a epoxy resin depends on the polymers' concentration, the type of carbon nanotubes, time of dispersion process and the method of disintegration. Carbon nanotubes were homogenized using ultrasonicator.

After that the mixture was injected into the moulds as soon as possible and kept at the temperature of 50°C for 24 h.

In the experiment polymethyl mehtacrylate moulds were used in due to that thermal properties of moulds are similar to properties of the composites (there are less thermal problems). However, the polymethyl mehtacrylate is much sensitive to deformations because of heating, that involves a deformation of the whole system.

After 24 hours the samples were taken from the heater, cleaned and cut. The samples dimensions are (Figs. 3 and 4):

- length 90 mm,
- width 12.8 mm,
- thickness 2.9 mm.

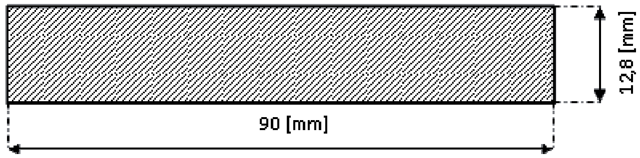

Fig. 3. Dimensions of the cutted samples

Fig. 4. The samples of: a) nanocomposite reinforced with MWCNT b) polymer material

Then the dust and other impurities from the cut specimens are removed with acetone.

Several experiments have been conducted to understand and to improve the manufacturing process, in order to succeed with improvement of the manufactured composites mechanical properties. The manufacture process and the weight fraction of the two various fillers are factors that greatly affect the mechanical properties of the manufactured composites. In all the case we used 50 PHR mix for all specimen in order to be able to compare all of them.

3. Results

The main factor that we wish to enhance in this study is the mechanical properties, in terms of stiffness and strength.

Hand molding method is mainly used for the production of the unit of simple shapes. The advantage of this method is relatively simple instrumentation and molds, while the defects manual methods include the forming a high laborious and material consumption.

The manufactured specimens were tested in 3 point-bending and tension with an universal testing machine (ZWICK Z/100) which measures the force and the displacement.

The test was performed in the laboratory, at ambient temperature (about 20°C) and humidity of about 65%.

Before attempting to the study were made preliminary assessment of surface of the samples (samples were a porous test), measurements of samples – samples was measured in the middle of their length with an accuracy of 0.1 mm, the height of the samples with an accuracy of 0.02 mm and chosen the appropriate spacing of supports.

Performed for each sample graph of stress-strain (Fig. 5), based on the basic properties were determined after the samples tested.

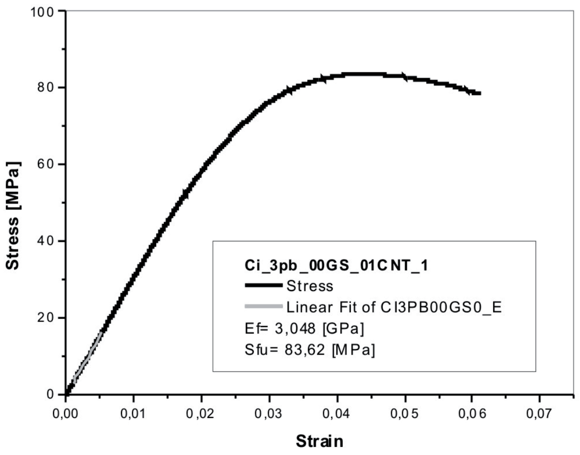

Fig. 5. A typical stress-strain curve of nanocomposite

Results of tensile tests for the obtained materials point to the dependence of the material composition from various parameters of the manufacturing process the composite and nanocomposite materials. Fig. 6 a) and b) shows summary from the results of analysis the polymer composites and nanocomposites formed for 2 minutes. The surface of received platelet was smooth, regular flat and showing a good level of polymerization and agglomeration of carbon nanotubes in a polymer. Based on the conducted research it was found that the modulus of elasticity (E) from the obtained samples increased after the application of carbon nanotubes on the weight fraction 0.1 % wt.

They affect positively on the mechanical properties of polymer composites and prove higher resistance to bending stress. By bending stress is meant the maximum stress at the outer surface of the material in the cross-section and their axis of symmetry. Focusing attention on technological parameters which significantly affect to the properties of the composite materials it was found that the most important parameter is the duration time of making the samples. Too long time of preparing components designed for the preparation of samples cause that the surface of samples is not smooth and numerous bubbles can be seen in the material. Figure 6 c) and d) shows summary from the results of analysis the polymer composites and nanocomposites formed for 5 minutes. Similar results were found like in the case of samples performed during two minutes, the modulus of elasticity (E) from the obtained samples increased after the application of carbon nanotubes on the 0.1 % wt.

Based on the conducted research it was observed well-defined affect of carbon nanotubes on the mechanical properties of polymer composites. They affect positively on the elasticity and tensile strength coefficient. This happens because the carbon nanotubes, in comparison with other engineering materials, have a much higher Young's Modulus. Furthermore, carbon nanotubes in combination with composite material causes that obtained material becomes much stiffer, while it is less fragile.

An important aspect which should be considered is the appropriate preparation of a polymer mould containing evenly distributed carbon nanotubes, which are hydrophobic. Conventional techniques for homogenization nanotubes are not always able to provide the obtainment of appropriate mixture which subsequently is subjected to a process of polymerization.

CNTs, are strong and flexible, but very consistent. They are difficult to disperse in liquids such as water, ethanol, oil, polymer or our case in a epoxy resin system. During manufacture process, a ultrasonic homogenizer was used in order to achieve a satisfied homogenity.

4. Conclusions

The paper presents the way of preparation of nanocomposite material reinforced with multiwalled carbon nanotubes. Not only the characteristics of strength of nanocomposites, but the ability to use it in a composite material determines their practical application possibilities.

Although the changes in properties indicated a general trend, it's important to bear in mind that the mean values of some of the properties of the nanocomposites were within the experimental error of the results for the mixture without MWCNTs.

In this case, we must take care, to ensure that the dispersion of MWCNTs to be adequate so that a more significant increase in properties may be achieved. The resin used in this work presents good stiffness and specific strength. The samples present also dimensional stability and strong adhesion to the embedded reinforcement.

The surface of received platelet was smooth, regular flat and showing a good level of polymerization and agglomeration of carbon nanotubes in a polymer.

In the future, the results of research will be enriched by detailed statistical analysis of the mechanical properties and structural studies received composite and nanocomposite materials.

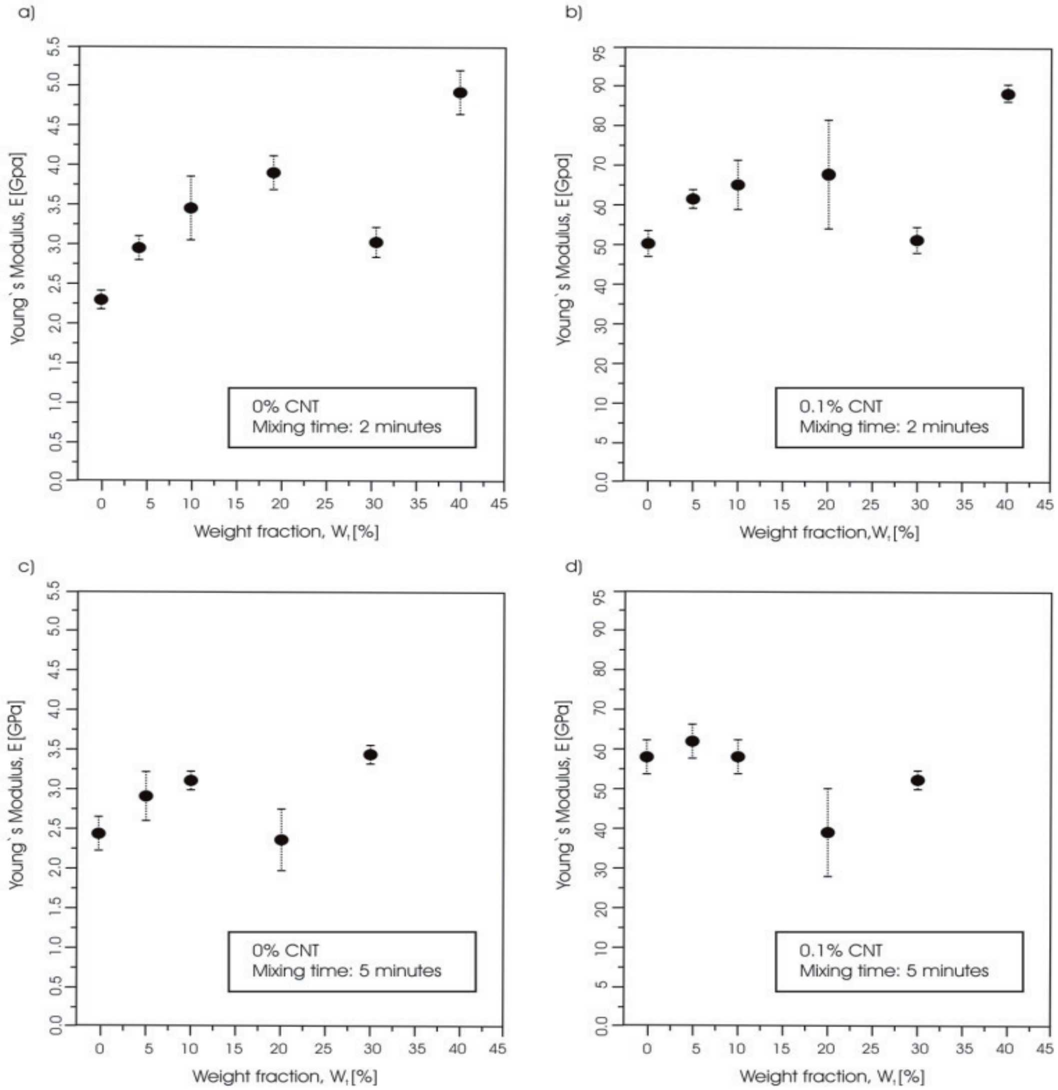

Fig. 6. Results of strength tests for samples during 2 minutes a) polymer composite, b) nanocomposites (containing W_t=0.1% CNT) and for samples during 5 minutes c) polymer composites, d) nanocomposites (containing wt. 0.1% CNT)

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