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SPECIFIC BENDING AND COMPRESSIVE STRENGHT OF POLY(VINYL ALCOHOL)-CNT COMPOSITES

Carbon nanotubes are one of the strongest materials of unique mechanical, optical, electrical and electronic properties. Because of that they are mainly used as semiconductor materials constituting the reinforcing phase in composite materials.

The paper presents properties of polymer composites reinforced with carbon nanotubes (CNT) containing various mixtures of dispersion. Produced composites featured various content carbon nanotubes: 20%, 30%, 40% i 50%. Macroscopic observations were carried out on ready to check composites, if pores exist in the structure and whether the reinforcement has been distributed in the entire volume. Bending and compressive strengths tests were performed and densities of individual composites were measured to determine the specific strength.

Composite materials strengthened with carbon nanotubes feature a very low density and a very good mechanical strength, which makes them a good structural material.

Keywords: carbon nanotubes, composites, mechanical strength, density

1. Introduction

The field of nanotechnology is one of the most popular areas for current research and development in basically all technical disciplines [1]. Ajayan et al. [2] reported the first polymernanocomposites using CNTs as a filler. Carbon nanotubes feature a low density of ~2.1 g/cm^3 and a highly developed specific surface area [3,4]. They have a high tensile strength up to 500 GPa, the elastic modulus reaches 7-8 TPa and they are characterised by high resistance to high temperatures (>3000°C in vacuum) [5,6]. The obtaining of high mechanical properties of a composite is substantially hindered by the aggregation of carbon nanotubes. Although individual carbon nanotubes feature very high strength properties, but after introduction to polymers they reveal only a fraction of their potential [7]. Therefore good properties of carbon nanotubes cannot be fully converted into a high strength of the produced composite.

To maximize benefits of carbon nanotubes obtaining high-strength composites, CNTs should not form agglomerates, should be well dispersed in the matrix and should have high interactions with it [8,9].

Carbon nanotubes added to polymers cause a substantial change of physical properties of material, even their small amount gives features of a conducting polymer [10]. Various polymer matrices are used for composites, among others including thermoplastics, thermosetting resins, liquid crystalline polymers, water-soluble polymers, conjugated polymers [11].

The paper presents the influence of carbon nanotubes content on strength properties of polymer nanocomposites and on their density.

2. Material and experimental methods

CNT CO. LTD carbon nanotubes, with commercial name C_{TUBE} 100, obtained using the thermal CVD method and polyvinyl alcohol with a water acrylate dispersion were used as the studied materials. As received CNTs were 1 to 25 μm long, 10 to 40 nm in diameter, with the bulk density of 0.03-0.06 g/cm^3, purity >93% and the specific surface area of 150-250 m^2/g. Polyvinyl alcohol (PVA) with a water acrylate dispersion was used as the matrix.

Composites were produced using the solvent method, i.e. via mixing in the solution. Carbon nanotubes used for the reinforcement of composites were not pre-treated or modified. In the first stage both polymers (PVA and acrylate) were blended and then an appropriate amount of carbon nanotubes has been added. The whole was mechanically mixed during 0.5 h to disperse carbon nanotubes well in the polymer. After spontaneous evaporation of the solvent, composites were crosslinked at room temperature during 30 days.

Composites containing from 20 to 50% of CNT were produced. All composites featured a low density. The method of density measurement consists of independent measurement

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of specimen's mass and volume. The mass of specimens was determined by means of an electronic balance ($\Delta \pm 0.01$ g) and the volume of cuboidal specimens via measuring their dimensions using a vernier caliper ($\Delta \pm 0.01$mm).

Two types of specimens were prepared: 10 mm × 10 mm × 60 mm and 10 mm × 10 mm × 30 mm used for three-point bending and compressive strength test respectively. The tests were carried out using a ZWICK/ROELL Z100 testing machine with the load cell capacity of 50 kN.

3. Results of Tests

Macroscopic observations were carried out on finished composites using an Olympus ZS61 stereoscopic microscope (Fig. 1). It it can be seen, the reinforcement is distributed throughout the entire matrix volume. Pores are visible in the composites, which could have originated during self-evaporation of the solvent. Also nanotubes agglomerates, which have not been well dispersed, are visible in the structure of composite.

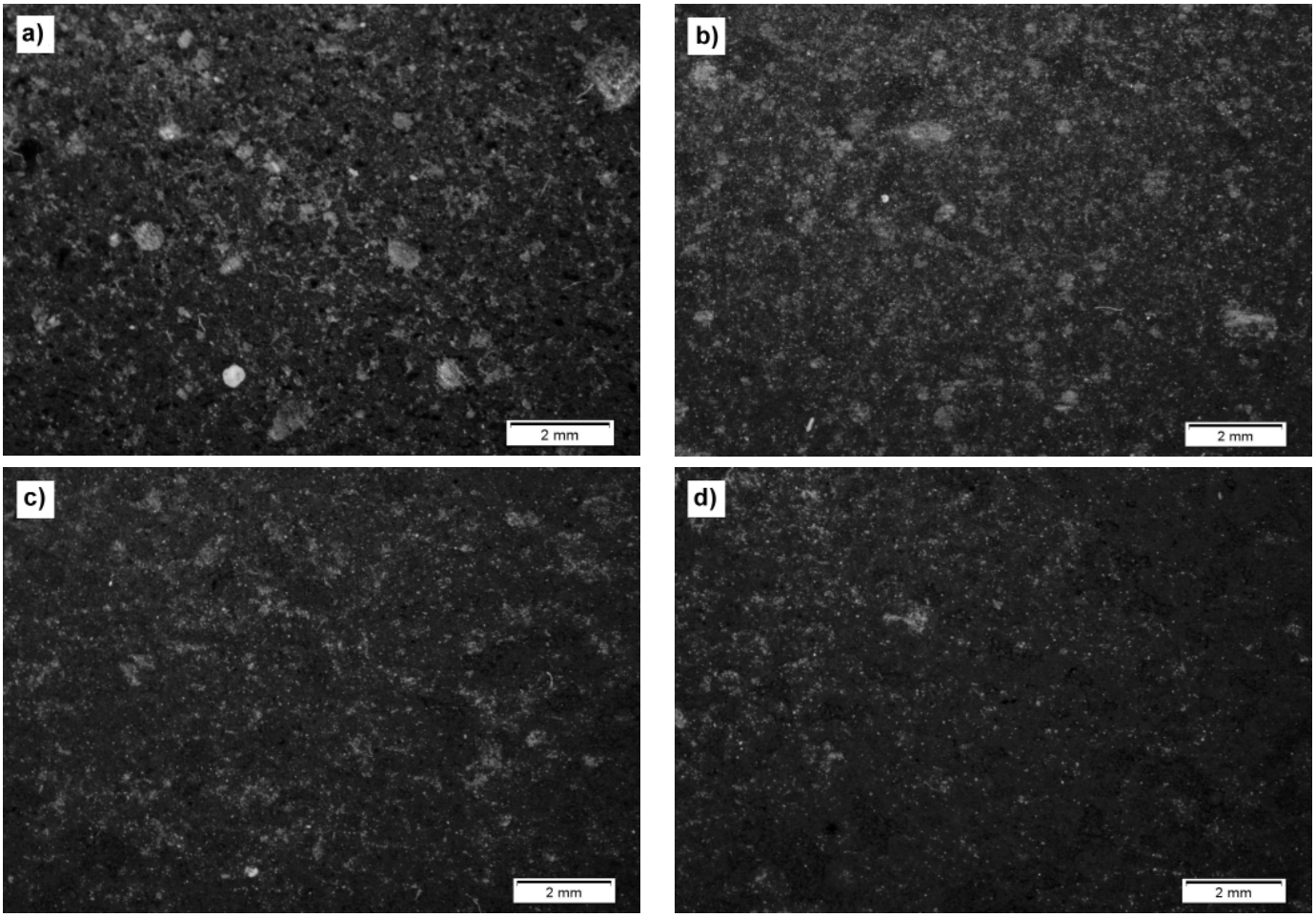

Fig. 1. Macroscopic structure individual composites: a) 20% CNT; b) 30% CNT; c) 40% CNT; d) 50% CNT

The density was the next determined parameter. The composites density is pretty low, which makes them light and strong. For the composite with 20% reinforcement content the density was 0.47 g/cm^3, for the composite with 30% reinforcement content – 0.42 g/cm^3. Lower density have composite with 40% reinforcement content – 0.31 g/cm^{3}and composite with 50% reinforcement content is 0.23 g/cm^3.

The curves shows in Fig. 2 were obtained during a three-point bend test, based on which the specific bending strength was determined for individual composites.

Curves of composites compression test (Fig. 3) allowed to determine the specific compressive strength (Fig. 4).

The specific strength is a significant indicator for the strength determination. Both specific bending and compressive strengths were determined based on the results obtained from mechanical and physical tests (Fig. 4).

Composites with the nanotubes content of 30% and 40% were characterised by the highest specific bending and compressive strength. The composite containing 30% of carbon nanotubes has the specific bending strength of 6.33 MPa and compressive strength of 6.6 MPa, while the composite containing 40% of carbon nanotubes features the specific bending strength of 4.10 MPa and compressive strength of 5.87 MPa.

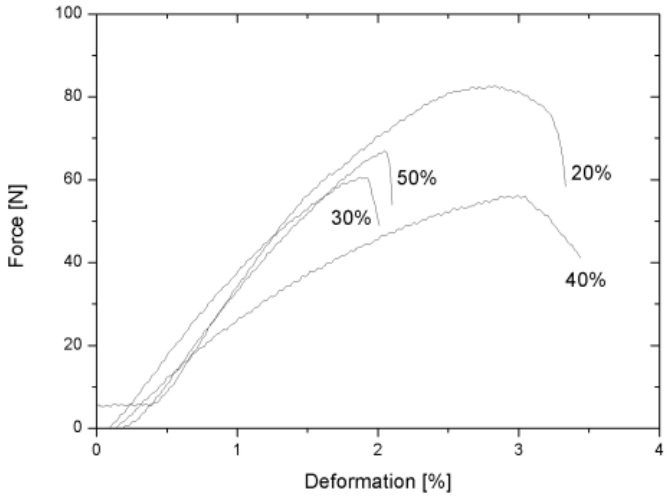

Fig. 2. Three-point bending test curves of composites with different CNT level

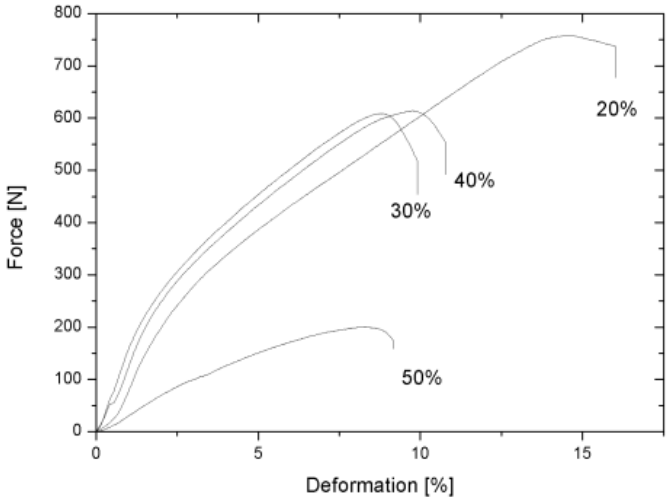

Fig. 3. Compression strength test curves of investigated composites

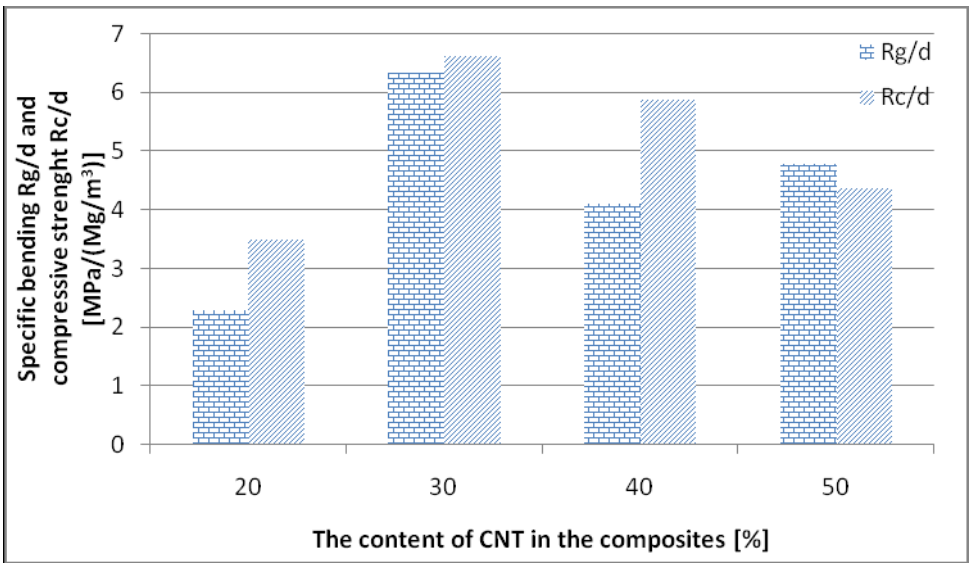

Fig. 4. Specific bending strength and compression of individual composites

4. Summary of results

The paper presents the method for obtaining polymer-carbon nanotube composites and their properties. The produced composites have a low density (from 0.23 g/cm^3 to 0.47 g/cm^3), which makes them a very light material, capable of applying as a structural material. Pores in composites decreasing their strength properties. In the next processes of composites production pores will be eliminated. To be fully utilized in the industry composites must additionally have a high mechanical strength. In our research we have been looking for an appropriate acrylate, to obtain a composite competing with properties of aluminium.

Composites presented in the paper feature a specific bending strength ranging from 2.28 MPa to 6.33 MPa and a specific compressive strength from 3.49 MPa to 6.6 MPa.

REFERENCES

[1] D.R. Paul, L.M. Robeson, Polymer nanotechnology: Nanocomposites, Polymer **49**, 3187-3204 (2008).

[2] P.M. Ajayan, O. Stephan, C. Colliex, D. Trauth, Aligned carbon nanotube arrays formed by cutting a polymer resin-nanotube composite. Science **265**,1212-4 (1994).

[3] P. Zygoń, M. Gwoździk, J. Peszke, Z. Nitkiewicz, C. Kolan, Properties of polymer composites reinforced with carbon nanotubes. Hutnik – Wiadomości Hutnicze **5**, 366-368 (2013).

[4] S. Iijima, Carbon nanotubes: past, present, and future. Physica B **323**, 3, 1-5 (2002).

[5] P. Zygoń, M. Gwoździk, J. Peszke, Z. Nitkiewicz, Surface Topography of Carbon Nanotubes Forming Reinforcing Phase in Composite Materials. Composites Theory and Practice **12**, 4, 262-265 (2012).

[6] Z. Spitalsky, D. Tasis, K. Papagelis, C. Galiotis, Carbon nanotube–polymer composites: Chemistry, processing, mechanical and electrical properties. Progress in Polymer Science **35**, 357-401 (2010).

[7] W. Królikowski, Z. Rosłaniec, Nanokompozyty polimerowe. Composites Theory and Practice **4**, 9, 3-16 (2004).

[8] Zygoń P., Gwoździk M., Peszke J., Nitkiewicz Z., Comparison of properties of polymer composite materials reinforced with carbon nanoubes. Archives of Metallurgy and Materials **60**, 1, 193-198 (2015).

[9] P. Zygoń, M. Gwoździk, J. Peszke, Z. Nitkiewicz, A. Jakubas, Zmiana rezystywności powierzchniowej kompozytów polimerowych wzmacnianych nanorurkami węglowymi. Przegląd Elektrotechniczny **80**, 12, 296-298 (2014).

[10] N.G. Sahoo, S. Rana, J.W. Cho, L. Li, S.H. Chan, Polymer nanocomposites based on functionalized carbon nanotubes. Progress in Polymer Science **35**, 837-867 (2010).

[11] P. Zygoń, M. Gwoździk, C. Kolan, Z. Nitkiewicz, P. Gębara, Copper-based composites strengthened with carbon nanotubes, Composites Theory and Practice **13**, 3, 198-202 (2013).