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CHARACTERIZATION OF A POLYMER-MATRIX COMPOSITE SUPPORT BEAM

KARAKTERIZACIJA KOMPOZITNEGA NOSILCA S POLIMERNO OSNOVO

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This paper deals with the characterization of a polymer-matrix composite support beam designed for the automotive industry. The discussed composite polymer-matrix material was characterized using light microscopy (LM), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), Vickers hardness (HV) measurements and mechanical testing under tensile loads. Using these characterization methods the diameter, distribution and arrangement of the fibres in the composite material were determined. The type of fibres used in this composite material was also established from the chemical composition determined by EDS. The mechanical properties of the discussed composite material under a tensile load were determined on proportional, sub-sized, tensile specimens prepared from the support beam.

Keywords: polymer-matrix composite, fibre, microstructure, tensile properties

Članek obravnava preiskavo kompozitnega nosilca na polimerni osnovi, namenjenega avtomobilski industriji. V ta namen so bile opravljene analize z metodami svetlobne mikroskopije (SM), vrstične elektronske mikroskopije (SEM), energijsko disperzijske spektroskopije (EDS), merjenja trdote po Vickersu (HV) in nateznega preizkusa. Omenjene metode so omogočile ugotavljanje povprečnega premera vlaken, površinskega deleža ter porazdelitve vlaken v kompozitu. Vrsta vlaken v kompozitu je bila ugotovljena s kemijsko sestavo po metodi EDS. Mehanske lastnosti so bile opredeljene na proporcionalnih pomanjšanih nateznih preizkušancih kompozitnega nosilca.

Ključne besede: kompozit s polimerno osnovo, vlakno, mikrostruktura, mehanske lastnosti

1 INTRODUCTION

The use of composite materials in automotive components and parts continues to grow, because the structural weight is becoming increasingly important in automotive vehicles.[1,2] A composite material is a macroscopic (nowadays also microscopic or nanoscopic) combination of two or more distinct materials, having a recognizable interface between them. Composites are used for their structural, electrical, thermal, etc. properties. Modern composite materials are usually optimized to achieve a particular balance of properties for a given range of applications.[3]

In general, the composites consist of a matrix and a reinforcement. To a large extent the matrix gives the shape and monolithic property to the composite. It ensures an even distribution of the reinforcement, it provides a suitable composite loading capacity by transferring the loads to the reinforcement (fibres), which is the main bearing element.[4,5]

Composites are commonly classified at two distinct levels. The first level of classification is usually made with respect to the matrix constituent. The major composite classes include organic-matrix composites (OMCs, which include polymer-matrix composites (PMCs) and carbon-matrix composites), metal-matrix composites (MMCs), and ceramic-matrix composites (CMCs). The second level of classification refers to the reinforcement form – particulate reinforcements, whisker reinforcements, continuous-fiber laminated composites and woven composites (braided and knitted fiber architectures are included in this category.[3,4] This kind of composite (with continuous fibres) represents the most important and common type of composites that have the potential to be used in the automotive industry, too. They are characterized by a high strength and stiffness at a very low density.[3]

The main objective of this work was to characterize the composition and the properties of a polymer-matrix composite part (support beam) designed for the automotive industry.

2 EXPERIMENTAL

A polymer-matrix composite support beam was manufactured using supplied fiberglass mats, which were placed into the mould and then impregnated with the resin (polycarbonate – PC).[2]

This step was followed by an air evacuation process in order to remove any residual air bubbles. Then the composite was placed in a furnace where the polymerization reactions took place above the glass-transition temperature (above 150 °C).[2] In this way the support beam permanently retains the shape of the mould.

The samples for the metallographic analyses and the hardness measurements were cut from the composite part presented in **Figure 1** in such a way that the fibres were either perpendicular or parallel to the surface of the observation. Samples cut from the part were mounted in a polymeric material, ground and polished. Light micro-

Figure 1: Composite support beam
Slika 1: Kompozitni nosilec

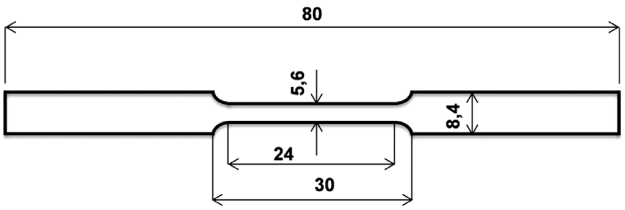

Figure 2: Dimensions of the test specimen used in the tensile test[5]
Slika 2: Dimenzije preizkušanca za natezni preizkus[5]

scopy (LM) was performed using an Axio Imager.A1m ZEISS.

LM was used for the microstructure observation and determining the average diameter of the fibres. The Vickers hardness (HV) was performed using a Shimadzu Microhardness Tester with a mass of 25 g and loading times of 10 s. This rather small load was chosen due to the small diameter of the fibres.

Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were performed with a JEOL JSM-5610. The samples for scanning electron microscopy were additionally coated with carbon due to the fact that the composite material is nonconductive.

Tensile tests were also executed to determine the tensile mechanical properties of the composite part.[6] Sub-sized test specimens were used as presented in **Figure 2** due to the dimensions of the composite part.[7] The test specimens were cut in such a way that the fibres were either perpendicular or parallel to the tensile load. An INSTRON 5567 was employed to perform tensile tests and determine the tensile strength, the elongation and the modulus of elasticity.

3 RESULTS AND DISCUSSION

3.1 Microstructure

The microstructure of the composites' main wall cross-section with a thickness of 3 mm showed that the fibre bundles were arranged almost perpendicular to each other and intertwined (plain weave, yarn interlacing), as presented in **Figure 3**. A single bundle consists of several thousands of individual fibres and has dimensions of approximately 3 mm (parallel to the fibres) and 0.3 mm to 0.5 mm (perpendicular to fibres). The intersection of the main wall contains approximately six layers of intertwined bundles.

The average diameter of the fibres in a single bundle was also estimated and the results of individual measurements of the fibres' diameters are compiled in **Table 1**. The average diameter of the fibres was found to be 18.5 µm.

Table 1: Average fibre diameter measurement (**Figure 4**)
Tabela 1: Povprečne vrednosti meritev premera vlaken (**slika 4**)

Measurement no.	Diameter (µm)
1	17.7
2	15.5
3	15.7
4	18.9
5	20.8
6	19.8
7	21.4
Average Value	18.5

The average surface fraction of the fibres in the bundle was also assessed from the backscattered electron image presented in **Figure 4**. These were then reformatted in binary images and processed using ZEISS (AXIO Imager.A1m) software for an assessment of the phase amount. As presented in **Table 2**, the average surface fraction of the fibres in a single bundle was around 65.7 %.

3.2 Hardness

The relation between the hardness and the number of fibres examined in **Figure 5** summarizes the results of the hardness measurements using the Vickers method. The average hardness of the fibres was around 537 HV and that of matrix, 20 HV. The hardness values of the fibres ranged between 513 and 572 HV, whereas for the matrix these values were between 19.3 HV and 21.9 HV.

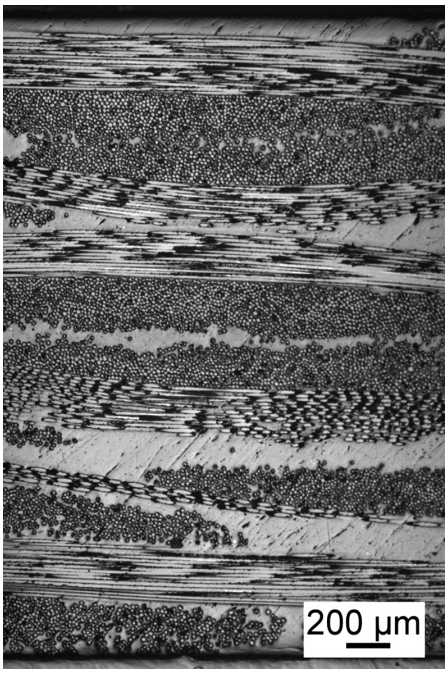

Figure 3: LM image of composite part's cross-section
Slika 3: SM-posnetek prereza dela kompozita

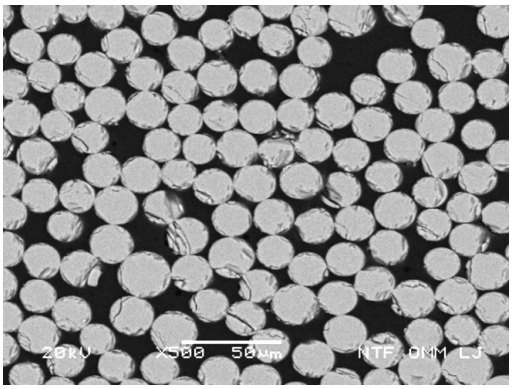

Figure 4: BSE (backscattered electron image) of composite part for estimation of fibre fraction in a single bundle

Slika 4: BSE-posnetek (povratno sipani elektroni) kompozita, namenjenega za ugotavljanje deleža vlaken v posameznem snopu

Table 2: Average surface fraction of the fibres in a single bundle (**Figure 4**)

Tabela 2: Povprečni površinski delež vlaken v posameznem snopu (**slika 4**)

Sample no.	Fibres fraction (%)
1	66.5
2	66.8
3	63.1
4	67.4
5	64.8
Average value	65.7

3.3 Chemical composition of fibres

The chemical composition of the fibres was determined using EDS analyses, as presented in **Figure 6** and **Table 3**. Both analyses showed very similar fibre compositions. It was found that silicon, calcium, oxygen, aluminium, magnesium, potassium and sodium are present for both cases of the analysed fibres. The oxygen content was not determined quantitatively (only qualitatively), and due to this fact it was assumed that these elements form oxides such as SiO_2, CaO, Al_2O_3, MgO, K_2O and Na_2O.[3,8,9] According to this assumption a new composition was calculated, as presented in **Tables 4** and **5**.

Based on the results presented in **Tables 4** and **5** the average fraction of the oxides in the fibres was estimated to be in mass fractions 57.4 % SiO_2, 28.9 % CaO, 11.6 % Al_2O_3, 1.5 % MgO, 0.4 % K_2O and 0.2 % Na_2O. It is known that some glasses also contain boron[3]. The EDS

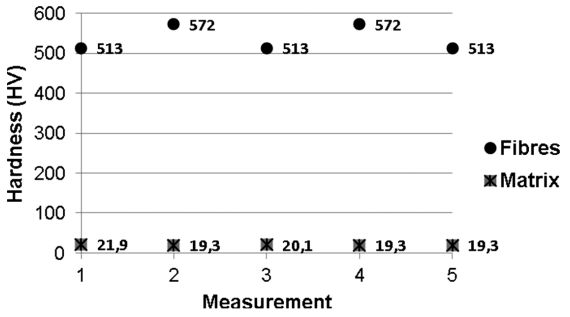

Figure 5: Hardness measurements

Slika 5: Izmerjene trdote

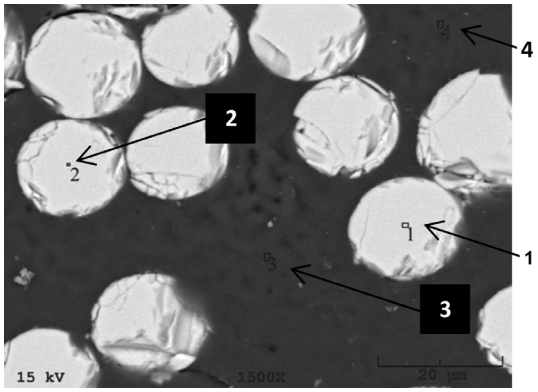

Figure 6: BSE (backscattered electron image) of micro-analysed fibres (points 1 and 2) and matrix (points 3 and 4)

Slika 6: BSE-posnetek (povratno sipani elektroni) analiziranih vlaken (točki 1 in 2) in osnove (točki 3 in 4)

Table 3: Chemical analyses of the fibres presented in **Figure 6**, mole fractions, *x*/%

Tabela 3: Kemijska analiza vlaken, prikazanih na **sliki 6**, molski deleži, *x*/%

	1	2
O	15.86	15.12
Na	0.26	0.33
Mg	1.70	1.85
Al	10.85	11.02
Si	46.01	46.23
K	0.42	0.46
Ca	24.90	25.00

detector used in this study was not able to detect boron and consequently this analysis could not evaluate the presence of boron. A comparison of these data with the literature[3] shows that the composition of the fibres was similar to the compositions in the literature designated as E-glass fibres for general purpose.

3.4 Tensile test

Tensile test results are presented in **Figure 7** as diagrams of load versus elongation. The backscattered

Table 4: Calculated oxide contents in fibre 1 (**Figure 6**, point 1)

Tabela 4: Izračunane vsebnosti oksidov v vlaknu 1 (**slika 6**, točka 1)

Element	Element content (*x*/%)	Oxides	Oxide content (*w*/%)
Si	46.01	SiO_2	57.5
Ca	24.90	CaO	29.0
Al	10.85	Al_2O_3	11.5
Mg	1.70	MgO	1.4
K	0.42	K_2O	0.4
Na	0.26	Na_2O	0.2

Table 5: Calculated oxide contents in fibre 2 (**Figure 6**, point 2)

Tabela 5: Izračunane vsebnosti oksidov v vlaknu 2 (**slika 6**, točka 2)

Element	Element content (*x*/%)	Oxides	Oxide content (*w*/%)
Si	46.23	SiO_2	57.3
Ca	25.00	CaO	28.9
Al	11.02	Al_2O_3	11.6
Mg	1.85	MgO	1.5
K	0.46	K_2O	0.4
Na	0.33	Na_2O	0.2

electron images in **Figure 8** show fractured samples after a tensile test. The fracture of the fibres after the tensile test occurred in those fibres oriented parallel to the direction of the load. The fractured fibres show smooth surfaces, which is a characteristic of brittle fracture. In **Figure 8** the decohesion of the fibres can also be observed.

The tensile properties determined by the tensile tests are presented in **Table 6**. Both samples show similar properties. It was found that the average tensile strength of the composite material is 332 MPa, with an elongation of 3.5 % and a modulus of elasticity of 11.87 GPa.

The tensile strength of the investigated composite samples was around 332 MPa, which is about a tenth of the tensile strength of a typical E-glass fibre for general purposes.[3] The modulus of elasticity of the composite was between six and seven times lower than the modulus of elasticity for a typical E-glass fibre for general purposes.[3]

4 CONCLUSIONS

The characterization of a polymer matrix composite material revealed that the material consists of intertwined bundles of fibres arranged perpendicular to each other (plain weave, yarn interlacing). Each bundle consists of several thousands of fibres with the fraction of the fibres within the bundle being 65.7 %. The average diameter of the fibres was found to be 18.5 µm and the average hardness was 537 HV. The average composition of the fibres, determined by EDS analyses and calculations, was in mass fractions 57.4 % SiO_2, 28.9 % CaO, 11.6 % Al_2O_3, 1.5 % MgO, 0.4 % K_2O and 0.2 % Na_2O. This composition corresponds well to the composition of E-glass fibres for general purposes[3]. The presence of boron could not be confirmed or refuted.

The tensile tests of composite parts performed parallel or perpendicular to the direction of the fibres gave a tensile strength of 332 MPa, an elongation of 3.5 % and a modulus of elasticity of 11.87 GPa.

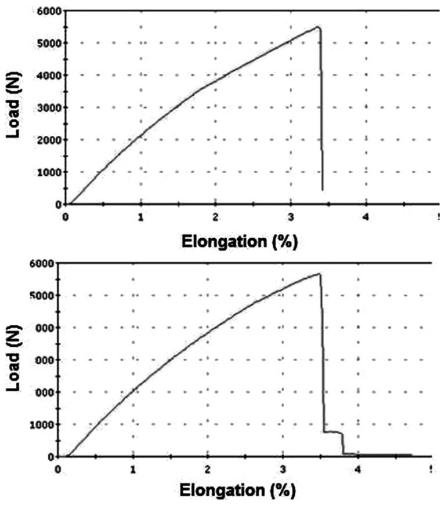

Figure7: Tensile load in dependence of elongation for two testing composite samples

Slika 7: Sila v odvisnosti od raztezka za dva preizkusna vzorca kompozita

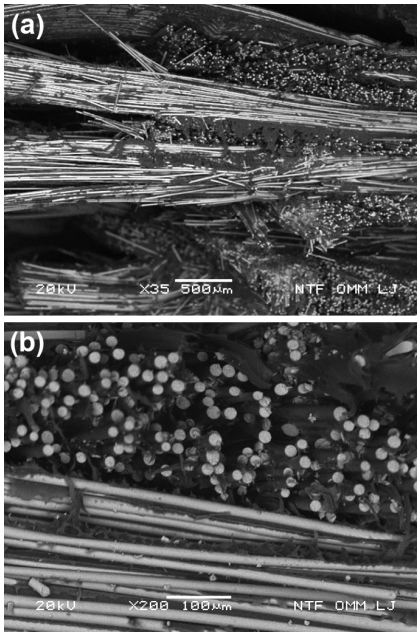

Figure 8: BSE (backscattered electron image) of composite sample after achieved tensile test

Slika 8: BSE-posnetek (povratno sipani elektroni) vzorca kompozita po izvedenem nateznem preizkusu

Table 6: Results of tensile test

Tabela 6: Rezultati nateznega preizkusa

	Maximal load (N)	Tensile strength (MPa)	Elongation (%)	Modulus of Elasticity (MPa)
Test 1	5494.7	327	3.4	11974
Test 2	5665.6	337	3.5	11768
Average value		332	3.5	11871

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