DEFORMATION BEHAVIOUR ANALYSIS OF POLYSTYRENE KRASTEN171 WITH MONTMORILLONITE NANOFILLERS

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Abstract
The paper is focused on the experimental investigation of the montmorillonite nanofillers effect on deformation properties of polystyrene KRASTEN 171. The combination of a low amount of clay with dispersed polymeric phase may cause synergistic effects leading to very fair balance of mechanical behaviour in some cases. The paper analyses the effect of nanocomposites and type of the material on the individual measured parameters, relations between them, strength and deformation behaviour. Deformations were evaluated by non-contact videoextensometry method. The results show that doping of the base material polystyrene with nanofillers particles has an effect on the plastic deformation increments.

Keywords: montmorillonite, videoextensometry, polystyrene, mechanical properties

1 Introduction

The aim of this paper is determination of the effect of montmorillonite nanofillers on mechanical properties of polystyrene KRASTEN 171 evaluated by a non-contact videoextensometry method, which provides new results from tensile tests.

Contactless strain measuring is currently used as a progressive method for metals, as well as plastics. This method provides many advantages and allows obtaining more information about materials than by conventional methods. Local deformation values better characterize the deformation behaviour of materials.

Videoextensometry is a non-contact method for strain measuring, which enables the scanning of both longitudinal and transverse strain components from the surface of the test specimen [1, 2]. Experimental equipment consists of CCD (Charge Coupled Device) camera and a computer, which process the camera signal by appropriate software. Suitable contrast marks (dots) are dashed on the scanned surface of the specimen. Specimen is appropriately illuminated during the measurement in such manner to obtain the best contrast between the specimen surface and dashed dots [3]. The PC program records a gravity centre position of individual dots during test and enables the saving of picture sequences simultaneously. After specimen scanning the evaluation of the strain components will be completed and final results from co-ordinates of gravity centre of individual dots will be calculated by used SW [4]. This method enables the scanning of the deformation in two directions by one camera system [5, 6] and deformation kinetics development is recorded during videoextensometry measuring.

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2 Materials and Experimental Procedure

The material used in this study is polystyrene KRASTEN 171 with addition of montmorillonite nanofillers Nanofil9 **Table 1**.

Table 1 Properties and method of preparation the investigated materials

Designation	**Krasten [g]**	**Nanofil9 [g]**	**Screw speed [min^{-1}]**	**Number of granulation n**
KR 1	4000	0	100	2
KR 2	3960	40	100	2
KR 3	3880	120	100	2
KR 4	3800	200	100	2

Testing specimens and specimens for Charpy impact tests used for experiments were standard tensile specimens according to ISO 3167 - type A.

The specimens were made by injection technology on machine Battenfeld of VA according to standard ISO 294-1. Melt temperature 220 °C, form temperature 45 °C, injection speed 200 mm/s, injection pressure 80 bar (8 MPa), holding pressure 60 bar (6 MPa), holding pressure time 12 s.

Evaluation of mechanical properties of polymers was done according to standard ISO 527-2/1A/50.

Montmorillonite (MMT), based on layered clays, was used as filler. MMT, aluminosilicate of the smectite family, is a 2:1 clay (three-layer structure), meaning that it has 2 tetrahedral sheets sandwiching $Si0_4$ a central octahedral sheet Al_2OH_6.

This configuration is periodically repeated by minerals, and between repeats the three-layer is interlayer area filled in the normal state of water and hydrated ions of alkali and alkaline earth metals. Cations in the interlayers can occur due to imperfections in tetrahedral and octahedral crystal lattice, the resulting imbalance of charge in the lattice [1].

The chemical composition of MMT is represented by the following crystal-chemical formula: $(Na,Ca)_{0,33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$ [2].

MMT belongs to the class of silicates, phyllosilicates subclass, smectite clays group.

Physical characteristics:

- Color: white, gray or pink with a tint of yellow, green, blue.
- Luster: dull.
- Transparency: crystals are translucent and material is opaque.
- Crystal system: monoclinic.
- Crystal growth: sometimes large individual crystals, usually located in a compact state or as a layered material.
- Hardness: is 1-2 on the Mohs scale.
- Density: variable from 2.3 to 3 g/cm^3.
- Other characteristics: crystals expand in water over several times their original volume.

Nanocomposite contains additives to support intercalation and exfoliation of the nanoclay and also small amounts of agents for easier processing.

The test was performed under static conditions on standard specimens by loading rate 1 mm/min. Results of tensile testing are in **Table 2** and tension diagrams shows in **Fig. 1**.

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Table 2 Mechanical properties of the investigated materials

Designation	F_m [N]	R_m [MPa]	A [%]
KR 1	2165 ± 31.3	54 ± 1.00	5.2 ± 0.09
KR 2	2108 ± 39.4	53 ± 1.53	4.5 ± 0.11
KR 3	2006 ± 52.3	50 ± 1.00	3.9 ± 0.09
KR 4	1878 ± 63.2	47 ± 2.31	4.4 ± 0.18

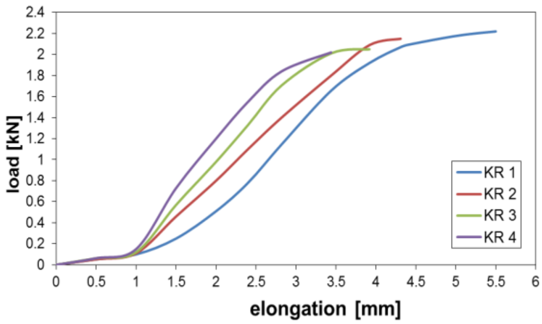

Fig. 1 The relation between tensile load and elongation of investigated materials

Surface of specimens was covered with grid of contrast (black) dots (5 x 10 dots) with size 0.5 mm and with step 1 mm (**Fig. 2**).

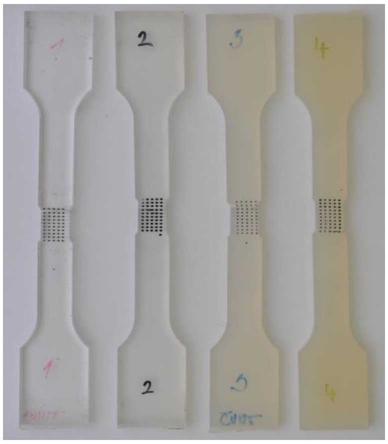

Fig. 2 Specimens with raster for videoextensometry measuring

Surface of specimen was scanned during all tensile tests by CCD camera with graphics resolution 640 x 480 pixels. The images were evaluated after a test and the coordinates of centers of dots were obtained. The deformations were determined according to Eq. (1.)

$$\varepsilon_L = \frac{dv}{dy} \tag{1.}$$

where: ε_L [-] - longitudinal deformation
v [mm] - displacement in direction y (direction y = direction of loading)

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The deformation was evaluated for each two adjacent points. Evaluation was performed by comparing the first image with the last one where the sample was still intact. Finally we obtained the matrix of values for any deformation, whose output is the deformation map (Matlab).

3 Results and discussion

New methodology for recording increments of deformations – videoextensometry - was used in this paper. It is a convenient tool to study of the deformation kinetics. Based on the deformation maps, the distribution of deformation, deformation gradients and values of local deformations we can to differentiate differences in the localization of deformation more sensitively.
The results of videoextensometric measurement of investigated materials are deformation maps (**Fig. 3**). Coordinate x and y in **Fig. 3** describe the position of dots on specimen. Deformations maps show distribution of increment of deformation, which represent colour range. Deformation increments were determined according to Eq. (1.) in the loading direction.

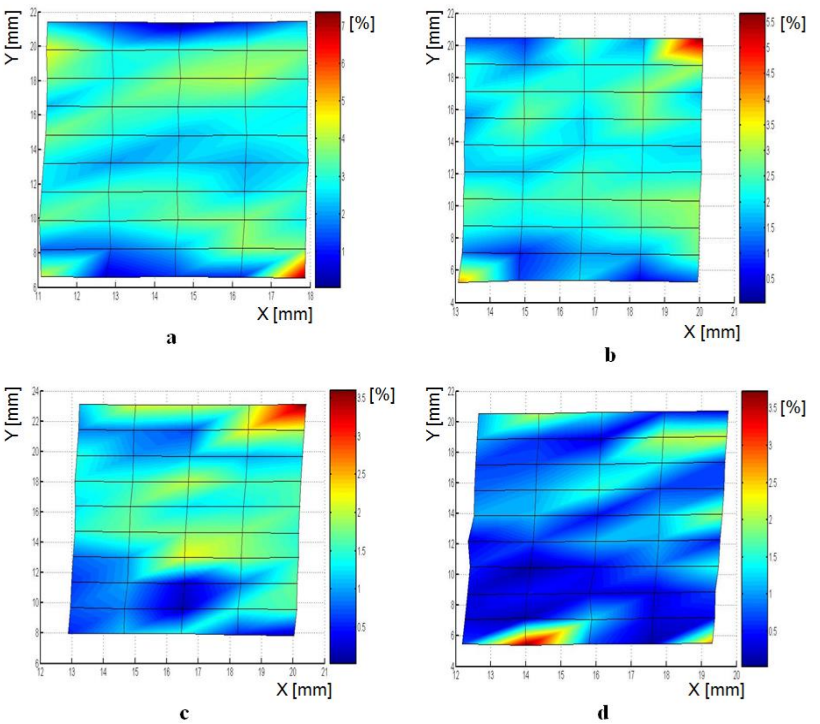

Fig. 3 Deformation maps of investigated materials KR 1 (a), KR 2 (b), KR 3 (c) and KR 4 (d)

In **Table 3** are statistical data of deformation increments ε_L, which correspond to maps in **Fig. 3**. The values of longitudinal deformation ε_L are decreased by adding of particles of nanofillers (**Table 3**). The maximal decrease was observed for material KR 4 with the highest proportion of montmorillonite.

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Table 3 Increment of deformation for investigated materials

Designation	**ε_L[%]**		
	Average	**Maximum**	**Minimum**
KR 1	2.82	7.43	0.15
KR 2	2.16	5.72	0.55
KR 3	1.34	3.62	0.11
KR 4	0.93	3.76	0.10

Doping of the base material polystyrene (PS) with nanofillers particles has an effect on the plastic deformation increments. Deformation is more heterogeneously distributed in the composite material than in the natural material.

3.1 Charpy impact tests

Impact toughness test was carried out Charpy method according to EN ISO 179-1. Samples (V-notch, type A according to standard) before the test are shown in **Fig. 4**.

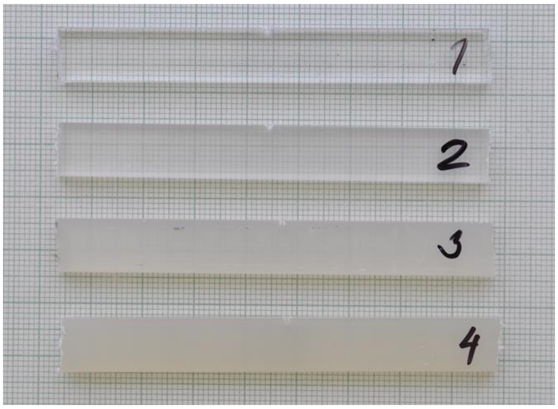

Fig. 4 Samples for the Charpy impact test

The results were calculated according to Eq. (2.) and are listed in **Table 4**.

$$a_{cN} = \frac{E_c}{h \cdot b_N} \cdot 10^3 \qquad (2.)$$

where: a_{cN} [J/m^2] - toughness

E_c [J] - corrected energy to breaking the sample

h [mm] – the height of the sample

b_N [mm]- the width of the sample under notch

Table 4 Results of toughness

Material	**a_{cN} [J/m^2]**
KR 1	1.343 ± 0.0376
KR 2	0.919 ± 0.0441
KR 3	1.226± 0.0515
KR 4	1.287± 0.0614

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In spite of improvement of many attractive properties, the application potential of polymer nanocomposites is still limited by their imbalanced mechanical behaviour, especially by low toughness [8, 9]. This fact has been confirmed by an increasing amount of papers dealing with application of elastomeric toughness in nanocomposites, but this approach leads usually to a certain compromise with an increase in toughness at the expense of stiffness and strength [10-21].

This fact was confirmed by impact toughness tests. The highest values of impact toughness tests were observed at KR 1 samples and samples KR 4 with most nanofillers.

4 Conclusion

1. Videoextensometric measurements were successfully applied to determinate the kinetics of local deformation processes in polystyrene KRASTEN 171.
2. Effect of fillers based on montmorillonite was investigated by tensile tests and impact toughness tests.
3. The highest values of strength properties, increment of deformation and values of impact toughness were observed at the Krasten 171 polystyrene without nanofillers according tests.
4. The montmorillonite filler influenced the change in the distribution of plastic deformation increments.
5. The most significant influence was observed at polystyrene with the highest proportion of nanofillers particles.

References

[1] J. Lis, A. Lis, K. Kolan: Journal of Materials Processing Technology, Vol. 162, 2005, p. 350-354
[2] X. Sun, K. S. Choi, W. N. Liu, M. A. Khaleel: International Journal of Plasticity, Vol. 25, 2009, No. 10, p. 1888-1909
[3] M. Mihaliková, Ľ. Ambriško: Chemické listy, Vol. 105, 2011, No. 14, p. s206-s209
[4] E. Čižmárová, M. Mihaliková, M. Német: Chemické Listy, Vol. 105, 2011, No. 16, p. s546-s548
[5] Y. Hamid, A.-A. Bakar, N. Deirram: Journal of Applied Polymer Science, Vol. 128, 2013, No. 2, p. 1170-1175
[6] T.-Y. Tsai, , M.-J. Lin, Y.-C. Chuang, P.-C. Chou: Materials Chemistry and Physics, Vol. 138, 2013, No. 1, p. 230-237
[7] Z. Weiss: *Clay minerals. Their structure and use*, Praha, 2005 (in Czech)
[8] J. Bidulská, R. Kočiško, R. Bidulský, M. Actis Grande, T. Donič, M. Martikán: Acta Metallurgica Slovaca, Vol. 16, 2010, No. 1, p. 4-11
[9] M. Mihaliková, M. Német: Acta Metallurgica Slovaca, Vol. 17, 2011, No. 1, p. 26-31
[10] E. Spišák, J. Majerníková: Acta Metallurgica Slovaca, Vol. 18, 2012, No. 2, p. 109-116
[11] W. S. Chow, J. K. Teoh: Polymer-Plastics Technology and Engineering, Vol. 47, 2008, p. 1040-1045
[12] I. Kelnar, J. Rotrekl, J. Kotek, L. Kaprálková, J. Hromádková: European Polymer Journal, Vol. 45, 2009, p. 2760-2766
[13] J. Ren, Y. Huang, Y. Liu, X. Tang: Polymer Testing, Vol. 24, 2005, p. 316-323
[14] K. Wang et al.: Polymer, Vol. 48, 2007, p. 2144-2154
[15] Y. C. Ahn, D. R. Paul: Polymer, Vol. 47, 2006, p. 2830-2838

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e-ISSN 1338-1156

[16] I. Gonzalez, J. I. Eguiazabal, J. Nazabal: Europen Polymer Journal, Vol. 42, 2006, p. 2905-2913
[17] E. Kormanikova, K. Kotrasová: Chemické Listy, Vol. 105, 2011, No. 16, p. 535-538
[18] I. Kelnar, J. Kotek, B. S. Munteanu, L. Kaprálková: Journal of Applied Polymer Science, Vol. 96, 2005, p. 288-293
[19] C. I. Wan, Y. Zhang, Y. X. Zhang, X. Y. Qiao, G. M. Teng: Journal of Polymer Science B, Vol. 42, 2004, p. 286-295
[20] J. Kelnar, L. Kotek, J. Kaprálková, J. Hromádková: Journal of Applied Polymer Science, Vol. 100, 2006, p. 1571-1576
[21] S. Pavlidou, C. D. Papaspyrides: Progress in Polymer Science, Vol. 33, 2008, p. 1119-1198

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