THE INFLUENCE OF CARBON NANOTUBES ON THE ELECTRICAL PROPERTIES OF INJECTION MOLDED THERMOPLASTIC POLYMER MATRIX

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Abstract

This work examines the electrical properties of composite thermoplastic polymer matrix and carbon nanotubes. As basic matrix was used polypropylene, to which were added nanoparticles in the weight percentage ratio. As filler was used multi-wall carbon nanotubes. The nanocomposite was made by the injection molding machine Arburg. For evaluation of electrical properties was measured volume resistivity of the final composite materials with added nanofillers and without it. In this paper are also measured mechanical properties.

Key words:

Carbon nanotubes, nanocomposite, resistivity, injection molding

1. INTRODUCTION

Carbon nanotubes are now frequently used fillers in plastic composites. Global market for electro-conductive polymer compounds is forecast to reach US$2.78 billion by 2014 and the filler-based composites segment currently accounts for 84 % of the segment. Growing application of these composites in electrostatic discharge (ESD), electro-conductive (EC), electromagnetic interference (EMI) and radio frequency interference (RFI) applications. Conductive compounds in manufactured products is dominated by injection moulding caused by fast growing demand for electronics goods and automotive components. Due to the ease of processing and improved heat dissipation properties, polymer nanocomposites with carbon nanotubes become attractive in the manufacture of automotive under-the-hood metals replacement in close proximity to a heat source such as an engine or in parts that would generate a high level of heat or in power computing [1]. For many applications, the ease of processing of polypropylene, and his resistance to moisture can make them good matrix in which to disperse nanotubes. Given the carbon-ring structure of nanotubes, it could be assumed that the dispersion of nanotubes in a matrix which also lacks polar functional groups might be quite good. Another advantage of polypropylene is his relatively low surface free energies in the melt (compared to polymers such as e.g. polycarbonate)[2]. Because of its relatively low weight ratio, typically at a fraction of conventional conductive fillers (e.g. 2 % wt. of CNT´s versus 10 % wt. of CNT´s conductive carbon black), the polymers can retain a higher degree of mechanical properties and an aesthetically nice surface finish. For an application requiring very high conductivity, the polymer nanocomposite with CNT could transform the design economy of connectors, switches, sensors, actuators, convertors, control modules, supercapacitors, batteries and transistors[1]. Carbon nanotubes (CNT) are elongated systems whose wall are created by carbon atoms (similar to spherical fullerenes) with the diameter from 1 up to 100 nanometers and length up to 100 μm. They can be found as single-wall carbon nanotubes (SWCNT) or multi-wall carbon nanotubes (MWCNT)

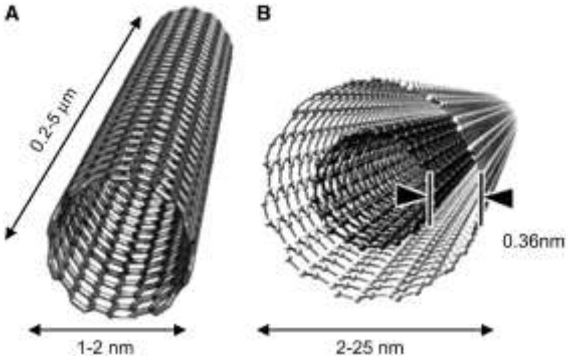


Fig. 1 Schematic diagrams of carbon nanotubes: single-wall SWCNT (left) and multi-wall MWCNT (right)[3].

see fig. 1. In this work are MWCNT used as a filler in polypropylene polymer matrix and examined the effect on the nanocomposite using tensile test, electron microscopy and measurement of resistivity of conductive plastic. Within the tensile test is specimen stressed in the direction of the axis with increasing force until it breaks. During the test is recorded strength and elongation of ensemble.

2. MATERIAL AND EXPERIMENTAL

2.1 Material

PLASTICYL PP2001 is a conductive masterbatch based on polypropylene loaded with 20% of Nanocyl's MWCNTs (NC7000™). The masterbatch was used as the parent matrix from which mixed polymer blends. There was chosen 1, 2, 5 and 20 % weight ratio of carbon nanotubes. The masterbatch has density 0.872 g/cm3. The result of surface resistivity of polypropylene without MWCNTs is 1 x 10^{13} Ohm·cm, melt flow index is 12 g/10min.

2.2 Machine and mould

Standard column-mounted injection machine ARBURG 270S 400-100 was used for injection. Injection moulding technological parameters had to ensure partly samples production. It was also necessary to avoid degradation of nanotubes structure. It was crucial to set proper plastication and injection moulding parameters (see tab. 1) mainly with regard to thermal and shear loading. Aggregate TA3 was used for injection mould tempering. Melting temperature was 230 °C. Injection rate was 30 cm^3/s and size of holding pressure 800 bars. For production testing samples was used injection mould with central ejector which had exchangeable plates according to requirements and individual ISO standards. Holding pressure time was 35s. Mould was cooled to a temperature of 50 °C for both the two halves of injection mould. Rate of cooling down was 120 °C.

Table 1 Injection moulding parameters

Barrel Temperature (°C)					**Injection Speed**
Zone 5	**Zone 4**	**Zone 3**	**Zone 2**	**Zone 1**	**cm^3/s**
230	225	225	220	210	30

2.3 Volume resistivity

Resistivity measurement was carried out according to ČSN EN ISO 3915. On test samples was measured volume resistivity of the device consisting by potentiometric electrodes which comply with the standards, see fig.2 and measuring equipment consisting of power supply, voltmeter and ammeter, see fig. 3. As the power

Fig. 2 Dielectric electrodes

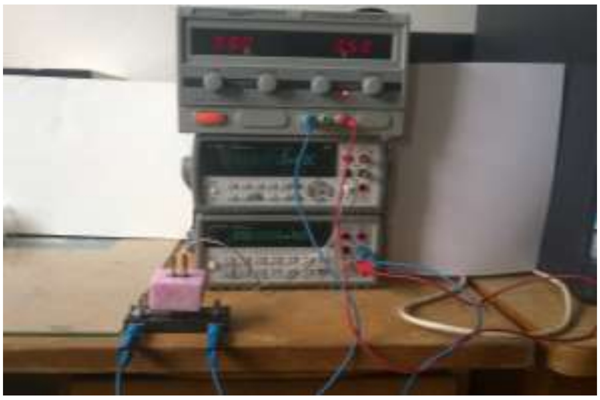


Fig. 3 Power supply, voltmetr, ammmetr

supply was used Hadex G855, as a voltmeter was used digital multimeter Agilent 34411A, as ammeter was used digital multimeter Agilent 34401A. The distance between the potentiometric electrodes is 1 cm. Measurements were carried out at a voltage of U = 5 V for all samples. The temperature was 22 °C and relative humidity in the room was 55 %. Measurement was performed always on 10 specimens.

2.4 Tensile test

Measurement of tensile properties of test samples were performed on a multipurpose Hounsfield H10KT tensile machine with the sensor head measuring power up to 10 kN. The measurement procedure was in accordance with standard ČSN EN ISO 527-1, 2. After clamping the sample to the clamping jaws, specimen was tensile loaded. Measurements were taken to the point of test specimen breakage. The loading speed was 50 mm/min.

3. RESULT AND DISCUSSION

Test specimens were made by injection molding from the chosen polymer blends. Test samples were evaluated on volume resistivity. At composite processing there was presumption that foliation of the carbon nanotubes is homogenous as it is written in [4- 8] and shown in the fig. 4.

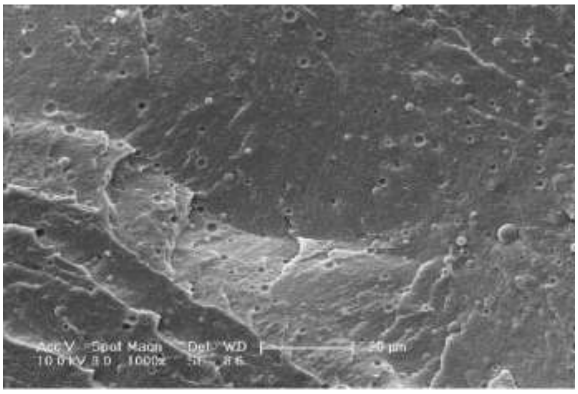


Fig. 4 The homogeneous dispersion of nanotubes in PA matrix [4]

Because a viscosity of PP without carbon nanotubes is lower than viscosity nanocomposites, were pressure parameters during filling phase and pressure phase for commonly adjusted temperature conditions at injection quite high: pressure at switch-over was 1100 bars, holding pressure was 800 bars. Adjusted technological parameters for production of testing samples were chosen from several testing variants of the technological parameters. Due to the higher viscosity of composite was necessary to increase the melt temperature of 180 °C to 230 °C. The structures not degrade at this temperature. The production parameters were the same for all polymer blends.

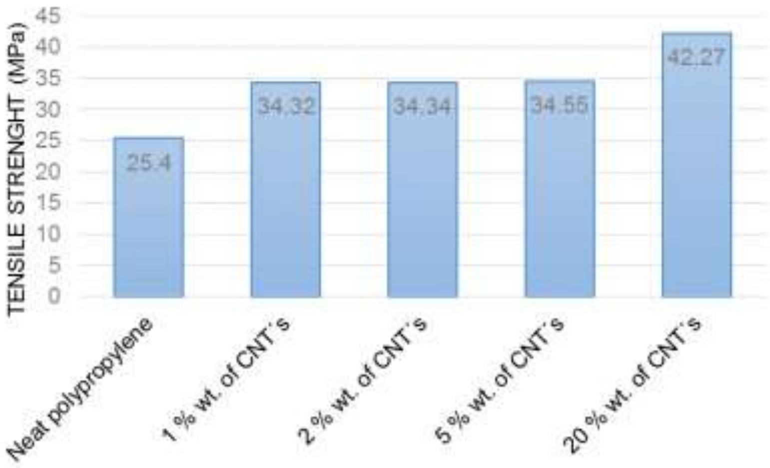
On 1, 2, 5, 20 % wt. ratio CNT´s in polymer blends made from masterbatch Plasticyl PP2001 was measured volume resistivity. Measurements of volume resistivity show us how good the material is conductor of electric charge. Measurements were performed on 10 samples of each polymer blend. The resulting values of volume resistivity we can see in Table 2.

Table 2 Volume resistivity of polypropylene

	Neat polypropylene	1 % wt. of CNT´s	2 % wt. of CNT´s	5 % wt. of CNT´s	20 % wt. of CNT´s
Volume resistivity (Ohm·cm)	1×10^{13}	8.5×10^{3}	3.3×10^{2}	3.4×10^{2}	0.3×10^{1}
Standard deviation	1×10^{2}	3.2×10^{2}	1.4×10^{2}	4.2×10^{1}	0.02×10^{1}

The resulting samples polymer blends with MWCNT indicates that this composite is a conductive plastic and that is good conductor of electric charge. These results also indicate that there was a homogeneous dispersion of MWCNTs and the injection moulding had not a great influence on the conductivity of the nanocomposite. Results PP without added nanofillers are not recorded, because the device is not able to measure. This is because the basic polymer matrix has a higher resistance than the device can detect. Result value of volume resistivity 1.10 x 10^{13} Ohm·cm of neat polypropylene is specified by producer of material. It cannot be used as a conductor of electric charge.

The resulting values of tensile test we can see in Figure 5. The tensile strength of PP without carbon nanotubes as fillers is 25.4 MPa, with 1 % wt. ratio CNT´s is 34.32 MPa, 2 % wt. ratio CNT´s is 34.35, 5 % wt. ratio CNT´s is 34.55 MPa and 20 % wt. ratio CNT´s is 42.27 MPa. The loading speed was 50 mm/min. The measurement procedure was in accordance with standard ČSN EN ISO 527-1, 2. From results, we see an increase in tensile strength, we also reduce the ductility, resulting in increased hardness and brittleness of the final composite. Due to the continually decreasing cost of a CNT perhaps be in the future use of these fillers to improve the mechanical properties.



4. CONCLUSION

The progression of composites with thermoplastic and carbon nanotubes is a constantly evolving process that will be influenced by expanding number of application possibilities, using not only excellent electrical properties of such composites. These properties and application potentials will be influenced not only by the type and form of nanotubes, their percentage weight ratio, but also the type and kind of the polymer matrix. The test results show an increase in the mechanical properties of tensile strength. Due to the decreasing cost of CNT's probably in the future will use these nanofillers to improve the mechanical properties of composites. Measurements of volume resistivity show us how good the material is conductor of electric charge. The resulting samples polymer blends with MWCNT indicates that this composite is a conductive plastic and that is good conductor of electric charge. These properties enable wide use of this composite, such as applications requiring superior electrical conductivity and electrostatic discharge (ESD) properties, electrically conductive parts, electrical and electronics (E&E). Influence of change of processing parameter will be examined in the near future.

ACKNOWLEDGEMENTS

The report has been developed and be financed under of project IRP 12 121

The report has been prepared under the terms of solution of SGS 21005

REFERENCES

[1] LEW, CY., DEWAGHE, C., CLAES, M. Injection moulding of polymer–carbon nanotube composites, *Polymer–Carbon Nanotube Composites- Preparation, Properties and Applications.* Chapter 6, Cambridge, 2011, ISBN: 978-1-84569-761-7

[2] BRANDRUP, J., IMMERGUT, E.H., GRULKE, E.A. Surface and interfacial tensions of polymers, oligomers, plasticizers and organic pigments. *Polymer Handbook.* 4 edition. New York, 1999

[3] CHOUDHARY, V., GUPTA, A., Polymer/Carbon Nanotube Nanocomposites, Carbon Nanotubes - Polymer Nanocomposites, Intech, chapter 4, 2011, ISBN: 978-953-307-498-6

[4] LENFELD, P., VÁCHA, J., Evaluation of plastication and injection molding influence on the morphology of polyamide with carbon nanotubes. *The 28th International conference of polymer processing society (PPS-28)*, Pattaya, Thailand, 2012

[5] PÖTSCHKE, P. and coll., A novel strategy to incorporate carbon nanotubes into thermoplastic matrices. *Macromolecular rapid communication*, Weinheim, 2008, ISSN: 1521-3927

[6] CHANDRA, A. and coll., Effect of injection molding parameters on the electrical conductivity of polycarbonate/carbon nanotube nanocomposites. *Antec 2007 Plastics: Annual Technical Conference Proceedings,* 2007, ISBN: 978-0-9753707-5-9

[7] PRASHANTHA, K., SOULESTIN, J., Masterbatch-based multi-walled carbon nanotube filled polypropylene nanocomposites: Assessment of rheological and mechanical properties. *Composites science and technology 69*, 2007, ISSN: 0266-3538

[8] SO, H.H, CHO J. W., SAHOO J.G., Effect of carbon nanotubes on mechanical and electrical properties of polyamide/carbon nanotubes nanocomposites. *European Polymer Journal 43,* 2007, ISSN: 0014-3057