Hindawi
Journal of Nanomaterials
Volume 2018, Article ID 8305721, 5 pages
https://doi.org/10.1155/2018/8305721

Research Article

Effect of Multiwalled Carbon Nanotubes (MWNT) on the Properties of High Impact Polystyrene (HIPS)

Juan Li

School of Mechanical Engineering, Nanjing Vocational Institute of Industry Technology, Nanjing 210023, China

Correspondence should be addressed to Juan Li; lijuan@niit.edu.cn

Received 16 May 2018; Accepted 13 August 2018; Published 5 September 2018

Academic Editor: Miguel A. Correa-Duarte

The composites of HIPS/MWNT were prepared by melt blending. The effects of the content of MWNT on the flow, mechanical, and flame retardancy properties of the composites were investigated. The morphologies of fracture surfaces were characterized through scanning electron microscopy (SEM). And the thermal stability of the composites was studied by thermogravimetric analysis. The results show that the flow properties, the impact strength, the elongation at break, and the flame retardancy are improved with the proper addition of MWNT. The morphological behavior indicates the fracture surface of HIPS/MWNT is more roughness than that of HIPS. The addition of MWNT has little influence on the thermal stability of HIPS.

1. Introduction

HIPS is a kind of polymer material with two-phase structure. It has good impact resistance, rigidity, and processability. HIPS is widely used in packaging materials, electronic products, and outer shell electronics [1, 2]. In recent years, special products have become the focus of HIPS product development. However, the mechanical properties of HIPS cannot meet the requirements of the special products completely, and it can be easily combustible when exposed to fire. In order to widen its application scope, it must be flame retardant and toughened. At present, the flame retardant modification of HIPS is mainly based on the addition of solid powder flame retardant [3–5]. However, after adding solid powder flame retardant, the impact strength of the HIPS will greatly decrease [3].

Since its discovery, carbon nanotubes (CNT) has attracted wide attention due to its unique structure and excellent electrical, mechanical, and thermal properties. In the field of polymer materials, polymer/CNT composites have been one of the focuses of research [6–14]. Choi et al. prepared composites of PS/CNT by melt blending. The results show that CNT increase the thermal decomposition temperature of the composites [15]. Li found that MWNT could improve the tensile strength and impact strength of PP [16]. Prashantha et al. used two steps of blending method to prepare PP/CNT nanocomposites. The experimental results show that the Young's modulus and yield stress increase with the content of CNT [17].

In this work, HIPS/MWNT composites were prepared by melt blending. Although the effect of melt blending is not as good as that of solution blending, melt blending is the most widely used method in industrial production. The influence of the content of MWNT on the properties of HIPS was studied.

2. Experimental

2.1. Material. HIPS (PH-88) was provided by Zhenjiang Qi Mei Chemical Co. Ltd. The relative density of HIPS is 1.05, and the relative molecular mass is $2.1 * 10^5$. MWNT (XFQ037) was supplied by Nanjing Xian Feng Nanometer Material Co. Ltd. The purity of the MWNT is greater than 95%. The diameter of the MWNT is 5–15 nm and the length is 10–30 um. There is no functional groups on the surface of MWNT.

2.2. Preparation of Composites. These raw materials were first placed in an oven (DGG-9003 Shanghai Sen Xin Experimental Instrument Co. Ltd.) and dried for 12 hours at 80°C to

Table 1: Formula of HIPS/MWNT.

	HIPS/wt.%	MWNT/wt.%
1	100	0
2	100	1
3	100	2
4	100	3
5	100	4
6	100	5

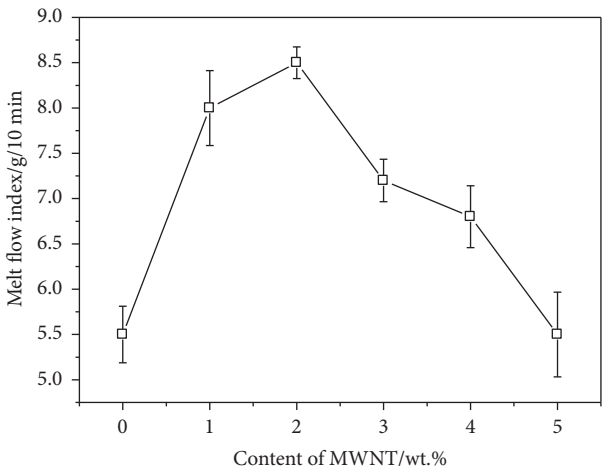


Figure 1: Effect of the content of MWNT on the flow performance of HIPS.

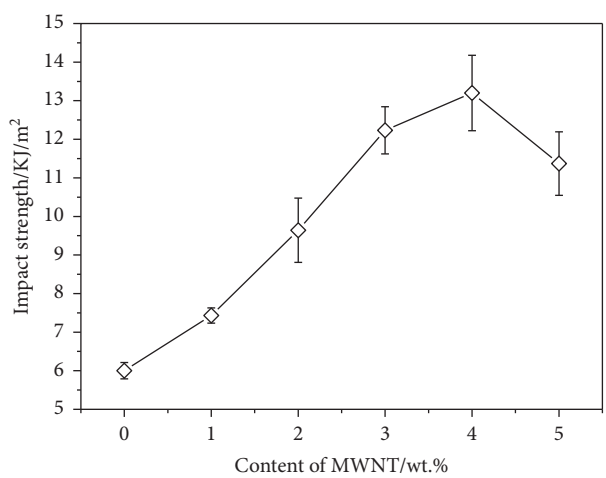


Figure 2: Effect of the content of MWNT on the impact strength of HIPS.

remove excess moisture. Then, the raw materials were premixed in the high-speed mixer (SHR-10 Zhangjiagang Second Light Industry Machinery Co. Ltd.) according to Table 1. The speed of the high-speed mixer is 2000 rpm and the time is 5 minutes. Then, raw materials were blended by a twin screw extruder (CTE35 Coperion (Nanjing) Machinery Co. Ltd.). The temperature range was set from 155°C to

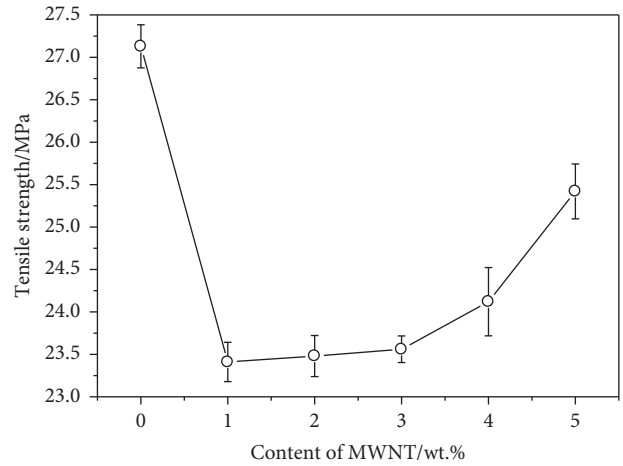


Figure 3: Effect of the content of MWNT on the tensile strength of HIPS.

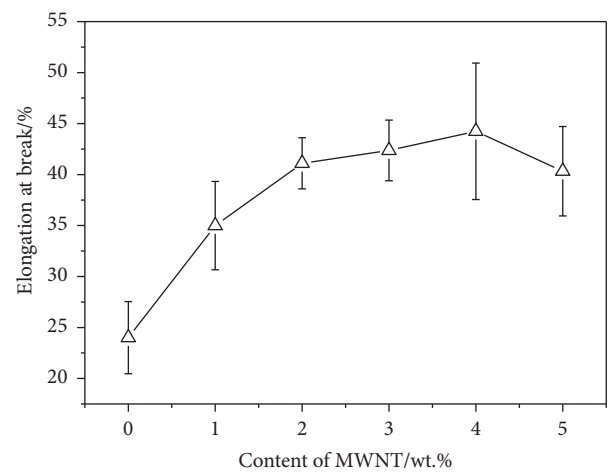
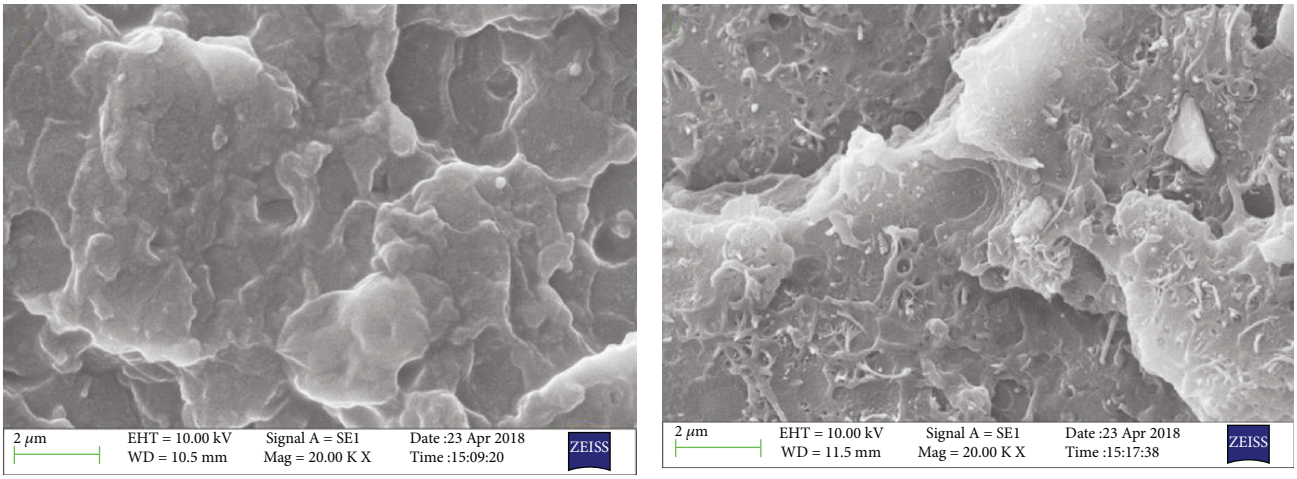


Figure 4: Effect of the content of MWNT on the elongation at break of HIPS.

195°C, and the rotational speed was 40 rpm. According to the requirements of the national standard, the extruded pellets were injected into the specimens by injection molding machine (FT-110 Zhejiang Sound Machine Manufacturing Co. Ltd.).

2.3. Characterization of Composites. The melt flow performance of the composites was carried out by melt flow indexer (XRL-400-A Chengde Precision Testing Machine Co. Ltd.) according to the test method in national standard GB/T 3682-2000 with the temperature of 230°C and load of 2.16 Kg. The tensile strength and elongation at break were measured by universal testing machine (WDT-W Chengde Precision Testing Machine Co. Ltd.) according to the national standard GB/T 1040-1992 with a speed of 50 mm/min, and the size of the specimens is 10 mm × 4 mm at the narrowest point. According to the national standard GB/T1043-1993, the cantilever impact tester (JC-5 Chengde Precision Testing Machine Co. Ltd.) was used to test the impact strength of the



(a) (b)

Figure 5: SEM of composite fracture surface ((a) 100% HIPS, (b) 96% HIPS/4% MWNT).

specimens. The limiting oxygen index (LOI) was measured using an oxygen index meter (HC-2 Nanjing Jiangning Analytical Instrument Factory) according to the standard oxygen index test GB/T 2406-93.

The morphologies of fracture surfaces after the impact test were observed by SEM (Evo18 Germany Zeiss Company). The thermal stability of the composites was studied by thermogravimetric analysis (Q500 TA Instruments) under nitrogen atmosphere. The temperature scope was from 0°C to 800°C, and the heating speed was 10°C/min.

3. Results and Discussions

3.1. Melt Flow Performance. Most of the molding processes require plastic to be in a flowing state, because the plastic in the flow state is easily deformed, transported, and molded. The flow behavior of plastic affects not only the material processing but also the final performance of the product. The effect of content of MWNT on the melt flow index of HIPS is presented in Figure 1. The results show that with the increase content of MWNT, the flow performance of HIPS increases and then decreases. MWNT is a kind of nanomaterial with larger aspect ratio. A small amount of addition of MWNT will help improve the flow performance of HIPS.

3.2. Mechanical Performance. Impact resistance is an important index to evaluate the performance of engineering plastics. Compared with PS, the impact resistance of HIPS has been greatly improved. However, compared with other engineering plastics, the impact resistance of HIPS still needs further improvement. The results of Figure 2 show that with the increase content of MWNT, the impact strength of HIPS increases and then decreases. When the content of MWNT is 4 wt.%, the impact strength of HIPS appears to be the maximum.

The effect of the content of MWNT on the tensile strength of HIPS is shown in Figure 3. With the increase content of MWNT, the tensile strength of HIPS decreases

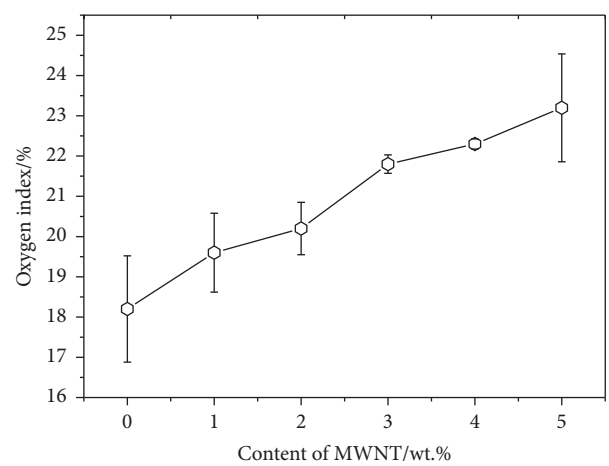


Figure 6: Effect of content of MWNT on the flame retardancy of HIPS.

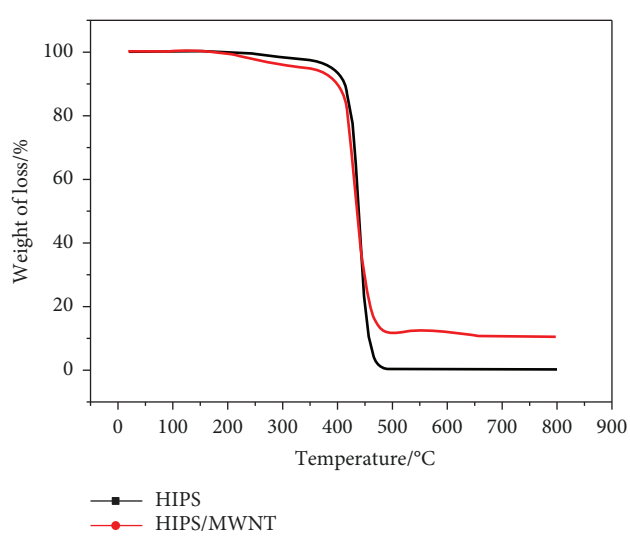


Figure 7: Thermal weight loss curve of composite materials ((a) 100% HIPS, (b) 96% HIPS/4% MWNT).

Table 2: Changes in properties of the composites.

Properties	Flow performance	Impact strength	Tensile strength	Elongation at break	Flame retardancy
Increase	●	●		●	●
Decrease			●		

and then increases. MWNT has a relatively large surface area and is easy to reunite. Therefore, a small amount of MWNT is easy to self-assemble, resulting in uneven dispersion in HIPS.

Figure 4 shows the changes of the elongation at break of HIPS with the addition of MWNT. The elongation at break of the material is related to the toughness of the material. MWNT can improve the toughness of HIPS, so adding MWNT can increase the elongation at break of HIPS.

3.3. Morphology of Fractured Surfaces. Figure 5 shows morphology of fractured surfaces of the composites with and without MWNT. The morphology of the fractured surface of the pure HIPS is shown in Figure 5(a). The fractured surface is smooth and have a brittle nature, thus the material exhibited low impact strength. Figure 5(b) shows the SEM micrograph of the fractured surface of the HIPS containing 4 wt% MWNT. In contrast to the fractured surface of pure HIPS, the fractured surface of the HIPS containing 4 wt% MWNT is rough. And it is clear that the carbon nanotubes pulled out of the surface are attached to a large number of HIPS. This indicates that after adding MWNT, the toughness of the HIPS increases, and the impact strength of the HIPS increases.

3.4. Flame Retardancy. The results of Figure 6 show that the flame retardancy of HIPS increases with the content of MWNT. The oxygen index of pure HIPS is 18, which belongs to combustible material. With the addition of 4% MWNT, the oxygen index of HIPS can reach 22, which attain the standard of self-extinguishing material.

Figure 7 presents the TG curves of the HIPS and HIPS containing 4 wt% MWNT. The results of Figure 7 show that after the addition of MWNT, the initial decomposition temperature of HIPS cannot be increased, but a stable residue is formed. This residue can shield the contact between HIPS and air and improve the flame retardancy of HIPS.

4. Conclusions

In this paper, HIPS/MWNT composites were prepared by melt blending, and the effects of content of MWNT on the properties of HIPS were studied. After adding MWNT, the changes in properties of the composites are shown in Table 2. The experimental results show that MWNT can improve the flow performance, the impact strength, the elongation at break, and the flame retardancy of HIPS. The SEM micrographs of fractured surfaces of the HIPS with and without MWNT show that MWNT could increase the toughness of the HIPS. The addition of MWNT has few influence on the thermal property, but the residue improves the flame retardancy of HIPS.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that they have no conflicts of interest.

Acknowledgments

The author is thankful for the funding received from Jiangsu Precision Manufacturing Center (ZK14-01-02).

References

[1] J. Wang, L. Bao, H. Zhao, and J. Lei, "Preparation and characterization of permanently anti-static packaging composites composed of high impact polystyrene and ion-conductive polyamide elastomer," *Composites Science and Technology*, vol. 72, no. 9, pp. 976–981, 2012.

[2] J. Z. Zhang, X. Wang, L. Lu, D. Li, and X. Yang, "Preparation and performance of high-impact polystyrene (HIPS)/nano-TiO_2 nanocomposites," *Journal of Applied Polymer Science*, vol. 87, no. 3, pp. 381–385, 2003.

[3] S. Q. Chang, T. X. Xie, and G. S. Yang, "Effects of elastomer on morphology, flammability and rheological properties of HIPS/PS-encapsulated $Mg(OH)_2$ composites," *Journal of Polymer Science Part B: Polymer Physics*, vol. 45, no. 15, pp. 2023–2030, 2007.

[4] F. Laoutid, L. Bonnaud, M. Alexandre, J. M. Lopez-Cuesta, and P. Dubois, "New prospects in flame retardant polymer materials: from fundamentals to nanocomposites," *Materials Science and Engineering: R: Reports*, vol. 63, no. 3, pp. 100–125, 2009.

[5] A. B. Morgan, L. L. Chu, and J. D. Harris, "A flammability performance comparison between synthetic and natural clays in polystyrene nanocomposites," *Fire and Materials*, vol. 29, no. 4, pp. 213–229, 2005.

[6] E. T. Thostenson, Z. Ren, and T. W. Chou, "Advances in the science and technology of carbon nanotubes and their composites: a review," *Composites Science and Technology*, vol. 61, no. 13, pp. 1899–1912, 2001.

[7] D. Tasis, N. Tagmatarchis, A. Bianco, and M. Prato, "Chemistry of carbon nanotubes," *Chemical Reviews*, vol. 106, no. 3, pp. 1105–1136, 2006.

[8] N. Grossiord, J. Loos, O. Regev, and C. E. Koning, "Toolbox for dispersing carbon nanotubes into polymers to get conductive nanocomposites," *Chemistry of Materials*, vol. 18, no. 5, pp. 1089–1099, 2006.

[9] B. K. Satapathy, R. Weidisch, P. Pötschke, and A. Janke, "Crack toughness behaviour of multiwalled carbon nanotube (MWNT)/polycarbonate nanocomposites," *Macromolecular Rapid Communications*, vol. 26, no. 15, pp. 1246–1252, 2005.

[10] C. L. Wu, H. C. Lin, J. S. Hsu, M. C. Yip, and W. Fang, "Static and dynamic mechanical properties of polydimethylsiloxane/carbon nanotube nanocomposites," *Thin Solid Films*, vol. 517, no. 17, pp. 4895–4901, 2009.

[11] X. Chen, J. Wang, M. Lin et al., "Mechanical and thermal properties of epoxy nanocomposites reinforced with amino-functionalized multi-walled carbon nanotubes," *Materials Science and Engineering A*, vol. 492, no. 1-2, pp. 236–242, 2008.

[12] S. T. Kim, H. J. Choi, and S. M. Hong, "Bulk polymerized polystyrene in the presence of multiwalled carbon nanotubes," *Colloid & Polymer Science*, vol. 285, no. 5, pp. 593–598, 2007.

[13] B. Fragneaud, K. Masenelli-Varlot, A. González-Montiel, M. Terrones, and J. Y. Cavaillé, "Electrical behavior of polymer grafted nanotubes/polymer nanocomposites using N-doped carbon nanotubes," *Chemical Physics Letters*, vol. 444, no. 1-3, pp. 1–8, 2007.

[14] D. Qian, E. C. Dickey, R. Andrews, and T. Rantell, "Load transfer and deformation mechanisms in carbon nanotube-polystyrene composites," *Applied Physics Letters*, vol. 76, no. 20, pp. 2868–2870, 2000.

[15] Y.-J. Choi, S. H. Hwang, Y. S. Hong et al., "Preparation and characterization of PS/multi-walled carbon nanotube nanocomposites," *Polymer Bulletin*, vol. 53, no. 5-6, pp. 393–400, 2005.

[16] J. Li, "Multiwalled carbon nanotubes reinforced polypropylene composite material," *Journal of Nanomaterials*, vol. 2017, Article ID 2171356, 5 pages, 2017.

[17] K. Prashantha, J. Soulestin, M. F. Lacrampe, P. Krawczak, G. Dupin, and M. Claes, "Masterbatch-based multi-walled carbon nanotube filled polypropylene nanocomposites: assessment of rheological and mechanical properties," *Composites Science and Technology*, vol. 69, no. 11-12, pp. 1756–1763, 2009.