

Research Article

Simultaneous Improvement in the Tensile and Impact Strength of Polypropylene Reinforced by Graphene

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The nanocomposites of polypropylene (PP)/graphene were prepared by melt blending. The effects of the dosage of graphene on the flow and mechanical properties of the nanocomposites were investigated. The morphologies of fracture surfaces were characterized through scanning electron microscopy (SEM). The graphene simultaneously enhanced tensile and impact properties of nanocomposites. A 3.22% increase in tensile strength, 39.8% increase in elongation at break, and 26.7% increase in impact strength are achieved by addition of only 1 wt.% of graphene loading. The morphological behavior indicates the fracture surface of PP/graphene is more rough than that of pure PP.

1. Introduction

PP is one of the most important resins with low cost, low density, high hardness, good heat resistance, good processability, etc. PP is widely used in the fields of automotive industry, packaging materials, textiles, biochemical industry, and so on [1]. However, owing to certain disadvantages, such as poor impact toughness, low stiffness, and high molding shrinkage, the applications of PP are limited. Because of their unique mechanical, electrical, optical, and thermal properties, the various nanomaterials have attracted enormous interest from both scientific and engineering standpoints. PP is usually modified through the introduction of nanofillers, such as nanoclay mineral [2], nanosilica [3], nanocellulose [4], nanocalcium carbonate [5], carbon nanotubes [6], and graphene [7].

Since discovered in 2004, graphene has attracted great interest because of its specific structure and properties. Graphene is a monolayer composed of sp^2 carbon atoms arranged in a two-dimensional lattice, which offers superior properties, such as excellent mechanical properties, excellent electronic properties, and high thermal conductivity. It was found that properties of polymers could be improved significantly only filled with a small amount of graphene. Various polymers have been used as matrices to fabricate polymer-

graphene nanocomposites. Kashyap et al. prepared nanocomposites of PVA and graphene and observed an increment of 150% in elastic modulus and tensile strength of nanocomposites with 0.3 wt.% graphene [8]. Sainsbury et al. reported the enhancement of 26 and 63% in Young's modulus and tensile strength of nanomaterials with 0.25 wt.% graphene [9]. Wu et al. found that up to 900% improvement in fracture toughness of epoxy nanocomposites with 0.8 vol% of graphene [10].

However, it is difficult to get homogeneous polymeric nanocomposites because of the graphene have strong tendencies to agglomerate. Solution method [11], in situ polymerization [12], and melt processing [13] can be employed. Among all these procedures, melt processing is considered most effective for the mass production, although its blending effect is not as good as solution method and in situ polymerization. In this work, PP/graphene nanocomposites were successfully fabricated by melt compounding.

There are a number of studies on the impact fracture behavior or tensile strength of PP. So far, there have been relatively few studies on both tensile strength and impact strength. The aim of this work is to improve both tensile strength and impact strength simultaneously. The graphene dosage on the melt flow index, tensile strength, elongation at break, and impact strength of the composites was studied.

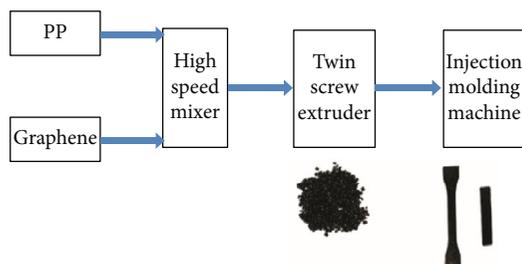


FIGURE 1: Schematic illustration of preparation process of PP/graphene nanocomposites.

TABLE 1: Formulations of the nanocomposites.

Sample number	PP (wt.%)	Graphene (wt.%)
1	100	0
2	99.8	0.2
3	99.6	0.4
4	99.4	0.6
5	99.2	0.8
6	99	1

2. Experimental

2.1. Materials. The PP with trademarked PP-H serving as the matrix resin was supplied by the Maoming Petro-Chemical Co., Ltd. in Maoming (Guangdong Province, PRC). The graphene with trademarked 7440-44-0 was supplied by the Nanjing Xianfeng Nano Co. Ltd. (Jiangsu Province, PRC).

2.2. Preparation of PP/Graphene Nanocomposites. The preparation process of PP/graphene nanocomposites is illustrated in Figure 1. First, graphene was dried in a vacuum oven (DGG-9003) supplied by Shanghai Sen Xin experimental instrument Co., Ltd. (Shanghai, PRC) for 12 h at 80°C to reduce volatiles. According to the formulation as shown in Table 1, the composites were premixed for 5 minutes at stirring speed of 2000 rpm using a high spread mixer (SHR-10) supplied by Zhangjiagang Second Light Industry Machinery Co., Ltd. (Jiangsu province, PRC). Then, the mixture of nanocomposite was blended by twin screw extruder (CTE35) supplied by Coperion (Nanjing) Machinery Co., Ltd. (Jiangsu province, PRC). The temperature range of the extruder was from 155°C to 195°C, and the shear rate was 40 rpm. Finally, put the mixture of the nanocomposite into the injection molding machine (FT-110) supplied by Zhejiang Sound machine manufacturing Co., Ltd. (Zhenjiang province, PRC) and mold it into standard spline.

2.3. Testing. The melt flow performance of the nanocomposites was carried out by melt flow indexer (XRL-400-A) supplied by Chengde precision testing machine Co., Ltd. (Hebei Province, PRC) according to the test method in national standard GB/T 3682-2000 with the temperature of 230°C and load of 2.16 kg. Tensile tests were carried out using a universal testing machine (WDT-W) supplied by Chengde

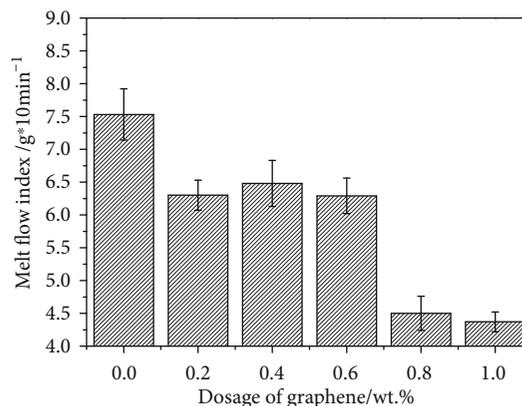


FIGURE 2: Relationship between melt flow performance and graphene weight fraction.

precision testing machine Co., Ltd. (Hebei Province, PRC) at the speed of 50 mm/min according to the national standard of China GB/T 1040-1992. The gauge length of the dumbbell-shaped samples is 20 mm, and cross-sections are 10 mm × 4 mm. And the impact strength tests were carried out using simple beam impact tester (JC-5, PRC) supplied by Chengde precision testing machine Co., Ltd. (Hebei Province, PRC) according to the national standard of China GB/T 1843-2008. The dimension of the sample is 10 mm × 4 mm. The test temperature is 23°C. For all the mechanical tests, five samples were tested and the standard deviations statistics.

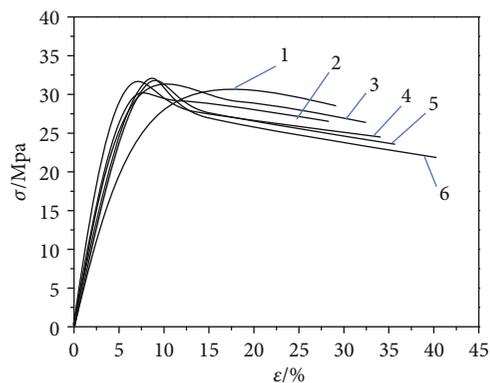
Impact-fractured surfaces of the PP/graphene nanocomposites containing 0 wt.%, 0.2 wt.%, 0.4 wt.%, 0.6 wt.%, 0.8 wt.%, 1 wt.%, were investigated by SEM (Zeiss evo18) Germany Zeiss company (Germany).

3. Results and Discussion

3.1. Melt Flow Property of PP/Graphene Nanocomposites. Polymers need to be melted and flowed before they can be processed into products. Melt flow index refers to the grams of resin melt flowing out in a certain period of time (generally 10 min) through standard capillary under a certain temperature and pressure. Figure 2 presents the dependence of the melt flow index on the graphene weight fraction of the PP/graphene nanocomposites. It is shown that the flow performance of the nanocomposites decreases with the addition of the graphene weight fraction. Graphene is a flake filler which increases the friction between the molecular chains which blocks the melt flow.

3.2. Mechanical Property of PP/Graphene Nanocomposites. Figure 3 is the results of the tensile test which presents the relationship between tensile strength and strain of PP/graphene at room temperature. The maximum values of the tensile strength and elongation at break of the nanocomposites are obviously higher than that of the unfilled PP when the graphene weight fraction is more than 0.2 wt.%.

Figure 4 shows the relationship between the tensile strength and graphene dosage. It can be seen the values of the tensile strength of the nanocomposites decrease firstly



1-PP
2-0.2wt.% graphene
3-0.4wt.% graphene
4-0.6wt.% graphene
5-0.8wt.% graphene
6-1.0wt.% graphene

FIGURE 3: Relationship between tensile stress and strain of nanocomposites.

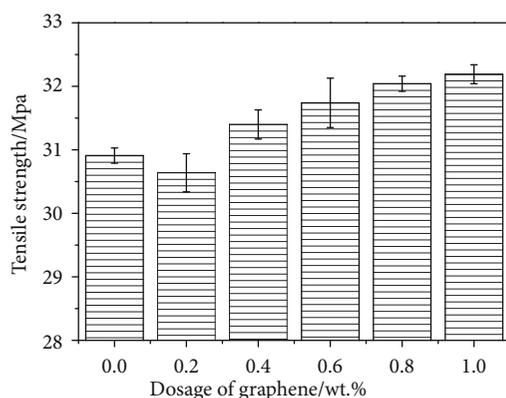


FIGURE 4: Relationship between tensile strength and graphene weight fraction.

and then increase with the increasing of graphene weight fraction. As a kind of filler, the graphene with high performance, the addition of graphene can result in increase in the values of tensile strength. And Zhao found that the crystallization morphology was significantly influenced by the presence of graphene. The size of the spherulites was very small because of the high nucleation density [14]. In general, small spherulites can give polymers higher mechanical properties. Ahmad [15] also found that graphene aided crystal nucleation and the addition of graphene lead to increase in tensile strength. Menbari and Ren found that graphene could increase the tensile strength of the PP [16, 17]. The tensile strength increases 3.22% by addition of only 1 wt.% of graphene loading. However, it is difficult to disperse a small amount of graphene uniformly in PP. Therefore, the addition of a small amount of graphene results in the decrease of values of the tensile strength of the nanocomposites.

The values of the elongation at break of the nanocomposites are plotted against the dosage of graphene in Figure 5. It is found that the values of elongation at break of the nano-

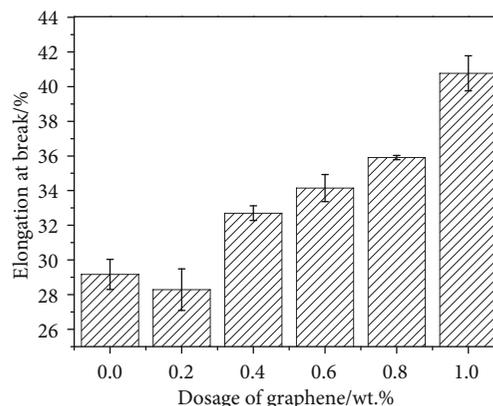


FIGURE 5: Relationship between elongation at break and graphene weight fraction.

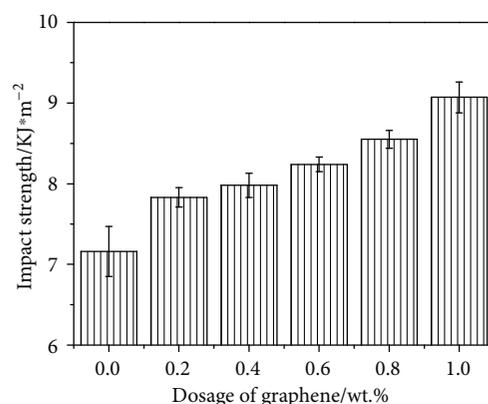


FIGURE 6: Relationship between impact strength and graphene weight fraction.

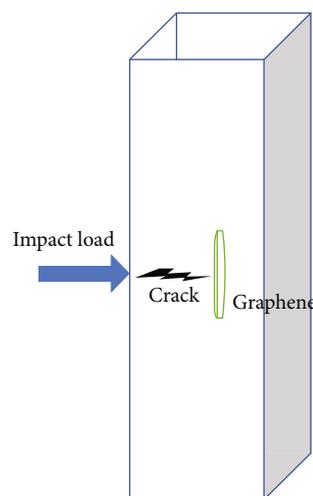


FIGURE 7: Simplified model of impact of specimen of graphene/PP nanocomposites.

composite decrease firstly and then increase with the increasing of the graphene dosage. As the loading of graphene increases to 1 wt.%, the elongation at break of the nanocomposite shows a substantial increase of about 39.8%.

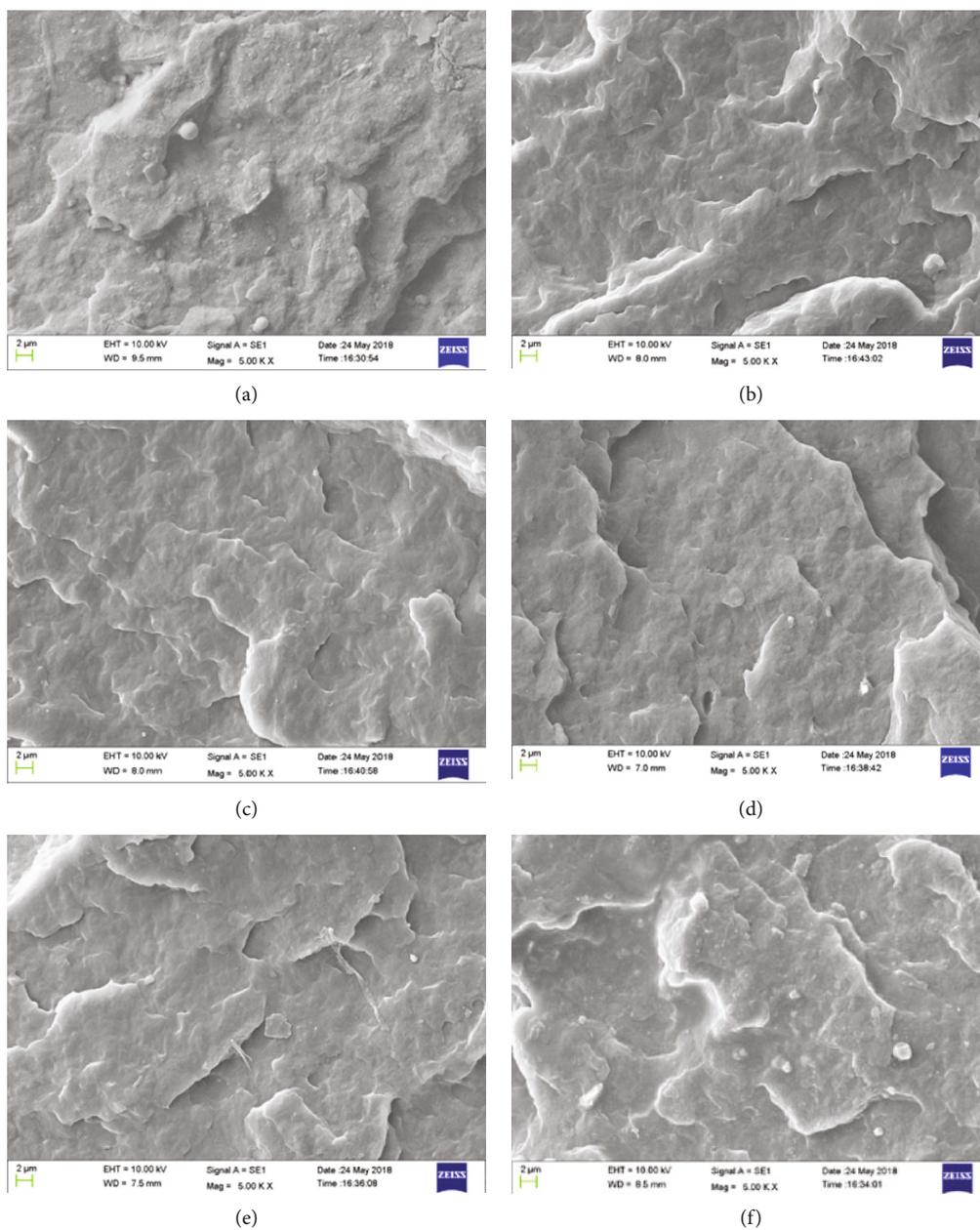


FIGURE 8: Scanning electron microscope pictures of nanocomposite material section: (a) graphene 0 wt.%; (b) graphene 0.2 wt.%; (c) graphene 0.4 wt.%; (d) graphene 0.6 wt.%; (e) graphene 0.8 wt.%; (f) graphene 1 wt.%.

Figure 6 displays the dependence of the impact strength on the graphene weight fraction. It is shown that the impact strength of the nanocomposite increases with the increasing of graphene weight fraction. As the loading of graphene increases to 1 wt.%, the impact strength of the nanocomposite increases about 26.7%. Liang found that the graphene could improve the impact strength of the PP, and the reason could be that graphene with high mechanical performance is more beneficial to block the development of crack in the matrix as shown in Figure 7, resulting in improvement of impact fracture toughness of the nanocomposites [18].

Figure 8 shows the SEM photograph of the nanocomposite material section of the impact test. The fracture surface morphology of specimens is related closely to the impact

strength of materials. Obviously, even if the graphene concentration was increased to 1 wt.%, any obvious agglomeration of graphene was not observed. Figure 8(a) is a SEM photograph of the fracture surface morphology of the specimen of the pure PP. It is shown that the impact fracture surface of the specimen is relatively smooth. It means that the microcracks in the specimen of pure PP expand directly under impact load, which leads to smooth fracture surface and low impact fracture strength. Figures 8(b)–8(f) is the SEM photograph of the fracture surface morphology of the specimens of the PP/graphene nanocomposites with various graphene weight fractions correspond to 0.2, 0.4, 0.6, 0.8, and 1.0 wt.% graphene. It can be observed that the impact fracture surface of the specimens of the nanocomposites is

rougher than that of the pure PP. Liang found the similar phenomena in the research of PP composites reinforced with multiwalled carbon nanotubes. And he thought that the nanomaterials induce the PP matrix generate deformation which absorbs the impact energy. Besides this, the nanomaterials will block the development of the microcracks [19].

4. Conclusion

The effects of graphene on the melt flow and mechanical properties of polypropylene were investigated. The summary of the results are as follows:

- (1) The melt flow performance of the nanocomposites decreases with the addition of the graphene weight fraction
- (2) PP/graphene nanocomposites were found to exhibit simultaneous superior tensile and impact properties compared to pure PP
- (3) The impact strength of the specimen was confirmed with the SEM micrographs on the fracture surface of the nanocomposites

Data Availability

The all the research data used to support the findings of this study (manuscript 7840802 titled “Simultaneous Improvement in the Tensile and Impact Strength of Polypropylene Reinforced by Graphene”) are included within the article.

Conflicts of Interest

The author declares that they have no conflicts of interest.

Acknowledgments

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References

- [1] J. Kang, J. Li, S. Chen et al., “Investigation of the crystallization behavior of isotactic polypropylene polymerized with different Ziegler-Natta catalysts,” *Journal of Applied Polymer Science*, vol. 129, no. 5, pp. 2663–2670, 2013.
- [2] A. Oya, Y. Kurokawa, and H. Yasuda, “Factors controlling mechanical properties of clay mineral/polypropylene nanocomposites[J],” *Journal of Materials Science*, vol. 35, no. 5, pp. 1045–1050, 2000.
- [3] F. U. A. Shaikh, Y. Shafaei, and P. K. Sarker, “Effect of nano and micro-silica on bond behaviour of steel and polypropylene fibres in high volume fly ash mortar,” *Construction and Building Materials*, vol. 115, pp. 690–698, 2016.
- [4] Y. Liu, S. Zhang, X. Wang, Y. Pan, F. Zhang, and J. Huang, “Mechanical and aging resistance properties of polypropylene (PP) reinforced with nanocellulose/attapulgite composites (NCC/AT),” *Composite Interfaces*, vol. 27, no. 1, pp. 73–85, 2020.
- [5] M. A. Ghaliya, I. Inuwa, A. Hassan, and Y. Dahman, “Viscoelastic behavior and mechanical properties of polypropylene/nano-calcium carbonate nanocomposites modified by a coupling agent,” *Macromolecular Research*, pp. 1–11, 2016.
- [6] J. Li, “Multiwalled carbon nanotubes reinforced polypropylene composite material[J],” *Journal of Nanomaterials*, vol. 2017, 5 pages, 2017.
- [7] J. Z. Liang, “Impact fracture behavior and morphology of polypropylene/graphene nanoplatelets composites[J],” *Polymer Composites*, vol. 40, no. S1, pp. E511–E516, 2019.
- [8] S. Kashyap, S. K. Pratihar, and S. K. Behera, “Strong and ductile graphene oxide reinforced PVA nanocomposites,” *Journal of Alloys and Compounds*, vol. 684, pp. 254–260, 2016.
- [9] T. Sainsbury, S. Gnaniyah, S. J. Spencer et al., “Extreme mechanical reinforcement in graphene oxide based thin-film nanocomposites via covalently tailored nanofiller matrix compatibilization,” *Carbon*, vol. 114, pp. 367–376, 2017.
- [10] S. Wu, R. B. Ladani, J. Zhang et al., “Aligning multilayer graphene flakes with an external electric field to improve multifunctional properties of epoxy nanocomposites,” *Carbon*, vol. 94, pp. 607–618, 2015.
- [11] E. Lago, P. S. Toth, G. Pugliese, V. Pellegrini, and F. Bonaccorso, “Solution blending preparation of polycarbonate/graphene composite: boosting the mechanical and electrical properties[J],” *RSC Advances*, vol. 6, no. 100, pp. 97931–97940, 2016.
- [12] X. Zhao, Y. Li, W. Chen, S. Li, Y. Zhao, and S. du, “Improved fracture toughness of epoxy resin reinforced with polyamide 6/graphene oxide nanocomposites prepared via in situ polymerization[J],” *Composites Science and Technology*, vol. 171, pp. 180–189, 2019.
- [13] B. Mayoral, E. Harkin-Jones, P. N. Khanam et al., “Melt processing and characterisation of polyamide 6/graphene nanoplatelet composites[J],” *RSC Advances*, vol. 5, no. 65, pp. 52395–52409, 2015.
- [14] S. Zhao, F. Chen, Y. Huang, J. Y. Dong, and C. C. Han, “Crystallization behaviors in the isotactic polypropylene/graphene composites[J],” *Polymer*, vol. 55, no. 16, pp. 4125–4135, 2014.
- [15] S. R. Ahmad, C. Xue, and R. J. Young, “The mechanisms of reinforcement of polypropylene by graphene nanoplatelets,” *Materials Science and Engineering: B*, vol. 216, pp. 2–9, 2017.
- [16] S. Menbari, F. Ashenai Ghasemi, and I. Ghasemi, “Simultaneous improvement in the strength and toughness of polypropylene by incorporating hybrid graphene/CaCO₃ reinforcement[J],” *Polymer Testing*, vol. 54, pp. 281–287, 2016.
- [17] Y. Ren, Y. Zhang, H. Fang, T. Ding, J. Li, and S. L. Bai, “Simultaneous enhancement on thermal and mechanical properties of polypropylene composites filled with graphite platelets and graphene sheets,” *Composites Part A Applied Science and Manufacturing*, vol. 112, pp. 57–63, 2018.
- [18] J.-Z. Liang, “Impact fracture behavior and morphology of polypropylene/graphene nanoplatelets composites,” *Polymer Composites*, vol. 40, no. S1, pp. E511–E516, 2019.
- [19] J.-Z. Liang, S.-Y. Zou, and Q. du, “Impact and flexural properties of polypropylene composites reinforced with multi-walled carbon nanotubes,” *Polymer Testing*, vol. 70, pp. 434–440, 2018.