The Modulus Enhancement of Polypropylene Fiber by Multiwall Carbon Nanotubes

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ABSTRACTS

Polypropylene-multiwall carbon nanotube (MWNT) composite fiber was prepared by a home-made melt spinning equipment. Fiber stretching was done at various draw ratios. Dispersing agents were used to disperse the MWNTs in polypropylene matrix. Mechanical and thermal properties of the composite fiber were investigated. By using 0.5-2 wt % of nanotubes, the Young's modulus of composite fibers increased for 29-62%. MWNT dispersion in the matrix was monitored by scanning electron microscopy.

Key words: Polypropylene composite fiber, Multiwall carbon nanotubes, Fiber spinning

INTRODUCTION

Polypropylene is a versatile thermoplastic which is used in many applications such as building materials, furniture, automobile and toy industries because of their well balanced physical and mechanical properties and their easy processability at a relatively low cost (Seo et al., 2005). Mechanical properties are generally modified by melt mixing with particulate fillers (e.g., talc, mica, and clay) and fibers (e.g., glass, aramid, and carbon fiber) as well as by melt blending with other polymers (Bhattacharyya et al., 2003; Seo and Park, 2004).

Carbon nanotubes have attention from many scientists for their potential applications in nano-scale polymer reinforcement because of their unusual mechanical and electrical properties (e.g., tensile strength as high as 50 GPa and modulus of 1 TPa), to improve the performance of a matrix or to achieve new properties (Wang et al., 2006). One of the advantages of CNTs as a reinforcement is their large surface area that can induce a better adhesion with a polymer matrix (Lopez et al., 2005). Reinforcement at nano scale to improve mechanical and other properties including changes in polymer crystallization behavior is being attempted by researchers (Seo et al., 2005 and Valentini et al., 2003)

Several researchers have used CNTs to enhance the strength of neat fibers, Jacob et al., dispersed SWNTs in polypropylene with 1 wt % loading, the tensile strength and modulus of fiber were increased by 40 % and 55 % respectively (Kearns and Shambaugh, 2002). Satish et al. dispersed 5 wt% carbon nanofibers in polypropylene fiber and found that the modulus was increased by 50 % (Kurmar et al., 2002). Chang et al. dispersed SWNTs in polypropylene fiber with 1-5 wt% to gain the 45% increasing of tensile stiffness but the modulus was slightly increase (Chang et al., 2005). On the other hand Arup et al. dispersed SWNTs in polypropylene with 1 wt % loading and found the decreasing of tensile properties (Bhattacharyya et al., 2003).

Because of their small size, carbon nanotubes tend to agglomerate when dispersed in a polymer resin. Therefore, how to disperse CNTs in polymer matrix is a challenge. In this work, we have investigated the effects of dispersing agent on dispersion and the effects of different contents of MWNTs on tensile properties. The thermal characterization of composite fiber was performed by means of differential scanning calorimetry (DSC).

MATERIALS AND METHODS

The polypropylene was supplied by IRPC Public Co., Ltd. It has a melt flow index of 11 g/min. MWNTs were purchased from Nanotechnologies Co., Ltd. The nanotubes have a diameter about 10 nm with a length ranging from 5 to 15 µm.

The 1 wt% MWNTs were sonicated in 20 ml of dispersing agent (Sodium laurylsulfate, Triton X-100 (Fisher Scientific) and 2-propanol) with Bandelin electronic type RK 106 sonicator for 3 h. Polypropylene powder was added to the solution and mixing by mechanical stirrer. The composite fibers were prepared with different MWNTs contents as 0.5, 1, 1.5 and 2 wt% by using 2-propanol as a dispersing agent. The sample was dried at 70°C in a vacuum oven. The sample was melt-blended using two-roll mixer for mixing time of about 20 min at 190°C. The fibers were spun using a home-made melt spinning equipment with a die diameter of 1.0 mm. Fiber spinning was carried out at 190°C (Figure 1). The fibers were subsequently drawn at a draw ratio of 5 on a hot plate at 80°C. As a controlled sample, as received polypropylene without carbon nanotubes was also spun using the same equipment and processing conditions.

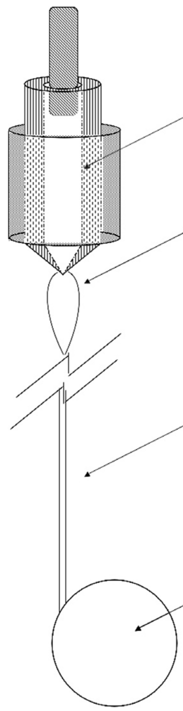

Figure 1. The melt spinning process.

Fiber tensile properties were measured with 30 mm gauge length samples at a cross-head speed of 30 mm/min. Fiber diameters were measured using micrometer. Chord moduli at 1 - 2% strain were reported. Scanning electron micrographs were obtained using JEOL JSM-6335F. Instrument-specialists DSC 550 was utilized at 10°C/min to obtain the melting peaks of composites.

RESULTS AND DISCUSSION

Tensile properties of neat PP fiber and PP composite fibers containing 1 wt % MWNTs with different dispersing agents are given in Table 1. Based on this data it is clear that the composite fibers have higher modulus and higher tensile strength as compared to neat PP fiber. Strain to failure was observed to decrease as a result of filling with the MWNTs. For different dispersing agents the modulus and tensile strength were not significantly affected, but the composite fibers with 2- propanol dispersing agent have higher modulus.

Table 1. Properties of fibers from PP and PP/ 1%wt MWNTs composite.

Dispersing agent	Tensile strength (MPa)	Tensile modules (MPa)	Elongation at break (%)
Neat PP	600	1172	120
PP/MWNTs 2-propanol	650 (+8%)	1772 (+51%)	91
PP/MWNTs SLS	675 (+12%)	1690 (+44%)	107
PP/MWNTs Triton X-100	674 (+12%)	1632 (+39%)	113

Figure 2 shows thermograms of melting temperatures (T_m) of the neat PP and PP-MWNTs composites. The melting temperatures and heat of fusion (ΔH_f) as a function of MWNTs contents are reported in Table 2. The slightly decrease of the ΔH_f of composites with increasing nanotubes contents could be directly attributed to the proportional reduction of the crystalline in the composite. Furthermore, the composites have higher melting points than that of the PP matrix because MWNTs in PP matrix make an enhancement in thermal stability of the composites.

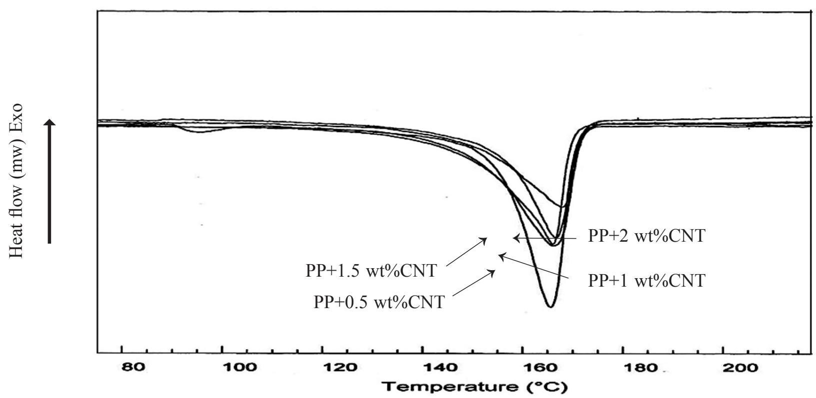

Figure 2. DSC thermograms of neat PP and PP-MWNTs composites.

Table 2. Melting temperature (T_m) and Heat of fusion (ΔH_f) of PP and PP-MWNTs composite.

Samples	T_m(°C)	ΔH_f (J/g of composite)	ΔH_f (J/g of PP matrix)
Neat PP	165.7		100.6
PP/ 0.5 wt % MWNTs	166.2	84.7	85.1
PP/ 1 wt % MWNTs	166.1	84.4	85.3
PP/ 1.5 wt % MWNTs	166.6	82.4	83.7
PP/ 2 wt % MWNTs	167.7	79.6	81.3

Figure 3 shows SEM image of the MWNTs, Figure 4 shows the dispersion of 2 wt% MWNTs in PP matrix. It is clearly seen a well dispersion of MWNTs in PP matrix. Moreover, the image seems to show a good interfacial bonding.

However, at the center of Figure 4 there is a clump of amorphous carbon, which could deteriorate mechanical properties of composite and composite fiber. If the MWNT are well dispersing in polymer matrix, improvements of mechanical properties should be observed.

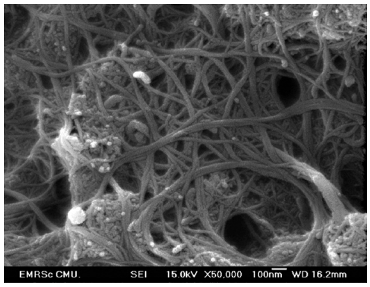

Figure 3. SEM image of MWNTs.

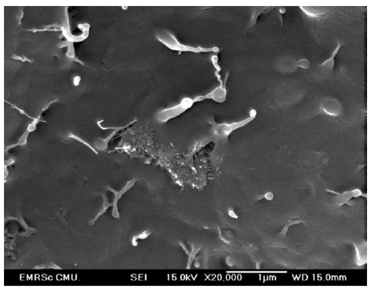

Figure 4. SEM image of 2 wt% MWNTs-PP composite.

Table 3. Properties of fibers from PP and PP/ MWNT composite with 2-propanol as a dispersing agent.

Fibers (with draw ratio of 5)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
Neat PP	600	1172	120
PP/ 0.5 wt % MWNT	612 (+2%)	1516 (+29%)	102
PP/ 1 wt % MWNT	650 (+8%)	1772 (+51%)	91
PP/ 1.5 wt % MWNT	655 (+9%)	1856 (+58%)	119
PP/ 2 wt % MWNT	736 (+22%)	1908 (+62%)	90

Figure 5 shows the stress-strain behavior of neat PP fiber and PP composite fibers loading different MWNTs amounts. The fibers shown in Figure 5 were all processed with 3 h sonification of the MWNT-2-propanol mixture. Tensile modulus defined as the stress-strain ratio at 1-2% strain region is presented in Figure 6 as a function of the MWNT concentration. The modulus and tensile strength of neat PP fiber and PP composite fibers containing 0.5-2 wt % MWNT concentrations are given in Table 3. The modulus of the fiber increases with an addition of MWNTs. The modulus increasing was significant in the range of 0.5-1 wt % of MWNTs; however, the modulus approached a plateau with further addition of MWNT (Figure 6). The addition of 2 wt% MWNTs led to the increasing of tensile strength and initial modulus by 29 % and 62 %, respectively. The high mechanical properties are attributed to the homogeneous dispersion of MWNTs in PP matrix.

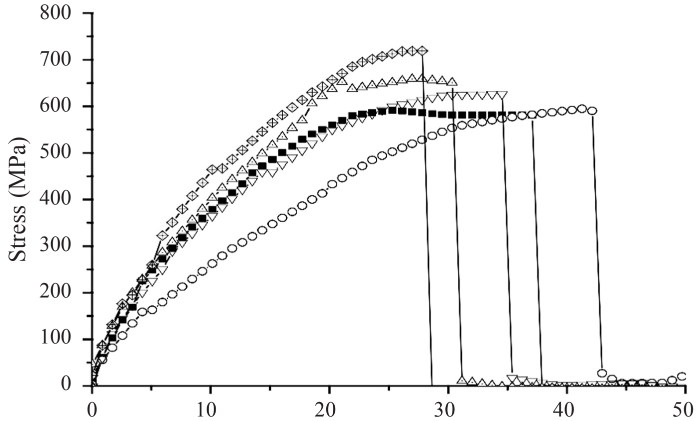

Figure 5. Stress-strain curves of neat PP and PP composite fibers with different contents of MWNTs.

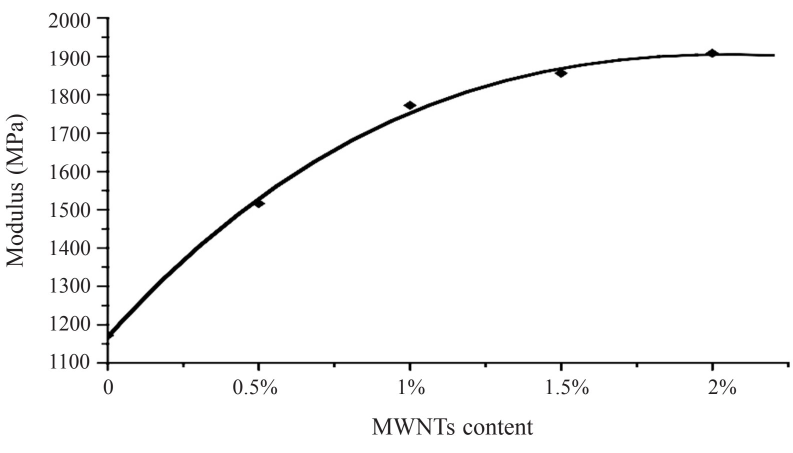

Figure 6. The Young's modulus of neat PP and PP composite fibers with different contents of MWNTs.

CONCLUSION

MWNTs reinforced PP composite fibers have been prepared by combination of dispersing agent and melt-spun. Mechanical test showed the improvement of tensile strength and modulus of PP composite fibers. For different dispersing agent the composite fibers prepared with 2- propanol dispersing agent have the highest modulus. The MWNTs in PP matrix make the enhancement in thermal stability of the composites. For the low MWNTs content, the PP is intercalated between nano-tubes in bundles which could be disaggregated. The increasing of fiber modulus was significant in the range of 0.5-1 wt % of MWNTs.

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REFERENCES

Bhattacharyya, A. R., T. V. Sreekumara, T. Liu, S. Kumar, L. M. Ericson, R. H. Hauge, and R. E. Smalley. 2003. Crystallization and orientation studies in polypropylene/single wall carbon nanotube composite. Polym. 44: 2373-2377.

Chantrasakul, S., and T. Amornsakchai. 2007. High Strength Polyethylene Fibers From High Density Polyethylene/Organoclay Composites. Polym. Eng. Sci. 47(6):943-950.

Chang, T. E., L. R. Jensen, A. Kisliuk, R. B. Pipes, R. Pyrz, and A. P. Sokolov. 2005. Microscopic mechanism of reinforcement in single-wall carbon nanotube/polypropylene nanocomposite. Polym. 46: 439-444.

Chen, W., X. Tao, and Y. Liu. 2006. Carbon nanotube-reinforced polyurethane composite fibers. Comp. Sci. Tech. 66: 3029-3034.

Kearns, J. C., and R. L. Shambaugh. 2002. Polypropylene Fibers Reinforced with Carbon Nanotubes. J. Appl. Polym. Sci. 86. 2079-2084.

Kumar, S., H. Doshi, M. Srinivasarao, J. O. Park, and D. A. Schiraldi. 2002. Fibers from polypropylene/nano carbon fiber composites. Polym. 43: 1701-1703.

Li, C., T. Liang, W. Lu, C. Tang, X. Hu, M. Cao, and J. Liang. 2004. Improving the antistatic ability of polypropylene fibers by inner antistatic agent filled with carbon nanotubes. Comp. Sci. Tech. 64: 2089-2096.

Lopez Manchado, M. A., L. Valentini, J. Biagiotti, and J. M. Kenny. 2005. Thermal and mechanical properties of single-walled carbon nanotubes-polypropylene composites prepared by melt processing. Carbon 43. 1499-1505.

Seo, M. K., and S. J. Park. 2004. Electrical resistivity and rheological behaviors of carbon nanotubes-filled polypropylene composites. Chem. Phys. Lett. 395: 44-48.

Seo, M. K., J. R. Lee, and S. J. Park. 2005. Crystallization kinetics and interfacial behaviors of polypropylene composites reinforced with multi-walled carbon nanotubes. Mater. Sci. Eng. A 404: 79-84.

Valentini, L., J. Biagiotti, J. M. Kenny, and S. Santucci. 2003. Morphological characterization of single-walled carbon nanotubes-PP composites. Comp. Sci. Tech. 63: 1149-1153.

Wang, Z., M. Lu, H. L. Li, and X. Y. Guob. 2006. SWNTs-polystyrene composites preparations and electrical properties research. Mater. Chem. Phys. 100: 77-81.

Zhang, Q., S. Rastogi, D. Chen, D. Lippits, and P. J. Lemstra. 2006. Low percolation threshold in single-walled carbon nanotube/high density polyethylene composites prepared by melt processing technique. Carbon 44: 778-785.