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Indian Journal of Advances in Chemical Science

Indian **J**ournal of **A**dvances in **C**hemical **S**cience **2** (2014) 6-8

Mechanical Behaviour of MWCNT Filled Polypropylene Thermoplastic Composites

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Received 6th April 2014; Accepted 20th April 2014.
Editor in Chief: Dr. K.S.V. Krishna Rao; Guest Editors: Dr. Siddaramaiah, Dr. G. M. Shashidhara.
Presented at the POLYCON-2014, 6th National Conferences on Advances in Polymeric Materials [Energy, Environment & Health] (NCAPM), Mysore, India, 25-26 April 2014.

ABSTRACT
Polypropylene (PP) is one of the most widely used engineering polymers. In this study, multiwalled carbon nanotubes (MWCNT) were melt blended into PP, in the ratio of 2.5, 5 and 10 wt.% using twin screw extrusion process. The extruded pellets were then injection moulded into standard tensile and flexural test specimens, conforming to ASTM specifications, using a 50 Ton injection moulding machine. The tensile strength increased marginally with addition of MWCNT, while there was a 30% increase in the flexural strength when compared to pure PP. The flexural modulus increased from 1470 to 2150 MPa, resulting in increased flexural stiffness of 45%. The presence of MWCNT hinders the crack propagation resulting in improved strength and stiffness. The melt flow index also showed a drastic drop from 11 gm/10 min to just 2 gm/10 min, which could be attributed to the increase in viscosity due to stiff MWCNT phase in PP matrix.

Keywords: *Polypropylene, carbon nanotubes, injection molding, nano-composites, Extrusion.*

1. INTRODUCTION

Natural and synthetic polymers play a useful role in everyday life. Existing research also indicates that polymer composites with nanofillers show superior performance versus microfillers [1]. Polypropylenes, polyamide (Nylon) belong to the family of crystalline polymers. Polypropylene (PP) has a wide spectrum of applications due to its processability, good balance of physical properties and price. This makes it good choice as matrix material for thermoplastic composites. Carbon Nano Tube (CNT) is an allotrope of carbon with a cylindrical form and classified into single-walled (SWCNT) and multi-walled CNTs (MWCNTs). CNTs have a sp^2 bond between carbon atoms which is responsible for its high tensile strength and elasticity modulus [2]. MWCNT has multiples layers of graphene sheets (concentric cylinders) which make them incredibly strong fibers. CNTs are shown to have tensile strengths up to 60 GPa, substantially stronger than steel with approximately one sixth the density. Tensile strength of CNT is high, which is 75 times than that of steel filaments of the same size, also 15 times higher than that of carbon fibers. On the other hand the densities of CNT are as low as 1.3 g/cm^3, which is one sixth of that of steel. Their special mechanical properties are due to strong bonding between the carbon atoms that form carbine plane. The bond length is 0.142 nm which is lower than that in diamond (0.154 nm) [3]. CNTs are promising reinforcement in polymer composites used as field effect transistors, nanowires, fuel cells and sensors, due to the outstanding physical properties such as low specific gravity, mechanical strength, thermal stability, and electrical and thermal conductivities [4]. CNT filled polymer composites combine the good processability of the polymers with the excellent mechanical and other functional properties of the CNTs [5]. The structure of PP is chemically simple and hence the effect of adding CNT to PP can be evaluated. PP/CNT composites produced at laboratory scale showed that low electrical percolation threshold and good reinforcement characteristics may be achieved [1]. PP / CNT would produce very strong materials which are light at the same time. Thermoplastics enhanced with CNTs might be a new family of light and strong composites [3].

In the present study, MWCNT has been selected as the re-inforcement for the Polypropylene matrix. Mechanical properties like tensile, flexural, impact and Melt flow index (MFI) are experimentally determined to study the influence of weight percentages of MWCNT as reinforcement in the composite.

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Table -1 : Mechanical properties of composited with differsnt wt% of MWCNT.* Specimen Codes

Sl. No.	Properties	ASTM Standard	Units	Pure matrix (PP)	TR-1*	TR-2*	TR-3*
1	Re-inforcement (MWCNT)		%	0	2.5	5	10
2	Tensile strength at yield	D638	MPa	35.7	37.3	38.1	40.8
3	Elongation at yield	D638	%	17.6	17.1	16.5	15.6
4	Tensile Modulus	D638	MPa	550.3	624.4	624.4	624.3
5	Flexural Strength	D790	MPa	45.3	51.9	52.9	60.8
6	Flexural Modulus	D790	Gpa	1.5	1.6	2.0	2.2
7	Melt Flow Index	D1238	g/10 min	11	7	5.5	2

2. EXPERIMENTAL

2.1 Materials

Polypropylene (PP) is used as the matrix material which is reinforced with the MWCNT. PP used is H110MA grade from Reliance polymers, with Specific gravity of 0.9, MFI 11, tensile strength 36 MPa and flexural modulus 1650 MPa. Multiwalled Carbon Nanotubes (purity >90%, outer diameter of 10-15 nm, mean number of walls 5-15, mean length 1-10 µm, apparent density 50 – 150 kg/m^3), of graphistrength C100 grade, supplied by Arkema Inc. (France) are used as reinforcements.

2.2 Preparation of Composites

Multiwalled carbon nanotubes (MWCNT) were melt blended into PP, in the ratio of 2.5, 5 and 10 wt.%, using twin screw extrusion process. Compounding was done with the main extruder rotating at 210 rpm and the feeder at 20-30 rpm. The temperature profile along the barrel and die with 7 zones was set to 172/187/195/191/204/220/207° C and the melting temperature at 167°C for all the samples.

The composite blends containing different compositions of the reinforcement material, MWCNT are fed into the Injection molding machine of 50 ton capacity to mold them into tensile and flexural test specimens according to ASTM standards.

2.3 Experiments

Tensile Test

The tensile properties of the standard dumbbell-shaped specimens were determined using the standard test method as per ASTM D638. The dimensions like length, width, gage length, radius of the fillet of the test specimens are conforming to the Type-1 in the standard. The specimen was loaded at speed of 50 mm/min and strain rate of 1 mm/min which is specified for type-1 specimen. The experimental results in terms of stresses and extension at the yield point and the rupture point are recorded.

Fluxural Test

Flexural properties of the composite materials were determined by using the standard test procedure explained in ASTM D790. The specimens were tested with 3 – point bending at crosshead speed of 1.3 mm/min, to determine the flexural strength and flexural modulus.

Measurement of Melt flow index (MFI)

Melt Flow Rate measures the rate of extrusion of thermoplastics through an orifice at a prescribed temperature and load. It is measured as mass of polmer in grams flowing for a period of ten minutes and expressed as g/10 min. The MFI was measured as described in the standard ASTM D1238.

All the experimental results discussed above are tabulated in Table 1.

3. RESULTS AND DISCUSSION

Experimental results are analysed by taking the mechanical properties of Polypropylene as reference as shown figures 1 -5, comparing them with the properties of MWCNT filled composites. Tensile strength is a measure of the maximum stress a material can withstand in the longitudinal direction before the material fails. Figure 1 shows the effect of weight % of MWCNT on the Tensile strength of the material. It can be observed the tensile strength is increased from 35 MPa for PP to 41 MPa for 10 % MWCNT composite. The elongation which was 17.5 % for PP is reduced to 15.5 % for 10 % MWCNT, as shown in Figure 2.

The presence of high stiffness CNT phase in the polymer phase, acts as stress concentrators, from which the crack begins to propagate. As the weight percentage of CNT increases, the number of stress concentration sites increases, thus resulting in reduction of elongation. The Tensile modulus is a measure of a material's stiffness, or rigidity. Figure 3 shows the effect of weight % of MWCNT on the Tensile Modulus of the material which has remained almost constant as the composition of weight % of MWCNT has increased. The increase in tensile strength and reduction in elongation is so proportional that the modulus remains constant according to the rule of mixtures.

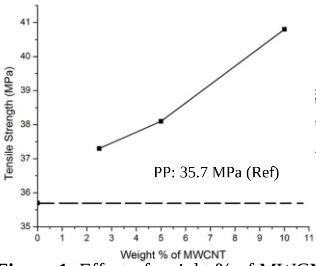

Figure 1: Effect of weight % of MWCNT on the Tensile strength.

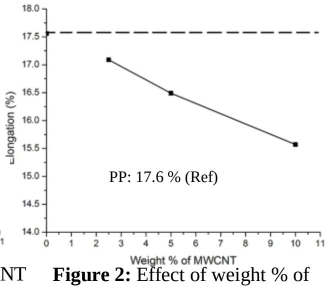

Figure 2: Effect of weight % of MWCNT on % Elongation.

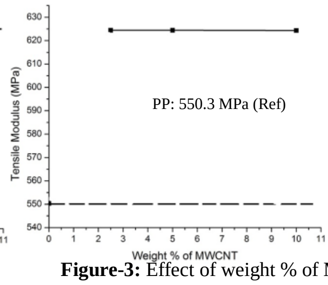

Figure-3: Effect of weight % of MWCNT on Tensile Modulus

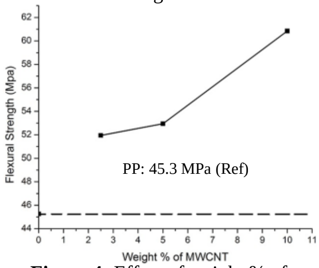

Figure 4: Effect of weight % of MWCNT on Flexural strength.

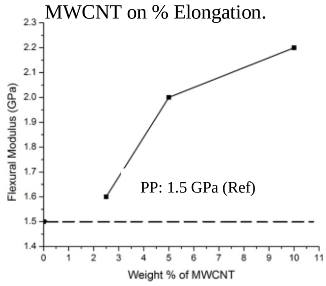

Figure 5: Effect of weight % of MWCNT on Flexural Modulus.

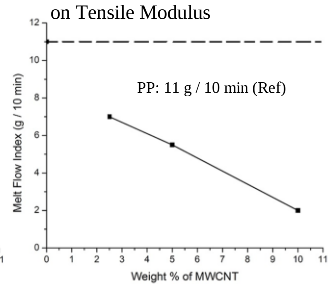

Figure 6: Effects of weight % of MWCNT on Melt Flow Index.

It can be observed the flexural strength increased from 45 MPa for PP to 61 MPa for 10 % MWCNT composite, as shown in Figure 4. This indicates a 36% increase in the property which is quite noticeable. Figure 5 shows that the flexural modulus which is 1.5 GPa for PP is increased to 1.6GPa, 2GPa and 2.2 GPa respectively for 2.5, 5 and 10 % wt. of MWCNT. This indicates 45-50% increase in the flexural modulus when compared to PP. Melt flow rate is a measure of the ability of the material's melt to flow under pressure and also the viscosity of the material. Figure 6 shows the effect of weight % of MWCNT on melt flow index (MFI). It is seen that the MFI decreased drastically from 11 g/10min for PP to 2 g/10 min for 10% MWCNT composite. This can be attributed to very high thermal conductivity of CNT, which is in the range of 2000 to 4000 W/m-K.

4. CONCLUSION

Polypropylene-MWCNT composites were produced using twin screw extruder and injection molding. It contained 2.5, 5 and 10 % by weight of MWCNT as reinforcements.. It was observed that the mechanical properties of the composite increased drastically, up to 50 %, by increasing the reinforcement percentages. Flexural Modulus and strength have improved noticeably due to the special properties of MWCNT. Hence this material can prove to be a promising one in many industrial sectors.

Acknowledgments - We acknowledge the financial support to this work by Department of Science and Technology, Govt. of India, under the project Ref. No. SR/NM/NS-43/2010 dated 27-09-2010.

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