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# Experimental Investigation on Multi-wall Carbon Nanotube/Polypropylene Nanocomposite under High and Low Velocity Impact

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**Abstract.** This study investigates low and high velocity impact response of nanocomposite containing 0.75, 1.0 and 1.5 wt% of multi-walled carbon nanotubes (MWNTs) in a Polypropylene (PP) matrix. MWNTs were incorporated into polypropylene via melt compounding in an internal mixer followed by injection molding. Izod impact test results indicated higher impact energy in nanocomposite containing MWNTs comparing with neat PP. A single stage gas gun in velocity range of 20-150 m/s using harden steel hemispherical tip projectile with diameter of 8.1 mm and weight of 11.34 g, was used to conduct high velocity impact tests. Result showed better energy absorption and ballistic limit velocity (the average of highest impact velocity causing perforation but unable to go through and lowest impact velocities with no residual velocity recording) for specimens containing MWNTs. Results eventually showed higher values for specimens containing 1 wt% MWNTs in both high and low velocity impact tests as compared with the neat PP.

**Keywords:** Nanocomposites, Carbon nanotube, Ballistic limit, Low velocity impact.

## 1. Introduction

Polymer nanocomposites have attracted considerable attention for many years in high performance applications [1]. As we know one of the most important applications of nanocomposites (in military, marine and structural applications) is the protection from low and high velocity impact. Among various nano particles, CNTs have received enormous attention because of their unique structure, with extraordinary mechanical, electrical and thermal properties [2, 3].

Polypropylene (PP) is the most widely used thermoplastic which have been utilized in military and marine vehicles, automobiles, appliances, constructions and other industrial sectors because of its well-balanced physical and mechanical properties and easy processability at a relatively low cost [4]. Many reports about mechanical and thermal properties of CNT nanocomposites have shown excellent results by addition of only very small amounts of CNTs into polymer matrix [5, 6]. Also many articles have studied on low velocity impact response of CNT nanocomposites [7]. In recent years textile composites have been used for protective applications but in open literature on investigation of high strain rate and high velocity impacts on CNT nanocomposites, most of the work has focused on layered laminated nanocomposites [8] and there exists no specific study and insufficient information available on non-layered polymer nanocomposites specially in PP/CNT nanocomposites.

The objectives of this study included: to describe the effect of MWCNTs on the low and high velocity impact of neat PP and to determine the increscent of energy absorption capacity of PP/CNT nanocomposites.

## 2. Experimental

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## 2.1. Materials

Commercially isotactic polypropylene (PP 570P) were supplied by Sabic company (Saudi Arabia) with melt flow Index (MFI) = 8 g/10 min (230 ºC/2.16 kg) and density = 905 kg/m$^3$. Multi-walled carbon nanotubes (MWNTs) were purchased from Times company (china) and were produced via a chemical vapor deposition process with purity higher than 95% and diameter range of 5-20 nm with a typical length of 10-30 um. Moreover, polypropylene grafted maleic anhydride (PP-g-MA) with MFI = 64 g/10 min (Priex; Netherlands) was employed as compatibilizer and modifier.

## 2.2. Preparation of nanocomposites

All Prior to the preparation of nanocomposites, all of the materials were dried in a vacuum oven for 48 hr at 80 ºC. 2 wt% PP-g-MA was added to each combinations in order to increase the carbon nanotube dispersion in nanocomposites [9]. PP/MWNT nanocomposites were carried out in an internal mixer (Haake Rheomix; HBI SYS90).The rotation speed and temperature of the mixing chamber were set at 120 rpm and 180 ºC, respectively, and blending continued for 10 min. Table 1. presented the formulations of the each sample. After pelletizing (using Wieser mill;Germany), blend granules were injection-moulded into standard test specimen for high and low velocity impact and (using Aslanian injection moulding machine;EM80;Iran). The mould temperature was kept at 25°C and the barrel temperature ranged from 200 to 220 ºC. The speed and holding 115 bar and 45 rpm, respectively. Neat PP was also similarly mixed-injection for property assessment, as a reference.

Table 1: Matrix of material investigated.

| Sample ID | PP (wt%) | PP-g-MA (wt %) | MWCNT (wt %) |
|---|---|---|---|
| PP | 100 | 0 | 0 |
| PP/0.75 | 97.25 | 2 | 0.75 |
| PP/1 | 97 | 2 | 1 |
| PP/1.5 | 96.5 | 2 | 1.5 |

## 2.3. High and Low velocity impact test procedure

A single stage gas gun was used to carry out high-velocity impact tests that it is designed and constructed at Iran Polymer and Petrochemical Institute. The schematic form of the gas gun is presented in Fig.1. All PP/CNTs nanocomposite samples were injection molded into square plates of size 120×120×2 mm. The projectile used for impact tests was hemispherical tip hardened steel (Rc60) of 25.6 mm total length, 8.1 mm diameter, shank length of 22.7 mm and 11.34 g weight. Helium gas was selected as propellant. High velocity impact tests were performed on all samples in the velocity range of 20-150 m/s. At first the gas gun was calibrated and the velocity of projectile (before impact) measured for helium gas at various gas pressures using the chronograph (F-1 model from Shooting Chrony Canada) depicted in Fig. 2. In all PP/MWNTs nanocomposite specimens the average of highest impact velocity which caused perforation but was unable to go through and lowest impact velocities with no residual velocity recordings was defined as ballistic limit (V50) recording by chronograph according to MIL-STD-662F standard.

Moreover, in order to conduct low velocity impact rectangular bars with a single-edge V-shape notch of a tip radius of 0.25 mm milled in the middle of them with 2.25 mm depth (according to the ASTM D256 standard) were employed using an Izod impact machine (Zwick 5102 model;Germany).

# 3. Results and discussion

## 3.1. Low Velocity Impact

Impact properties of PP and PP/MWNT nanocomposites are shown in Fig. 3. The Izod impact strength slightly increases with addition of MWNT to PP matrix. It is observed that specimens containing 1 wt% MWNT improve impact properties by 33.4% compared with neat PP. This may be due to nanotube bridging effects that appear as a multiplier impact resistance factors. However more than this value, at 1.5 wt% MWNT content, impact strength tends to decrease. This might be attributed to the presence of nanotube clusters or aggregates in the PP matrix which unlimbers points of stress concentrations.

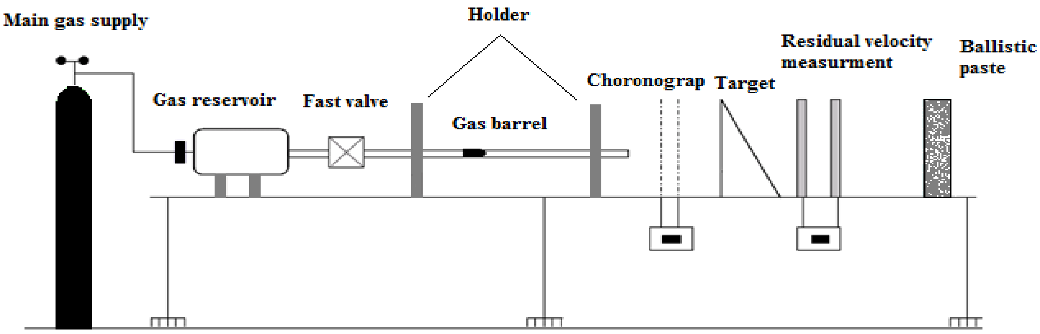


Fig. 1: High velocity impact testing machine (Gas Gun).

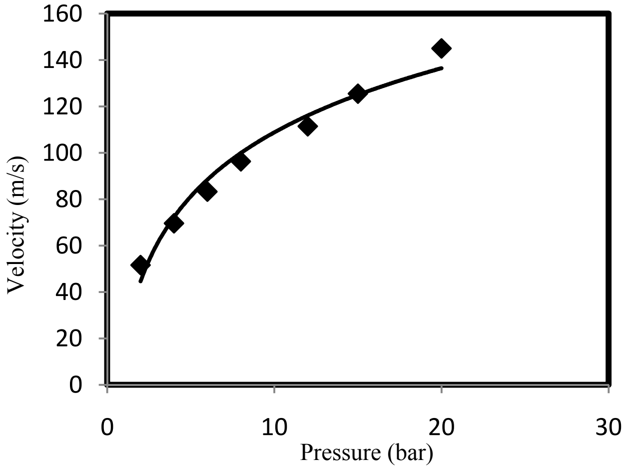


Fig. 2: Projectile velocity calibrations for various helium gas pressures.

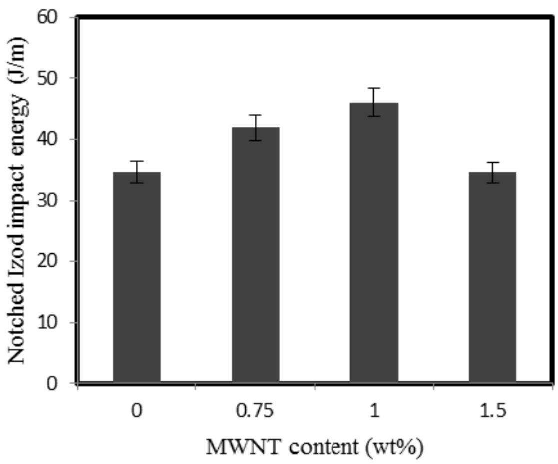


Fig. 3: Izod impact properties of PP and PP/MWNT nanocomposites.

## 3.2. High Velocity Impact

Fig. 4(a) demonstrates impact residual velocity as a function of impact velocity. The figure obviously shows lower residual velocities for different strike velocities and resulting better ballistic performance for CNT nanocomposites compared with neat PP. The ballistic limit velocity term is depicted in Fig. 4(b). This figure shows higher ballistic limit values (V50) for the specimens with MWNT fillers as compared with the neat PP plates, therefore nanocomposites containing 1 wt% MWNT increase the ballistic limit velocity by 43%, compared with pure PP. Such increase in ballistic limit may possibly linked to the nanotube bridging effects, similar to what was observed in low velocity impact tests, as a result of MWNT addition in comparison with neat UP resin. Moreover in doubled wt% MWNT i.e. in 1.5 wt% MWNT content, ballistic limit velocity tend to decrease. This might be due to aggregate formation of CNTs in PP matrix which reduce the ballistic potential.

Estimated ballistic limits (EV50) were calculated for fully perforated composite plates using the impact and residual velocity using the following relationships.

$$
\begin{gathered}
{}^{1}\!/_{2}\, mV_r^2 = {}^{1}\!/_{2}\, mV_i^2 - {}^{1}\!/_{2}\, m(V_{50})^2 \\
E_{V50} = (V_i^2 - V_r^2)^2 \text{ For } V_r > 0
\end{gathered} \tag{1}
$$

Equation (1) assume non deformable and rigid projectile (no deformation and mass loss of projectile). $V_i$ is the initial impact velocity, $V_r$ is the residual velocity, and m is the mass of projectile (11.34 g).

Fig. 5(a) indicates clustered column for estimated ballistic limits from equation (1) and experimentally determined values. It is observed from Fig. 5(a) that there is very low inequality, and comparatively good correlation among them. Some of these variations might be due to contact phenomenon or other energy absorbing parameters or data scatter. In addition initial and residual impact velocities were used to achieve energy absorption at full perforation. Fig. 5(b) indicates increase in energy absorption values as a result of MWNT addition in comparison with pure PP so that nanocomposites containing 1 wt% MWNT indicates 100 % increase in energy absorption potential.

In summary nanocomposites containing 1 wt% MWNT show the maximum ballistic limit velocity and energy absorption, while in the nanocomposites bearing 1.5 wt% MWNT, impact strength is reduced probably due to poor dispersion of MWNTs.

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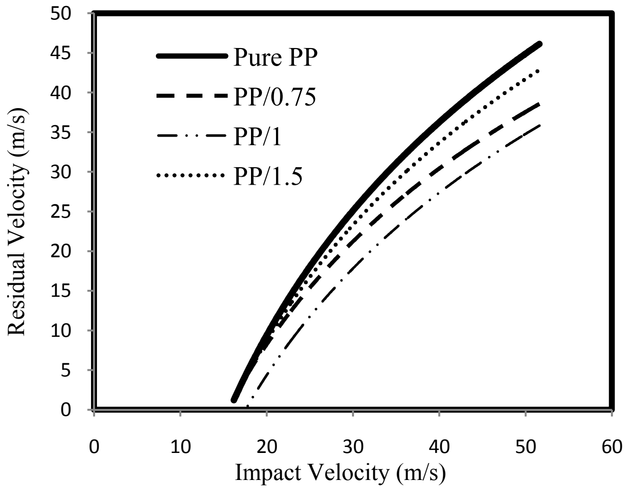
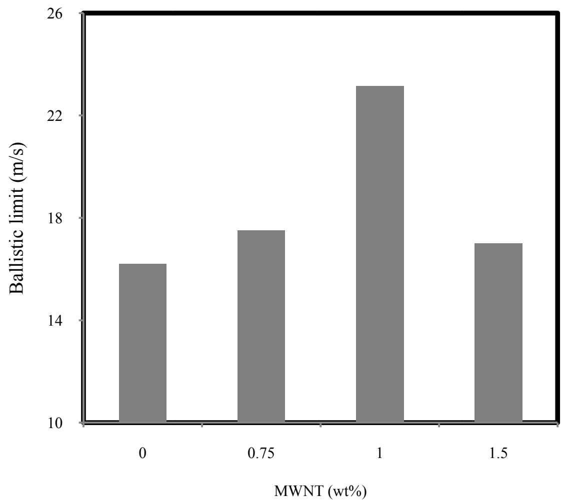
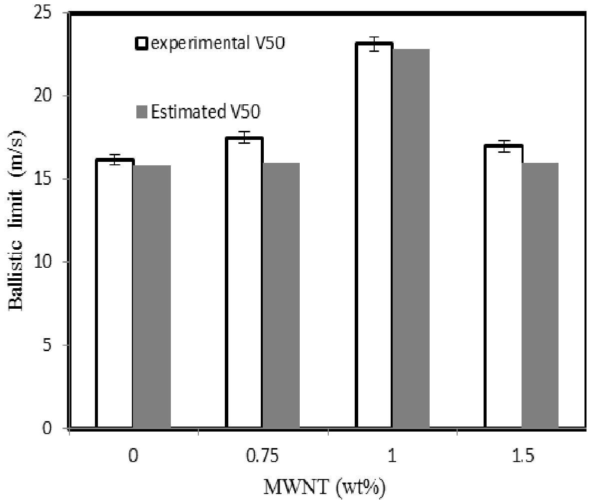
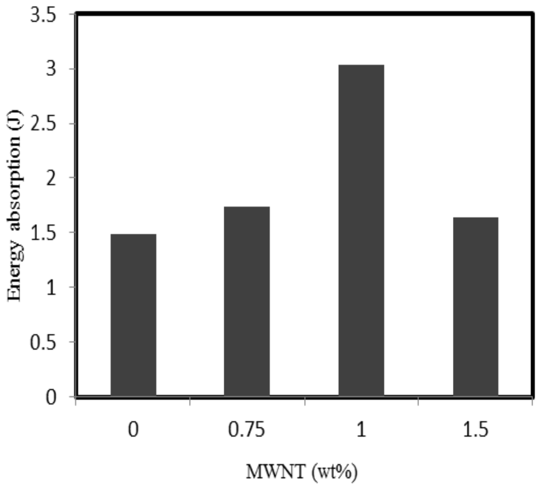



(a) (b)

Fig. 4: (a). Residual velocity as a function of the initial impact velocity and 4(b). Ballistic limits velocity (V50) as a function of MWNT content (wt%).




(a) (b)

Fig. 5: (a). Clustered column compares energy absorption values at V50 and 5(b). Energy absorption as a function of MWNT content (wt%).