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Study on the Properties of Carbon Reinforced Unsaturated Thermoset Polyester Resin Nanocomposites

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ABSTRACT

The recent emergence of nano science and nano technology has added another dimension to the staple of the modern composite technology. In this study, the composites were prepared from unsaturated polyester with excess of ethylene glycol UPER loaded with various contents of multi-wall carbon nanotube (MWCNT) and carbon black nanoparticles (CNP) at different wt %. Transmission electron microscope TEM of MWCNT and CNP indicated the dimension of the nano filler. The samples have been examined by X-ray diffraction (XRD) technique, Fourier transform infrared (FTIR) spectroscopy, mechanical test, electrical test, differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA). FTIR spectra confirmed the physical and chemical bond formations between nanofiller and matrix. The mechanical properties such as tensile strength, elongation at break, and hardness for MWCNT and CNP nanocomposites were investigated at room temperature. The results showed that tensile strength and hardness shore D were improved with MWCNT than CNP filler and reached their optimum values when loaded with concentration 0.04% for both MWCNT and CNP. Electrical conductivity of nanocomposites with MWCNT was obtained to be higher than those with CNP at the same filler content due to the ability of MWCNT to form a three-dimensional conductive network within the matrix, hence electron can tunnel from one filler to another and in doing so, it overcomes the high resistance offered by insulating polymer matrix. The thermal stability of UPER/MWCNT and CNP was enhanced compared to that of unfilled UPER.

INTRODUCTION

Polymer nanocomposites have attracted a great deal of interest in fields ranging from the scientific to the industrial fields because of remarkable improvement in the physical and mechanical properties of polymer matrix at low filler loadings. In fact, the electrical properties of conductive polymer composites depend on the nature of the polymer; the amount of filler, structure and porosity of filler; filler matrix interaction; mixing condition; etc. (Fabio *et al.*, 2009; Trchova *et al.*, 2006; Sapurina *et al.*, 2001; Kang *et al.*, 2001; Punchaipetch *et al.*, 2001). Therefore, for excellent physical and chemical properties, strong interfaces between polymer and fillers are needed. Carbon black, graphite or multiwall carbon nanotubes (MWCNTs) as conductive fillers are commonly used as a component of conductive and reinforcement polymer composites (Punchaipetch *et al.*, 2001, Iijima, s.,1991). In particular, excellent mechanical strength, thermal and electrical conductivity, have created a high level of activity in materials research for potential applications (Ishihara *et al.*, 2001; Zhang *et al.*, 2008; Kim *et al.*, 2007; Wu *et al.*, 2006). Unsaturated polyester resins (UPERs) are one of the most widely used thermosetting materials because they are relatively inexpensive and offer advantages such as being light in weight and possessing reasonably good mechanical properties. The use of UPERs in bulk and sheet molding

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compounds results in composite materials that have high strength, dimension stability, and very good surface qualities. They have many applications in automotive, aircraft, electrical, and appliance components as substitutes for traditional materials (Alan *et al.*, 2003). Efforts have been reported to the development of well-dispersed nanocomposites in order to tailor the material properties (Beg *et al.*, 2015; Alam *et al.*, 2014; Nassir 2013; Muraescu *et al.*, 2011; Abdel-Aal *et al.*, 2008; Yasmin *et al.*, 2006; Huang 2002). Beg M.D.H *et al* have studied the improvement of the interaction between pre-dispersed multi-walled carbon nanotubes and unsaturated polyester resin (Beg *et al.*, 2015). Alam, K. M. and his coworkers confirmed the structural, mechanical, thermal, and electrical properties of nano carbon black reinforced Polyester resin composites (Alam *et al.*, 2014).

In the present study, the effects of adding multiwall carbon nanotube (MWCNT) and carbon nanoparticles (CNP) separately at different weight ratios 0.01, 0.02, 0.03, 0.04 and 0.05 % to the unsaturated polyesters resin (UPER) have been investigated. Mechanical, dielectric and thermal properties of the prepared nanocomposites in comparison with the neat UPER were measured. Ultra-sonication technique was used to disperse nanofiller in the matrix.

Experimental:

2.1. Materials:

Dimethyl terephthalate and maleic acid anhydride were supplied from Sigma Aldrich Co. Styrene monomer 40wt% was used as reactive diluent and paratoluene sulphonic acid was used as catalyst for esterification process and were purchased from Sigma Aldrich Co. Ethylene glycol and cobalt octoate, as an accelerator for the curing process, were purchased from El-Nasr Pharmaceutical Co. Methyl ethyl ketone peroxide was purchased from Fluka Chemical and used as an initiator for the curing process. Multiwall carbon nanotube (MWCNT) was prepared by a chemical vapor deposition method, supplied from EPRI, Egypt with diameter and length ranged between 10 - 20 nm and 10 - 50 μm , respectively, and with an estimated aspect ratio of 500–5000, according to the supplier's specification. Carbon nanoparticles (CNP) (Vulcan XC72, Cabot Corp., Boston, MA), has a spherical shape with a diameter in the range of 20-60 nm. Images of these fillers were taken from a transmission electron microscope (TEM; JEOL-1230) as shown in Figure 1. All chemicals were chemical grade and used without further purifications.

Preparation of prepolymer of unsaturated polyester resin (UPER):

Dimethyl terephthalate (100 ml), maleic anhydride (100ml), ethylene glycol (200 ml) were mixed in a 500 ml flask in the presences of paratoluene sulfonic acid (0.5wt%) as a catalyst. The formed prepolymer was dissolved in styrene monomer 40wt%. And excess ethylene glycol (10wt%) was added with sonication for 30 min. (Motawie *et al.*, 2014).

Preparation of UPER nanocomposites:

In 100 ml beaker the prepared unsaturated polyester prepolymer (20gm), was initially mixed with different weight percentages of MWCNT or CNP (i.e. 0.0, 0.01, 0.02, 0.03, 0.04, and 0.05) by mechanical stirrer for 20 min. at 2000 rpm. Then, the mixture was sonicated at 30°C for 40 min by a 14-mm diameter probe sonicator, (Branson Sonic Power s125 sonicator). The samples were poured in Petri dishes then cobalt octoate (0.05%) was added as an accelerator and methyl ethyl ketone peroxide (0.05wt%) as an initiator for curing process at room temperature.

RESULTS AND DISCUSSIONS

3.1. XRD Analysis:

X-ray diffraction (XRD) pattern have been investigated using a modern PAN analytical diffract meter, Xpert PRO model. Nickel filtered copper radiation ($\lambda = 1.542 \text{ \AA}$) was used. All the diffraction patterns were examined at room temperature and under constant operating conditions (40 KV & 40 mA). The scanning rate was 1 degree ($2\theta/\text{min}$). Figures 2 & 3 show the XRD profiles of UPER, MWCNT, UPER/0.04 wt% MWCNT, and UPER, CNP, UPER/0.04 wt% CNP respectively. The XRD profiles reveal that polyester resin shows a broad peak at 20.29° that corresponds to its amorphous nature. The average lattice spacing estimated from the peak is about 4.47 \AA . The MWCNT contain a peak at the scattering angle of $2\theta = 26.1^\circ$ with average lattice spacing 3.51 \AA which can be graphitized of the MWCNT (Wang *et al.*, 2005). The CNP contain a sharp peak at the scattering angle of $2\theta = 25.23^\circ$ with lattice spacing was 3.58 \AA . New peaks were appeared at $2\theta = 17.82^\circ$ and 25.71° with lattice spacing 4.96 \AA & 3.55 \AA in case of 0.04wt% MWCNT/UPER and 0.04 wt% CNP/UPER respectively. This increase in lattice parameter or the shift to lower angle on using 0.04 MWCNT may be attributed to the intercalation of nanofillers into the matrix. On the other hand, the slight increase in 2θ values upon using 0.04 wt% CNP was observed (Fig.3). This means that crystallinity increases at 0.04 wt% CB in composites. This was in agreement with the previously reported result for carbon black reinforced epoxy resin

(Abdel-Aal *et al.*, 2008). From these results, it can be inferred that the nanofillers are distributed well in resin matrix, leading to an increase in the interfacial adhesion among filler and matrix. Moreover, a slight decrease in peak width and increase in peak intensity for the nanocomposites was also observed.

3.2. FTIR Analysis:

The structure of the samples was characterized by Fourier transform infrared analysis (FTIR) on a Mattson 1000, series LC operating, Issue I (0791) spectrophotometer, in the wave number range of 4000- 500 cm^{-1} . Figure 4 illustrates the FTIR spectra of UPER, UPER/0.04% MWCNT and UPER/0.04% CNP.

For UPER spectrum absorption band appears at 1068 cm^{-1} which is attributed to C–O stretching vibrations (Abdalla *et al.*, 2007). The peaks that appear at 1288 cm^{-1} may be assigned to CH_2 twisting, 1380 cm^{-1} to CH_3 symmetrical bending, 1600 cm^{-1} to aromatic ring stretching, and 1724 cm^{-1} to C=O stretching vibrations. The bands in the range of 2885–3027 cm^{-1} correspond to stretching vibrations of C–H groups, such as CH_2 and CH_3 . The ester bonds (C–O–C) usually appear at 1250 cm^{-1} , which is seemingly overlapped with the intense peak at 1288 cm^{-1} . These results prove that UPER molecules bind together through chemical bond, especially ester bond.

It was observed that the carbonyl (C=O) stretching band of UPER at 1724 cm^{-1} has been shifted to a higher frequency of 1734 cm^{-1} & 1731 for UPER/MWCNT and UPER/CNP respectively. This may be indicated to ester bond formation (C–O–C) of UPER with the used nanofillers. Two peaks appearing at 1450 and 1380 cm^{-1} for pure UPER has been shifted to higher frequency of 1454, 1394 cm^{-1} and 1455, 1395 for UPER/MWCNT and UPER/CNP respectively. This may be donated the bond formation between the used nanofillers and UPER (Beg *et al.*, 2015)

Table 1: The T_{50} , T_d and residue contents of different samples (unsaturated polyester UPER resin and nanocomposites with multiwall carbon nanotube (MWCNT)).

Samples code	Wt% of MWCNT	T_{50}^{a0} °C	T_d^{b0} °C	Char Yield at 500°C
UPER	0	343	378	4.4
UPER/MWCNT1	0.01	351	384	5.7
UPER/MWCNT2	0.02	354	387	6.1
UPER/MWCNT3	0.03	355	388	6.8
UPER/MWCNT4	0.04	357	390	7.9
UPER/MWCNT5	0.05	350	381	5.2

Table 2: The T_{50} , T_d and residue contents of different samples (unsaturated polyester UPER resin and nanocomposites with carbon nanoparticle (CNP)).

Samples Code	Wt% of CNP	T_{50}^{a0} °C	T_d^{b0} °C	Char Yield at 500°C
UPER	0	343	378	4.4
UPER/CNP1	0.01	344	380	4.6
UPER/CNP2	0.02	346	381	5.91
UPER/CNP3	0.03	351	382	6.5
UPER/CNP4	0.04	354	383	7.8
UPER/CNP5	0.05	341	372	3.4

a Decomposition temperatures at 50% weight loss.

b Decomposition temperature at the maximum decomposition rate.

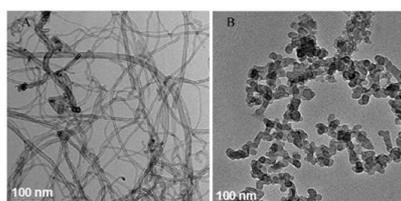


Fig. 1: TEM of a) MWCNT & b) CNP.

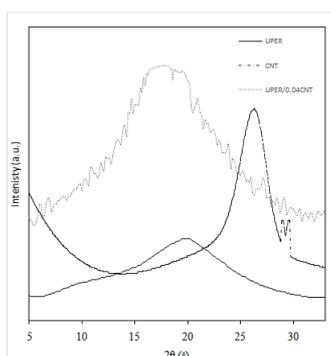


Fig. 2: XRD of UPER, MWCNT, & UPER/0.04% MWCNT.

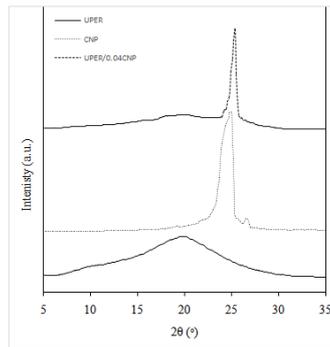


Fig. 3: XRD of UPER, CNP, & UPER/0.04%CNP.

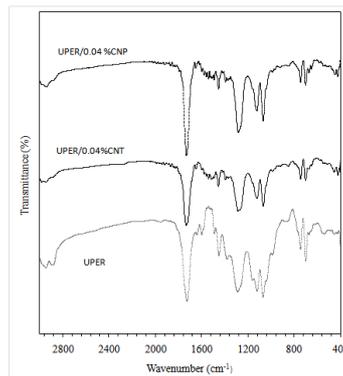


Fig. 4: FTIR of UPER, UPER/0.04%MWCNT & UPER/0.04%CNP.

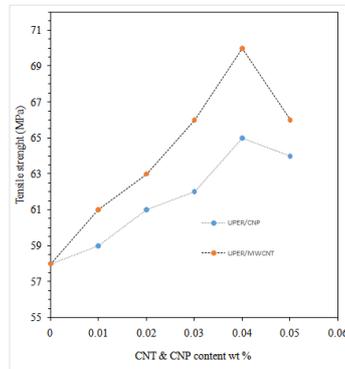


Fig. 5: Tensile strength of UPER/MWCNT and UPER/CNP with filler content wt %

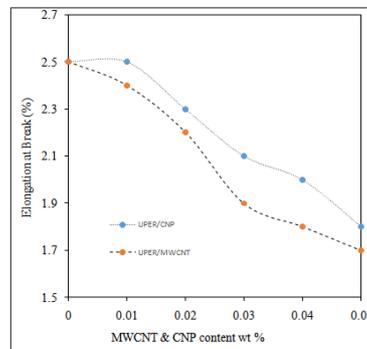


Fig. 6: Elongation at break of UPER/MWCNT and UPER/CNP with filler content wt %.

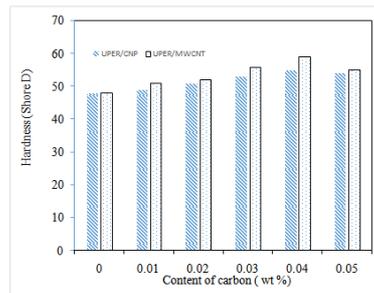


Fig. 7: Hardness of UPER/MWCNT and UPER/CNP with filler content wt%.

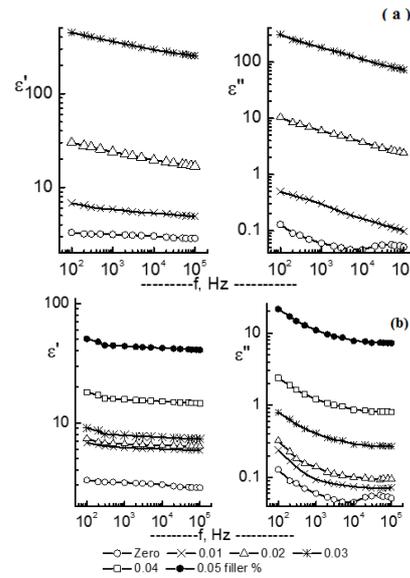


Fig. 8: The permittivity ϵ' and dielectric loss ϵ'' versus the applied frequency for (a) MWCNT and (b) CNP unsaturated polyester nanocomposites

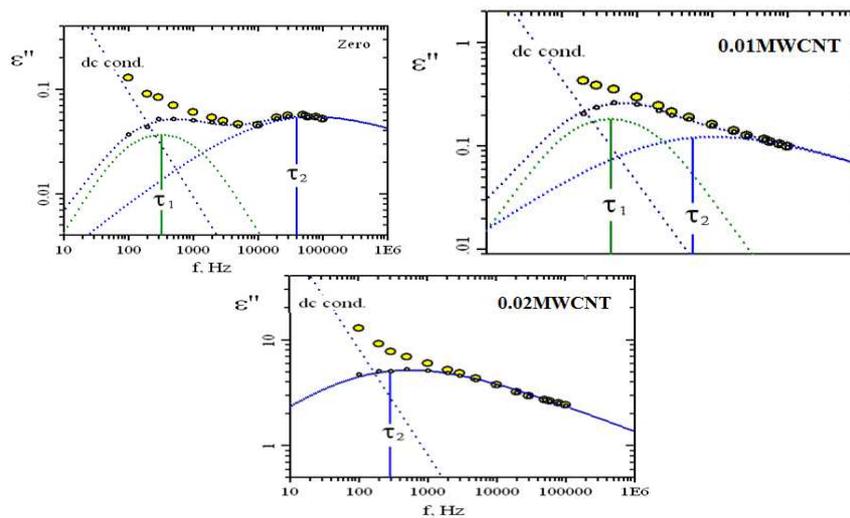


Fig. 9: Absorption curves of MWCNT unsaturated polyester composites loaded with 0, and UPER/0.01% MWCNT&UPER/0.02% MWCNT.

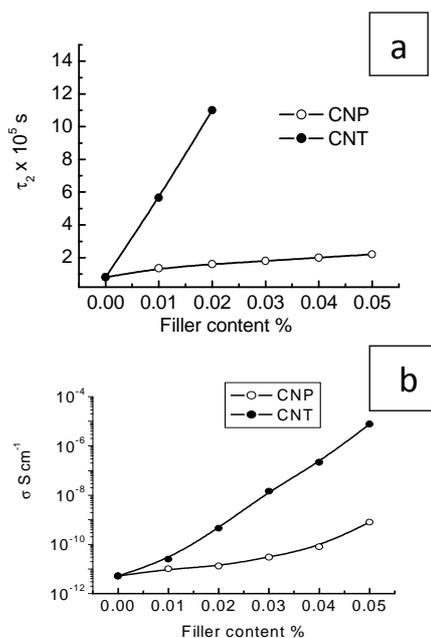


Fig. 10: a) Relaxation time τ_2 & b). Electrical conductivity versus filler content.

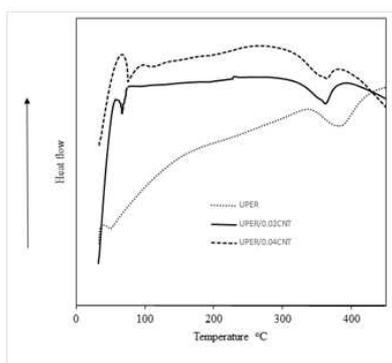


Fig. 11: DSC of UPER, UPER/0.02%MWCNT & UPER/0.04%MWCNT.

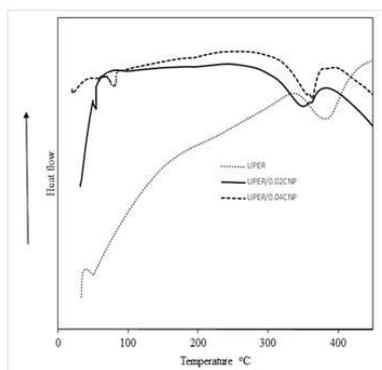


Fig 12: DSC of UPER, UPER/0.02%CNP & UPER/0.04%CNP.

3.3. Mechanical Analysis:

Mechanical measurements (i.e tensile strength, elongation at break) were determined with an Instron 1026 testing machine, according to ASTM-D638, 08. Hardness of the test specimens was measured with Shore D durometer according to ASTM-D2240-05. All these tests were performed at room temperature ($25 \pm 1^\circ\text{C}$) and the reported results were averaged from a minimum of five specimens.

The effect of multiwall carbon nanotubes and carbon nanoparticles loading on the mechanical properties of unsaturated polyester nanocomposites is shown in Figures 5-7.

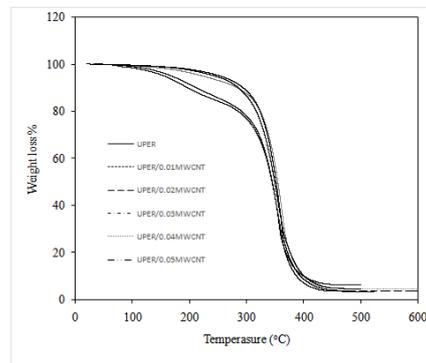


Fig. 13: TGA curve of UPER and nanocomposite samples loaded with different wt% MWCNT.

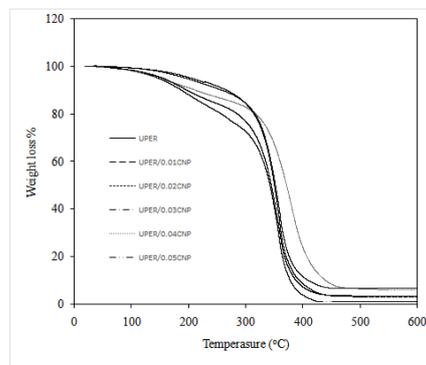


Fig. 14: TGA curve of UPER and nanocomposite samples loaded with different wt% CNP.

The tensile strength (Figure 5) of MWCNT nanocomposites are 61, 63, 66, 70 and 66 MPa for 0.01, 0.02, 0.03, 0.04 and 0.05 wt %, respectively. Unsaturated polyester with 0.04 wt. % of MWCNT shows maximum strength as compared with the neat matrix.

In case of UPER/CNP, Figure 5 the pure unsaturated polyester shows tensile strength of 58 MPa. In comparison with 59, 61, 62, 65 and 64 MPa for the prepared nanocomposites with 0.01, 0.02, 0.03, 0.04 and 0.05 wt % CNP, respectively. Also unsaturated polyester with 0.04 wt. % of CNP shows maximum strength. Tensile strength of nanocomposites was enhanced when the interfacial adhesion was improved. This result can be described to better stress transfer at the interface between matrix and nano filler (Yasmin *et al.*, 2006).

For higher loading of nanofiller (i.e. beyond 0.04 wt%) in the resin matrix, filler agglomeration is easier. The stress concentration due to external force, resulting in decreased tensile properties (Abdul Khalil *et al.*, 2007, Ismail *et al.*, 2004). Moreover, at each loading rate, composite specimen containing MWCNT has higher values than that with CNP. For instance, the nanocomposites with 0.04 wt% of MWCNT and CNP are 20% and 12% higher strength than those with the neat resin UPER, respectively.

Figure 6 shows the elongation at break percentages of the prepared composites versus the weight percentage of nanofiller. The elongation at break (%) decreases gradually with increasing of filler loading. The reduction of elongation at break may be due to stiffening of the polymer matrix by the filler. The increase in filler loading causes the molecular mobility to decrease due to the extensive formation of physical bonds between the filler and the polymer chains that stiffen the matrix (Mitchell, 2004).

As shown in Figure 7 hardness test type Shore (D), the hardness values increase with increasing weight percentages of both fillers up to 0.04%. (Hanna *et al.*, 2011). Hardness had reached its maximum value of 60 and 56 at 0.04% wt of MWCNT & CNP, respectively. Beyond 0.04 wt % loading hardness values decrease as explained before in the previous section.

3.4. dielectrically Analyses:

Dielectric measurements were carried out in the frequency range 100 Hz up to 100 kHz by using an LCR meter type AG-411 B (Ando electric Ltd. Japan). The capacitance C, the loss tangent $\tan \delta$ and the resistance R

were obtained direct from the bridge from which the permittivity ϵ' , dielectric loss ϵ'' and electrical conductivity σ were calculated. The samples were molded in the form of discs with 5 cm diameter and 3mm thickness. A guard ring capacitor (type NFM/5T Wiss Tech. Werkstätten GMBH, Germany) was used as a measuring cell. The cell was calibrated with standard materials (Abd-El-Messieh *et al.*, 2003) and the experimental errors in ϵ' and ϵ'' were found to be ± 3 and $\pm 5\%$, respectively.

The permittivity ϵ' and dielectric loss ϵ'' were measured in the frequency range from 100 Hz up to 100 kHz at 30 °C for unsaturated polyester resin loaded with carbon nanotube (MWCNT) and carbon nanoparticles (CNP) with different concentrations ranging from 0 up to 0.05%. The data obtained for MWCNT and CNP are given in Figure 8. The ϵ' for whole investigated composites decreases with increasing the frequency showing an anomalous dispersion. The rotational motion of the polar molecules of dielectric is not sufficiently rapid to attain equilibrium with the field. (Pathania *et al.*, 2009). This behavior is expected in most polymer dielectrics and is due to the dielectric relaxation phenomena of the polymer materials. Within the measured frequency range, the dielectric relaxation includes the dipolar (rotational) polarization, which depends on the molecular structure of the material. At higher frequencies, the rotational motion of the molecules lags behind the electric field, leading to reduced permittivity with increasing frequency (Zhan *et al.*, 2011). The data of ϵ' and ϵ'' given in Figure 8 at different frequencies indicate that an abrupt increase is noticed at higher concentration of filler. With this increases, the tendency of conductivity chain formation increases through the aggregation of the carbon nanoparticles network, while with low concentration, the carbon nanoparticles are widely dispersed through the unsaturated polyester matrix. On the other hand, the absorption curves of ϵ'' versus the frequency f shown in Figure 8 are broad indicating that, in addition to the electrical conductivity, more than one relaxation mechanism is present (Ben Amor *et al.*, 2009). After subtracting the losses due to the conductivity, the analysis of the absorption curves relating dielectric loss ϵ'' and the applied frequency f , are analyzed using "Fröhlich" and a "Havriliak-Negami" functions according to the equations given elsewhere (Abd-El-Messieh, 2003). Example of the analyses is given in Figure 9. The first relaxation observed at low frequency range with relaxation time about 3.8×10^{-4} s can be attributed to an interfacial polarization, known as the Maxwell-Wagner-Sillars (MWS) effect (Arous, 2007). This relaxation arises from the fact that free ingredients added to unsaturated polyester resin during preparation, which were present at the stage of processing, are now immobilized in materials which lead to the certain of conductivity of the media and consequently the charges can migrate in the applied electric field. It was interesting to notice that the relaxation time associated with this region, τ_1 was not affected by either filler content or filler type. It was of great interest to notice that in case of MWCNT composites after the critical concentrations 0.02%, this region disappears as it becomes predominant with the dc conductivity, Figure 9. The second absorption region at the higher frequency range with relaxation time τ_2 was found to be in the order of 10^{-5} s, and fitted by "Havriliak-Negami" function was attributed to the orientation of the large aggregates caused by movement of the main chain. It was found that τ_2 increased by increasing filler content. The higher values of τ_2 obtained at higher concentrations reflect filler-polymer interaction, which could takes place which increase the molar volume of the rotating units and consequently the relaxation time (Abd-El-Messieh *et al.*, 2013). It was also interesting to mention that the dielectric parameters ϵ' and ϵ'' were measured only for concentrations up till 0.02% for MWCNT composites after which the measurements cannot be detected due to the expected high values of ϵ' and ϵ'' than the available range of the apparatus see Figure 9. The second relaxation time associated with such mechanism for the completely investigated systems are illustrated graphically versus filler content in Figure 10 (a). From this figure., it is clear that the increase in τ_2 is large in case of MWCNT composites when compared with that for CNP which reflect much more filler-polymer interaction. This interaction may be the reason for the better properties of the MWCNT unsaturated polyester composites at 0.02MWCNT.

Figure 10 (b) illustrates the electrical conductivity σ dc of the different composite systems as a function of the percentage of filler content. For the two investigated systems, conductivity of the composites initially increases slowly with increasing the concentration of carbon black (up to concentrations of 0.02- 0.03 % for CNP and 0.01% for MWCNT) followed by a sharp increase. This increase is called the percolation threshold concentration (Abd-El-Messieh *et al.*, 2013). Before the percolation, conductive particles remain isolated from each other in the insulating unsaturated polyester matrix and at the percolation the continuous conductive network is just formed. Therefore, there is an abrupt change in the conductivity of the system due to transition from insulating to conducting state. The physical picture of this conductivity change with filler concentration may be described as follows. With the addition of sufficient conductive filler (percolated quantity) in an insulating matrix as if a continuous end to end conducting chain like metal wire is just formed. Before the percolation, this metal wire is not continuous and net conductivity is significantly less. After the percolation, there was only increase in the number of conductive chains as if there is only increase the diameter of metal wire leading to relatively very small increase in conductivity (Abd-El-Messieh *et al.*, 2013).

From Figure 10 (b), it is clear that the conductivity values σ increases dramatically by increasing MWCNT content to reach the order of 10^{-5} S cm^{-1} for 0.05% MWCNT which highly recommend these composites to be used for electrostatic dissipation applications as the range for such purpose is $10^{-5} - 10^{-9}$ S cm^{-1} . On the other

hand, the values of σ for CNP composites are found to be in the order of 10^{-10} S cm^{-1} which recommend such composites to be used for the anti-static applications as the range needed for such application is 10^{-9} – 10^{-14} S cm^{-1} (Huang, 2002).

3.5. Thermal Analyses:

Differential scanning calorimetry (DSC) was performed to determine the thermal transitions in the material, using a TA/Q1000 apparatus under nitrogen atmosphere and ramp method. During DSC analysis, the samples were heated at temperatures in the range of 30–450 °C with a heating rate of 10 °C min^{-1} .

DSC investigated thermal characterization of the samples and the results are presented in Figures 11 & 12

The endothermic peak at the lower temperature region around 55–72 °C for all samples under investigation is ascribed to the glass transition temperature (T_g), allowing information of thermal transitions of polymer chain molecules. Furthermore, the endothermic peak around 378–402 °C is related to the deformation temperature (T_d) of UPER. Instead of one endothermic peak as shown by UPER matrix, both nanocomposites exhibit a split melting endotherm into two peaks (T_{d1} and T_{d2}). The presence of double-degradation peaks for the nanocomposites may indicate the bond formation between fillers (MWCNT&CNP) and UPER.

The T_g of UPER, UPER/0.02%MWCNT and UPER/0.04%MWCNT were 52 °C, 68 °C, 70 °C respectively. The T_g of UPER, UPER/0.02%CNP and UPER/0.04%CNP were 52 °C, 58 °C, 60 °C respectively. In the presence of MWCNT & CNP nanofillers, a localized crystallization within nano-range takes place in the host matrix. The nanocrystalline regions in matrix relatively become well-ordered as well as enhance the degree of curing, which restrict the resin chain mobility in the surrounding area of MWCNT leading to higher values of T_g as compared with those of nanocomposites loaded with CNP. This was inconsistent with the elongation at break data (Allaoui *et al.*, 2009; Seymour *et al.*, 1973).

Thermal stability was determined by the thermo gravimetric analysis (TGA) with Shimadzu TGA-50H thermal analyzer using 8–10 mg samples in nitrogen atmosphere and at a heating rate of 10 °C/min from 50–500 °C. TGA curves of UPER/MWCNT and UPER/CNP were demonstrated in Figures 13 & 14. In this study, TGA of both resin and nanocomposites seem to fall at 173 °C, indicating the emission of volatile components such as unreacted styrene, residual solvents, and uncross-linked polyester resin (Xia Cao *et al.*, 2003; Troitzsch, 1990). Thermal degradation of UPER takes place in four steps in which the onset of weight loss takes place at about 303 °C. On the other hand, this degradation in composites starts at relatively higher temperature than that found in neat resin. Moreover, the decomposition was occurred at 318 °C for UPER/MWCNT and UPER/CNP composites, looks different from the UPER. These may be connected to the decomposition behavior of cross-linked resin composites. The degradation of cross-linked resin has been ascribed by the dissociation of C–C chain bonds and release of styrene at the site of dissociation (Alam *et al.*, 2014; Abdel-Aal *et al.*, 2008). There was an enhancement of thermal properties at 0.04% for both fillers. MWCNT has high thermal properties and high char yield more than carbon nanoparticles as we mention above. The T_{50} (357, 354), T_d (390, 383) and the residue content at 500 °C (7.9, 7.8) for UPER/MWCNT and UPER/CNP composites respectively. This fact is suggested to be due to either by the bond formation or by the barrier effect of rigid MWCNTs, which strictly hinder the thermal motion of the cross-linked chain segments in UPER/MWCNT composites. (Beg *et al.*, 2015) (Table 1 & 2).

Conclusion:

MWCNTs and CNP/unsaturated polyester nanocomposites were successfully produced by using sonication process technique. It was found that the incorporation of very low amount of MWCNTs into the resin system induced an electrical conduction in the resulting nanocomposites more than CNPs nanofiller. The increasing in tensile strength and hardness are due to the increasing in nanofiller loading of both fillers up to 0.04%. DSC confirmed the interaction between UPER and nanofillers which has effect on the thermal properties. TGA analysis exhibits covalent bond formation and an increased thermal degradation temperature for MWCNTs and CNP/unsaturated polyester nanocomposites as compared with neat resin.

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