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MECHANICAL CHARACTERIZATION OF POLYESTER/ E-GLASS FIBER REINFORCED/MWCNTS NANOCOMPOSITES

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ABSTRACT: Mechanical properties of polyester/glass fiber reinforced by multiwalled carbon nanotubes (MWCNTs) were studied. MWCNTs nano particles are mixed within resin in various weight fractions of 0.1, 0.2, 0.4 and 0.6 % using sonication. E-Glass fiber (chopped strand mat) is used in various weight fractions within the composite like 80/20 wt%, 70/30 wt%, 50/50 wt% to fabricate polyester/CSM/MWCNTs composites. The effect of the addition of MWCNTs nanoparticles on the mechanical characteristics such as hardness and tensile strength were investigated. The effect of various E-glass fiber chopped strand mat (CSM) wt.% reinforcement is also investigated. A scanning electron microscope (SEM) was used to show the nanocomposites morphological properties such as reinforcement orientation and the bonding between matrix and fiber. It was found that the addition of 0.4 wt% MWCNTs improves the mechanical properties of composites, especially the 50 wt% polyester / 50 wt% CSM composite. The tensile strength improved by 39.8%, and the hardness improved by 38%.

ABSTRAK: Ciri-ciri mekanikal bagi poliester / gelas fiber diperkukuh dengan dinding berbilang karbon nanotiub (MWCNTs) dikaji. Partikel nano MWCNT telah dicampur ke dalam resin pelbagai berat pada pecahan 0.1, 0.2, 0.4 dan 0.6 % menggunakan sonikasi. Gentian Kaca-E (potongan lembaran) telah digunakan dalam pelbagai pecahan berat dalam komposit 80/20 wt%, 70/30 wt%, 50/50 wt% bagi menghasilkan komposit poliester/CSM/MWCNT. Kesan penambahan nanopartikel MWCNT pada ciri-ciri mekanikal seperti kekerasan dan kekuatan tensil diuji. Kesan pelbagai gentian Kaca-E (potongan lembaran) (CSM) wt.% bersama agen pengukuh turut dikaji. Pengimbas Mikroskop Elektron (SEM) digunakan bagi menilai ciri-ciri morfologi komposit nano seperti orientasi pengukuh dan ikatan antara matrik dan gentian. Dapatan kajian menunjukkan dengan penambahan sebanyak 0.4 wt% MWCNT dapat memperbaiki ciri-ciri mekanikal komposit terutama komposit campuran (50 wt% polyester / 50 wt% CSM). Ketahanan tensil meningkat sebanyak 39.8%, dan kekerasan telah bertambah sebanyak 38%.

KEYWORDS: *MWCNTs; nanoparticles; mechanical properties; polymer nanocomposites; E-glass fiber*

1. INTRODUCTION

Glass fiber-reinforced composite materials (GFRPs) are increasingly used due to their high rigidity, high durability limit, high corrosive resistance, low thermal expansion coefficient and close-net shape, and greater production viability compared to conventional engineering materials [1]. Nanocomposites became significant, in the last few decades in particular, to boost mechanical properties for different applications [2]. Such nanomaterials are capable of improving mechanical, thermal, and electrical characteristics. Recent research has been carried out to investigate the utility of polyester/glass fiber/MWCNTs composites in many fields like aerospace and automotive industries because of their light weight and high performance [3-6]. Composites based on CNTs have been widely studied using a variety of matrix materials like ceramics [4-6], metals [7], and polymers [8-12]. Breton [13] improved epoxy resin by adding different kinds of MWCNTs and subsequently mechanical characteristics of MWCNTs were tested. The results showed that a higher tensile modulus was acquired by the enhancement of MWCNTs within epoxy resin of 1, 3, and 6 weight percentage. Liu et al. [14] dispersed 2 wt.% of MWCNTs in a nylon-6 matrix, they found that the tensile modulus increased about 214% and the yield strength about 162%.

Allaoui et. al. [15] investigated the mechanical and electrical characteristics of the MWCNTs/epoxy composite and concluded that 1 wt.% and 4 wt.% of carbon nano-tubes greatly enhanced the composite's young's modulus and yield strength. Zhou [16] filled epoxy resin of 0.1 wt%, 0.2 wt%, 0.3 wt%, and 0.4 wt% CNTs and studied the loading effects on the mechanical properties of composites. The results show the increased modulus with a higher CNT material content, while the maximum strength was reached by the 0.3 wt% CNT. Schadler et. al. [17] investigated the load transition in epoxy composite reinforced by MWCNTs and observed that the compression modulus was significantly scattered; its maximum value was 6 MPa which was large compared to the tension modulus of 4.2 MPa. Shekar et al. [18] used a sonication technique to distribute MWCNTs within polymer matrices efficiently and homogenously. The author also pointed out that the flexural force and flexural modulus of nanocomposites were increased by amino functionalized MWCNT in the epoxy composites. The calendar technique for standardized distribution of MWCNTs in epoxy resin was introduced by Gojnyet et al. [19] the mechanical properties were improved by the addition of a small wt% of nanotubes compared to the same wt% of carbon black dispersed in the epoxy resin. Results indicated that nanotube-filled epoxy resin had improved fracture toughness, tensile strength, and elasticity modulus under ductility retention.

Shokrieha et al. [20] studied the effect of adding MWNTs on properties of mat/polyester composites. They concluded that the flexural strength of the composites was improved by 45% at only 0.05 wt.% of MWNT. Furthermore, increasing the amount of MWNTs in composites enhanced their tensile, flexural, and compressive moduli.

Multi-wall carbon nanotubes (MWCNTs) were used as a secondary improvement in the current study to strengthen the mechanical properties of the polyester/CSM composite. polyester/CSM laminate was developed using a hand-layup technique. It was discovered that adding 0.4 wt% MWCNTs to composites improved their mechanical properties, especially in 50/50 wt% composites.

2. MATERIALS

2.1 Fabrication of MWCNTs Based Nanocomposites

Chopped strand mat (CSM) has a fiber length between 20 and 30 mm. Fiber mass of 450 g/m^2 was used as a first reinforcement and polyester as a matrix. Multiwalled carbon nano tubes MWCNTs (93%, diameter 10–40 nm and length 5–20 μm) were provided by Sigma-Aldrich and were used as secondary reinforcement. Figure 1 shows the fiber and the MWCNTs nanofiller used to fabricate polyester/CSM nanocomposites. Methyl ethyl ketone peroxide (MEKP) was added as a catalyst to the orthophthalic unsaturated polyester as a cure for ambient temperature. Both fibers and polyester materials were purchased from Al-Joumhouria Co. Cairo, Egypt. The polyester/CSM/MWCNTs nano composites were manufactured using a hand-layup technique [21] these composites were manufactured using a flat wooden mold, as shown in Fig. 2, which was horizontally mounted and covered with a thin layer of a release agent of liquid polyvinyl acetate (PVA). Firstly, MWCNTs were added to polyester resin using sonication, then a first layer of MWCNTs/polymer resin was rolled across a single roller. Next, a layer of CSM was laid on top of the first layer of nano-MWCNTs/polyester resin. The layer was subsequently mounted on the mold surface. A smooth steel roller was employed to squeeze air out of the layers, which also ensured that the polyester resin layers were evenly distributed across the surfaces. An additional layer of MWCNTs / polyester resin was added to the glass fiber sheet. Polyester/CSM/MWCNTs nanocomposites were made up of three layers of CSM. Glass fibers, were constructed at 4 mm of thickness during the same process. The substance was then treated for 24 hours at room temperature.

The composites are produced in various fractions of weight such as:

Sample code	Polyester (wt%)	CSM (wt%)	MWCNTs (wt%)
S1	80	20	0
S2	80	20	0.1
S3	80	20	0.2
S4	80	20	0.4
S5	80	20	0.6
S6	70	30	0
S7	70	30	0.1
S8	70	30	0.2
S9	70	30	0.4
S10	70	30	0.6
S11	50	50	0
S12	50	50	0.1
S13	50	50	0.2
S14	50	50	0.4
S15	50	50	0.6

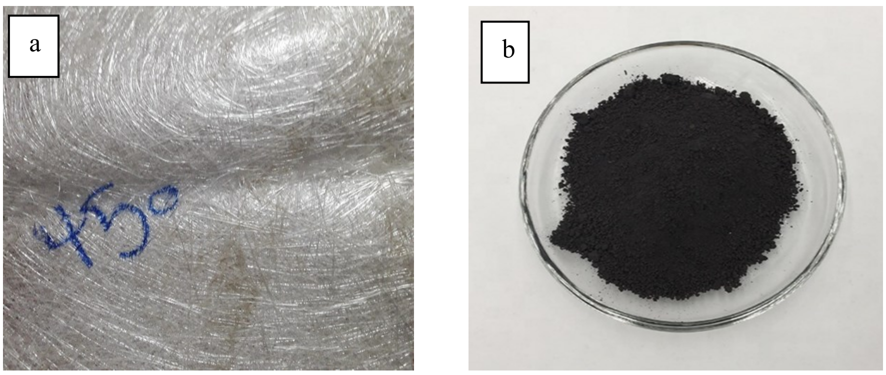

Fig. 1: (a) E-glass fiber chopped strand mat glass fiber, (b) MWCNTs nano-powder.

Fig. 2: Hand-layup technique.

3. TESTING

3.1 Tensile Strength

MWCNTs nanoparticles in various percentages as 0.1%, 0.2%, 0.4% and 0.6% were introduced to various weight percentages of polyester/glass fiber like 80/20 wt%, 70/30 wt%, and 50/50 wt% then tensile test was conducted using WAW-300B (300 kN, Zhejiang Jingyuan Mechanical Equipment Co., Ltd., Jinhua, China) tensile testing machine with a constant strain rate of 1 mm/min, according to ASTM D3039. Six samples were tested and an average value was chosen for each nanocomposite. The model tensile specimens are presented in Fig. 3 before conducting the tensile test.

3.2 Hardness

Hardness tester (Barcol hardness test type 934-1) was used to test specimens according to the ASTM D638 type IV (Fig. 4). About six samples were checked and the average value was chosen for each nanocomposite. The specimen was put under the Barcol hardness tester indentor and the specimen was subjected to a uniform pressure up to meeting the optimum dial indicator. The deep penetration was converted to absolute numbers of Barcol to obtain hardness in Brinell. Different weight percent of MWCNTs nanoparticles were introduced to investigate different (polyester/CSM/MWCNTs) composites hardness.

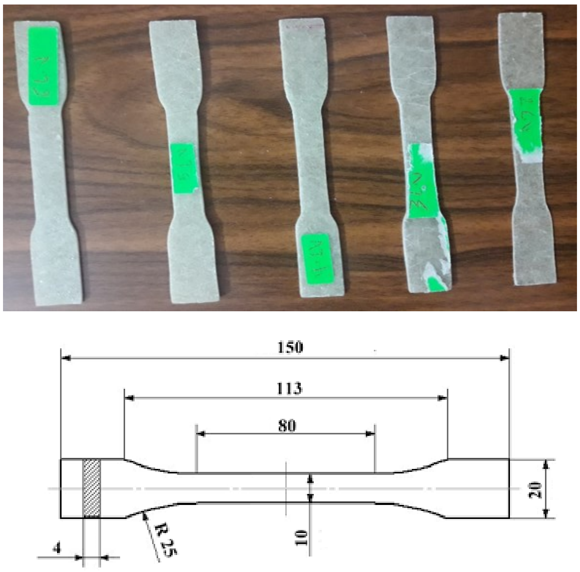

Fig. 3: The standard tensile specimens.

Fig. 4: ASTM D638 Type IV standard specimen using Barcol tester.

4. RESULTS AND DISCUSSION

4.1 Tensile Strength of Polyester/CSM/MWCNTs Nanocomposites

The tensile strength variations versus the weight percent of MWCNTs nanoparticles are shown in Figs. 5(a-c), various wt.% of polyester/CSM/MWCNTs specimens were fabricated. Fig.5(a) indicates that the tensile strength of (80 wt.% polyester / 20 wt.% CSM) without MWCNTs has a value of 75.4 MPa. While in case of (80 wt.% polyester / 20 wt.% CSM + 0.1 wt.% of MWCNTs) the tensile strength value increased from 75.4 MPa to 101 MPa. The maximum tensile strength is then observed to be 104.5 MPa at 0.4 wt.% of MWCNTs specimen, that means the tensile strength is improved by 38.5%. by more reinforcement with MWCNTs. Over 0.4 wt.% the tensile strength was then reduced and it reached a low value of 77.03MPa when MWCNTs were added by 0.6 wt.%.

It is observed from Fig. 5(b) that tensile strength of polyester/fiber (70/30 wt.%) composite has a value of 97.01 MPa. By being reinforced up to 0.1 wt.% with MWCNTs nanoparticles, the tensile strength value was increased from 97.01 MPa to 123.11 MPa and reached a maximum value of 140.07 with the addition of MWCNTs up to 0.4 wt.% (tensile strength of composite improved by 44%). It was observed that tensile strength decreased by further addition of MWCNTs nanoparticles over 0.4 wt.%, and dropped to 94.74 MPa at the 0.6 wt.% of MWCNTs. This is close to the pattern of 80/20 wt.% of Polyester/CSM shown in Fig. 5(a).

Figure 5(c) shows a similar pattern of tensile strength variation of polyester/CSM 50/50 weight percentage and the tendency for variation in strength of nanoparticles with various wt.% of the MWCNT. As discussed previously, results were found to be similar. This shows that the percentage value of the material composition changed its tensile strength. Also, the addition of MWCNTs nanoparticles affects the polyester/CSM composite tensile strength values. It is observed that the further increase of MWCNTs nanoparticles leads to decrease in tensile strength for all polyester/CSM composites.

Figure 6 indicates a comparison between tensile strength variation vs different wt. percentages of MWCNTs nanoparticles reinforces polyester/CSM (80/20 wt.%, 70/30 wt.% and 50/50 wt.%). It is concluded that the nanocomposite of 50/50 wt.% of polyester/CSM/MWCNTs at the same content of 0.4 wt.% of MWCNTs has a tensile strength value of 170 MPa compared to 80/20 wt% (about 105 MPa) and 70/30 wt.% composite (about 140 MPa).

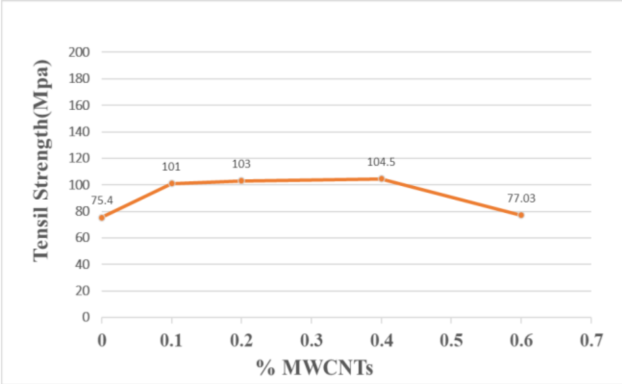

Fig. 5: (a) Tensile strength vs % MWCNTs of polyester/CSM (80/20 wt.%).

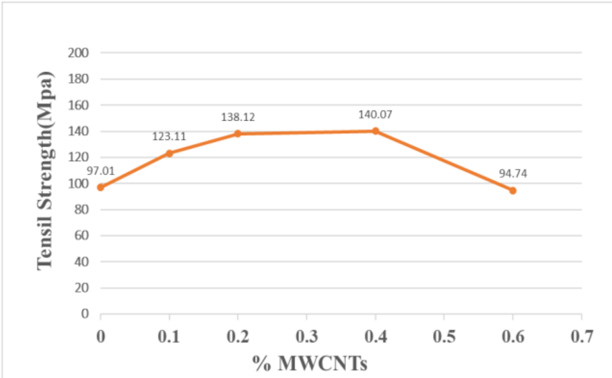

Fig. 5: (b) Tensile strength vs % MWCNTs of polyester/CSM (70/30 wt.%).

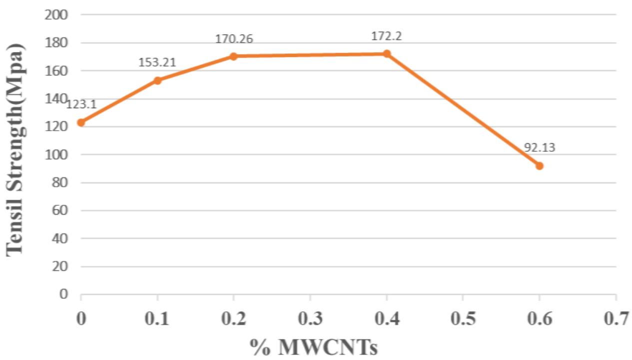

Fig. 5: (c) Tensile strength vs % MWCNTs of polyester/CSM (50/50 wt.%).

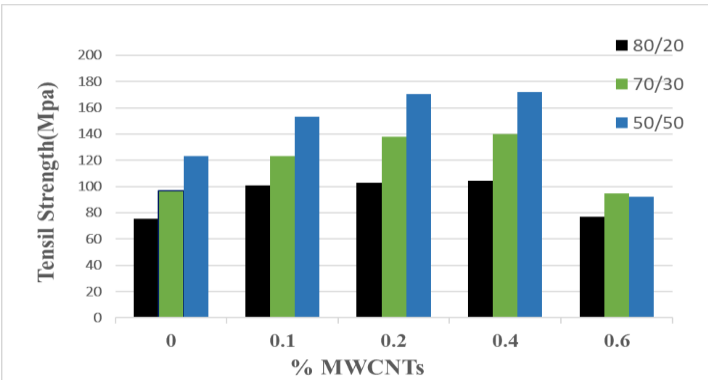

Fig. 6: Comparison between tensile strength variation and different wt. percentages of MWCNTs reinforces polyester/CSM (80/20 wt.%, 70/30 wt.% and 50/50 wt.%).

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4.2 SEM Microscopy

Figure 7(a) shows an SEM image of 0.4 wt.% MWCNT-reinforced 50/50 wt.% of polyester/CSM. From this figure, a matrix-fiber adhesion is observed. This explains the higher value of tensile strength of this composite. Figure 7(b) shows SEM image of 0.6 wt.% MWCNT-reinforced 50/50 wt.% of polyester/CSM. From Fig. 7(b) it is clear that introduction of more MWCNTs causes agglomeration of particles and leads to decrease in mechanical properties, explaining the reduced value of tensile strength by further addition of MWCNTs.

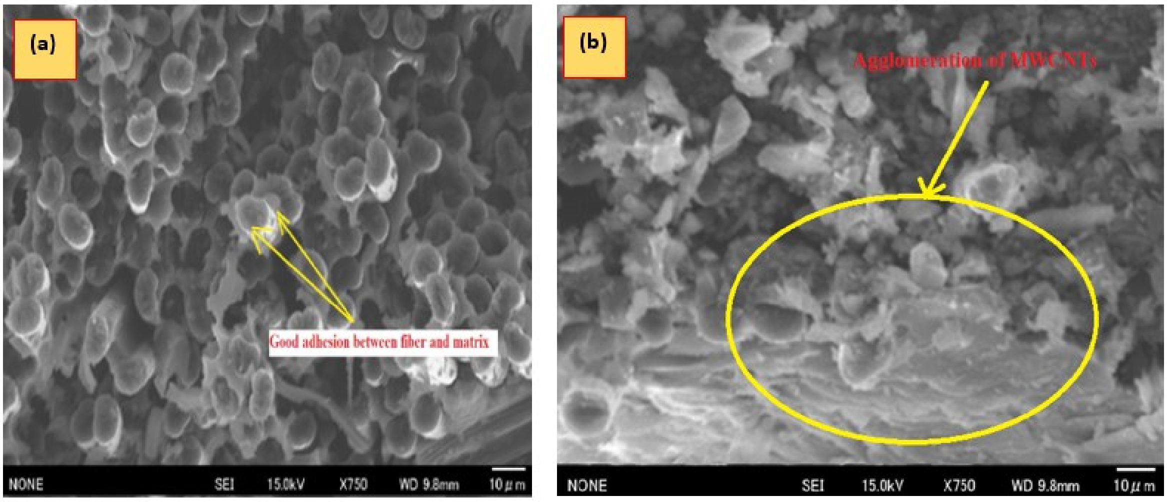

Fig. 7: SEM image of 50/50 wt.% of polyester/CSM reinforced by (a) 0.4 wt.% MWCNTs., (b) 0.6 wt.% MWCNTs.

4.3 Hardness Test

4.3.1 Hardness of Polyester/CSM/MWCNTs Nanocomposites

Figure 8(a) shows hardness variation of wt.% nano MWCNT-reinforced polyester/CSM (80/20 wt.%). It is observed that by the addition of 0.1 wt.% of MWCNTs, the hardness value is increased from 32.3 to 40.01 and by adding 0.4 wt.% of MWCNTs, the hardness is increased to 41.5%. Therefore, the hardness improved by 23.8% and 28.4% by reinforcing with 0.1 wt.% and 0.4 wt.% of MWCNTs, respectively. It is obvious that the hardness of 0.1 wt.% and 0.4 wt.% of MWCNTs composites is improved. It is also observed that the hardness values are decreased after 0.4 wt.%. Figure 8(b) and Fig. 8(c) show the hardness variation of MWCNTs reinforced (60 wt.% polyester / 40 wt.% CSM) and (50 wt.% polyester / 50 wt.% CSM), respectively. From the graphs, it is clear that hardness values increase by increasing the weight percent of MWCNTs. However, further increase up to 0.6 wt.% of MWCNTs leads to a decrease in hardness values for both (60 wt.% polyester / 40 wt.% CSM) and (50 wt.% polyester / 50 wt.% CSM) composites. Comparative plots show that the (50 wt.% polyester / 50 wt.% CSM) composite has higher values of hardness about 47 BHN as demonstrated in Fig. 9. It is noted from the previous data that, with the increase in MWCNTs nanoparticles, tensile strength and hardness first increase and then decrease with more addition of MWCNTs nanoparticles. The maximum tensile strength value is seen at 0.4 wt.% of MWCNTs nanoparticles and the characteristics are reduced with a higher introduction of MWCNTs nanoparticles. The increase in the adhesion of fiber matrix is due to tensile characteristic enhancement by introducing MWCNTs. Nano particles have an increasing, unique surface and low surface strength. Thus, they can react with the macro-molecular chain chemically and physically to improve the connection between the matrix and the fiber. The reduction of the tensile strength for composites reinforced by 0.6 wt% MWCNTs could be attributed to nano filler accumulation in the glass fiber polyester matrix. However, with an increase of MWCNTs nanoparticle material, the accumulation activity increased, suggesting that nanocomposites of polyester/CSM/MWCNTs were more incompatible with an excess of MWCNTs nanoparticles addition.

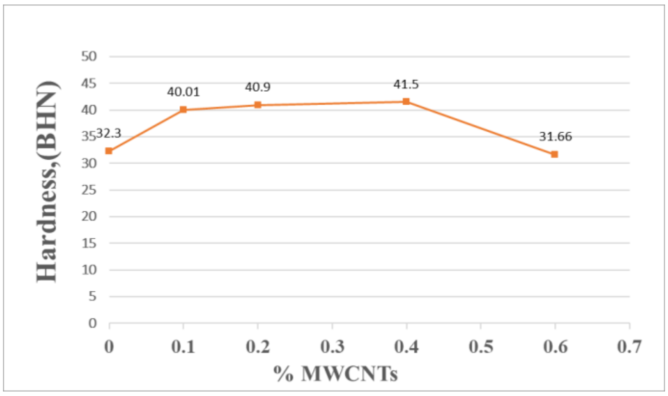

Fig. 8: (a) Hardness variation of wt.% nano MWCNTs reinforces polyester/CSM (80/20 wt.%).

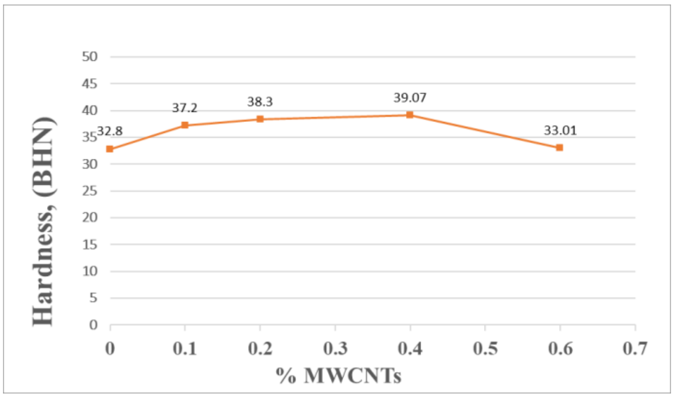

Fig. 8: (b) Hardness variation of wt.% nano MWCNTs reinforces polyester/CSM (70/30 wt.%).

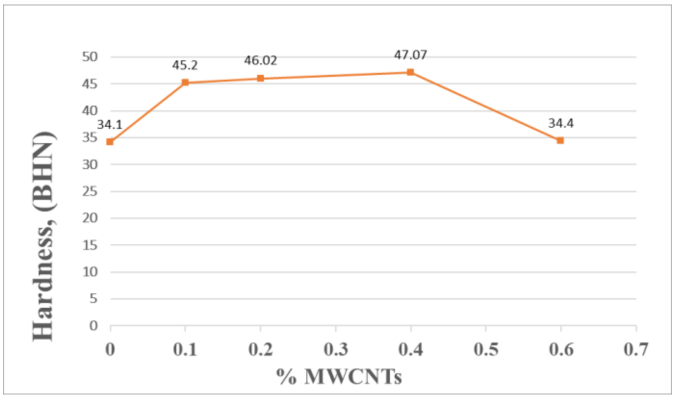

Fig. 8: (c) Hardness variation of wt.% nano MWCNTs reinforces polyester/CSM (50/50 wt.%).

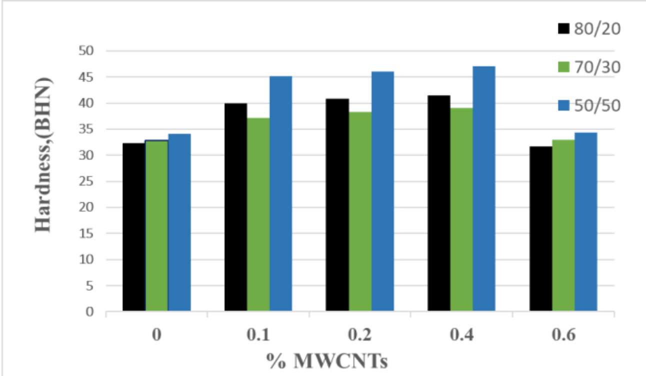

Fig. 9: Comparison between hardness variation and different weight percentages of MWCNTs reinforces polyester/CSM (80/20 wt.%, 70/30 wt.% and 50/50 wt.%).

5. CONCLUSION

Polyester reinforced by E-glass fiber CSM composites were manufactured by means of the hand layup method. Different wt.% of MWCNTs nanoparticles were used to reinforce composites. Tensile and hardness tests were conducted to investigate the effect of MWCNTs addition. The experimental data support the following conclusions:

1. The mechanical properties of (polyester/CSM/MWCNTs) are enhanced due to the presence of MWCNTs nanoparticles. Adding up to 0.4 wt.% of MWCNTs nanoparticles greatly improves the strength and hardness of various composites, especially in the 50 wt.% polyester / 50 wt.% CSM composite, where it enhanced both the tensile strength and the hardness by 39.8% and 38%, respectively. However, further addition of MWCNTs nanoparticles reduced tensile strength and hardness values. The addition of MWCNTs nanoparticles gives strong adhesion between matrix and fiber. It also leads to the improvements of the mechanical properties for different composites. Nanoparticle agglomerates cause the decrease in values of both tensile strength and hardness. The presence of further wt.% of MWCNTs nanoparticles leads to decrease in mechanical properties as nanoparticles agglomerate and leads the polymer matrix to weaken. In the 50 wt.% polyester / 50 wt.% CSM composite, tensile strength decreased by 25.1% by adding 0.6 wt.% of MWCNTs over polyester / CSM without MWCNTs addition. Also, hardness value of 50 wt.% polyester / 50 wt.% CSM without MWCNTs addition was slightly enhanced by 0.8% when 0.6 wt.% of MWCNTs was added.
2. For 80/20, 70/30 and 50/50 wt.% of polyester/CSM adding MWCNTs nanocomposites up to 0.4 wt.%, enhanced hardness and tensile strengths for all composites compared to polyester/CSM composites without MWCNTs nano particles.
3. 50/50 wt.% of polyester/CSM + 0.4 wt.% MWCNTs nanocomposite has a hardness of 47 BHN and a tensile strength of 172 MPa and these are the highest values, above all other composites.

REFERENCES

[1] Palanikumar K. (2010) Modeling and analysis of delamination factor and surface roughness in drilling GFRP composites. Mater Manuf Process., 25:1059–1067.

[2] Murugan S, Rajendran R, Fei W. (2016) Graphene-zinc oxide (G-MWCNTs) nanocomposite for electrochemical supercapacitor applications. J. Sci. Adv. Mater. Dev., 1:454-460.
[3] Sandhya CP, John B, Gouri C. (2017) Sn/Al_2O_3/C/CNT composite prepared by wet milling as anode material for lithium-ion cells, J. Sci. Adv. Mater. Dev., 2:210-214.
[4] Peigney A, Laurent C, Flahaut E, Rousset A. (2000) Carbon nanotubes in novel ceramic matrix nanocomposites. Ceramics International., 26(6):677-683.
[5] Flahaut E, Peigney A, Laurent C, Marliere C, Chastel F, Rousset A. (2000) Carbon nanotubemetal- oxide nanocomposites: microstructure, electrical conductivity and mechanical properties. Acta Materialia., 48(14):3803-3812.
[6] Peigney A, Flahaut E, Laurent C, Chastel F, Rousset A. (2002) Aligned carbon nanotubes in ceramic-matrix nanocomposites prepared by high-temperature extrusion. Chemical Physics Letters., 352(1-2):20-25.
[7] Xu CL, Wei BQ, Ma RZ, Liang J, Ma XK, Wu DH. (1999) Fabrication of aluminum-carbon nanotube composites and their electrical properties. Carbon., 37(5):855-858.
[8] Cochet M, Maser WK, Benito AM, Callejas MA, Martínez ME, Benoit JM, Schreiberb J, Chauvet O. (2001) Synthesis of a new polyaniline/nanotube composite: ‘‘in-situ’’ polymerization and charge transfer through site selective interaction. Chem Comm., 16:1450-1451.
[9] Jin Z, Sun X, Xu G, Goh SH, Ji W. (2000) Nonlinear optical properties of some polymer/multiwalled carbon nanotube-based composites. Chem Phys Lett., 318:505-510.
[10] Jin Z, Pramoda KP, Xu G, Goh SH. (2001) Dynamic mechanical behavior of melt-processed multi-walled carbon nanotube/poly (methyl methacry-late) composites. Chem Phys Lett., 337(1-3):43-47.
[11] Kumar S, Doshi H, Srinivasarao M, Park JO, Schiraldi DA. (2002) Fibers from polypropylene/ nano carbon fiber composites. Polymer, 43(5):1701-1733.
[12] Lourie O, Wagner HD. (1999) Evidence of stress transfer and formation of fracture clusters in carbon nanotube-based composites. Composite Science and Technology., 59(6):975-977.
[13] Breton Y, Esarmot GD, Salvetat JP, Delpeux S, Sinturel C, Béguin F, Bonnamy S. (2004) Mechanical properties of multiwall carbon nanotubes/epoxy composites: influence of network morphology. Carbon., 42(5-6):1027-1030.
[14] Liu T, Phang I, Shen L, Chow S, Zhang W. (2004) Morphology and mechanical properties of multiwalled carbon nanotubes reinforced nylon-6 composites. Macromolecules, 37(19):7214-7222.
[15] Allaoui A, Bai S, Cheng HM, Bai JB. (2002) Mechanical and electrical properties of a MWNT/epoxy composite. Composites Science and Technology, 62:1993-1998.
[16] Zhou Y, Pervin F, Lewis L, Jeelani S. (2006) Experimental study on the thermal and mechanical properties of multi-walled carbon nanotube- reinforced epoxy. Materials Science and Engineering., 452-453:657-664.
[17] Schadler LS, Giannaris SC, Ajayan PM. (1998) Load transfer in carbon nanotube epoxy composites. Appl Phys Lett., 73(26):3842-3844.
[18] Shekar KC, Prasad BA, Prasad NE. (2014) Effect of amino multiwalled carbon nanotubes reinforcement on the flexural properties of neat epoxy. Appl Mech Mater., 592:912-916.
[19] Gojny FH, Wichmann MHG., Fiedler B, Schulte K. (2005) Influence of different carbon nanotubes on the mechanical properties of epoxy matrix composites – a comparative study. Compos Sci Technol., 65:2300-2313.
[20] Shokrieh MM, Saeedi A, Chitsazzadeh M. (2014) Evaluating the effects of multi-walled carbon nanotubes on the mechanical properties of chopped strand mat/polyester composites, Materials & Design, 56:274-279.
[21] El-Tayeb NSM, Yousif BF, Yap TC. (2006) Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface. Wear., 261:443-452.