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Tensile Properties of UHMWPE Nanocomposites Reinforced by CNTs and nHA for Acetabular Cup in Hip Joint Replacement

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Abstract: UHMWPE is a semi-crystalline polymer which used as a acetabular cup in total hip joint replacement with some failure for a long time, therefore in this research, we attempted to improve tensile properties of UHMWPE polymer by addition of CNTs and nHA with four weight fractions (1, 2, 3 and 5%) to produce nanocomposites. The measured properties included tensile strength, modulus of elasticity and elongation percentage. All the results indicated enhancing the properties, especially for UHMWPE/3% CNTs and UHMWPE/5% nHA. FE-SEM examination was done for specimens at the fracture region to identify the structure of nanocomposites that confirm the good cross linking between the matrix and reinforcements.

Key words: UHMWPE, CNTs, nHA, tensile properties and FE-SEM, elasticity, examination

INTRODUCTION

In last decades, using Ultra High Molecular Weight Polyethylene (UHMWPE) has an important role for its properties to use in bioapplications due to superior wear resistance along with high fracture toughness and biocompatibility compared to other polymers (Del Prever *et al*., 2009; Eddin and Kurtz, 2000; Kurtz *et al*., 2002). In general the biopolymers, especially, the UHMWPE has unique physical, chemical and mechanical properties that used in bioimplants (Kurtz, 2004; Tanner, 2010; Hashim *et al*., 2016; Zhang *et al*., 2007). A new type of carbon is nanotube with rolled hexagonal networks and they consist of two forms; The first is single-walled carbon nanotubes and multi-walled carbon nanotubes (Manoharan, 2009). These nanotubes have good interactions (Van der Waals) among their atoms because of the high polarizability and smooth surfaces (Girifalco *et al*., 2000). To using CNTs as reinforcements it's required to tailor these nanotubes with the polymeric chains by load-transfer efficiency between the two components. This can be achieved by functionalizing these tubes to get good adhesion between the carbon nanotubes and the polymeric matrix (Ajayan *et al*., 2000; Breuer and Sundararaj, 2004; Coleman *et al*., 2006). Jin *et al*. (1998) described based composite formation with carbon nanotubes. On the other hand, hydroxyapatite is represented a biocompatible material with properties closest to the bone, therefore, it was used in implantation of artificial joints or used with a polymer as a biocomposites in the implants (Oleiwi *et al*., 2016; Oleiwi and Hamad, 2018; Oleiwi and Mohammed, 2017; Oleiwi *et al*., 2015).

In the current study, CNTs and nHA have been added to UHMWPE to produce nanocomposites with good tensile properties such as tensile strength and modulus of elasticity in addition to percentage of elongation. The addition was done with 1, 2, 3 and 5% as weight fraction and FE-SEM examination were used to confirm the good cross linking within the composites.

MATERIALS AND METHODS

Ultra-High Molecular Weight Polyethylene (UHMWPE) from (Max Pipe Industry Co. Ltd.) with average molecular weight (5.5×10^6 g/mol), density (0.935 g/cm^3) and average particle size of (20-50 μm) was used as matrix to prepared eight nanocomposites. These nanocomposites were reinforced with 4 weight fraction (%) of each Carbon Nano Tubes (CNTs) and nano-Hydroxyapatite (nHA). Multi-Walled Carbon Nano Tubes (MWCNTs) (>95% with an average diameter (30-80 nm) and lengths of 10-30 μm) were synthesis via. AAO templates as describes in our previous study (Oleiwi *et al*., 2018) while nano-Hydroxyapatite (nHA) was supplied as nanoparticles from (Merck, Darmstad, Germany Company) with average particle size (80 nm).

Four weight fractions include 1, 2, 3 and 5% of each nano additives to produce nanocomposites that prepared by weighing of chosen nano fillers (CNTs and nHA) to

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Fig. 1a, b): Nanocomposite specimens before and after test

reinforce polymer matrix UHMWPE and mixed with 30 mL of ethanol and then stirred the mixture by hot magnetic stirrer for 45 min and 60°C to disperse the additive in solution. The final mixture (Ethanol+Additive+ UHMWPE) was put in siliphon study and input inside dry oven for 20 min at 60°C after drying it left in atmospheric for 72 h. To evaporate the residual ethanol.

The hydraulic hot press was used to fabricate UHMWPE nanocomposites. After the previous steps, the final produced mixture was put in a hot plate of hydraulic press with a temperature range of (195-200°C) and then pressed under 12 MPa for 1.5 h at polymer Department in Materials Engineering College, Babylon University. Cooling the molds were done in the air to room temperature to get specimens and then they cut by CNC laser machine according to international standard specifications for each test in this research which agreement with ASTM standard.

Tensile test: The tensile test used to construct a stress-strain curve for prepared nanocomposites. This curve is used to get tensile properties about specimens like modulus of elasticity, tensile strength and percentage of elongation at break. The tensile test was performed according to the international standard test (ASTM D638-03). The tensile test was carried out by the tensile device type (Instron) with load equal to (50 kN). The rate of strain was 5mm/min and the load gradually applied until the fracture occurs. This test was carried out in air at room temperature (25±2°C) all results were taken as an average for five records (Salih *et al*., 2015). Figure 1 shows the specimens before and after the test.

Scanning Electron Microscopy (SEM): SEM technique was used in this research to identify the fracture region in the tensile test. To get good electric conductivity, nanocomposites were sputtered with gold from the surface along the edge using a special technique. Then, electron pictures are recorded with the working voltage is retained at 10 kV.

RESULTS AND DISCUSSION

Tensile test of UHMWPE nanocomposites

Stress-strain curves: The tensile test was carried out mainly to investigate the mechanical behavior of (stress-strain) curve for UHMWPE nanocomposite. The (stress-strain) curves for all prepared nanocomposites in a current study are shown in Fig. 2 and 3 reinforced with CNTs and nHA, respectively. The mechanical behavior of these curves depends upon the nature of the matrix material (UHMWPE) and reinforced additive (CNTs or nHA) as well as on the adhesion bond (bond strength) between the matrix and reinforcement (Oleiwi *et al*., 2014; Hadi and Oleiwi, 2015; Oleiwi and Hadi, 2018).

It can be noticed that the initial part of the (stress-strain) curve is linear where the specimen behaves in an elastic mode and finally develops into non-linear due to the deformation of the specimen in plastic mode. The plastic deformation increases with increasing stress, until the fracture occurs in the specimen at this time, the tensile strength can be estimated.

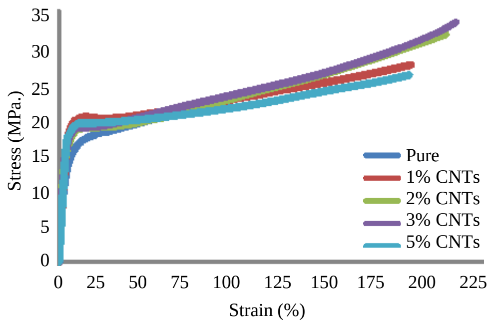

Fig. 2: The (Stress-strain) curves for UHMWPE/CNTs nanocomposites

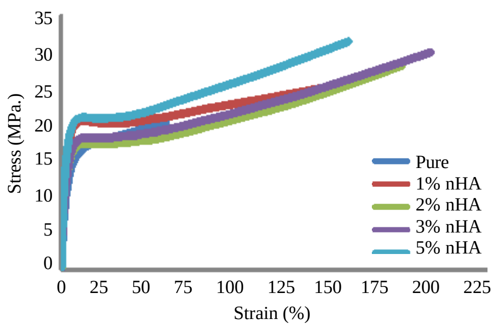

Fig. 3: The (Stress-strain) curves for UHMWPE/nHA nanocomposites

Furthermore, the slop was obtained through these curves in elastic region for every curve drawn to represent the modulus of elasticity of prepared nanocomposites. The (stress-strain) curve in Fig. 2 and 3 illustrates that the stress increases with increasing weight fraction (%) of nano additives (i.e., CNTs and nHA) particles. This behavior is due to the strengthening mechanism of CNTs and nHA particles compared with the polymer matrix of UHMWPE, the amount of these particles plays a vital role by impeding the slipping of UHMWPE chains within composites (Salih *et al*., 2015a, b).

Also, the nature of the bonding between the matrix and the reinforcements depends on the ability of a nanomaterial to spread through the matrix (Micro-size material of UHMWPE) with a dispersed solution (Ethanol) by using magnetic stirrer and ultrasonic mixing. As well as a good wettability and that may cause an increase of the bonding force between the matrix and reinforcement is important to produce the composites that require high stress to break their physical bonding (Oleiwi *et al*., 2017; Salih *et al*., 2017).

Tensile strength: The tensile strength behavior of UHMWPE nanocomposites is presented in Fig. 4. This

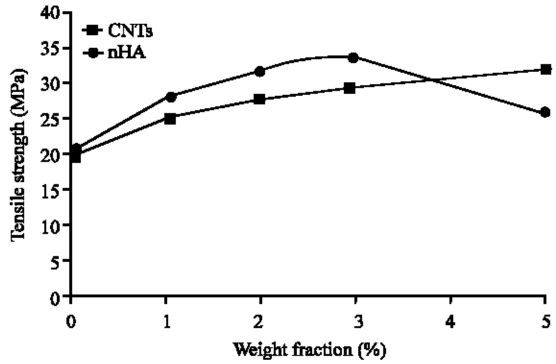

Fig. 4: Tensile strength of UHMWPE nanocomposites with different additives

figure indicates that the tensile strength which increased with increasing of the volume fraction for both types of additives (CNTs and nHA). This behavior is due to the strengthening and bond nature between reinforced additive (CNTs and nHA) and polymer matrix (UHMWPE) (Yu *et al*., 1990; Oleiwi and Kushnaw, 2013). As well as, this increase in values of tensile strength for nanocomposites is due to the homogeneous and uniform distribution of reinforcement (CNT and nHA) within polymer matrix, especially, at the 3% percentage ratio of additive in the nanocomposites and this reduces agglomeration of the nanoparticles and that may lead to decrease internal stresses concentration in nanocomposites and such small internal stresses are not enough to break the interactions at the interface region. Therefore, these small internal stresses can be easily transported from the matrix material to the nano additives that participate with high stiffness characteristic to the nanocomposites, so, the tensile strength will increase (Oleiwi and Mohammed, 2017).

It can also be noticed in Fig. 4 that the addition of CNTs particles has a noticeable effect on the tensile strength of composites more than the nHA particles which related to the nature of CNTs particles that have high strength comparing with nHA particles. Therefore, the values of tensile strength for (UHMWPE/CNTs) composites are higher than the values of tensile strength for (UHMWPE/nHA) composites. Increasing weight fraction of CNTs led to increasing tensile strength up to 3% followed by little reducing at 5% due to the agglomeration of CNTs particles. Thus, the tensile strength values increased from (20 MPa) for pure UHMWPE to (33.45 MPa) for (UHMWPE/3% CNTs) and (30.0 MPa) for (UHMWPE/3% nHA) composite. This increase in tensile strength for UHMWPE nanocomposites may be due to the strengthening

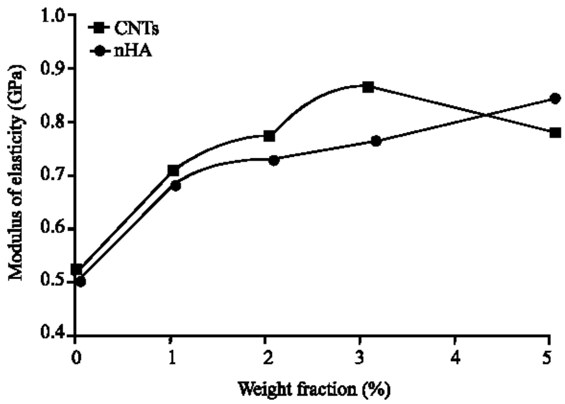

Fig. 5: Modulus of elasticity of UHMWPE nanocomposite with different additives

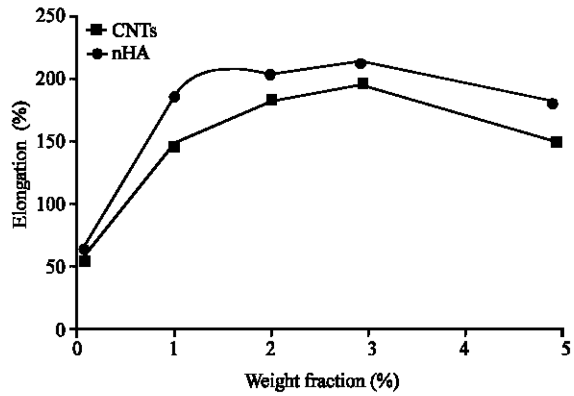

Fig. 6: Elongation of UHMWPE nanocomposites with different additives

mechanism of reinforcing material in the polymer matrix. Adding a higher weight fraction of nHA (5%) led to increasing the tensile strength to reach (31.5 MPa).

The decreasing in tensile strength also explain the weak physical bonding between the nanoparticles and polymer matrix UHMWPE and therefore, this requires low tensile stresses for the failure to occurs (Salih *et al*., 2015a, b; Mahanwar, 2010). Generally, CNTs have a greater effect than nHA for increasing tensile strength of nanocomposites which attributed to the difference in higher mechanical properties for CNTs compared with nHA.

Modulus of elasticity: The modulus of elasticity for UHMWPE nanocomposites with two types of additives is presented in Fig. 5, this figure shows the values of modulus of elasticity which increased with increasing the weight fraction of both types of additives. This may be due to the strengthening mechanism and the nature of the bonding strength and create a full interface between reinforcing materials and UHMWPE matrix with good dispersion of nanofillers in the matrix.

Additionally, the modulus of elasticity of nHA or CNTs is much higher compared with pure UHMWPE and then the modulus of elasticity of nanocomposites with the addition of CNTs higher than that for nanocomposites with nHA particles up to weight fraction of 3% due to the improvement of mechanical properties that is associated with the addition of CNTs. Thus, the modulus of elasticity values increased from (0.5127 GPa) for pure UHMWPE to (0.8645 GPa) for (UHMWPE/3% CNTs) composite and (0.762 GPa) for (UHMWPE/3% nHA) composite. After that, adding 5% nHA increases the modulus of elasticity to (0.8426 GPa) but 5% CNTs decrease the modulus of elasticity to (0.7811 GPa) which due to agglomeration of CNTs when they added in a higher concentration of 5%.

Elongation percentage: Addition of nanomaterials as reinforcement to polymer matrix composite has an important role in elongation percentage. The effect of addition of CNTs and nHA on elongation percentage of UHMWPE composite is illustrated in Fig. 6. This figure indicates the association between the weight fraction % of (CNTs and nHA) and UHMWPE matrix and the elongation percentage of the nanocomposites that increased with increasing of the weight fraction of both types of additives. The reinforcing of UHMWPE with nanomaterials leads to fill the voids in polymer matrix and get more cohesive composite which withstand the elongation. As noticed in Fig. 6, the increase of weight fraction up to 3% increases the elongation and then little decreases can occur due to some agglomeration of nanomaterials (Kumar *et al*., 2015; Salih *et al*., 2017).

The increasing in the elongation percentage was from (55.612%) for pure UHMWPE to (210%) for (UHMWPE/3% CNTs) and to (195 %) for (UHMWPE/3% nHA). In general, the increment by reinforcing with CNTs is more than reinforcing with nHA because of the nature and structure of CNTs and stronger interface bonding with matrix, the functionalized CNTs have functional groups to contact with polyethylene than that presented in nanohydroxyapatite molecules and this allows to get more strength and more interface bonding in (UHMWPE/CNTs) compared with (UHMWPE/nHA) composites.

FE-SEM examination at fracture zone: The examination of the fracture zone for all nanocomposites was done by FE-SEM technique. Figure 7 indicates the cross section of fracture region in tensile test, the SEM images at two magnified (30 and 60 k) show the cross-linking between the reinforcement represented by CNTs and matrix of UHMWPE. These tubes not only act as nanofiller but also

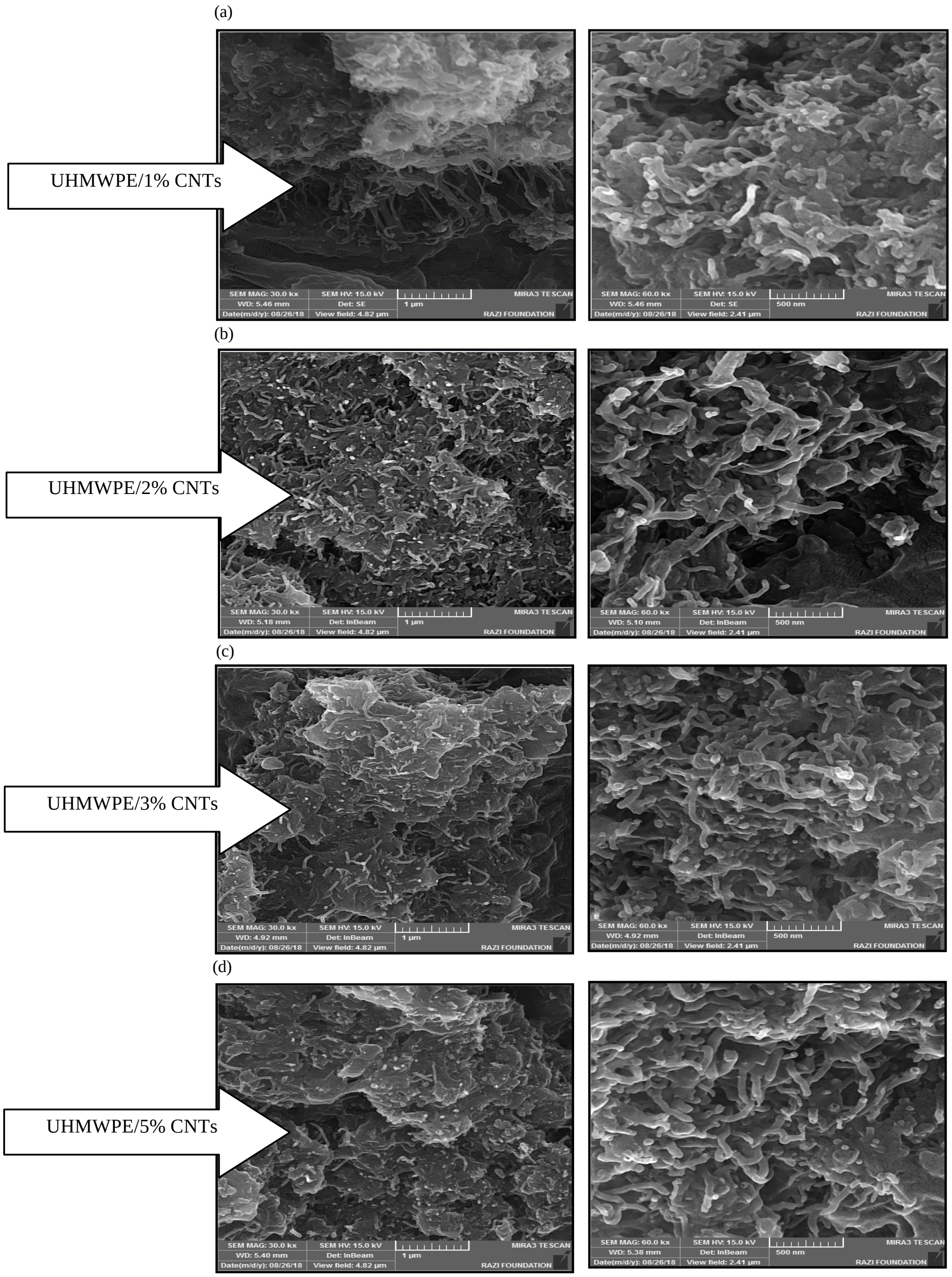

Fig. 7a-d): SEM of cross section for tensile test of UHMWPE/CNTs composites

they cross linked with polymer molecules, this cross linking improved the tensile strength with modulus of elasticity in addition to elongation of prepared nanocomposites and it is clear that the 3 and 5% of CNTs gave the most incorporation between additive and matrix.

Figure 8 shows the examination of a fracture zone in UHMWPE/nHA nanocomposites by SEM technique at two magnified (5 and 30 K). These images indicate the good incorporation that occurs between nHA particles and UHMWPE chains and the fracture didn't give any

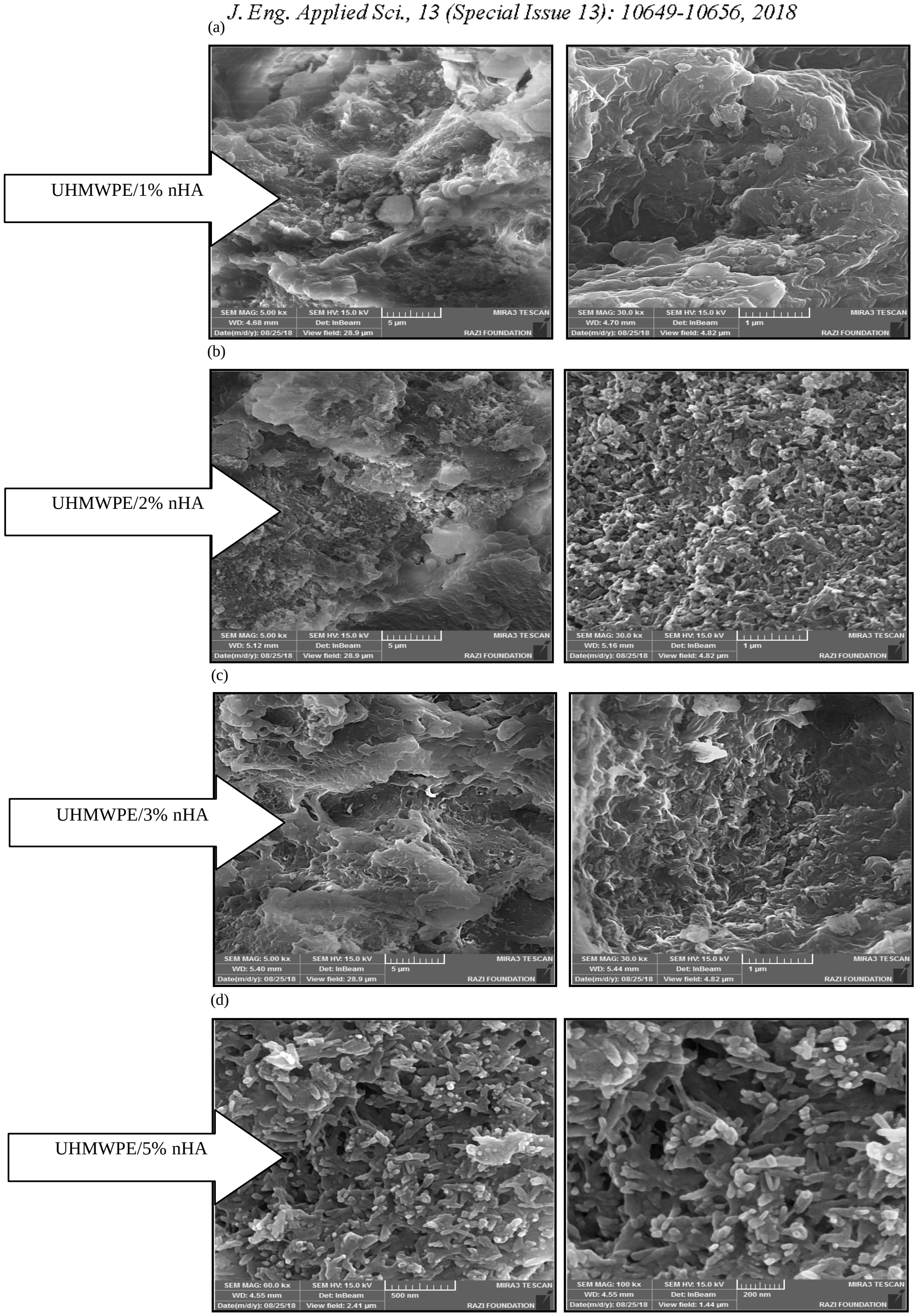

Fig. 8a-d): SEM of cross section for tensile test of UHMWPE/nHA composites

clear voids between the reinforcing and matrix but it gave rupture for one bulk and the best cross linking was observed at 3% of nHA and this the reason for the good mechanical properties at this weight fraction.

CONCLUSION

Adding CNTs and nHA to UHMWPE matrix led to improving tensile properties of produced nanocomposites. The addition includes four weight fraction (%) of each nano additive (1, 2, 3 and 5%). The 3% CNTs gave nanocomposites the best results for tensile strength with modulus of elasticity and elongation) while 3 and 5% nHA gave the best results for UHMWPE/nHA nanocomposites. The obtained observation by FE-SEM confirmed the good cross linking for produced nanocomposites by filling the holes and voids and reducing the defects in composites structure.

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