Investigation of The Effect of Carbon Nanotube Ratio on The Wear Behavior of Carbon Nanotube/Epoxy Nanocomposites

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ABSTRACT

In this work, the wear behavior of carbon nanotube/epoxy nanocomposites produced with varying ratios of multi-walled nanotube (MWCNT) (0.5, 1, 1.5, 2 wt %) was examined. MWCNTs have external diameter of 5-50 nm and lengths of 10-30 microns. MWCNFs were incorporated to the epoxy matrix using an ultrasonic homogenizer. Wear tests were carried out using a pin-on-disk test machine where a disc of epoxy/CNTs nanocomposite (90 mm in diameter and 4 mm in thickness) was used under a ball of steel (8 mm of diameter). The surface roughness of the specimens was about 0.1 µm Ra. Sliding distance was 500 m with a sliding speed of 0.44 m/s and a loads of 5, 10, 15 N were applied. As a result, the friction coefficient and surface roughness was measured. Lastly, wear surfaces were studied by scanning electron microscopy (SEM) and atomic force microscopy (AFM) in order to determine the wear mechanism.

Keywords: Epoxy resin, Sliding wear, Sliding friction, MWCNT, Nanocomposite.

INTRODUCTION

Epoxy resin applications are found in automotive, architecture, air and railway transport systems due to their light weight properties. One of the problems has been the low wear resistance, i.e. tribological properties, of this material. On the other hand, carbon nanotubes (CNT) possess an unusual combination of properties that include high surface area, high Young's modulus, high tensile strength and high electrical and thermal conductivities which means the CNTs can realistically be a possibility in the manufacture of new advanced materials, especially based on polymer matrices. Due to the effects of the reinforcement, CNTs can be used to manufacture the nanocomposites with excellent tribological properties. This nanocomposite type exhibited lower friction coefficient and wear rate compared with the pure matrix, which results in the improvements on reduced friction and wear resistance. Nowadays polymeric materials are used in wide variety of engineering applications. The high thermal conductivity and improved mechanical properties can be achieved by several reinforcements [1]. There are several works on the addition of nano particles [2,3]. For example, boron nitride (BN) and carbon nano tube (CNT) additions have been reported to improve elasticity and tensile strength [4-10]. Chen et al [11] reported a considerable decrease in both friction coefficient and wear loss of MWCNT modified PTFE. Zoo et al. [12] reported that wear loss of carbon/carbon composites decreases with increasing CNT content. The friction coefficient is another parameter that needs to be considered [13-14].

In this work, the effect of various weight ratios of carbon nanotube (0.5, 1, 1.5 and 2 % wt) additions on the wear properties of epoxy resin has been investigated. Pin-on-disk method was used with 5, 10 and 15 N at a constant distance of 500 m. Friction coefficient and surface roughness were measured by using SEM and AFM.

MATERIALS AND METHODS

Carbon nanotube reinforced epoxy resin composites were produced in the shape of 90 mm diameter and 4 mm height disks (Fig. 1). Carbon nanotube additions varied between 0.5, 1, 1.5 and 2 % wt. The matrix used in this study consists in a commercial epoxy resin MGS-L285 with an extremely low viscosity. The hardener was MGS-H285 and all samples were provided from Momentive firm.

Fig 1. MWCNT composites produced in a steel template

For homogeneous distribution of the carbon nano tubes, solution stirring method was used. The schematic diagram of the process is given in Fig. 2. The samples were weigh and then MWCNT was mixed with acetone (100 g/ml) and stirred for 5 minutes at 15 minute interval with a probe homogenizer. Epoxy resin was added and stirred for 25 minutes in a cold ice container. The solution was held in a vacuum chamber (-0.75 bar) at 65oC for 24 hours. In this way, bubbling of samples was eliminated. The ratio of epoxy and curing agent was 100 to 40 which was mechanically stirred for 10 minutes. The samples were then held under -0.75 bar vacuum at room temperature for 10 minutes. Finally, the mixture was poured into the template (Fig 1) and removed from the template after 24 hours. Post-curing was carried out at 80oC for 15 hours. The samples were then subjected to pin-on-disk wear tests.

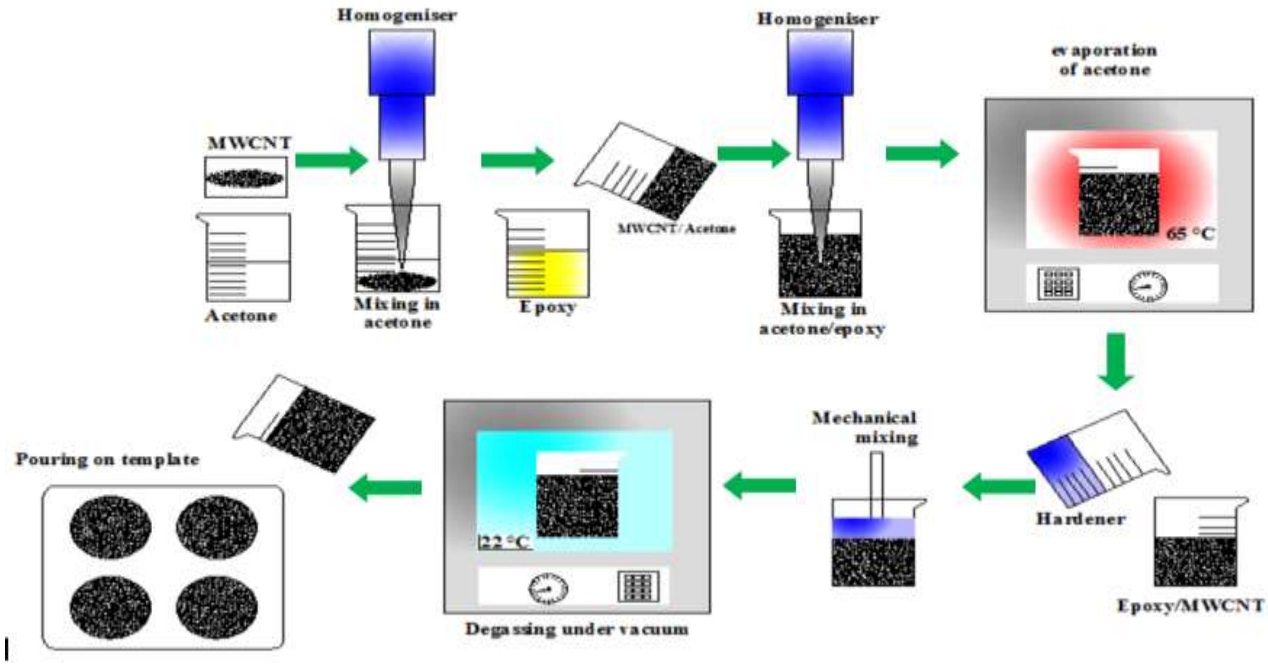
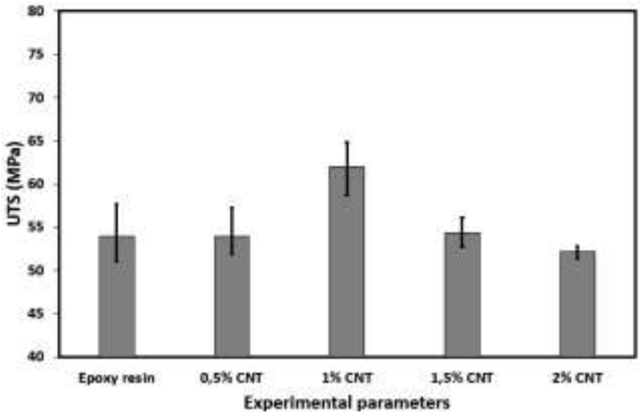


Fig. 2. Schematic representation of the sample preparation

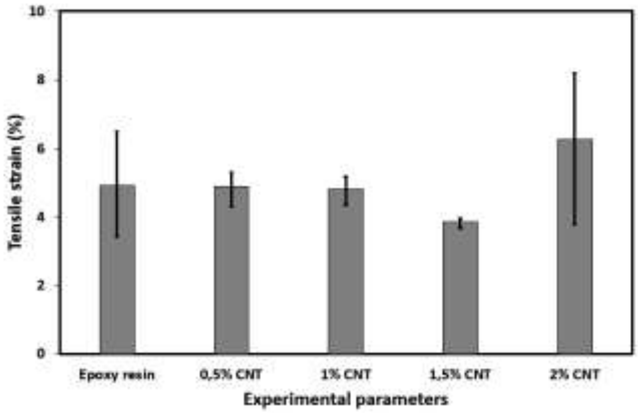
Prior to the testing, surfaces of the disc wear samples were polished with 1000 grid paper. The surface roughness of the specimens was about 0.1 µm Ra. The test environment was kept at a temperature of 25–30◦C and a relative humidity of 27%. Sliding distance was 500 m under a sliding speed of 0.44 m/s and a loads of 5, 10, 15 N were applied. The friction coefficient and surface roughness was measured. Lastly, wear surfaces were studied by scanning electron microscopy (SEM) and atomic force microscopy (AFM) in order to determine the wear mechanism. Samples were subjected to tensile testing for mechanical property characterization.

RESULTS AND DISCUSSION

The tensile test results of MWCNT epoxy composites are given in Fig. 3. As can be seen in Fig. 3, the highest tensile strength (63 MPa) was obtained where carbon nano tube weight ratio was 1 %. The rest of the samples had almost similar results around 55 MPa. The elongation at fracture values around 5 % for all the samples except 2 % carbon nano tube addition which was 6 %. According to these findings, it is difficult to conclude that there is a strong effect of carbon nano tube additions over the tensile properties of epoxy resin composites.



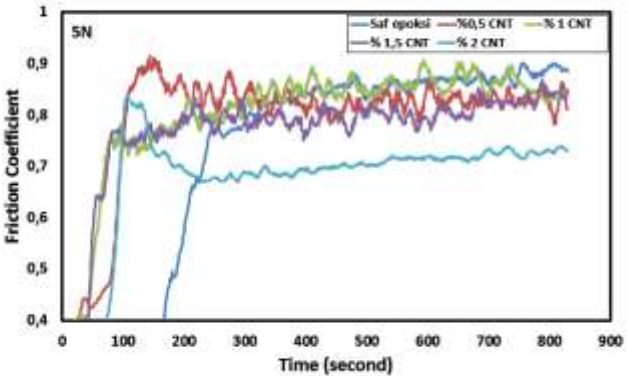
(a) Tensile stress



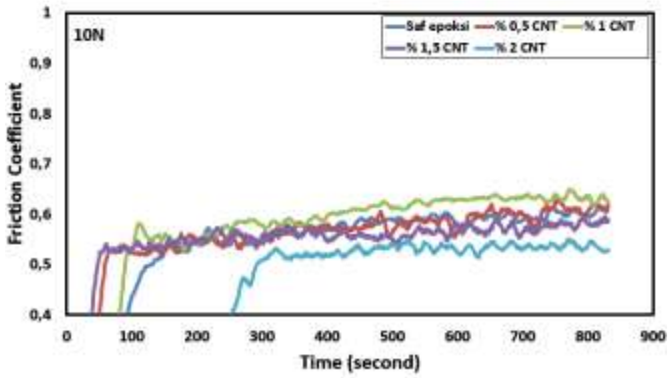
(b) Tensile strain

Fig 3. Tensile test results of MWCNT

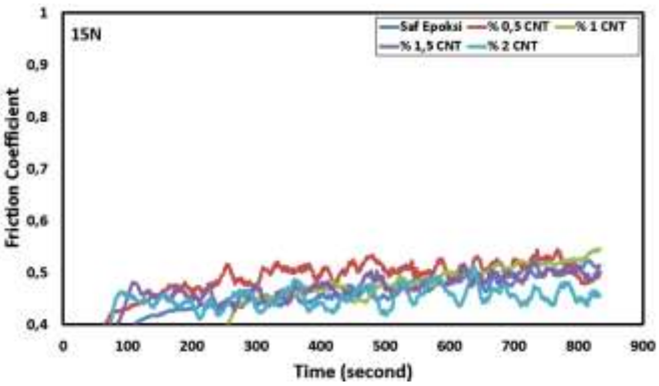
The friction coefficient changes of the samples under various loads were given in Fig. 4. As seen from Fig. 4, friction coefficient was decreased with increased load. Within all the samples, 2 wt% CNT added samples revealed the lowest friction coefficient. The normalized values and the average friction coefficient is given Fig 5.



a) 5N

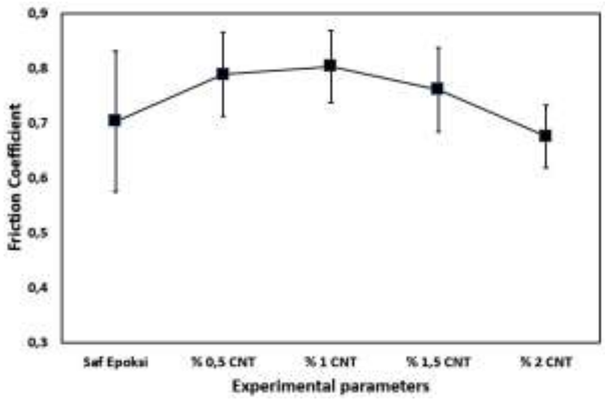


b) 10N

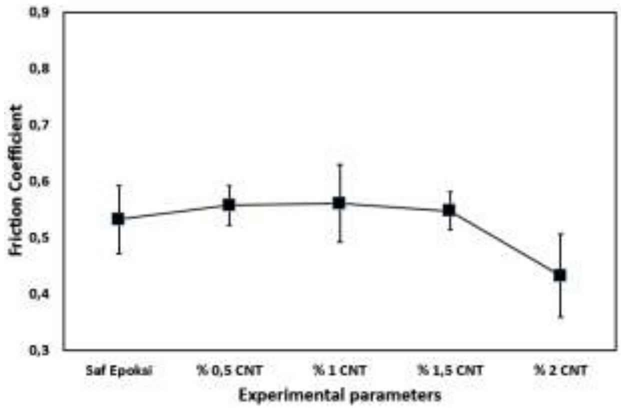


c) 15N

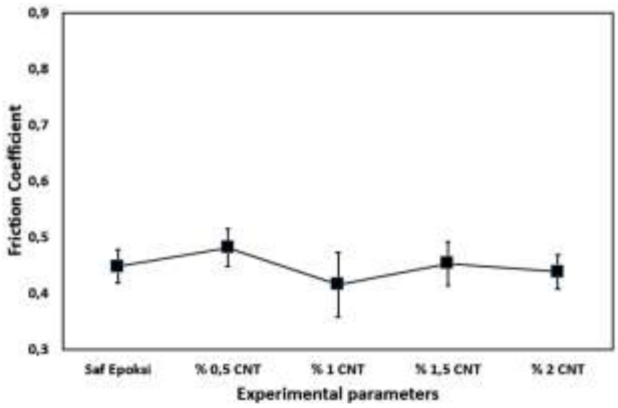
Fig 4. Friction coefficient change with carbon nano tube additions under varying loads.



a) 5N



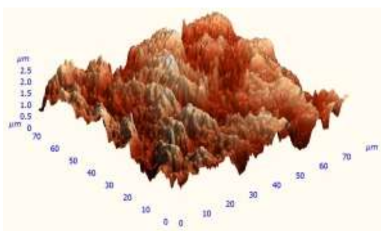
b) 10N



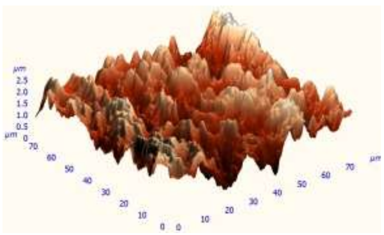
c) 15N

Fig 5. Average friction coefficient change with CNT ratio and load

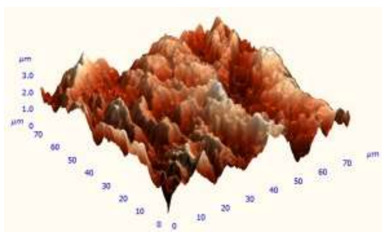
When 5 N load was used in the wear tests, friction coefficient was increased up to 1 wt% CNT addition and was decreased when CNT addition was increased up to 2 wt%. For these tests, it was found that friction coefficient was changing between 0.6 and 0.8. When the load was increased to 10 N, the average friction coefficient was around 0.5 for almost all the samples, except 2 wt% CNT addition which had the lowest value of 0.4 For the tests at 15 N, the friction coefficient was lowered to 0.45 and regardless of CNT addition, the average friction coefficient was almost the same for all samples. AFM results of all the wear test samples are given in Fig. 6.



5N

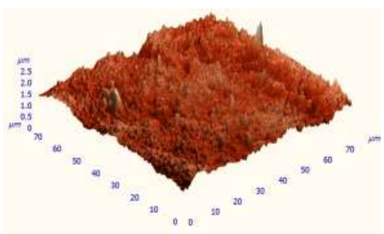


10N

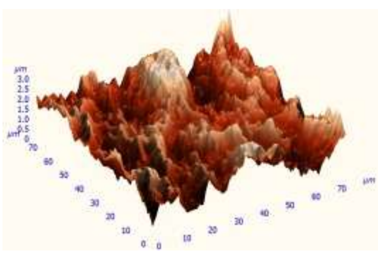


15N

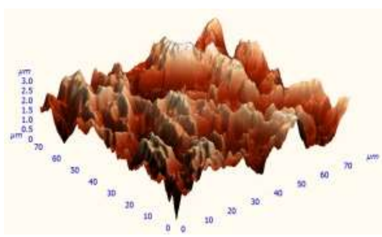
a) Neat Epoxy



5N

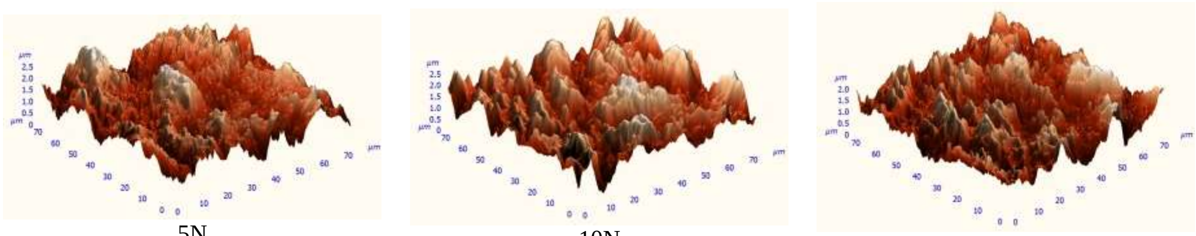


10N



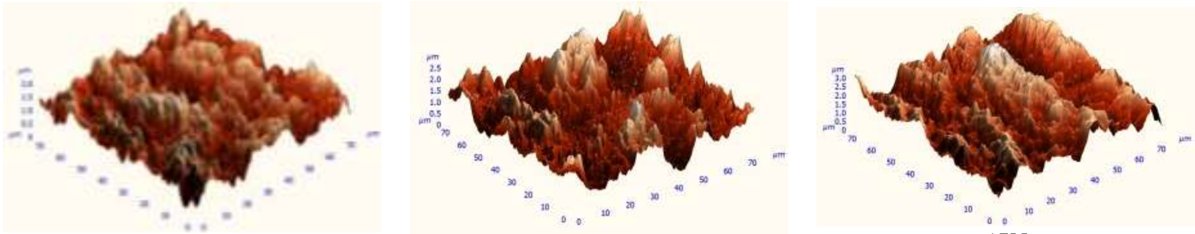
15N

b) %0,5 MWCNT/Epoxy



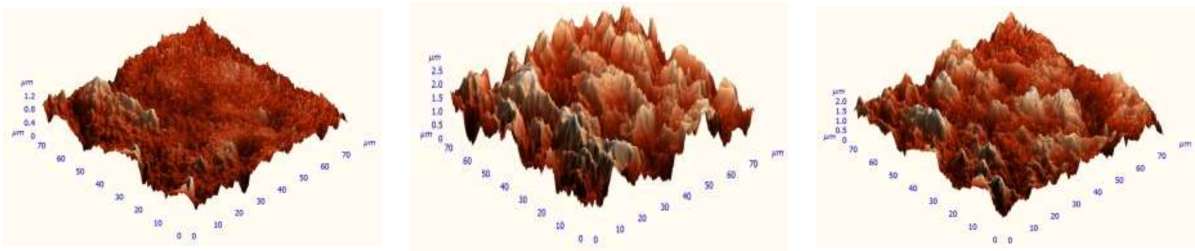
5N 10N 15N

c) %1 MWCNT/Epoxy



5N 10N 15N

d) %1,5 MWCNT/Epoxy



5N 10N 15N

e) %2 MWCNT/Epoxy

Fig 6. AFM images of worn areas within 75 μm range

Surface roughness was measured from AFM images and the results are given in Fig 7. And surface SEM images given in Fig. 8. For all the samples subjected to wear tests, as the load was increased, surface roughness was increased as seen in Fig 7.

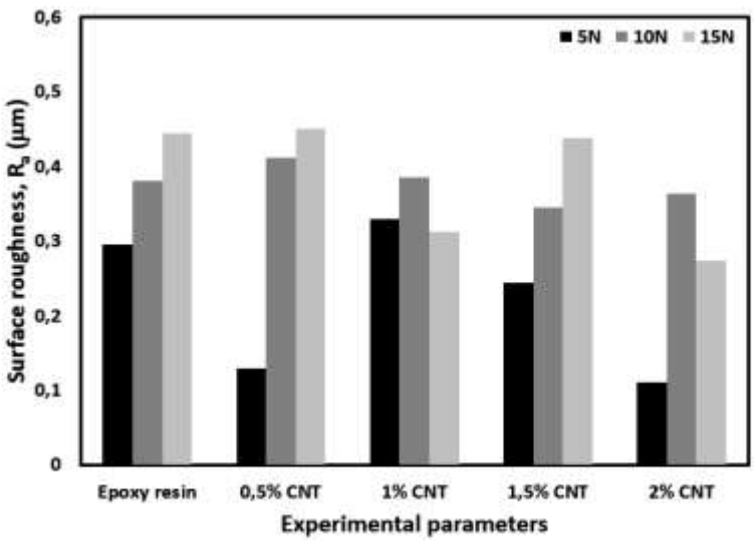


Fig 7. Surface roughness of the worn areas

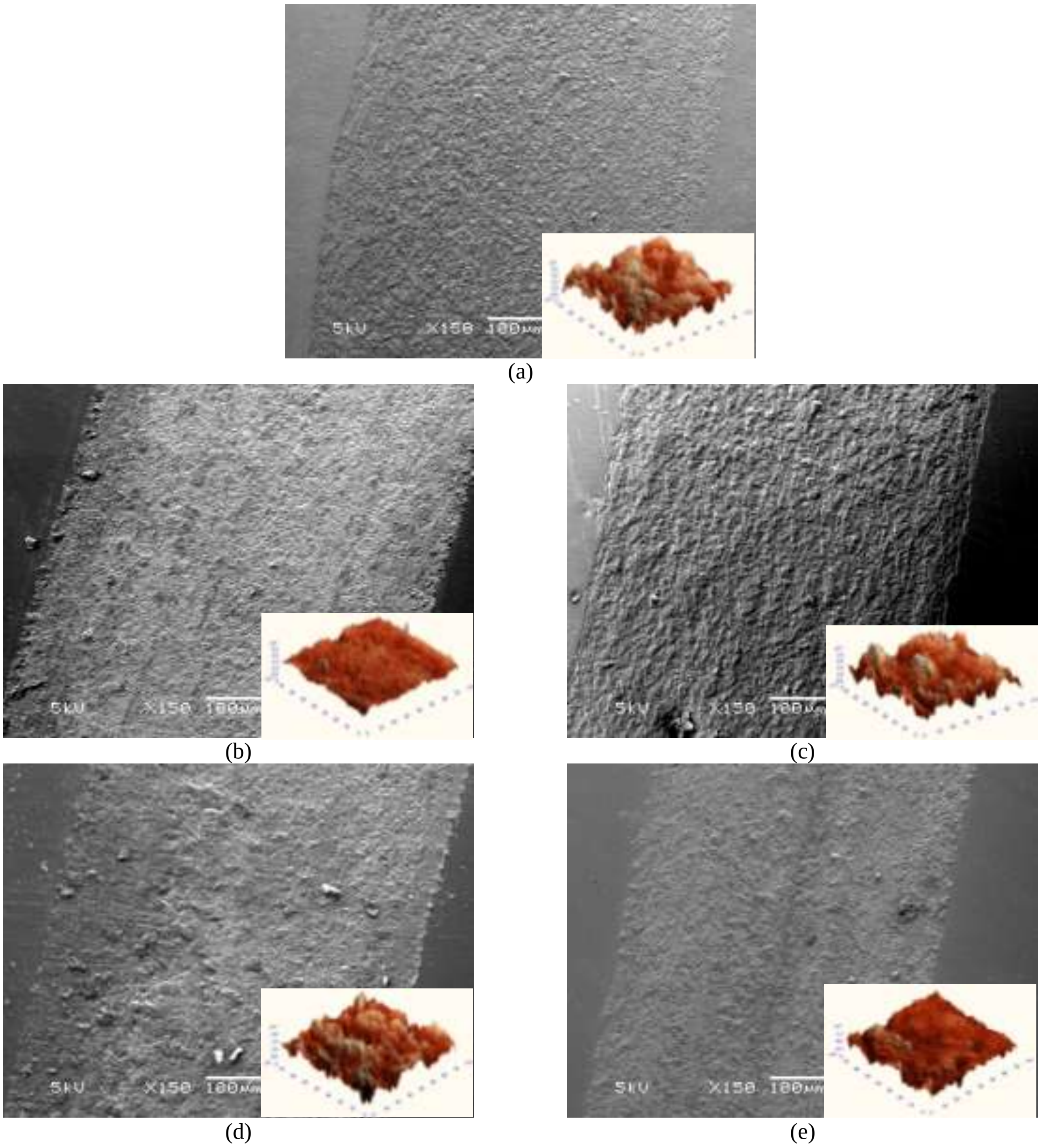


Fig 8. SEM images of the samples tested under 5 N (a) neat epoxy, b) 0.5 wt % MWCNT, c) 1 wt % MWCNT, d) 1.5 wt % MWCNT, e) 2 wt % MWCNT

CONCLUSIONS

1. Tensile properties of carbon nano tube added epoxy resin composites are not affected from the weight ratios between 0.5-2 wt%.

2. The average friction coefficient of CNT epoxy resin composites (0.5-2 wt%) is around 0.9 under 5 N load, 0.55 for 10 N and 0.45 for 15 N after 500 m pin-on-disk wear tests. In all cases, the lowest friction coefficient value was observed with the highest CNT added samples (2 wt%).

3. The surface roughness was increased with increased load.

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