EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 21, No. 4, October 2024, pp. 45 - 58 **ISSN 2090 - 5882**
(Received August 09. 2024, Accepted in final form August 18. 2024) **jest.journals.ekb.eg**

IMPROVING EROSION PROTECTION PROPERTIES OF EPOXY RESIN COATING BY USING DIFFERENT CONTENTS OF MULTIWALL CARBON NANOTUBES

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ABSTRACT

The aim of this work is to improve the tribological properties of epoxy composite as water pipeline internal coating material, against water jet erosion wear analysis and investigating the effect of adding Multi Wall Carbon Nanotubes (MWCNT) to epoxy with different weight percentages (0, 0.1, 0.2, and 0.3). Then, morphologies, erosion resistance, and tensile strength are assessed. To simulate how the epoxy coating would erode under water jet contact, water cutting equipment was utilized. The total test time was 5 minutes. Analyzing and revealing the damage behavior and damage mechanism of coating, a damage evolution curves was developed by using a digital microscope and a scanning electron microscope (SEM) to evaluate the damage morphology of samples at different stages of damage. In the experimental work, steady-state erosion values of the epoxy coating have been evaluated at different impact angles (15°, 30°, 45° and 60°) and different impact distances (100 and 200 mm), with constant water jet velocity of 5 m/s Compared with pure epoxy, the results showed that the elongation characteristics improved by 46.67% and the tensile strength improved by 66.7%. Improved interfacial contacts and efficient stress transmission result in improved tensile and elongation properties when MWCNTs are added. Meanwhile, the experimental results showed that 0.3 wt. % MWCNT/EP composite indicated the maximum erosion resistance at the impact angles ranged from 15° to 30° and impact distance of 200 mm, whereas the EP pure coating material exhibited the maximum erosion values at the impact angle of 45° and 60° and impact distance of 100 mm.

KEYWORDS

Epoxy coating, nano additives, mechanical properties, MWCNT, erosion.

INTRODUCTION

Because of their remarkable mechanical properties and low weight, [1], polymer composites have drawn a lot of interest from a variety of industries. Advanced components with better characteristics have become increasingly necessary to replace existing materials or to get new requirements, [2]. Numerous studies have been conducted on carbon nanotubes. Amazing mechanical and physical features of this novel type of carbon have now been documented by several researchers, [3]. The

mechanical proper ties, including tensile, flexural, and fracture toughness, were greatly improved by adding 1.5 % MWCNT to the epoxy resin, [4]. Analysis revealed that multi-walled car-bon nanotube and jet pressure are found to significantly affect the overall responses. The influence of parameters such as multi-walled carbon nanotube weight percentage, jet pressure, traverse rate, and standoff distance on surface roughness, delamination factor at jet entry and exit, has been investigated. In comparison to the initial parameter setting, the findings demonstrated a reduction in surface roughness of 25.31 %, kerf taper of 23.94 %, entry delamination factor of 26.08 %, exit delamination of 26.16 %, and an improvement in material removal rate of 4.25 %, [5]. On metallic substrates, poly (arylene ether nitrile) (PEN) was used as a protective coating. To improve the PEN coating's mechanical properties and resistance to corrosion, cyano-functionalized multiwalled carbon nanotubes (MWCNTs-CN) were added. The composite coating with MWCNTs and CN integrated exhibited exceptional corrosion resistance, as evidenced by the electrochemical data. After 100 days of immersion in a 3.5 wt. % NaCl solution, the |Z|0.01Hz remained 196.9 MΩ cm2, which was two orders of magnitude greater than the pure PEN coating. Additionally, a clear improvement in the tensile strength of MWCNTs-CN/PEN coatings was examined, and the results indicated that the addition of 1 weight percent of MWCNTs-CN increased the tensile strength by around 20.1 %, [6]. The study examined the mechanical and electrical characteristics of several epoxy composites reinforced with basalt fibers covered with multiwall carbon nanotubes (MWCNTs). The unique interactions between MWCNT and basalt fibers via SDS surfactant were detected by FT-IR and Raman spectroscopy. As a result, it was observed that the amount of MWCNT coated on basalt fibers increased from 0 to 10 during the dip-dry coating cycle. As the dip-dry coating cycle was ex-tended, the electrical conductivity of the epoxy composites containing basalt fibers coated with MWCNT rose dramatically from 3.25×10^{-9} S/cm to 1.44×10^{-1} S/cm. Furthermore, flexural mechanical properties of the epoxy composites reinforced with MWCNT-coated basalt fibers were found to be much better than those of the epoxy composite reinforced with plain basalt fibers, [7]. The study used temperature variation of 40°C, 50°C, and 60°C together with fluid speeds of 1 m/s, 2 m/s, and 3 m/s. According to the findings of human calculations, the erosion corrosion rate at flow rates of 1 m/s, 2 and 3 m/s is, in that order, 0.0030, 0.0440 mmpy, and 0.1946 mm / year. The test results using testing method at a temperature of 40, 50, and 60 °C show that the erosion-corrosion rate is 0.0315 mmpy, 0.0450 mmpy, and 0.0531 mmpy for flow rate of 1 m/s, erosion-corrosion rate of 0,0596 mmpy, 0,0781 mmpy, 0,0950 mmpy for flow rate of 2 m/s, and 0.1044 mmpy, 0.1274 mmpy, and 0.1497 mmpy for flow rate of 2 m/s. Thus, it may be said that the higher flow rate, [8]. In order to investigate the effect of various clay types and contents on the mechanical characteristics and structure of the nanocomposites, epoxy-clay nanocomposites were created. Montmorillonite of the 0.5 - 11 wt. % natural (Cloisite Na+) and organically modified (Cloisite 30B) varieties was used to strengthen the diglycidyl ether of bisphenol-A (epoxy). According to SEM data, there were bigger clay agglomerates evident as the clay content rose. At 1 weight percent modified clay loading, the tensile strength reached its maximum. The impact strength of the epoxy resin increased by 137 % when 0.5 weight percent of organically modified clay was added; by comparison, the impact strength increased by 72 % when 0.5 wt. % of unmodified clay was added. With increasing clay loading, the tensile modulus rose in both varieties of nanocomposites, [9]. Due to their exceptional mechanical properties, single-walled carbon nanotubes (SWNTs) are seen as extremely promising reinforcing materials for use in polymeric matrices in high

performance applications. Such composite materials can only be produced by purifying the SWNTs and achieving a homogenous dispersion in the matrix.

A purification/dispersion method was reported in research. Their mechanical properties are achieved by applying two distinct curing cycles. In both situations, the tensile strength and the Young's modulus are examined, [10]. Carbon nanotubes (CNTs) have the potential to provide remarkable mechanical qualities and multifunctional features. Continued efforts to develop dispersion and functionalization processes are a result of the growing interest in using CNTs in many different industries. Appropriate dispersion and interfacial adhesion between the carbon nanotubes and polymer matrix must be ensured in order to use CNTs as efficient reinforcement in polymer nanocomposites, [11]. After the functionalized nanotubes were incorporated into the epoxy resin, transmission electron microscopy (TEM) was used to examine the resultant composite. Evidence of enhanced interaction between the nanotubes and the epoxy resin is pro-vided, and the functionalization resulted in a decrease in agglomeration, [12]. Oxy fluorination of multi-walled carbon nanotubes (MWNTs) was carried out at various temperatures. With the use of FT-IR, EDS, and XRD, the surface characteristics of oxy-fluorinated MWNTs were examined. Impact and fracture toughness tests were used to assess the fracture behavior of the composites created after the treated MWNTs were inserted in the epoxy resin. Based on the surface examination, it was discovered that the highest level of surface fluorine and oxygen contents was seen at 100 °C, and these contents rose as the oxy-fluorination temperature increased. As a result, the MWNTs' surface polarity increased, improving the interfacial adhesion force between them and the epoxy matrix and raising the composites' KIC and impact strength, [13]. Electrochemical impedance spectroscopy investigations demonstrated that the coating's ability to offer long-term corrosion protection is made possible by the HKUST-1-BTA@e-Mica (HBeM) composite. After 30 days of immersion, the HBeM/EP composite coating's low frequency impedance, $|Z|_{f=0.01\ Hz}$, improved by about three orders of magnitude and stayed higher than that of the pure epoxy coating. The inclusion of fillers also improves the mechanical properties of the coating. To sum up, this work offers a straightforward, quick, and energy-efficient way for creating intelligent coatings that resist corrosion, with a lot of industrial applications [14]. By using a hydrothermal process, new erosion-resistant hybrid nanofiller molybdenum disulphide (MoS_2) functionalized MWCNTs have been created. When compared to typical MWCNT nanocomposites, the epoxy nanocomposite containing MoS_2 functionalized MWCNTs demonstrated improved mechanical characteristics and SPE resistance. At 15° and 90° impact angles, the erosion rates of the epoxy/MoS_2/MWCNTs – 1 nanocomposite were 471 mg/Kg and 132 mg/Kg, respectively, whereas the erosion rates of the epoxy/MWCNTs nanocomposite were 548 mg/Kg and 300 mg/Kg, respectively. The erosion mechanism was predicted using the erosion efficiency parameter (η), and its validity was confirmed using FE-SEM analysis, [15]. Tensile and tribological test results demonstrated the superiority of specimens containing 0.45wt% MWCNT + 0.45 wt. % nano silica over similar single-type nanoparticles with the same total weight percentages. In particular, after comparing the composite specimens with 0.45 weight percent MWCNT + 0.45 weight percent nano silica to the neat composites, the tensile strength and tensile modulus rose by 25.2 % and 31 %, respectively, [16]. Multiwalled carbon nanotubes (MWCNTs) were mixed with an epoxy-polyamide blend by dispersing them in a hardener. It was investigated how various weight ratio percentages of MWCNTs affected the results. The samples were created using an

axillary ultrasonic approach in conjunction with a mechanical molding procedure. To determine the ideal filler ratio, the MWCNTs ratio was varied between 0.1 and 0.9 weight percent. The tribological characteristics were found to be improved by the addition of MWCNTs. MWCNTs with a weight percentage of 0.5 have superior tribological characteristics, [17]. Using sandblasting equipment, the erosion of epoxy glass fiber composites (Epoxy/GF) is examined. The study examines the filling epoxy matrix's oil content (2.5, 5, 7.5 and 10) as well as the impact angles (30°, 60° and 90°) and distance from the sand jet. The findings indicate that the behavior of the material changes from brittle to ductile strongly depending on the oil concentration. Under a microscope, the degraded surface's morphology is examined, and the damage mechanisms are explored, [18]. The impact angle inclination (30º, 60º, and 90º) and oil content (2.5, 5, 7.5 and 10 weight percent) in the epoxy resin matrix are examined. Comparing reinforced epoxy to un-reinforced epoxy, the former shows less erosion resistance [19]. Ali et al. studied the effects of filling epoxy with various vegetable oils and carbon nanotubes. Carbon nanotubes with contents of 0.25, 0.5, 0.75 and 1 wt. % are combined with 10 weight percent of vegetable oils in an epoxy matrix. The friction co-efficient was shown to significantly drop as the CNT content increased, according to the testing data, [20].

EXPERIMENTAL

In this study, PORKEM SPECIALITY CHEMICALS epoxy resin KEMCOAT-E43 is used to protect water pipelines, and experiments conducted to investigate how nanoparticles affect the tribological and mechanical characteristics of the coating. The objective is to gain a thorough understanding of how nanoparticles enhance the mechanical strength and erosion properties of composite materials as a protective coating, epoxy specifications shown in table 1. The type of Nano fillers used as reinforcing agents, is multi-walled carbon nanotubes (MWCNTs), and scanning electron microscope of multi wall carbon Nano tubes at 200 nm which manufactured by mechanical engineering department, national research Centre, Cairo, Egypt. Their technical properties are listed in Table 2. The epoxy and multi wall carbon nanotubes solution was mechanically stirred for 10 min to form a homogeneous suspension with MWCNT contents. Then, the mixtures filled by (0.1, 0.2 and 0.3 wt. % of MWCNTs). And then an epoxy hardener was mixed into the epoxy /multi wall carbon nanotubes suspension gradually (i.e. drop by drop) while the mixture was being stirred mechanically at 100 rpm to prevent as much as possible the creation of bubbles. The hardener was added to the suspension with a volume ratio of 1 : 4. A carbon steel plate specimens were cut into square pieces of 40 × 40 × 6 mm^3. The epoxy nanocomposites were coated on the sample surface with a layer with a thickness of 200 micrometers and cleaned with acetone before and after the erosion test. To achieve a uniform dispersion, the mixture was quietly softly stirred for about 10 minutes and then left for two hours. Finally, the silicon mold was filled with the composite suspension was poured into the silicon mold to create tensile specimen dog-bone-like steel tensile (to avoid bubble formation which causes specimen damage) and allow to cure for 10 days at room temperature. All of steps of the prepa-ration of epoxy Nano composites added by MWCNTs with different percentages (0.1%wt, 0.2%wt, 0.3%wt) shown in Fig. 1.

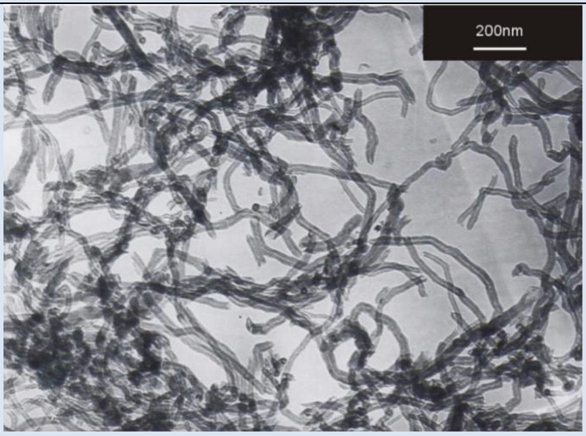
The specimens used in the present work were produced according to EN ISO 527-2:2012, as represented in Fig. 2. The mixture of two resin components was made mechanically and then the homogenized compound was cast into a silicon mold. The samples were taken out from the molds. One day after casting and then they were kept

in lab for 7 days at an average temperature around 25 °C and relative humidity close to 30 %.

Table 1 Technical properties of Kemcoat E43 (provided by the supplier).

Specific gravity	**1.57±0.06**	
Solids content	**100% (by volume)**	
Flash point	**145°C**	
Application method	**Airless spraying, roller or stiffed brush**	
Pot life at 23°C	**40 minutes**	
Dry to recoat	**24Hours**	
Fully curved	**7 days**	
Abrasion resistance	**Excellent.**	
Temperature resistance	**+ 80°C**	
Standards	**DIN 53156 , 53151 ,53153 ASTM D5895,522,2369,BS6920**	

Table 1 Technical properties of multi-wall carbon nanotube (provided by the supplier).

Product name	**Multi wall carbon Nano tubes**	
colour	**Black**	
Particle size	**10-30 nm**	
length	**1-2 µm**	
content	**≥99%**	
PH	**7-8**	
H2O	**0.4%**	
Cu	**< 0.8 ppm**	
Fe	**< 1ppm**	
Mo	**< 0.090%**	
Mg	**< 0.92 ppm**	
Ni	**< 0.085%**	
Resistivity	**948.7 uΩ. m**	
Conclusion	**The specifications conform with enterprise standard**	
Main Inspect Verifier	**He Wei Lv Qingzhen**	

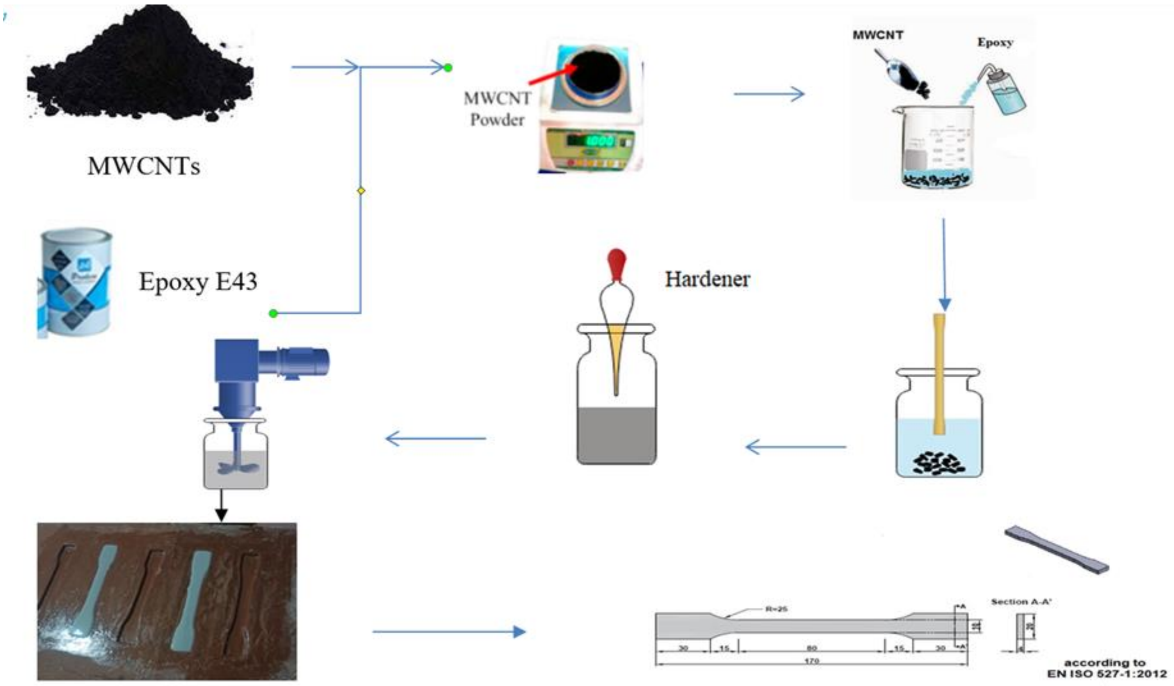


Fig. 1 The scheme of preparation of epoxy Nano composites added by MWCNTs.

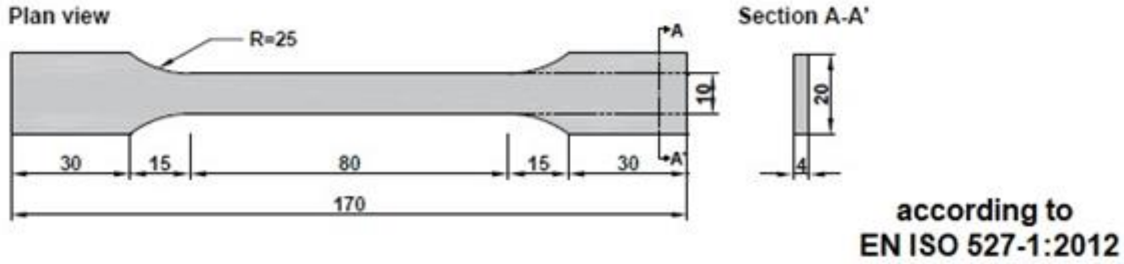


Fig. 2 Specimen geometry (all dimensions are in mm).

RESULTS AND DISCUSSION

Tension test of epoxy / MWCNTs with different contents were performed according to EN ISO 527-2:2012 standard. The tensile tests were conducted at Materials Lab, Facul-ty of Engineering, South Valley University using a universal testing machine WDW-300. The specimen was fixed straight by using two jaws with 5 KN maximum loads with constant speed rate of 0.5 mm/min. and measure the applied load and the result taken for each sample. The tensile specimen is shown in Fig. 3. The readings were taken for each sample.

Erosion test is carried out using Water jet test technique that have been used to investigate erosion in a controlled environment. By conducting the water jet tests, it is aimed to damage (erode) the sample within a required short time whereas in the real field erosion is expected to occur after a long duration of exposure Fig 4. Erosion test carried out according to certain standards to have scientific validity and to be reproducible. The ASTM established standard methods using specific conditions under the (ASTM G134) [12]. The water jet technique (ASTM G134) is the most popular laboratory technique for testing erosion characteristics of materials.

The specimens were subjected to four impingement angles between 15º to 60º with an increment of 15º. And were subjected to standoff distances of 100 and 200 mm. and the erosion test times were 5 minutes. Erosion was measured by the weight loss of the specimen. An electronic balance with a sensitivity of 1mg was used to measure the weight loss before and after the erosion test. The test were conducted at Materials Lab, Faculty of science, South Valley University using a Scanning Electron Microscopy (SEM) JEOL-JSM 5400L(30kv) with EDX and WDX400 used Fig. 5 was used to investigate the fracture surfaces of the tensile specimens. Observation in Scanning Electron Microscope (SEM) was done on tensile specimens and specimens. The observation has been done in back scattered electrons mode (BSED), to provide information about the chemical structure of the present phases, in the inorganic charges. The observation was complemented by the possibility of doing micro-analysis by energy dispersive spectrometry (EDS).

During the study, multi-walled carbon nanotubes (MWCNTs) were used as the reinforcement in the epoxy resin with weight percentages (0, 0.1, 0.2 and 0.3) wt. % respectively, by using mechanical dispersion mixing processes to prepare (epoxy/MWCNTs) nanocomposites. Tensile and erosion tests were carried out to evaluate the mechanical, tribological and medical properties of the composites. The relationships of stress-strain, load - displacement, mass loss - impingement angles, and mass loss - time for each impingement angle were obtained from experimental data as follows:

The tensile properties of MWCNTs/epoxy, composites are shown in Fig. 6 and in Table 3. The tensile load of MWCNTs/epoxy composites increased from 180N for epoxy resin to 300 N for MWCNTs/epoxy composites by 66.7 %. The tensile strength of MWCNTs/epoxy composites Fig. 6 increased from 4.5 MPa for epoxy resin to 7.5 MPa for epoxy / MWCNTs by only 66.7 % Compared to the epoxy composite.

Fig. 3 Tension test for epoxy Nano composites specimens.

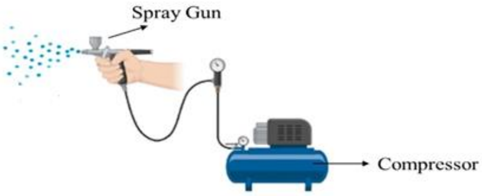


Fig. 4 Erosion test for epoxy / MWCNTs.

Fig. 5 Scanning Electron Microscopy JEOL-JSM 5400LV (30kv) with EDX and WDX400.

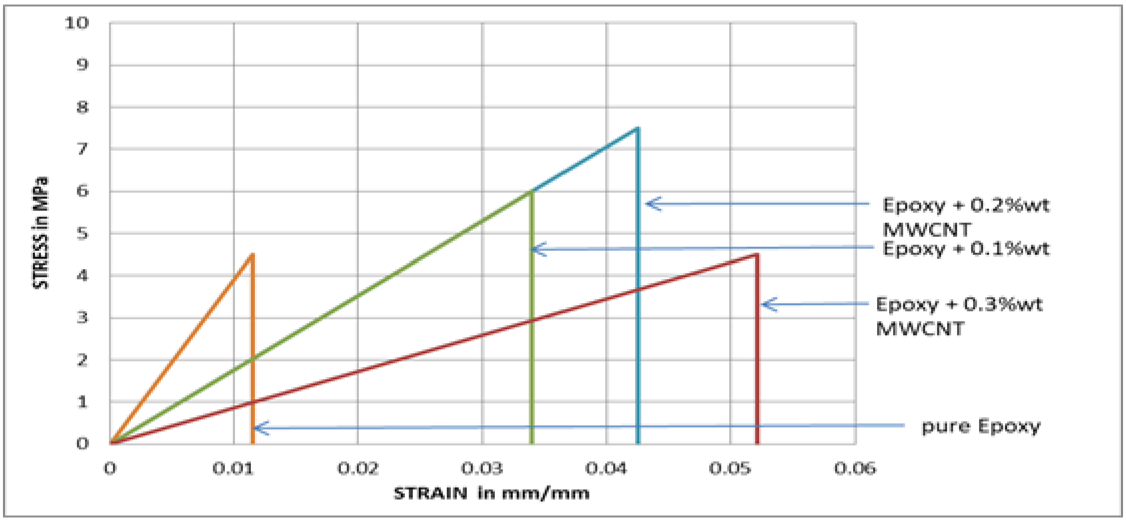


Fig. 6 Stress – strain curve for Epoxy with Different Contents of MWCNT.

Table 2 Mechanical properties of MWCNTs / EP composites with different content of MWCNTs.

Sample number	Sample code	Tensile load (N)	Tensile strength (MPa)	Elongation (%)
EP-0	EP	180	4.5	1.15%
EP-0.1	0.1 MWCNTs/EP	240	6	3.40%
EP-0.2	0.2 MWCNTs/EP	300	7.5	4.25%
EP-0.3	0.3 MWCNTs/EP	180	4.5	5.21%

The results of tensile test showed that the content of MWCNT of 0.2 wt. % had a maximal influence on the tensile properties of MWCNTs /epoxy composite that is attributed to the fact that the tensile properties are dominated by the Nanotubes reinforcement rather than the matrix. Also contributes to insignificant change in tensile properties shown in Fig 7. Epoxy resin shows brittle behavior at room temperature. Data on tensile strength, elastic modulus, and failure strain can be obtained from stress-strain curves. Tensile strength of MWCNT/epoxy nano composites improves with MWCNT addition. Only for the samples with the 0.1 and 0.2 wt. % MWCNT content, the nano composite tensile strength is greater than that

of the epoxy matrix. This is because the mechanical strength of epoxy Nano composites strongly depends on the MWCNTs-epoxy interfacial bonding.

Figure (8-a, 9-a. outer surface of 2 specimens) is the fracture surface morphologies of neat EP and 0.2 wt. % MWCNTs/EP composites. The surface of neat epoxy is smooth, presenting a typical brittle fracture as can be seen in Fig. 8-a; the fracture surface of pure epoxy is fairly smooth with no particular structural features (Fig. 8, b). The smooth surface of pure epoxy, common in brittle fracture, may contribute to its lower fracture toughness. In contrast, nanocomposite fracture surfaces display distinct fractographic features and increased roughness due to added filler, Fig. 9 a, b. With the addition of MWCNTs, the fracture morphology becomes rough and uneven indicating the excellent reinforcing effect and improving the mechanical performance of the composite. Figure (11-b fracture zone of EP/MWCNTs) is the SEM image of a typical area. MWCNTs are pulled out from the EP matrix, demonstrating another reinforcing mechanism. Uniform dispersion of MWCNTs without entanglement or agglomeration ensures their reinforcing effect, resulting in excellent mechanical properties in MWCNTs/EP composites with proper MWCNT content. At high MWCNTs content, aggregated MWCNTs form in the epoxy matrix, resulting in lower strength because of weak MWCNT-polymer interactions and high-stress concentrations, resulting in the reduction of the tensile strength. So for the sample with the high wt. % MWCNT con-tent, the Nano composite tensile strength is slightly like that of the epoxy matrix.

Fig. 7 fracture of both (a) Pure Epoxy (b) Epoxy with 0.2 wt. % MWCNTs.

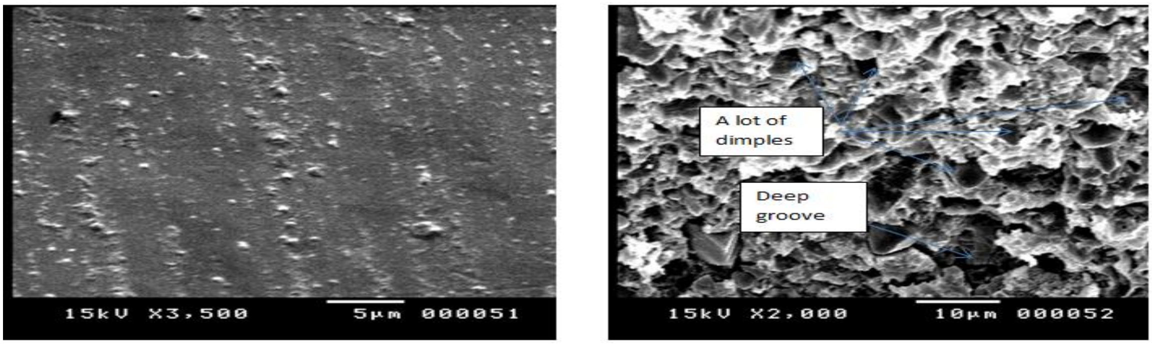


Fig. 8 (a) Epoxy outer surface(b) Epoxy resin fracture surface.

The mechanism of erosion failure can be grouped into ductile, brittle and semi ductile ones. In general ductile behavior will occur on thermoplastic and brittle behavior on thermosetting polymer. Figure 10 shows erosion test mechanism. Tests were performed to determine the effect of impact angle on the erosion of epoxy coating. The mass loss of specimens measured according to different impact distances 100 mm and 200 mm at 5 m/s velocity for different impact angles 15°, 30°, 45° and 60° on wear rate can be seen in Figs. 11, 12, 13 and 14. The constant impact of the water jet, which

causes fatigue accumulation early in the damage development process, is the primary cause of rising erosion values. Following the creation of the first fracture, the coating samples start to peel and separate due to the lateral jet shearing action. This causes the damage range to rapidly expand and a roughly circular damage morphology to form.

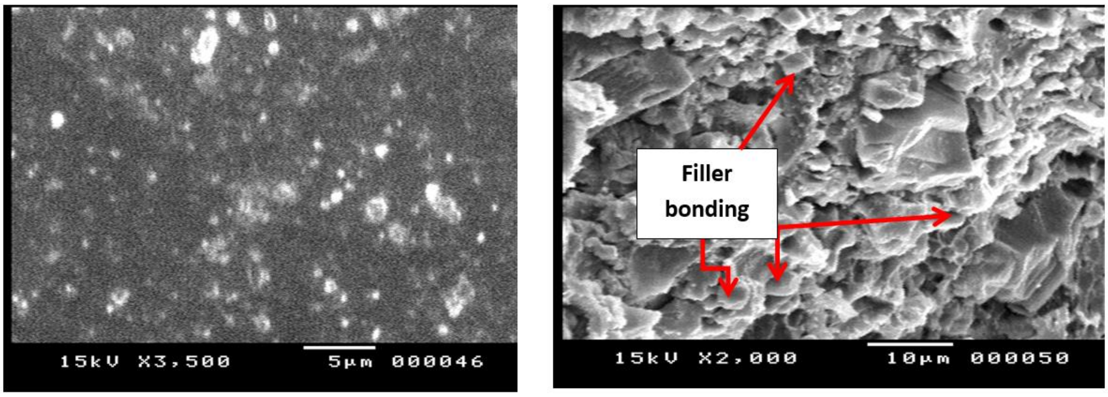


Fig. 9 (a) 0.2 wt. % MWCNTs / Epoxy composite surface good dispersion of MWCNTs in epoxy (b) 0.2 wt. % MWCNTs / Epoxy composites have no

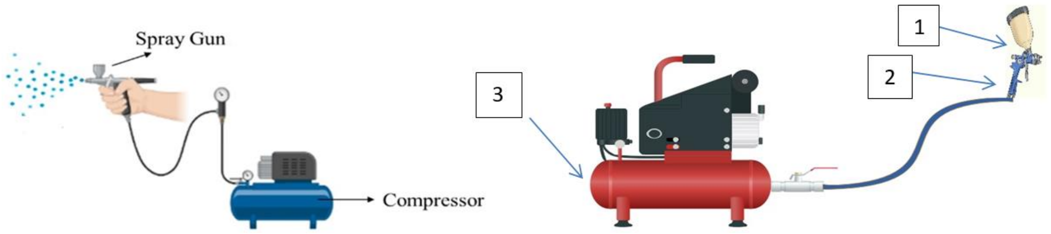


Fig. 10 Erosion test mechanism (1) water container (2) spray gun (3) air compressor.

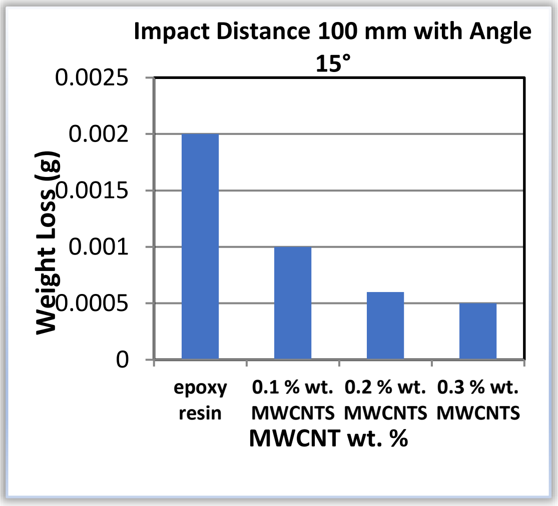


Fig. 11 Effect of different contents of MWCNT wt. % in Weight loss of epoxy coating with impact distance of 100 mm.

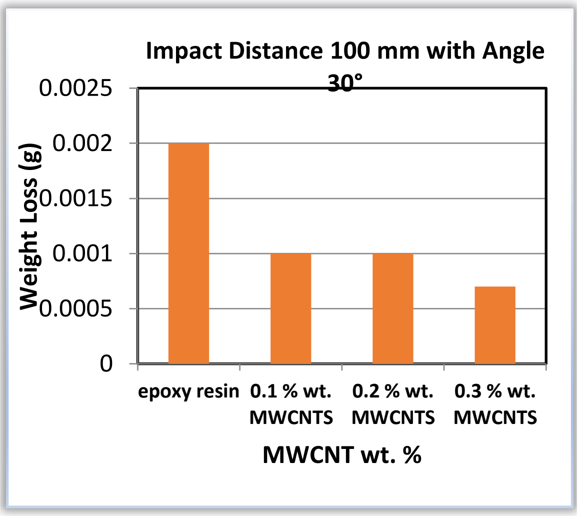


Fig. 12 Erosion values with impact with impact distance of 100 mm.

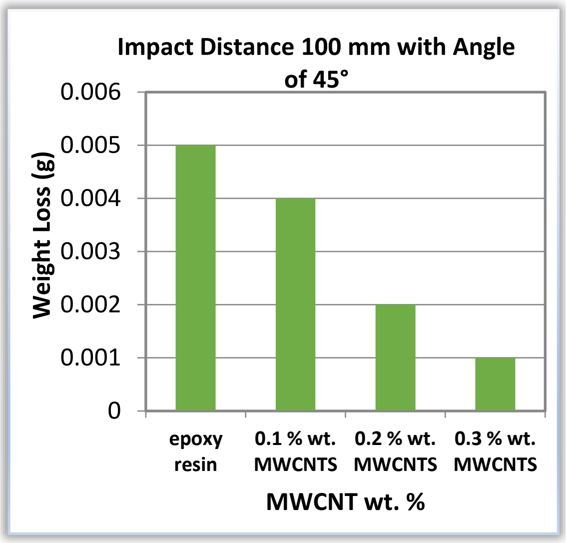


Fig. 13 Effect of Impact water-jet distance of 100 mm in weight loss values

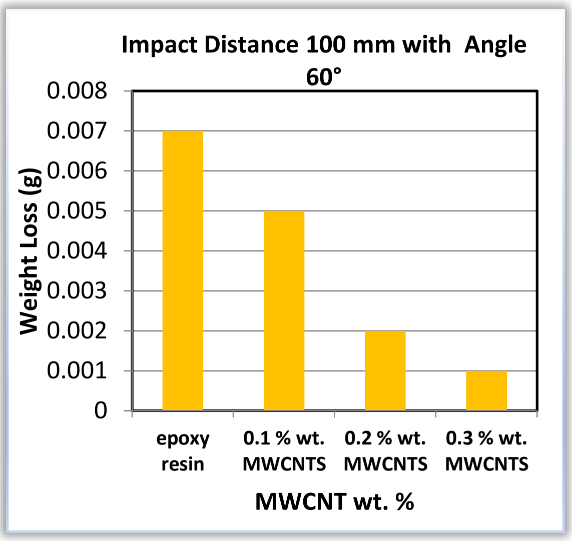


Fig. 14 Weight loss Values due to erosion with different contents of MWCNT wt. %

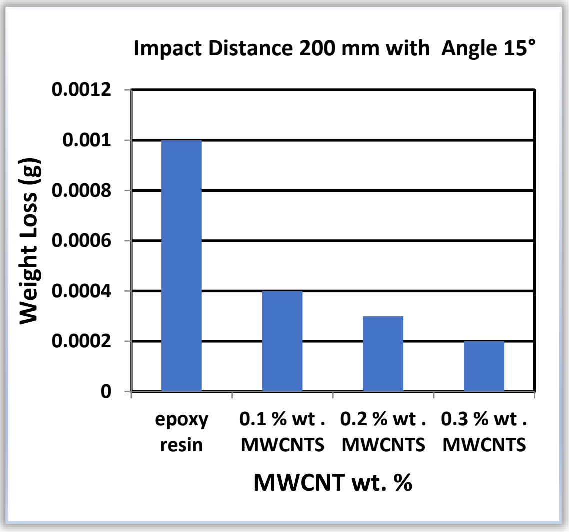


Fig. 15 Effect of different contents of MWCNT wt. % in Weight loss of epoxy coating with impact distance of 200 mm.

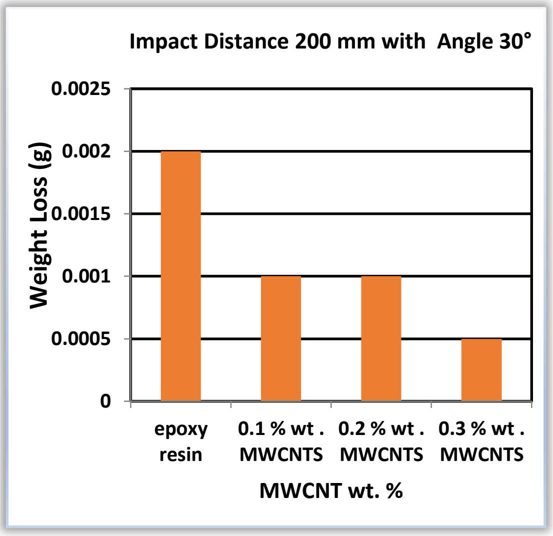
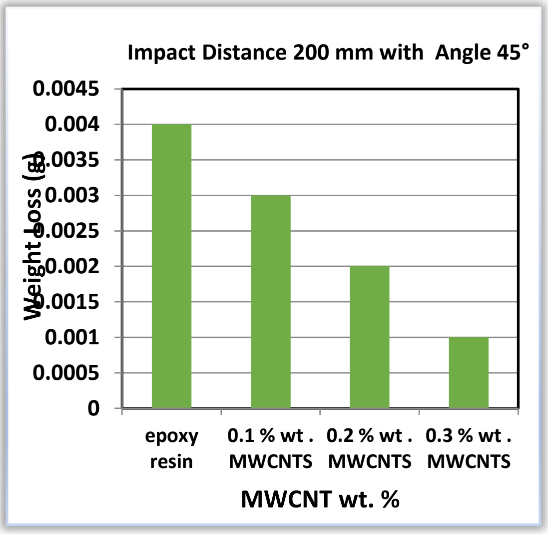


Fig. 16 Erosion values with impact angle of 30°.



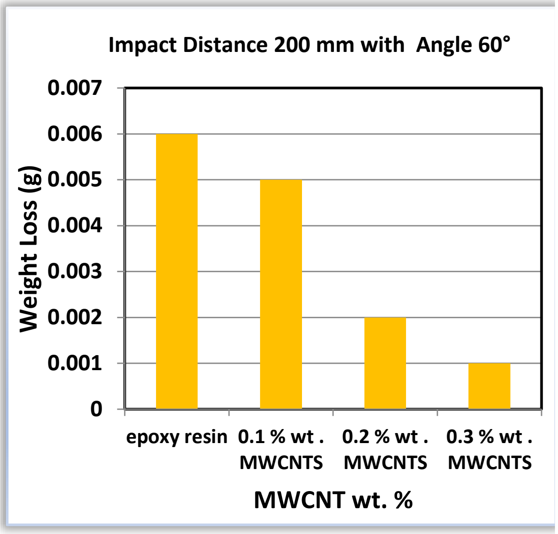


Fig. 17 Effect of Impact angle of 45° in weight loss values.

Fig. 18 Weight loss Values due to erosion with different contents of MWCNT.

The impact angles affect erosion along with impact distance and different contents of MWCNT. Semi-ductile and brittle material's erosion weight loss was measured depending on these factors. Taking these factors as a reference, the experiments conducted have shown that the maximum weight loss due to erosion was found at an impact angle of 45° to 60°. As the contact angle increases, the pressure will increase. Thus, on bodies with hydrophobic surfaces, the impact of the water jet will have a stronger influence.

Adding MWCNT to epoxy increase erosion resistance to epoxy coating, meanwhile increasing the content of MWCNT decreases the weight loss of EP coating. The damage volume increases proportionally with the impact angle; among the four coating materials. Meanwhile, weight loss decreased with increasing impact distance from 100 mm to 200 mm, as shown in Fig. 15,16,17,18. That results might have occurred because the water jet lost some of its impact forces because of the increased impact distance with the coating surfaces, where the weight losses values were decreased from 0.005 g to 0.0002 g after increasing the impact distance from 100 mm to 200 mm for the epoxy coating with 0.3 wt. % MWCNT.

CONCLUSIONS

In this research, based on the experimental results, different numbers of continuous water jet impact coating mate tests were carried out at impact angles of 15°, 30°, 45° and 60° with two different impact distances 100 and 200 mm. The results show that the typical damage of continuous water jet impact on film coating has the following observations:

The four skin coatings (pure epoxy and epoxy with three different contents of MWCNT) exhibit almost the same failure mode when subjected to water jet impact, there are obvious cracks at the junction of the coating interface. As the impact angle increases, the damaged area of the four coating samples gradually increases, and the damage morphology gradually transitions from minor scratches to peeling damage. In the four coatings, the damage morphology primarily consists of isolated pits from

peeling and surface scratches. Increasing the impact distance decreased the weight loss values. Among the four coating materials, adding 0.3 wt. % of MWCNT has the best resistance to water erosion with a smoother failure evolution, followed by 0.2 wt. % MWCNT, while pure epoxy exhibits the poorest resistance.

REFERENCES

1. Sahare, P. H., Dhole L. P., and Burande S. W., "A review paper on investigation of mechanical and wear properties of polymer composites subjected to environmental degradation", Materials Today: Proceedings, (2024).

2. Park, M.-S., Lee S., and Y. S. Lee, Mechanical properties of epoxy composites reinforced with ammonia-treated graphene oxides. Carbon letters, 21: pp. 1-7, (2017).

3. Thostenson, E. T., Ren Z., and Chou T. W., "Advances in the science and technology of carbon nanotubes and their composites: a review", Composites Science and Technology, 61(13): pp. 1899-1912, (2001).

4. Sarath Kumar P., Jayanarayanan K., and Balachandran M., "Thermal and Mechanical Behavior of Functionalized MWCNT Reinforced Epoxy Carbon Fabric Composites", Materials Today: Proceedings, 24: pp. 1157-1166, (2020).

5. Thakur R. K. and Singh K. K., "Experimental investigation and optimization of abrasive water jet machining parameter on multi-walled carbon nanotube doped epoxy/carbon laminate", Measurement, 164: p. 108093, (2020).

6. Xia Y., et al., "Introducing cyano-functionalized multiwalled carbon nanotubes to improve corrosion resistance and mechanical performance of poly(arylene ether nitrile) coating", Surface and Coatings Technology, 432: p. 128058, (2022).

7. Kim M., et al., "Structures, electrical and mechanical properties of epoxy composites reinforced with MWCNT-coated basalt fibers", Composites Part A: Applied Science and Manufacturing, 123: pp. 123-131, (2019).

8. Prasojo B., et al., "Effect of Flow Rate and Temperature on Erosion Corrosion Rate of Crude Palm Oil Against Elbow A53 Grade B Carbon Steel Material", IOP Conference Series: Materials Science and Engineering, 462: p. 012038, (2019).

9. Basara C., Yilmazer U., and Bayram G., "Synthesis and characterization of epoxy based nanocomposites", Journal of Applied Polymer Science, 98(3): pp. 1081-1086, (2005).

10. de Villoria R. G., et al., "Mechanical properties of SWNT/epoxy composites using two different curing cycles", Composites Part B: Engineering, 37(4): pp. 273 - 277, (2006).

11. Ma P. C., et al., "Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review", Composites Part A: Applied Science and Manufacturing, 41(10): pp. 1345 - 1367, (2010).

12. Gojny, F. H., et al., "Surface modified multi-walled carbon nanotubes in CNT/epoxy-composites", Chemical Physics Letters, 370(5): pp. 820 - 824, (2003).

13. Park, S.-J., H.-J. Jeong, and C. Nah, A study of oxyfluorination of multi-walled carbon nanotubes on mechanical interfacial properties of epoxy matrix nanocomposites. Materials Science and Engineering: A, 385(1): p. 13-16, (2004).

14. Li K., et al., "Improving the corrosion protection properties of epoxy resin coating by using HKUST-1-BTA@e-Mica two-dimensional nanocomposites", Colloids and Surfaces A: Physicochemical and Engineering Aspects, 701: p. 134869, (2024).

15. Varghese, A. S. and Searl M. S., "Evaluation of improved tribo-performance characteristics of MoS_2 functionalized MWCNTs hybrid reinforced epoxy composites for severe erosion conditions. Tribology International, 197: p. 109766, (2024).

16. Moghimi Monfared, R., M.R. Ayatollahi, and R. Barbaz Isfahani, Synergistic effects of hybrid MWCNT/nanosilica on the tensile and tribological properties of woven carbon fabric epoxy composites. Theoretical and Applied Fracture Mechanics, 96: pp. 272 - 284, (2018).
17. Al Shaabania, Y. A., “Wear and Friction Properties of Epoxy- Polyamide Blend Nanocomposites Reinforced by MWCNTs”, Energy Procedia, 157: pp. 1561 - 1567, (2019).
18. Atia A. M. and Ali W. Y., “Erosion Behavior of Epoxy Composites Reinforced by Glass Fibre and Filled by Synthetic Oil”, Journal of the Egyptian Society of Tribology, 13 (2): pp. 50 - 59, (2016).
19. Atia, A. M. and Ali W. Y., “Erosion of Glass Fibre Reinforced Epoxy Composites”, Journal of the Egyptian Society of Tribology, 14 (2): pp. 28 - 41, (2017).
20. Badran, A. H., Hasan M. K., and Ali W. Y., “Tribological Behavior of Epoxy Reinforced with Carbon Nanotubes and Filled by Vegetables Oils”, Journal of the Egyptian Society of Tribology, 14(1): pp. 51 - 61, (2017).