RESEARCH PAPER

UV-Induced Changes in Mechanical Behavior of Epoxy / MWCNTs Nanocomposite

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ABSTRACT

This study examines the impact of ultraviolet (UV) exposure on the mechanical properties of epoxy/MWCNT (Multi-walled Carbon Nanotube) nanocomposites. The research includes an investigation of tensile strength, surface morphology through FE-SEM (Field Emission Scanning Electron Microscopy), compressive strength, and hardness. The study involves epoxy resin (Dupoks 50A) and MWCNTs from Sky Spring Nanomaterials. Results, based on UV exposure times of 60, 120, and 180 minutes, reveal nuanced effects on mechanical properties. Tensile strength increases up to 45.77 MPa with 0.6 gm MWCNTs, while compressive strength peaks at 4.712 MPa. Hardness reaches 81.17 Shore D at 0.6 gm MWCNTs. FE-SEM analysis shows good interfacial bonding. The findings offer precise insights into optimizing epoxy/MWCNT nanocomposites under varied UV exposure durations.

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INTRODUCTION

Polymer is a large molecule composed of repeating subunits called monomers. These monomers are bonded together through chemical reactions, forming long chains or networks.[1]. In the field of materials science, polymers are widely used due to their diverse properties and applications in various industries. Polymer composites, in particular, are important commercial materials with a wide range of applications such as filled elastomers for damping, electrical insulators, thermal conductors, and high-performance composites for aircraft. The development of polymeric nanocomposites has shown great promise in enhancing the properties and performance of these materials. Polymeric materials have great scientific-technological relevance in food packaging, engineering materials, and biomedicine. Furthermore, the unique characteristics and behavior of polymer nanocomposites at the nanoscale have opened up new possibilities in the development of sensors, electronic devices, and optical nanodevices [2].

Polymers constitute a significant group in modern industries, distinguished by their properties that surpass those of traditional materials. In addition to being cost-effective to prepare, many polymers are non-corrosive, lightweight, and exhibit favorable mechanical properties [3].

Composite materials can be defined as a material that consists of two or more different phase's separated by interface. Thus, the properties of the composite materials depend on

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the properties of the individual phases [4]. The primary phase is called the matrix phase. Matrix is generally less hard and more ductile than the dispersed phase. It surrounds the dispersed phase and carries a load with it. The secondary phase is known as the dispersed phase and it's incorporated in the matrix phase in a continuous or discontinuous form. The dispersed phase is generally stronger than the matrix phase, therefore, it's sometimes known as the reinforcing phase. Reinforcing phases act together to give the stiffness or mechanical strength to the composite material. Thus, the composite materials have properties different from the original material [5].

Exposure to ultraviolet radiation can have adverse effects on the mechanical properties of polymeric nanocomposites. UV-induced changes in the mechanical behavior of polymeric nanocomposites are a subject of active research. Previous studies have reported that inappropriate UV curing can deteriorate the mechanical properties of polymeric resins [6].

In the context of nanocomposites, UV radiation can degrade the polymeric structure, leading to a degradation of fundamental electrical insulating properties and tensile strength. Hence, it is essential to study the impact of UV radiation on the mechanical properties, specifically tensile strength and strain distribution, of polymeric nanocomposites. The decrease in mechanical properties due to UV radiation exposure is mainly attributed to photochemical degradation and structural changes of the polymer matrix [7].

Several studies have investigated the effect of ultraviolet (UV) radiation on the mechanical properties of polymers They investigated the effect of UV radiation on the mechanical properties of glass/polyester composites. The study found that UV radiation can result in the breakage of bonds between the polymer chains, reducing the molecular weight of the polymer, which eventually deteriorates the mechanical properties of the composite [8]. Another study found that prolonged exposure to UV radiation leads to discoloration and loss of mechanical properties of polymers. In summary, these studies suggest that UV radiation can cause a reduction in the mechanical properties of polymers, and the extent of these changes depends on the type of polymer and the exposure conditions for ultraviolet (UV) [9].

The effect of UV-Vis on the mechanical properties of epoxy/MWCNT nanocomposites has been studied in various research. UV irradiation has been found to impact the degradation of MWCNT/epoxy nanocomposites, leading to the formation of an entangled surface layer and mechanisms of release resistance. Additionally, UV-Vis spectroscopy has been used to confirm the proper dispersion of MWCNTs in the epoxy, which is crucial for enhancing the mechanical properties of the nanocomposites[10]. Furthermore, the durability of epoxy nanocomposites under UV light has been demonstrated, preventing the yellowing and deterioration of the mechanical properties of the epoxy resin. These findings suggest that UV-Vis spectroscopy and UV irradiation play a significant role in understanding and improving the mechanical properties of epoxy/MWCNT nanocomposites [11, 12].

MATERIALS AND METHODS

Materials

The trademarked Dupoks 50A epoxy resin is a low-viscosity liquid thermoset that, when mixed with the hardener Dupoks 50B in a ratio of 100/50, solidifies into a thermoset. The resin was supplied by the Turkish kimyacibaba firm. According to the Product Company's specifications, Table 1 shows the characteristics of the epoxy resin utilized in this project. In this study, Sky Spring Nanomaterials supplied the multi-walled carbon nanotubes (MWCNTs). Table 2 displays, according to the Product Company's specifications, the characteristics of the multi-walled carbon nanotubes utilized in this study. The following is a table listing the characteristics of the epoxy utilized in this project, as reported by the product company.

The plastic molds were made of Teflon for the mechanical test According to the ASTM -D256-

Table 1. Properties of (Dupoks 50A) epoxy used.

Density at 20°C (gm/cm^3	Viscosity at°C	Flexural Strength (Mpa)	Modules of Elasticity (Mpa)	Color
1.05	300	63	2800	colorless

87. The nanocomposites samples (including pure Epoxy, Epoxy- MWCNTs.The nanocomposites were prepared with (0.2, 0.6, 0.8 and 1) gm of (MWCNTs). Five samples were prepared for each test, the nanocomposites samples were coded according to the added weight ratio gmof (MWCNTS) according to the following Table 3.

Epoxy Resin preparation

To prepare a pure epoxy sample, we use glass containers. In addition, a sensitive balance (0.0001g) was used to calculate the empty glass containers' weight. After that, the epoxy resin was weighed in the sensitive balance. The percentage of mixing was weighted (100:50). The hardener was added to the epoxy Resin and mixed well until homogenization of the mixture was completed. After removing any air bubbles from the mixture using the ultrasonic cleaner, the sample was put into the plastic molds that had been made in advance. The plastic molds were made of Teflon in circular form for thermal tests and rectangular form for the mechanical test According to the ASTM -D256-87 stander and left for 24 hours to solidify and then extracted; the samples from the molds and placed in the dryer at a temperature of 60 for heat treatment. After that, smoothing sample with sandpaper and work for mechanical properties tests.

Preparation of (Epoxy -MWCNTs) nanocomposite

For all examination, (5) samples were performed. The weight ratios used for MWCNTs (0.2,0.6,0.8 and 1) gm with epoxy resins. Each ratio of MWCNTs, epoxy and hardener were weighted separately using a sensitive balance and mixing the MWCNTs to epoxy resin approximately for 10 minutes at room temperature continuously and slowly to avoid bubbles formed through the mixing to reaches a homogeneous case of the blend. Intermixing mixture concoction by use magnetic stirrer for 10 min to avoid temperature formed through the mixing and this heat directly effects on the properties of epoxy resins and acts on the dispersion of MWCNTs. After the liquid was dried in a desiccator to get rid of any remaining air bubbles, it was poured into the molds that had been made earlier.

RESULTS AND DISCUSSION

Tensile Test

Fig. 1 showed the pure epoxy that the effect of ultraviolet rays is the opposite effect, as it reduces the quality of the mechanical properties of the epoxy, with increasing time, exposed of ultraviolet radiation till 180 min

Strength of epoxy reinforced with MWCNTs increase in a non-linear relationship with the increase in the weight ratio of the superimposed nanomaterials, due to the small amount from MWCNTs with epoxy-filled homogeneously dispersed to a strong interface between particle surface and epoxy thus improving tensile strength. When the weight of carbon nanotube added to the epoxy increases above 0.6 grams, we notice an increase in the effect of ultraviolet rays with a decrease in tensile strength.

With an increase in the weight ratio of MWCNTs, the particles agglomerate, which is difficult to disperse in the epoxy, which leads

Table 2. properties of the multi-walled carbon nanotubes (MWCNTs).

Appearance	Outer diameter (nm)	Length	Purity MWCNTs
powder	20-40 nm	10-30 μ	99%

Table 3. Symbols of nanocomposites samples.

Nanocomposites symbol	MWCNTs /gm
A1(Epoxy -MWCNTs)	0.2
A2(Epoxy -MWCNTs)	0.6
A3 (Epoxy -MWCNTs)	0.8
A4(Epoxy- MWCNTs)	1

to a weak interface between the particles and the epoxy matrix, and thus the tensile strength decrease. As the tensile strength of epoxy improved when adding MWCNTs, the Table 4 shows tensile strength values for pure epoxy and nanocomposites according to the added weight ratios. We note that the highest value of tensile strength in the (epoxy- MWCNTS) was at an addition ratio of 0.6 gm

Increasing the percentage of carbon nanotubes in epoxy can lead to weaknesses due to various factors. Agglomeration of nanotubes creates stress concentrations, diminishing overall strength. Uniform dispersion is crucial for optimal reinforcement; poor dispersion results in weaker regions. Effective reinforcement relies on a strong bond between nanotubes and the epoxy matrix; compromised bonding reduces tensile strength. Excessive nanotubes may impede the epoxy's ability to form a cohesive matrix, decreasing overall strength. Processing conditions, like mixing and curing, influence final properties, contributing to weaknesses if improper. Material compatibility between nanotubes and epoxy is vital; a mismatch can lead to reduced performance. The size and length of nanotubes also impact mechanical properties; improper dimensions affect their ability to reinforce the epoxy.

UV light can have an impact on the mechanical properties of epoxy/MWCNT nanocomposites. A study found that the brittleness and bending resistance of epoxy resin are deteriorated substantially after long-term ultraviolet radiation [11]. Another study investigated the effects of UV light on the chemical and mechanical properties of a transparent epoxy-diamine system and

Table 4. Values of tensile strength (MPa) for pure Epoxy and their nanocomposites.

Time of UV exposure	Epoxy pure	E+MWCNTs 0.2 gm	E+MWCNTs 0.6gm	E+MWCNTs 0.8 gm	E+MWCNTs 1 gm
60 min	20	43.51	45.77	34.92	28.065
120min	18.45	33.42	36.22	29.85	24.12
180min	14.78	26.39	29.21	23.61	17.93

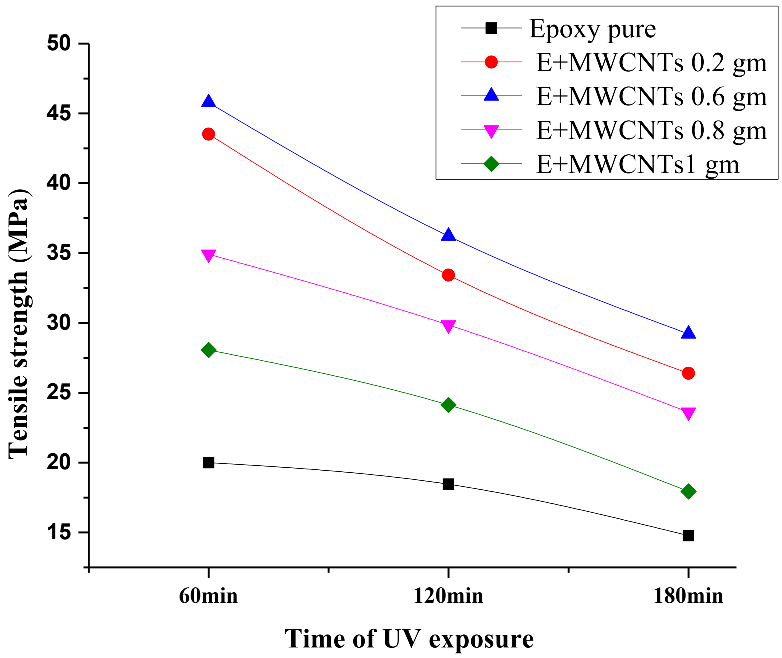

Fig. 1. Tensile strength of pure epoxy and nanocomposite.

found that the lack of a UV absorber can lead to a ~30% reduction in tensile strength after 800 hours of UV radiation [13]. The durability of epoxy nanocomposites under UV light has also been demonstrated, preventing the yellowing and deterioration of the mechanical properties of the epoxy resin [14]. The effect of UV light on the mechanical properties of epoxy/MWCNT nanocomposites can be both positive and negative, depending on the specific conditions and materials used. that UV exposure can cause degradation and erosion in epoxy materials, but the presence of MWCNTs fillers can improve UV resistance, mechanical properties With appropriate weight ratios, as is the case in the experiment, where the amount of 0.6 grams of carbon nanotube is considered a good enhancer of the ability of the epoxy in addition to increasing its resistance to ultraviolet rays.

The mechanical properties of epoxy/MWCNT nanocomposites can decrease with increasing exposure to ultraviolet radiation due to factors such as photodegradation, formation of entangled surface layers, hydrophobicity changes, and stress

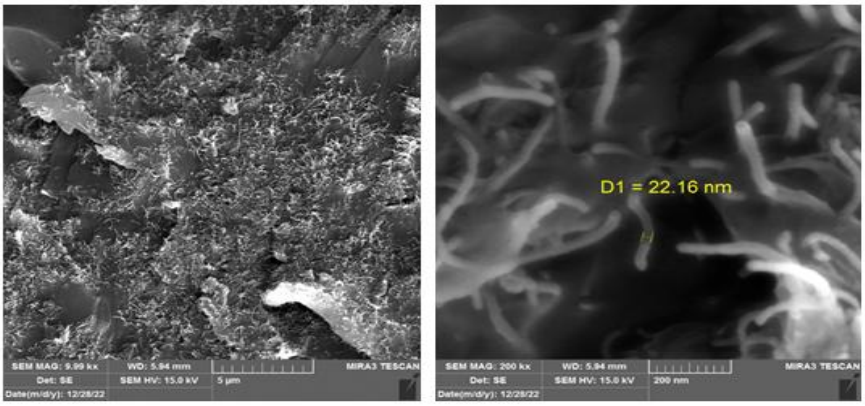

Fig. 2. (FE-SEM) Analysis Show the Surface Morphology for Epoxy -MWCNTs.

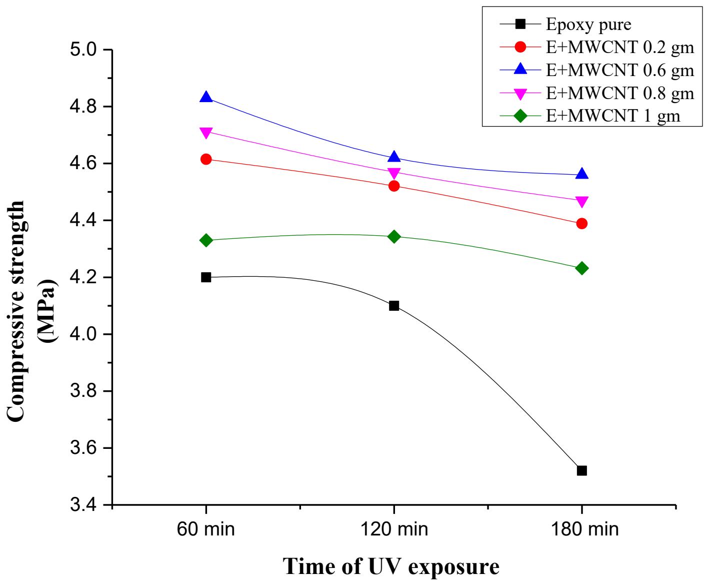

Fig. 3. Compressive Strength for Pure Epoxy and their nanocomposites.

cracking [15].

Scanning Electron Microscopy (FE-SEM) Analysis

The surface morphology is studied by use of FE-SEM images showing the surface morphology of the nanocomposite Fig. 2 shows the surface morphology of tensile fractures for epoxy reinforced with MWCNT Figure is demonstrated that the interfacial bonding between the MWCNT and epoxy matrix is good adhesion because the small size of the multi-walled carbon nanotube led to good bonding between the reinforcement material and the epoxy the good interfacial bonding and high adhesion between reinforcement and matrix because of the ability of these MWCNTs to absorb and get saturated from the matrix.

Compression Test Result

Fig. 3 has been showed the values of compressive strength (C.S) as a function of material type. From this figure, it can be noticed that the value of (C.S) for Epoxy reinforced with MWCNTs nanocomposites material is almost equal to pure epoxy, and as the percentage of addition increases, the samples become more brittle and their ability to withstand compressive stress is low. This is due to the breakage of the molecular chains of the polymer during the polymerization process. As a result, it leads to weak interconnection and cohesion between the base material and the reinforcement material.

The effect of UV light on the mechanical properties of epoxy/MWCNT nanocomposites is

Table 5. Values of Compressive Strength (MPa) for Pure Epoxy and their nanocomposites.

Time of UV exposure	Epoxy pure	E+MWCNTs 0.2 gm	E+MWCNTs 0.6gm	E+MWCNTs 0.8 gm	E+MWCNTs 1 gm
60 min	4.615	4.83	4.712	4.33	4.2
120min	4.521	4.62	4.57	4.343	4.1
180min	4.38	4.56	4.47	4.232	3.52

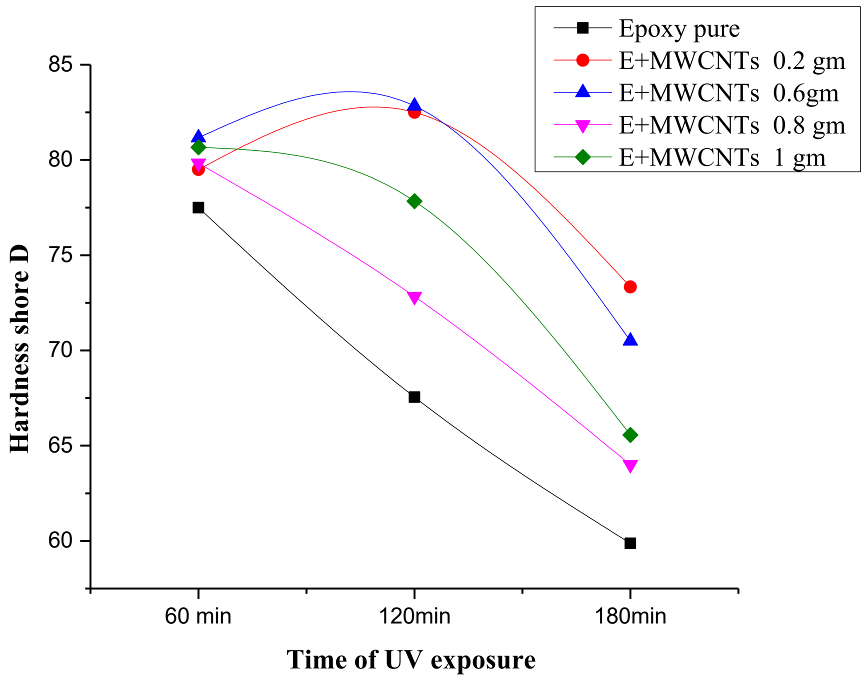

Fig. 4. Hardness shore D of epoxy pure and nanocomposites.

Table 6. Values of Hardness for Epoxy pure and nanocomposites.

Time of UV exposure	Epoxy pure	E+MWCNTs 0.2 gm	E+MWCNTs 0.6gm	E+MWCNTs 0.8 gm	E+MWCNTs 1 gm
60 min	77.5	79.5	81.17	79.83	80.67
120min	67.55	82.5	82.83	72.83	77.83
180min	59.87	73.33	70.5	64	65.56

indeed influenced by the duration of exposure. When the exposure period is short, UV radiation can rearrange the polymer chains, leading to greater compatibility in the final polymerization process and an increase in compressive strength. However, as the exposure period increases, these chains become susceptible to breakage and photodegradation, resulting in a weakening of the mechanical properties. This phenomenon is supported by research showing that the compressive strength initially increases after short UV exposure, but with longer periods of exposure, a decrease in mechanical properties is observed. Additionally, studies have demonstrated that the tensile strength decreases as UV exposure time increases, indicating a negative impact on mechanical properties over prolonged exposure [10]. Incorporating 0.6 grams of carbon nanotubes into the epoxy not only provides increased resistance to ultraviolet rays but also boosts its compressive strength. This improvement suggests a dual benefit, where the composite material gains enhanced durability against environmental factors and improved performance under compressive loads.

Therefore, the duration of UV exposure plays a crucial role in determining the mechanical behavior of epoxy/MWCNT nanocomposites, with short exposures potentially leading to enhanced mechanical properties and longer exposures resulting in degradation and reduced strength as show in Table 5.

Hardness test result

Hardness, a material's resistance to indentation or scratching, was investigated in various epoxy nanocomposites, as illustrated in Fig. 4 and detailed in Table 6. When Multi-Walled Carbon Nanotubes (MWCNTs) concentrations were elevated, there was a noticeable enhancement in hardness. MWCNTs-epoxy nanocomposites exhibited superior hardness compared to pure epoxy, with optimal percentage increases observed at weight fractions of A1, A2, A3, and A4. The hardness values demonstrated an increasing trend at low MWCNT concentrations, reaching a peak at (0.6) grams of carbon nanotubes, registering at (81 Shore D). However, concentrations higher than (0.6 gm) resulted in a decrease in hardness due to weakened bonding forces between the base material and the additive. Additionally, epoxy reinforced with MWCNTs displayed heightened rigidity or stiffness, contributing to the overall improvement in hardness.

CONCLUSION

In conclusion, this study underscores the nuanced effects of UV exposure on epoxy/MWCNT nanocomposites. Tensile strength optimization is achieved with 0.6 gm MWCNTs, emphasizing the delicate balance required for reinforcing effects. Compressive strength peaks at 4.712 MPa, showcasing the impact of UV exposure duration on mechanical properties. The hardness attains its maximum at 81.17 Shore D with 0.6 gm MWCNTs, highlighting the potential for improved rigidity. FE-SEM analysis confirms good interfacial bonding, supporting the mechanical property enhancements. The study provides precise insights into tailoring epoxy/MWCNT nanocomposites for optimal performance under varying UV exposure conditions.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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