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Characterization and Evaluation of Mechanical Properties of Carbon Nanotube Filler Epoxy Composite

Chockalingam Palanisamy* , Logah Perumal, Ganeshkumar Krishnan

***Abstract* – The outstanding mechanical properties of carbon nanotubes (CNT) have made them the focus of extensive investigation. To characterize and study the effects of the different volume fraction of multi walled carbon nanotubes (MWCNTs) on the mechanical properties of the nanocomposites attempted. The purpose of this work is to use experimental techniques to ascertain the mechanical characteristics of the nanocomposite. Tests on mechanical tensile strength were conducted to see how the MWCNT filler content affected the reinforced epoxy nanocomposite. The result of altered percentage of MWCNTs on the mechanical properties of the composites had been inspected. Results showed that 0.2 wt% MWCNT addition has the best effect on the mechanical properties of the matrix.**

*Keywords— **MWCNT, Epoxy, Tensile Strength, Weight Percentage, Young's Modulus***

I. Introduction

Advancements in materials science have paved the way for the development of innovative materials with enhanced properties. One such ground-breaking material is the Multi-Walled Carbon Nanotube (MWCNT) nanocomposite, which exhibits remarkable strength, conductivity, and lightweight characteristics. The unique features of MWCNT nanocomposites make them ideal candidates for enhancing the performance of robot and automation machine parts [1]. The usage of composites as a substitute on behalf of conventional engineering materials is increasing due to their unique properties such as strength/density ratio, less cost, and eco-friendly manufacturing processes. Carbon nanotubes (CNTs) have garnered much attention from researchers due to their exceptional mechanical, electrical, thermal, and tribological properties [2]. When dispersed well in a composite, CNTs provide superior properties. Polymer nanocomposites are proposed as a substitute to conventional fibre filled polymer composites, with MWCNTs as the filler material [3]. In this study, a composite was prepared using MWCNTs as reinforcement in epoxy matrix. Several samples were prepared with different compositions of MWCNTs, and their tensile properties were studied. The outcome indicated that the optimal composition of MWCNTs improved the tensile properties of the composite. The physical nature of the nano-sized CNTs plays a significant role in dispersing them into a polymer matrix, and better fabrication techniques can enhance their properties even further. Further research should focus

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on optimizing the controlling parameters to prepare composites with the best set of factors.

MWCNT was used as the filler material in a composite made of epoxy resin and hardener for its high modulus, strength, low aspect ratio, high flexibility, low density, and considerable mechanical abilities [4]. When mixed with carbon or other fibres, epoxy resins make composite materials with qualities that are advantageous in many applications [5] because they operate well in harsh circumstances. Due to their special high-performance qualities, they are well suited to work in a variety of situations with harsh conditions. You can change the resin, modifier, and cross-linking agent to make a unique epoxy that works well in a particular environment. Epoxy resins are the preferred material for a wide range of applications and situations because of these qualities. Scientifically, epoxy resins are a group of monomeric substances that can undergo additional reactions to form a thermosetting polymer with better linkage to many surfaces, a low order of reduction after forming, bearing resistance, elasticity, and better electrical characteristics [6]. The incorporation of MWCNT nanocomposites with varying volume fractions in the production of robot parts enhances structural integrity and strength [7]. The lightweight nature of MWCNT nanocomposites is particularly advantageous in the field of robotics. In automation machine parts subjected to continuous movement and friction, wear resistance is crucial for prolonged lifespan. MWCNT nanocomposites, with their exceptional mechanical properties, provide effective resistance against abrasion and wear [8].

II. Experiment Details

In this study, a composite was created using epoxy as a matrix and multi-wall carbon nanotubes as reinforcement. Clear epoxy with a density of 1.1 g/cm^3 and an epoxy value of 0.47 eq/kg and hardener with a density of 1.1 g/cm^3 and a hydroxyl value of 350 mg KOH/g were used as matrix materials. The epoxy resin was poured into a glass, and different wt% (0%, 0.1%, 0.2%, 0.3%, and 0.4%) of MWCNT were added to the epoxy resin [9]. A stirrer was used for the consistent diffusion of MWCNT in epoxy resin for the proposed quantity of volume percentage for 10 minutes at room temperature. MWCNT was thoroughly dispersed before being combined with the hardener solution in a 1:3 ratio. To lessen the possibility of air bubbles forming in the mixture, slowly stir using a stick. It is slowly stirred to let any air bubbles in the blend to rise to the surface. It is then left to settle for 5 minutes. The MWCNT composite was produced using a 200 x 200 x 3 mm rectangular mould. A layer silicone mould release agent was applied to the mould via spraying, in preparation for producing composites. Rolling the resin with a roller ensures even spreading into the mould and removes trapped air [4]. The composite was then given 24 hours to fully cure at room temperature. The preparation of several specimens used MWCNT at various weight percentages, ranging from 0% to 0.4%. The tensile characteristics of the composite were tested. From the moulded composite, test specimens for stiffness were cut. Tensile testing equipment was used to measure the composites' mechanical characteristics in accordance with ASTM standards.

III. Results and Discussion

The properties of the produced MWCNT-epoxy composites were measured using a tensile testing machine with automatic loading. The extensometer was used to measure both the applied force and the elongations concurrently. The load was measured in Newton and the elongation was measured in millimeters. The tensile properties were measured according to the specific ASTM standard. Figure 1 shows the stress-strain curve of the epoxy resin without addition of filler material.

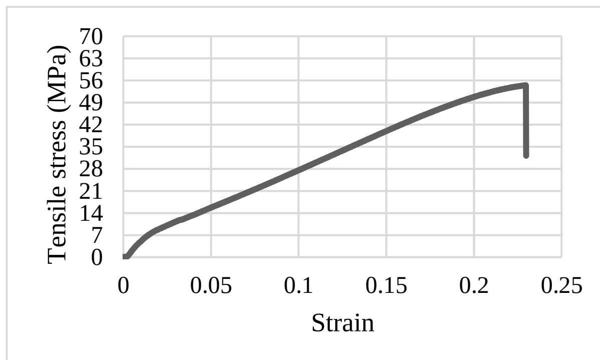


FIGURE 1. Epoxy tensile test result.

Figure 2 illustrates the stress-strain outcomes for composites used in this study with varying reinforcements of multi-walled carbon nanotubes (MWCNTs) at concentrations of 0.1, 0.2, 0.3, and 0.4 wt%, all uniformly dispersed. Our findings showed that increasing the amount of multi-walled carbon nanotubes enhanced the rigidity and Young's modulus of composites within an epoxy resin framework. The addition of 0.2 weight percent of multi-walled carbon nanotubes had the greatest impact on the matrix's mechanical properties in this investigation. This shows that a strong network structure was created, which can withstand increased mechanical loads when the matrix is stressed. This indicates that the carbon nanotubes have good stress transmission when the applied loading is greater than the elastic deformation stress.

Experiment results are tabulated in Table 1. Figures 3-7 shows tensile properties results of the Multi-Walled Carbon Nanotubes (MWCNTs) composites with: 0, 0.1, 0.2, 0.3, and 0.4, wt%. percentages of reinforcement in the epoxy respectively. The tensile stress indicates the amount of force that the epoxy material can withstand per unit area before it fails. It is measured by dividing applied load applied by the area of the samples. The units of tensile stress are typically expressed in MPa (megapascals). If the stress value is high, it means that the material is strong and can resist large amounts of force before breaking. However, it is important to note that high stress values do not necessarily mean that the material is suitable for all applications, as other factors such as temperature, humidity, and chemical resistance may also be important. Figure 3 shows that the content of 0.2 wt% MWCNTs raises the tensile stress to the maximum value of 110.8 MPa, whereas it is reduced for 0.3 – 0.4 Wt%. This is due to the grouping of nanotubes in the epoxy matrix that decreases the strengthening effects of the MWCNTs [10].

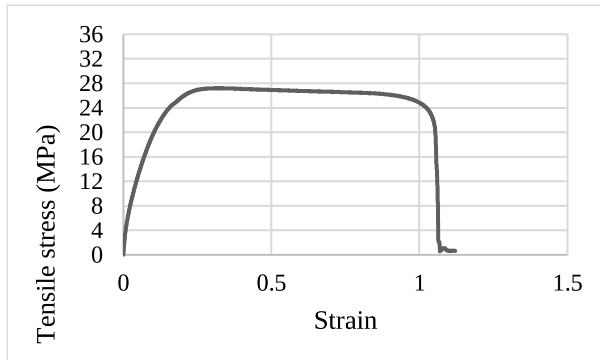
S. No.	MW CNT (%)	Tensile stress (MPa)	Tensile strain (mm/mm)	Young's Modulus (MPa)	Load at Break (N)	Load at Yield (N)
1	0	54.46	0.10	679.19	1415.99	0
2	0.1	27.19	0.14	499.36	16.87	707.26
3	0.2	110.80	0.07	2679.79	117.42	3003.25
4	0.3	18.39	0.49	845.09	479.16	472.94
5	0.4	24.97	0.083	826.13	462.00	650.67

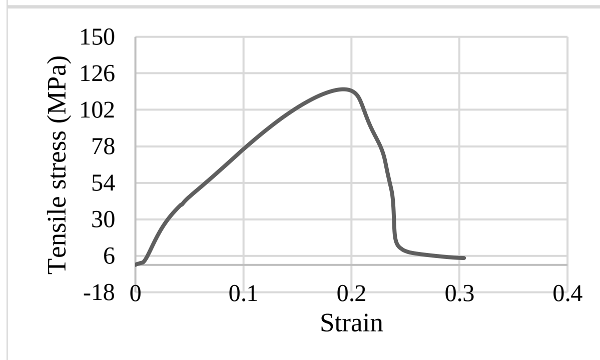
TABLE 1. Test results of epoxy with different wt% of MWCNT.

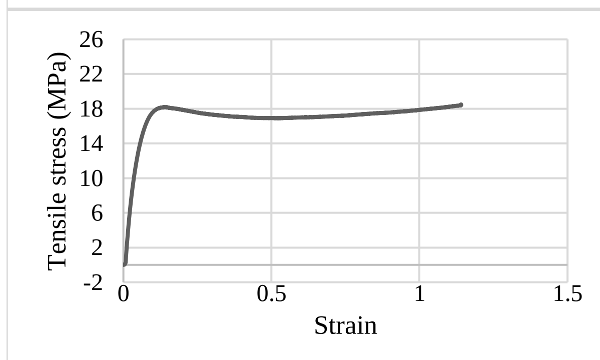
Tensile strain is defined as the change in length of a material per unit actual length. It is measured by dividing the change in length by actual length. The tensile strain indicates how much the material can stretch or elongate before breaking. A high strain value means that the material is ductile and can undergo large amounts of deformation without fracturing. However, high strain values can also indicate that the material may be prone to creep or plastic deformation under load. Figure.4 shows that in MWCNTs the strain was increased for MWCNTs content of 0.3%. Beyond this percentage, the strain values decrease.

The modulus of elasticity gauges a composite's resilience or its ability to resist deformation when stressed. This is determined by the relationship between stress and strain within the material's elastic segment on its stress-strain graph. Tensile modulus is typically expressed in units of GPa (gigapascals) or psi. In addition to these parameters, the Tensile modulus and load at yield are also important for understanding the mechanical behaviour of epoxy materials. The modulus of elasticity indicates stiffness of the composite, while the load at yield indicates the maximum load that the material can withstand before undergoing significant plastic deformation.

The elastic modulus of composite without filler was 679 MPa. Figure 8 shows that the modulus reaches an optimal value of 2679 MPa for 0.2 wt% of MWCNTs. Changing the weight percentage of MWCNTs beyond this optimal level leads to increasing the constraint between epoxy chains. This in turn decreases the length of epoxy chains, leading to decreasing young's modulus [10]. The breaking load is the ultimate load that the composite can withstand before it breaks. It is typically measured in Newton (N). The breaking load indicates the maximum force that the material can withstand before breaking.







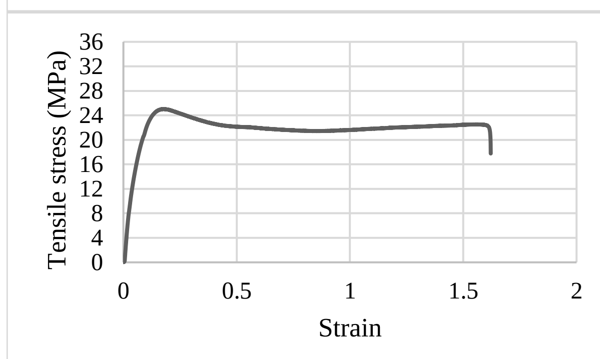


FIGURE 2. Epoxy with different wt% of MWCNT a) 0.1% b) 0.2% c) 0.3%, d) 0.4%.

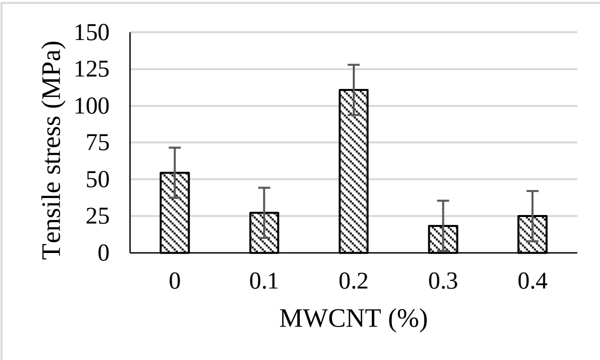


FIGURE 3. Tensile stress for different MWCNT percentage.

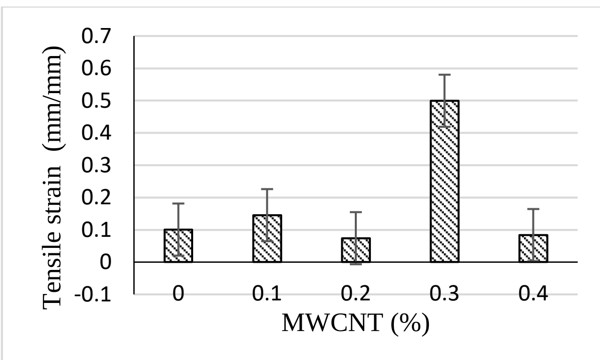


FIGURE 4. Tensile strain for different MWCNT percentage.

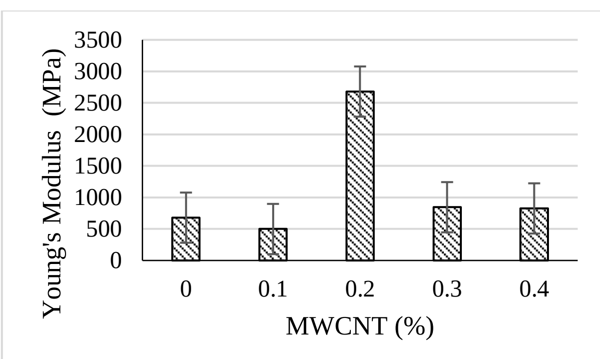


FIGURE 5. Young’s for different MWCNT percentage.

This value is important for determining the maximum load that can be applied to the material in a given application. If the breaking load is high, it means that the material can withstand large amounts of force without fracturing. The load at yield is the ultimate load that a composite can withstand before it undergoes significant plastic deformation. It is typically measured in Newton (N). At higher MWCNT concentrations, the high viscosity of the polymer matrix may make it more difficult to achieve uniform dispersion of the nanotubes, leading to the formation of clusters or agglomerates. These agglomerates can act as stress concentrators and create weak points in the composite material, leading to a decrease in mechanical properties. Through tensile testing and evaluating these factors, one can gain a comprehensive insight into a material's mechanical characteristics and establish its attributes. This knowledge enables predictions about the material's response to various load types, proving valuable for diverse engineering uses. When the wt% of MWCNTs added more, yield load of composites declined. The not as much of improvement at upper content is due to an increased quantity of grouping of MWCNT that cannot efficiently transfer the load [11]. As researchers continue to explore novel formulations and fabrication techniques, the integration of MWCNT nanocomposites is likely to play a pivotal role in shaping the future of intelligent machines and robotic systems [12].

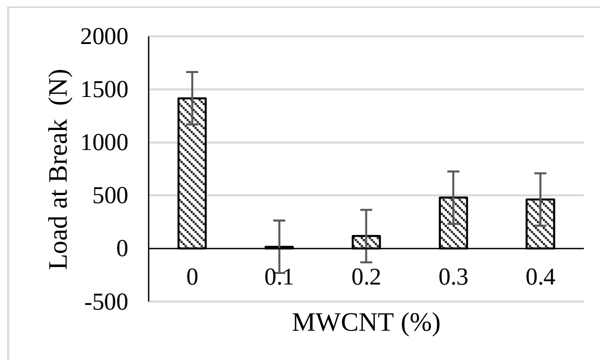


FIGURE 6. Load at break for different MWCNT percentage.

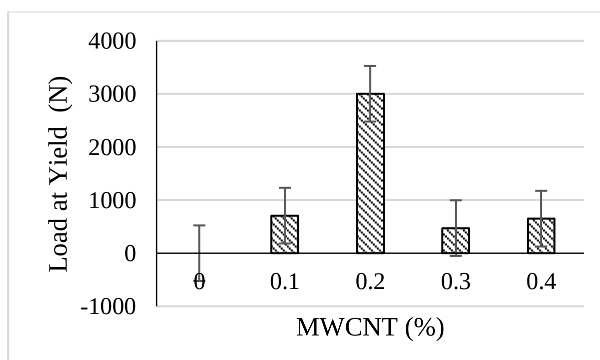


FIGURE 7. Load at yield for different MWCNT percentage.

IV. CONCLUSION

Overall, the study found that the introduction of MWCNT to the epoxy matrix must be done at an optimal weight percentage. The optimal value is 0.2 wt%. Beyond this optimal value, the concentration of MWCNT becomes too high, resulting in decreased tensile strength due to inefficient dispersion and increased viscosity. The reason behind this fluctuation could be conglomeration of MWCNTs and inefficient mixture. Also, as the filler concentration rises, the polymer's high viscosity makes it more difficult for MWCNTs to be properly disseminated across the resin. The versatile applications of Multi-Walled Carbon Nanotube (MWCNT) nanocomposites with different volume fractions in robot and automation machine parts underscore the transformative potential of these advanced materials. From improving structural integrity and strength to enhancing thermal and electrical conductivity, MWCNT nanocomposites contribute significantly to the evolution of robotics and automation.

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AUTHOR CONTRIBUTIONS

Chockalingam Palanisamy: Writing – Original Draft Preparation;

Logah Perumal: Writing – Review & Editing;

Ganeshkumar Krishnan: Writing – Review & Editing.

CONFLICT OF INTERESTS

No conflict of interests were disclosed.

ETHICS STATEMENTS

Our publication ethics follow The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org/

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