ARCENG
INTERNATIONAL JOURNAL OF ARCHITECTURE AND ENGINEERING

ISSN
2822-6895

Article Arrival Date	**Article Type**	**Article Published Date**
15.03.2024	**Research Article**	**20.06.2024**

EXPLORING CHARPY IMPACT AND HARDNESS TESTING OF CARBON NANOFIBER-REINFORCED EPOXY COMPOSITES WITH VARIED WEIGHT PERCENTAGES

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ABSTRACT

This study encompasses research involving Charpy impact tests and hardness tests conducted to determine the mechanical properties of carbon nanofiber (CNF) reinforced samples used in epoxy matrix materials for composite structures. The utilization of CNFs as filler materials to enhance the mechanical strength of composite structures holds significant importance, particularly in industries demanding advanced technologies such as aerospace, space exploration, automotive, and marine engineering. This study evaluates the mechanical properties of epoxy composites with varying concentrations of CNF additives, presenting the comparative results of Charpy impact tests and hardness tests.

The results of the Charpy impact tests indicate that epoxy composites with 0.8 wt % CNF additives demonstrate the highest performance, whereas those with 1.2 wt % CNF additives exhibit the lowest performance. Similarly, the outcomes of the hardness tests corroborate that epoxy composites with 1.2 wt % CNF additives possess the lowest hardness values.

This study contributes to understanding CNF-reinforced epoxy composites' mechanical properties and emphasizes their potential in industrial applications. Furthermore, focusing on standard test methods for determining the mechanical properties of CNF-reinforced epoxy composites provides guidance for future research in this field.

Keywords: Carbon Nano Fiber, Charpy Impact Test, Hardness Test, Impact Energy Absorbed

1. Introduction

The world of nanomaterials, offering a wide range of extraordinary physical and chemical properties, has been enriched with various intriguing materials. These materials include zero-dimensional nanoparticles or quantum dots, one-dimensional nanowires, nanorods, nanofibers, nanotubes, and two-dimensional nano-layers. Particularly, nanofibers stand out among nanomaterials. An essential characteristic of nanofibers is their exceptionally high surface area-to-volume ratio and high porosity, making them ideal candidates for many advanced applications.

Integrating nanoparticles into polymer matrices has opened paradigms for optimizing certain properties of polymer matrices, such as optimizing fibre orientation in traditional advanced composites. For example, carbon nanofibers (CNFs) and carbon nanotubes (CNTs) are promising nanomaterials in polymer nanocomposites due to their excellent electrical, thermal, and mechanical properties [1].

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Carbon nanofibers (CNFs) are nanostructures that resemble cylinders, featuring graphene layers arranged in a regular fashion. While their lengths typically fall within the micrometer range, their diameters can vary from tens to hundreds of nanometers. CNFs exhibit mechanical durability and electrical properties akin to carbon nanotubes, yet they offer better controllability in terms of size and graphene arrangement. A notable distinction between CNFs and nanotubes lies in the stacking of graphene layers, resulting in diverse shapes and more edge regions on the surface of CNFs. This greater outer surface area allows for an increased presence of edge plane defects, facilitating electron transfer for electroactive analytes.

Moreover, CNFs possess a unique capacity to activate all surface areas effectively. Treatment with nitric acid or electrochemical oxidation activates CNFs, introducing various oxygen-containing groups without compromising their structural integrity. This activation process results in a significantly larger functionalized surface area compared to carbon nanotubes, leading to a higher proportion of surface-active groups. These attributes make CNFs well-suited matrices for immobilizing biomolecules and transmitting electrochemical signals.[9-12].

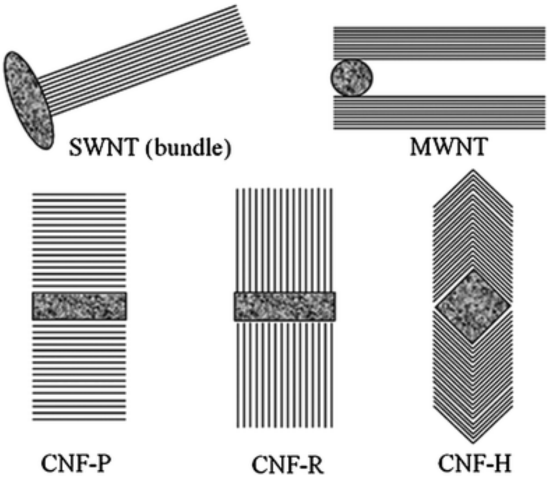


Figure 1. Different types of CNF structures [9]

In recent years, there has been a significant increase in research and development focused on the dispersion and functionalization of graphite-based materials, particularly carbon nanofibers and nanotubes. These materials are being investigated as superior functional additives and reinforcements to realize their full potential for composite applications[13].

Compared to traditional graphite powders and by-products, nano-scale additives, particularly carbon nanotubes and nanofibers, which have significantly higher production costs, are not widely used in the composite industry. However, due to their distinct structure and large surface area, these expensive materials can play a crucial role in developing new composite materials. By substantially enhancing their physical and chemical properties, these materials can surpass applications that might be justified only by a few improved property combinations. Nanofibers Figure 2. is also shown.

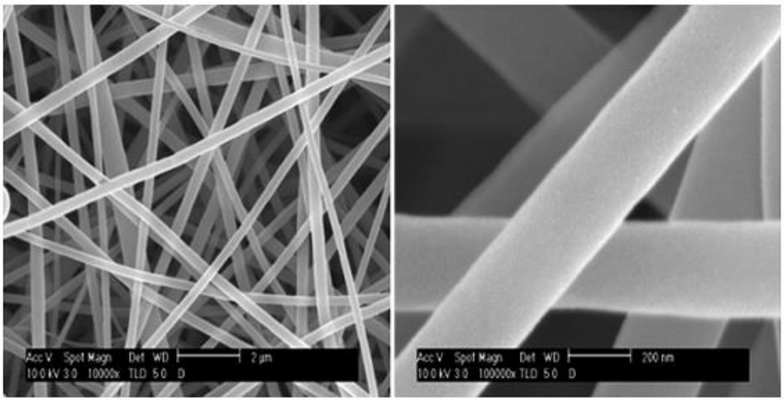


Figure 2. SEM images of electrospun nanofiber [14]

Tibbetts and Beetz et al. conducted research on vapor-grown carbon fibers (VGCFs) and directly assessed their tensile characteristics across a spectrum of fiber diameters ranging from 6.5 to 31.5 µm. They observed an inverse relationship between carbon fiber diameter and tensile strength: as the diameter increased, the tensile strength decreased. For instance, they found that a carbon nanofiber

(CNF) with a diameter of 7.5 μm exhibited a tensile strength of 2.92 GPa and a tensile modulus of 237 GPa. However, as the diameter increased to 31.5 μm, the tensile strength and modulus decreased to 0.73 GPa and 120 GPa, respectively.

On a related note, Patton and colleagues estimated the minimum values for the tensile modulus and strength of CNFs using the rule of mixtures. They further conducted experiments involving epoxy reinforced with 15.5 vol% CNF to determine the mechanical properties. Their calculations yielded a lower limit for the tensile modulus and strength ranging between 88-166 GPa and 1.7-3.38 GPa, respectively.

2. MATERIAL and METHOD

2.1. Material Preparation

The aim was to determine the most effective additive ratio by adding nanofibers in different proportions (%0.5, %0.8, and %1.2). Nanofibers were weighed on a precision scale. It was mixed homogeneously with epoxy resin. The mixture was mechanically stirred for 5 minutes to achieve homogeneity and then subjected to ultrasonic mixing using a metal-tipped sonicator for 15 minutes. The mix of CNFs with epoxy in the sonicator is also shown in Figure 3.

Figure 3. Sonicator mixing process of CNF and Epoxy

The mixture underwent cooling to room temperature following ultrasonic mixing, only to later heat up again. Once at room temperature, the nano fiber-epoxy blend, featuring a hardener content of 29%, was poured into moulds designed for Charpy impact testing specimens. These specimens were then left to cure at room temperature for a period of 24 hours. The epoxy utilized in the experiment was formulated with a medium-viscosity silicone. The carbon nanofibers (CNFs) utilized boasted properties including

99.9% purity, a size of 5 nm, a surface area of 170 m2/g, and a diameter of 18 nm. Post-mould removal, the experimental specimens were subjected to both hardness and Charpy impact testing. The Charpy testing apparatus was equipped with an impact mass of 7.5 kg. All experiments were conducted at the Mechanical Test Laboratory housed within the Faculty of Metallurgy and Materials Engineering at Selçuk University.

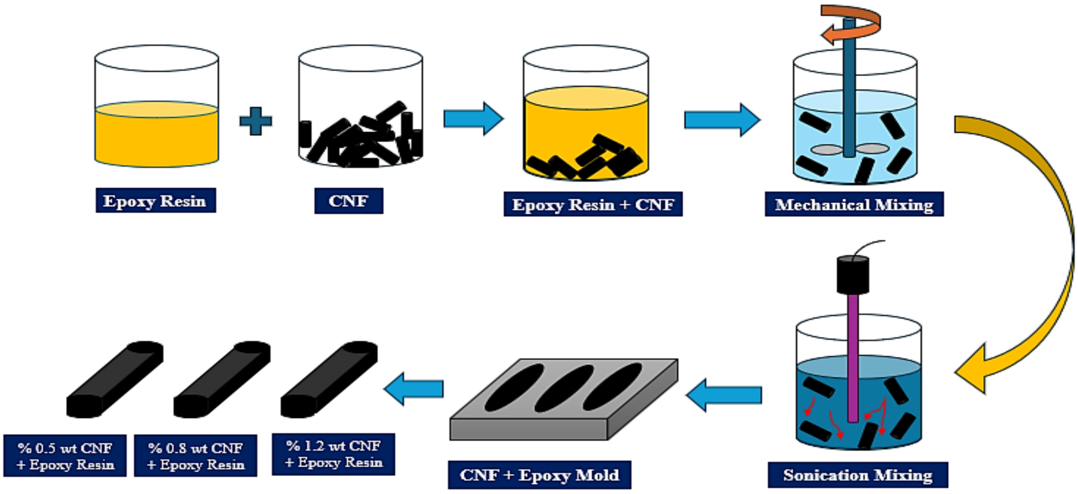


Figure 4. Schematic representation of 0.5 wt%, 0.8 wt%, 1.2 wt% CNF + Epoxy resin production

Figure 5. CNF filled and unfilled epoxy composites prepared for testing

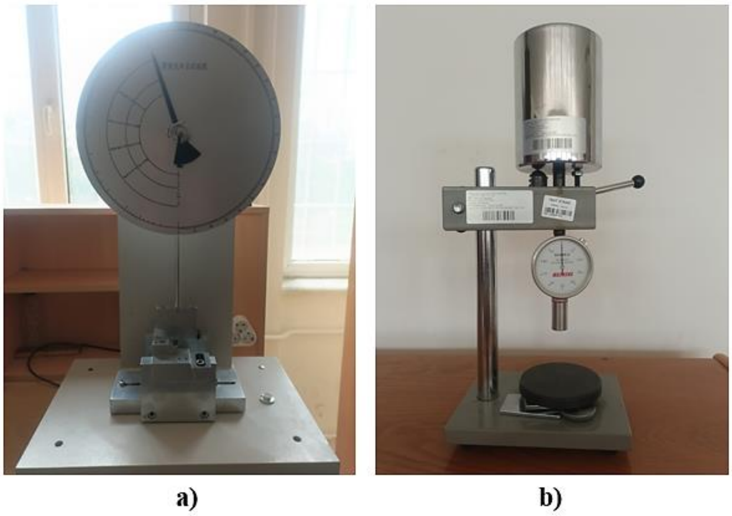
2.2. Charpy Impact and Hardness Test

Charpy impact tests were carried out utilizing a Charpy impact test machine, as illustrated in Figure 5, adhering to ISO 179/2 standards. Hardness testing, specifically D hardness, was conducted in accordance with ASTM D 2240 standards utilizing the hardness testing apparatus depicted in Figure 6.

The impact specimens were subjected to notch-less and flat impact loads. Each parameter underwent three separate experiments, all performed at room temperature. The absorbed impact energy of each specimen was determined using Equation (1):

$$E=Ea-Eb$$

Here, Esignifies the total absorbed impact energy, Ea denotes the energy of the weighted pendulum prior to impact, and Eb represents the potential energy.



a) b)

Figure 6. Charpy impact tester and Hardness Test Device

3. EXPERIMENTAL RESULTS and DISCUSSION

To investigate the effect of CNF addition on the mechanical properties of the epoxy matrix, epoxy matrices with weight percentages of 0.5%, 0.8%, 1.2%, and pure epoxy were produced. Epoxy matrices produced at different weight ratios were initially subjected to hardness testing. Subsequently, each specimen underwent Charpy impact tests. The experimental results obtained after the Charpy test are shown in Figure 7.

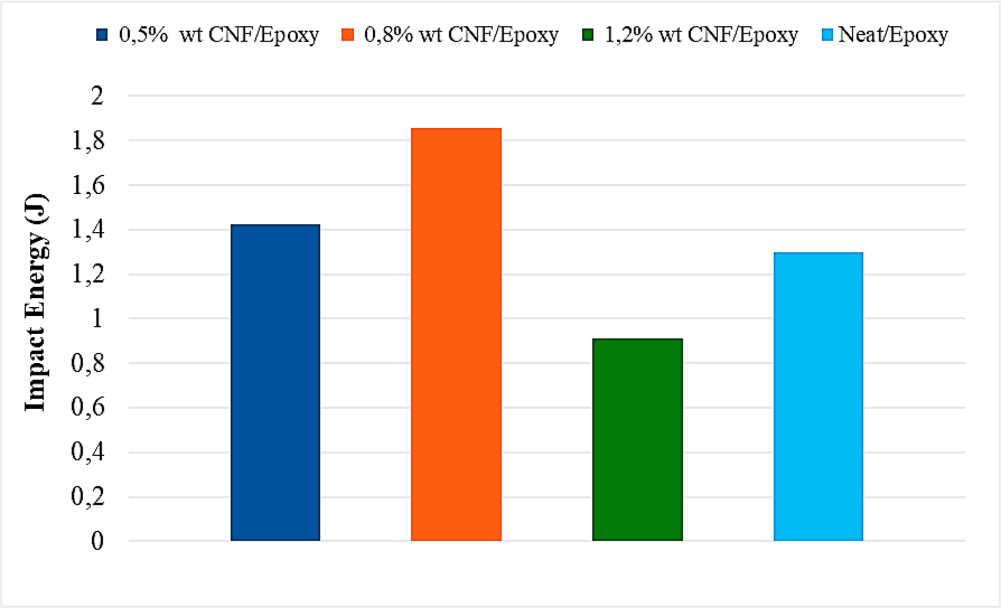


Figure 7. Charpy impact energy plot of 0.5%, 0.8% and 1.2% CNF/Epoxy composites by weight

Figure 7. illustrates the test results conducted on epoxy matrices with weight percentages of 0.5%, 0.8%, 1.2%, and without CNF addition. According to these results, epoxy matrices with a weight percentage of 0.8% CNF showed the best performance. Subsequently, epoxy matrices with weight percentages of 0.5% and without CNF addition followed. The weakest performance in the Charpy impact test graph was observed in epoxy matrices with a weight percentage of 1.2% CNF. While the best performance was recorded as 1.8582 J in 0.8% CNF/epoxy composites, the closest value was 1.424 J in 0.5% CNF/epoxy composites. The 23.3% difference between these two epoxy composites determined 0.8% CNF addition as the optimal ratio. Properly adding CNFs can prevent microcracks in the matrix material and create various crack-prevention mechanisms. However, an increase in the CNF addition ratio may decrease the homogeneous distribution within the epoxy matrix, thereby reducing the mechanical properties [15-17]. When Figure 7. is examined, it is observed that epoxy composites with a weight percentage of 1.2% CNF exhibit the lowest performance.

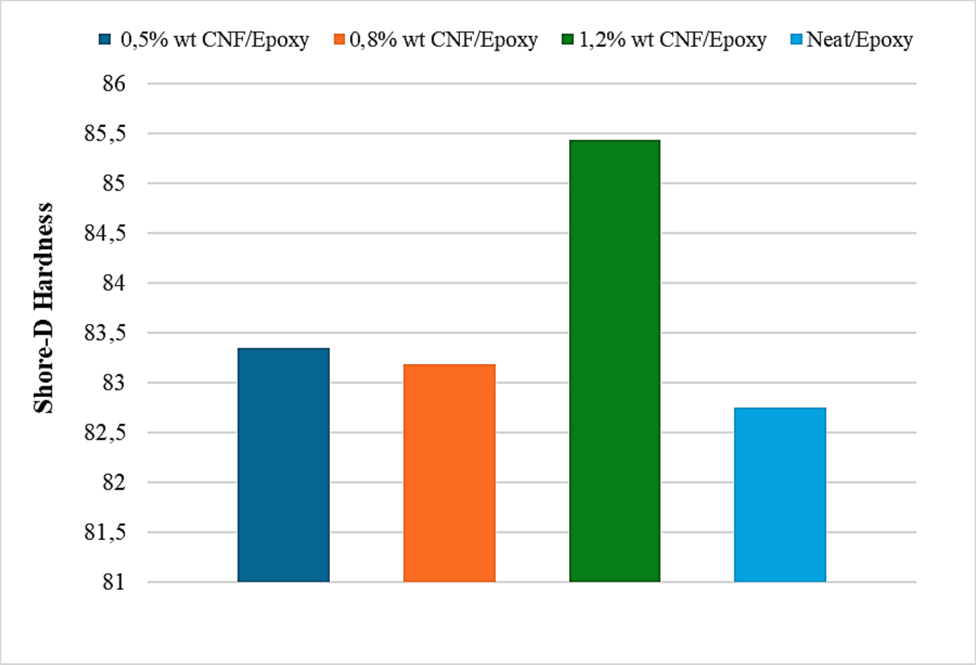


Figure 8. Hardness graphs of CNF/Epoxy

Figure 8. depicts the hardness tests conducted on epoxy matrices with weight percentages of 0.5%, 0.8%, 1.2%, and pure CNF. Upon examining the graph, it is evident that the composites with 1.2% CNF addition exhibit the highest hardness ratio. This is followed by the 0.5% and 0.8% CNF-added epoxy composites. The lowest hardness ratios are observed in the CNF-free epoxy composites. The addition of CNFs to epoxy matrices has increased the hardness values. However, the increase in hardness has reduced the mechanical durability of the epoxy composites. Upon scrutinizing Figure 7, it can be observed that the epoxy composites with 1.2% CNF addition have significantly higher hardness values

than other epoxy composites. This indicates a decrease in the energy absorption capability of the epoxy composites with the increase in hardness. While the hardness value for the 1.2 wt% CNF-added epoxy composites is 85.435 J, the closest value is 83.35 J for the 0.5 wt% CNF-added epoxy composites. Subsequently, the 0.8 wt% CNF-added epoxy composites exhibited a hardness value of 83.35 J, and finally, the CNF-free epoxy composites recorded a hardness value of 82.75 J. It has been previously stated that the excessive increase in the addition of CNFs results in homogenous distribution issues within the epoxy matrices. Upon examining the hardness values taken from different points in the 1.2 wt% CNF-added composites, it is observed that there is a more significant difference compared to other epoxy composites. This indicates that the 1.2 wt% CNF-added epoxy composites experience homogenous distribution problems with nanoparticles.

4. CONCLUSION

This study aimed to determine the optimal weight percentage of carbon nanofiber (CNF) addition to enhance the mechanical properties of epoxy matrix composites. Composites were prepared with CNF additions at weight percentages of 0.5, 0.8, and 1.2 wt and subjected to Charpy impact testing and hardness testing compared to neat epoxy composites. The results elucidated the relationship between different CNF addition levels, Charpy impact test outcomes, energy absorption capabilities, and hardness.

Charpy impact tests revealed that epoxy composites with 0.8 wt% CNF exhibited the highest performance, while those with 1.2 wt% CNF showed the lowest performance. An increase in the weight percentage of CNF led to a decrease in impact strength, with 1.2 wt% CNF epoxy composites demonstrating lower mechanical strength compared to neat epoxy composites.

Hardness test results demonstrated that adding CNF increased the hardness of epoxy matrices, with epoxy composites containing 1.2 wt% CNF exhibiting the highest hardness values. However, it was observed that as hardness increased, mechanical strength decreased. Additionally, hardness negatively impacted the energy absorption capability of epoxy composites.

In conclusion, Charpy impact and hardness tests provide significant and influential results for determining the mechanical properties of CNF/epoxy composites.

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