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An Experimental Study of the Mechanical and Thermal Properties of Polymer-Based Hybrid Composite Materials

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ABSTRACT

This research aims to investigate how the incorporation of nanomaterials and carbon fibres influences the mechanical and thermal properties of silicone rubber resins. Hybrid composite materials were developed by adding various proportions of CuO nano-fillers (3% and 5% wt) and carbon fibres (0.5% and 1% wt). The samples were evaluated for tensile strength, compressive strength, thermal conductivity, and thermal expansion. Notably, adding 1% wt carbon fibre increased the compressive strength from 2.078MPa to 4.549MPa when combined with 5% wt CuO nanomaterial. However, a more balanced enhancement was observed in hybrid samples containing 3% wt nano-CuO and 0.5% wt carbon fibre, which resulted in a compressive strength of 3.631MPa and improved thermal performance, albeit with a reduction in tensile strength from 0.497MPa to 0.454MPa. Further increasing the CuO nanomaterial to 5% wt and carbon fibre to 1% wt led to significant improvements in compressive and thermal properties by 84% and 35%, respectively, although tensile strength decreased. This study demonstrates that while the addition of CuO nanomaterials and carbon fibres enhances compressive strength and thermal properties, it can also lead to a reduction in tensile strength.

1. INTRODUCTION

A composite material is a substance formed by combining two or more distinct materials or constituents, which retain their separate identities at the macroscopic level. These materials do not dissolve into each other, and their combination results in a composite with unique properties that differ from those of the individual components [1]. The unique combination of these elements gives the specific qualities that neither component could possess individually. An illustration, from history is mud bricks, an age building material made by mixing mud with straw bringing together the durability of mud, with the pliancy of straw.

Composite materials typically include three components; (a) the matrix, which acts as the bonding agent, for the composite; (b) the reinforcement for providing strength and can be in the form of continuous (such as long fibers) or discontinuous (like short fibers or particles); and (c) the interface, an essential boundary area that separates the matrix from the reinforcement ensuring proper adhesion and stress transfer, between them. These materials have played a role throughout history allowing ancient societies to construct shelters and continuing to contribute to technological progress. Composites are widely utilized in products and fields including construction projects, medical equipment, energy systems, transportation infrastructure, sports equipment, airplanes and cars. Their attractiveness stems from their sought after traits and strong structure. Moreover, composite materials provide a balance, between strength and weight along, with heat durability. The unique properties and uses of materials are influenced by factors, including the type of binder utilized the reinforcing material chosen, the proportion of matrix, to reinforcement elements and the production methods employed [2-4].

Hybrid composite materials bring together the concepts of both "hybrid" and "composite," showcasing a mix of material types. This procedure typically involves integrating types of fibers or composite structures into a composite material. Instances include composites strengthened with fiber types or layered composites crafted from fiber reinforced metals and thin metal foils. In scenarios the term "hybrid" signifies the merging of structures on a microscopic scale leading to unique material properties and performance attributes.

In some cases, the term "materials" might be a better fit especially when referring to composites, like carbon/carbon composites and metallic matrix composites that are well known. For scientists studying materials the term "composites" could appear standard or too general. Hence "hybrid materials" is employed to depict materials that combine elements with properties or structures, for purposes.

2. MOTIVATION

Silicone rubber stands out as a top notch elastomer known for its characteristics such, as its ability to withstand temperatures long lasting durability, excellent electrical insulation and see through quality. This strong substance is crafted from silicone a polymer consisting of silicon atoms connected to elements, like carbon, hydrogen and oxygen. Silicone rubber is characterized by a backbone of siloxane which consists of a series of silicon and oxygen atoms linked to groups that improve its flexibility. These characteristics render silicone rubber for uses such as, in medical devices [5].

Carbon fibre is a type of fibre that consists of at least 92% carbon by weight, with fibres containing 99% or more carbon typically referred to as graphite fibres. Carbon fibres are celebrated for their outstanding tensile strength, low density, high thermal and chemical stability (as long as no oxidizing agents are present), superior thermal and electrical conductivity, and exceptional creep resistance. These characteristics make carbon fibres highly sought after in numerous applications, including aerospace, automotive, sports equipment, and structural engineering, where strength and durability are essential [6-8]. The carbon fiber industry has experienced expansion in recent years due to increased demand across various sectors such as aerospace (for aircraft and space systems) military applications, turbine blades construction (both structural and non-structural systems) lightweight cylinders and pressure vessels offshore tethers and drilling risers medical devices automotive and sporting goods. This demand is fuelled by carbon fibre's unique combination of lightweight strength, durability, and versatility, making it an attractive option for high-performance applications [9]. Carbon fibres are generally classified by their mechanical properties into ultra-high modulus (>500GPa), high modulus (>300GPa), intermediate modulus (>200GPa), low modulus (100GPa), and high strength (>4GPa) categories [10, 11].

CuO nanoparticles, particularly copper (II) oxide (CuO), along with other metal oxide nanoparticles, have garnered significant interest for their wide-ranging applications in fields such as optoelectronics, nanodevices, nano sensors, information storage, and catalysis. Copper oxide (Cu) showcases characteristics such as high temperature superconductivity and the influence of electron correlations on its behavior. It is being utilized frequently in various applications like catalysis reactions and battery technology as well as, in gas sensors and solar energy devices. The unique crystal structures of CuO, characterized by their bandgap, make them suitable for photocatalysis and photovoltaic applications. Metal oxide nanoparticles, including CuO, demonstrate distinct chemical and physical properties compared to their bulk counterparts. These properties are crucial in various applications, such as diffusivity, electrical conductivity, mechanical strength, chemical reactivity, and biological interactions. The widespread use of metal oxide nanoparticles spans industries such as catalyst production, chemical sensing technologies, medical equipment development, disinfection processes, antimicrobial applications, filler materials in manufacturing, opacifiers in cosmetic products, reaction catalysts, and semiconductors in electronics manufacturing. CuO antimicrobial and biocidal properties make it a versatile option for biomedical applications. As a semiconductor with transparency and electrical conductivity, coupled with magnetic properties, CuO is valuable in the production of supercapacitors, near-infrared filters, magnetic storage media, sensors, catalytic converters, and semiconductor devices. Creating copper oxide nanoparticles with sizes and shapes involves using various precise methods like sonochemistry and sol gel techniques. Other approaches include laser ablation and electrochemical methods well, as chemical precipitation and surfactant-based processes. These techniques allow for the customized production of copper oxide nanoparticles to meet specific technological needs [12-27].

Nanoparticles are known for their size, which can be carefully adjusted during manufacturing. This precise manipulation enables the enhancement of their biological characteristics making nanoparticles incredibly adaptable. The capacity to refine these traits has resulted in their use in a range of industries, such, as beauty products, medicines, paints and coatings. This ability to customize nanoparticles on such a scale opens doors, for products and progress in different fields [28].

3. OBJECTIVE

A review of literature was carried out to investigate the qualities of polymer-based materials gathering insights, from a variety of sources including both theoretical studies. In research conducted by Goulart et al. [29] the mechanical characteristics of composites reinforced with glass fiber, sisal and jute within an epoxy matrix were scrutinized using scanning electron microscopy (SEM). The study delved into aspects like properties fracture surface features and material structure. The findings revealed that incorporating sisal fibers improved strength whereas jute fiber reinforced composites exhibited bending properties. Bhoopathi et al. [30] delved into the exploration of natural/glass fiber reinforced polymer composites for applications in engineering and technology with a focus, on building construction. This investigation discussed advancements in molding and pressing methods utilized for creating hybrid polymer composites that integrate natural fibers. It also looked into the properties of vehicles when natural fibers are mixed with glass fiber reinforced polymer composites. The study emphasized the increasing focus, on combining types of fibers with glass fibers, in composites, which has led to advancements in different applications.

Akash et al. [31] investigated the development of a composite material by combining untreated double raw silk fibres with epoxy resin and silicon carbide fillers. The standard samples underwent testing to evaluate their tensile strength, flexural strength, and hardness, as well as microstructural characteristics using SEM. The study also explored the potential use of the biocomposite in orthotics and bone fixation. The results indicated that the bio-based material composed of 6 percent silicon carbide filled double silk fiber combined with epoxy showed a strength of about 41 0 megapascals (MPa) flexural strength of approximately 53 megapascals (MPa) and a hardness rating of, around 88 Rockwell Hardness B scale number (RBHN). The study suggested that this composite material could potentially serve as an alternative, to bones if adequately coated and compared with the properties of the femur.

Parvej et al. [32] The study has been looking into how nanoparticle infused polymer blends can be applied in areas, like healthcare, energy storage and solar energy. These blends combine nanoparticles with a base material to achieve functions. The effectiveness of these blends largely depends on the modifications made to both the nanoparticles and the base material. The process involves three steps; preparing the nanoparticles and the base material separately then combining them using chemical methods. The study provides a breakdown of these preparation steps stressing the importance of understanding the core materials involved. It also briefly explains methods, for creating metal and polymer nanocomposites highlighting their uses, thermal and mechanical properties as procedural considerations. The section wraps up by discussing the limitations associated with these methods giving an overview of the processes, applications and challenges linked to nanoparticle based polymer blends.

Mohanty et al. [33] conducted experiments, on materials that included epoxy alumina nanoparticles, glass fibers and carbon fibers to evaluate their strength and elasticity modulus. They created the composites by adjusting the amount of alumina in the epoxy blend starting at 1% and gradually increasing to 5% by weight. Composite types II and III were formulated by adding percentages of short glassy carbon fibers ranging from 5% to 15% by weight. A novel composite was developed by blending fibers with 2% alumina in an epoxy matrix. The addition of fillers is crucial for enhancing material properties. By integrating alumina particles into composites their modulus can be improved. Furthermore, mixing alumina particles, with glass or carbon fibers also enhances the strength and modulus of these composites.

Crafting composites involves combining a butadiene styrene (SBS) copolymer matrix, with curaua fibers and nanoparticles like clay (MMT). Patricia and her research team showcased the advantages of blending fillers to create composites with improved properties. These enhancements are especially beneficial in industries such as manufacturing components and building materials, where durability and strength play a role. Borba et al. [34] focused on exploring the utilization of melt blending in material development. The researchers studied mixtures containing proportions (5%, 10% and 20% by weight) of curaua fibers and styrene fibers treated with anhydride (ethylene butylene styrene) ((MA-g-SEBS) to assess characteristics, like strength, tear resistance, elasticity, fatigue resistance, resilience wear resistance, rigidity and water absorption. Furthermore, the research delved into how metal plasticizers affect the strength of materials. The best mechanical performance was seen in an SBS blend, with 2% clay (MMT) and 5% curaua fiber. Interestingly when the fiber content was increased to 20% there was a decrease in strength. Similarly, a rise in MMT content to 5% also led to a drop in strength. The decrease in performance observed in composites with levels of curaua and MMT fibers may be due to the distribution of tactoids, within the composite structure. This uneven distribution can compromise the materials integrity and performance resulting in decreased properties.

Yang et al. [35] conducted a study, on incorporating rod shaped CaCO3 nanoparticles into an epoxy matrix to assess their effect on the stability and mechanical properties of CaCO3/epoxy composites. They explored how these characteristics relate to the morphology of CaCO3. The EP rod CaCO3/epoxy composites exhibited a breakdown temperature, about 4.5°C higher than regular epoxy. Both cube and rod shaped CaCO3/epoxy composites showed enhancements in strength, flexural modulus and fracture toughness. The researchers observed that increasing the CaCO3 amount initially improved properties. The benefits leveled off at a filler concentration of 2%. Compared to epoxy the cube and rod shaped CaCO3/epoxy composites demonstrated fracture toughness (Kic) and fracture energy release rate (Gic) with values of 0.85 and 0.74MPa $\surd$ m as well, as 318.7 and 229.5 J/m^2 respectively.

Arash et al. [36] examined the characteristics of carbon nanotubes highlighting their elasticity and tensile strength, which make them ideal, for improving the mechanical properties of carbon nanotube/polymer blends. The interaction between nanotubes and polymer matrices is crucial in determining the strength of these materials. Understanding the flexibility of the interface is essential, for designing nanocomposites. To tackle this challenge researchers devised a method using simulations to explore how elastic properties alter at the interface of poly (methyl methacrylate) (PMMA) matrix composites reinforced with carbon nanotubes when subjected to tension. They studied how the aspect ratio of carbon nanotubes influences Youngs yield strength and overall mechanical performance of these materials.

Sharma et al. [37] investigated the application of carbon fiber reinforced polymer (CFRP) composites, in industries due to their combination of strength and lightweight properties. One common issue faced with these composites is ensuring a bond between the carbon fibers and the polymer matrix to prevent failures. In order to tackle this challenge researchers looked into using oxide (GO) to improve adhesion and increase bonding surface area. They conducted experiments to incorporate GO nanosheets onto the surface of carbon fibers or within the epoxy matrix of CFRP materials. By introducing oxide, between the fibers and polymer matrix it promoted adhesion facilitating stress transfer and enhancing energy absorption capabilities. The distinct makeup of GO nanoparticles and the chemical groups located on the peripheries of the nanosheets were vital, in forming connections, with both the epoxy matrix and the carbon fibers fostering enduring π π interactions. The study also investigated how incorporating modified graphene oxide affected the electrical and viscoelastic properties of composites reinforced with carbon fibers.

Pinto et al. [38] conducted a study to improve the strength and capabilities of carbon fiber reinforced polymer composites by altering the matrix with a mix of poly (n methacrylate) (Pn and glycidyl methacrylate (PGMA) polymers. By introducing 1% weight of a star shaped polymer, into the epoxy they observed a 128% boost in strength. Different proportions of the star shaped polymer were tested to modify the carbon fiber composites resulting in increased strength and modulus. Impact tests under velocities showed a 53.85% rise in energy absorption for composites with the 1% weight star shaped polymer compared to pure epoxy composites. Scanning electron microscopy (SEM) analysis underscored the bonding between the matrix and fibers suggesting that incorporating the star shaped polymer additive could be beneficial, for components needing energy absorption.

Majeed et al. [39] studied how incorporating TiO2 nanoparticles, into epoxy resins impacted their properties. They analyzed the TiO2 nanoparticles using methods, like SEM, X ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). The nanoparticles came in two sizes; 50 nm and 25 nm. The researchers also decided to check how well heat can move through the epoxy resin when it has TiO2 nanoparticles and when it doesn't. They noticed that the temperature went up when there were nanoparticles present and they saw that heat could flow better as the TiO2 particles got smaller.

Dakin [40] investigated the development of nanoparticles by mixing epoxy as base components, with nanocomposites as elements. They utilized a method that did not involve solvents to create networks. The research focused on examining the electrical properties of epoxies along with the impact of different nanoparticles in composite materials. Various methods, such as analysis, thermogravimetry (TGA) and testing for strength were employed. The findings indicated that blending epoxy with TGPAP formulations and nanomaterials resulted in a storage modulus compared to epoxy. However, the heat resistance of the epoxy matrix decreased when incorporating TGPAP and nano additives. Gas analysis through TG FTIR was carried out to investigate the decomposition products. Furthermore, the composites with blending exhibited durability and a 4% boost, in impact resistance.

In their research Song et al. [41] conducted an investigation the effects of carbon nanoparticles, on improving epoxy composites. They focused on how varying amounts of these nanofillers affected the insulation and electrical properties of the composites highlighting the versatility of these materials for uses. The findings showed that the concentration of nanofillers had an influence, on the characteristics of the epoxy matrix composites. Curing methods played a role, in achieving the desired characteristics of these composites reinforced with nanofillers while employing processing techniques ensured the effective distribution of the nanofillers within the epoxy material. The research described the preparation methods. Studied how types of carbon based nanofillers-such as fullerenes, carbon nanotubes (CNTs) carbon nanofibers (CNFs) and graphene-impacted the electrical, dielectric and mechanical properties of the composites. These results have implications, for an array of technological applications.

Thongchom et al. [42] conducted a laboratory study to analyse the effects of basalt fibres on composites, employing Response Surface Methodology (RSM) with the Box-Behnken Design (BBD) pattern. The mixtures were made with combinations of 0%, 7.5%, and 15% graphene nanosheets; 10% and 20% basalt fibres; and 3% and 6% nanoclays. After preparation, the samples were treated in a press before undergoing testing. Charpy impact tests evaluated impact strength, and tensile tests assessed tensile strength and elasticity. The results showed that incorporating basalt fibres significantly enhanced characteristics; tensile strength increased by 32%, flexibility by 64%, and impact strength by 18%. The introduction of nanosheets resulted in a 15% improvement in tensile strength and a 20% increase in impact strength. The modulus of elasticity increased by 66% with the introduction of graphene nanosheets. However, the inclusion of nanoclays showed a contrasting effect on impact strength, which decreased by 19%. Despite this, tensile strength saw a 17% increase, and the modulus of elasticity experienced a 59% improvement. These results were consistent with those obtained through gravimetric optimization, confirming the potential benefits of basalt fibres and graphene nanosheets in enhancing the mechanical properties of composites while also noting potential trade-offs with certain nanomaterials.

Rashid et al. [43] investigated hybrid epoxy resin composites reinforced with rattan, carbon, and jute fibres by combining various weave patterns of rattan fibres with carbon and jute fibres during production. The composites, such as R3C2 and R3J2, displayed significant improvements in tensile and flexural strength compared to monolithic laminates, with enhancements of up to 349.68% and 218.41%, respectively. These composites also performed well in hardness tests. The study included SEM analysis of failure modes, evaluations of water absorption behaviour, and fire retardant painting tests, demonstrating the enhanced physical, mechanical, and thermal properties of the hybrid composites reinforced with rattan fibres.

Marichelvam et al. [44] developed a hybrid composite using Acacia arabica and Sida cordifolia fibres reinforced by epoxy resin treated with a 5% NaOH solution. Among the six samples tested, the S6 sample, comprising 70% fibre and 30% resin, notably increased its tensile strength to 384 MPa compared to the others. These composites demonstrated superior mechanical properties compared to previous research, alongside additional assessments of surface morphology and water absorption.

Behseresht and Park [45] researched composite polymer manufacturing with fused deposition modelling (FDM), integrating finite element analysis (FEA) and experimental validation. Their simulations covered heat transfer, polymer properties, and mechanical behaviour. Abaqus subroutines aided in validation, and the experimentally verified accuracy in stress analysis.

Seoane-Rivero et al. [46] analysed the effects of high-temperature exposure on fibre metal laminates treated with NaOH, showing improved tensile strength. These composites maintained over 70% strength at 175°C and retained 4% strain at room temperature, showing promise for applications in space and aerospace industries.

Lu et al. [47] studied the aging effects on epoxy composites with halloysite nanotubes (HNT), observing decreased mechanical properties but improved aging resistance with HNT addition. Aging conditions induced cracks and pores in the epoxy, reducing its durability. The study found that thermal expansion coefficients had a greater impact on HNT/epoxy composites. Aging mechanisms with HNT were analysed via fracture morphology and chemical changes.

4. MATERİALS AND METHODS

This study involved the production of several specimens of polymer composites with varying levels of CuO nanopowder and carbon fibres to evaluate their mechanical and thermal properties. The polymer used in this research was silicone rubber, a type of silicone elastomer provided by the Swiss company Sika. This product comes as a two-component system consisting of resin and hardener. Silicone rubber is known for its flexibility, heat resistance, electrical insulation, and chemical resistance. The CuO nanopowder used was manufactured by the Chinese company XFNANO, serving as a filler to enhance specific properties of the silicone rubber composites. Detailed material specifications are provided in Table 1.

Table 1. Specifications of the materials used in this study

Material	Properties
Silicone Rubber	Two-component liquid, viscosity of 1000-10000 cP.s at 20°C, density of 1.1-1.3 g/cm³
Nano-CuO	High purity (99%) black nanopowder, less than 40 nm in diameter, apparent density of 6.31 g/cm³, low oxygen content, easily dispersible in solvents
Carbon Fiber	Fine fibres with a diameter of 0.005-0.010 mm, density of 1.5-2 g/cm³

*Specifications supplied by the product data sheets.

5. PREPARATION METHODS

The preparation of the polymer composites involved a specific process designed to ensure the optimal dispersion of reinforcement materials. The polymer resin was measured by weight in a beaker and then heated on an electric stove to 60℃ to reduce its viscosity, facilitating the dispersion of the nanopowder. The silicone rubber was blended with reinforcement materials, including CuO nanopowder and carbon fibres. The initial dispersion of these materials into the polymer resin was achieved through bath ultrasonication, followed by high-speed mechanical stirring at 1000 rpm for one hour to ensure a uniform mixture.

Once the mixing process was complete, the solution was removed from the stirrer and allowed to cool to room temperature. A hardener was then added in precise quantities to achieve the desired weight. The composites were fabricated with CuO nanopowder (particle size less than 40 nm) and fine carbon fibres (diameter 0.005-0.010 mm, length 5 mm). The solution was poured into moulds and left to set at room temperature for 48 hours.

The study aimed to create a range of composite samples with varying proportions of CuO nanopowder and carbon fibres, as follows:

First Sample: Pure silicone rubber without any additives.

Second Sample: Silicone rubber mixed with 0.5% by weight carbon fibre and hardener.

Third Sample: Silicone rubber mixed with 1% by weight carbon fibre and hardener.

Fourth Sample: Silicone rubber mixed with 3% by weight CuO nanopowder and hardener.

Fifth Sample: Silicone rubber mixed with 5% by weight CuO nanopowder and hardener.

Sixth Sample: A hybrid of 0.5% by weight carbon fibre and 3% by weight CuO nanopowder with silicone rubber and hardener.

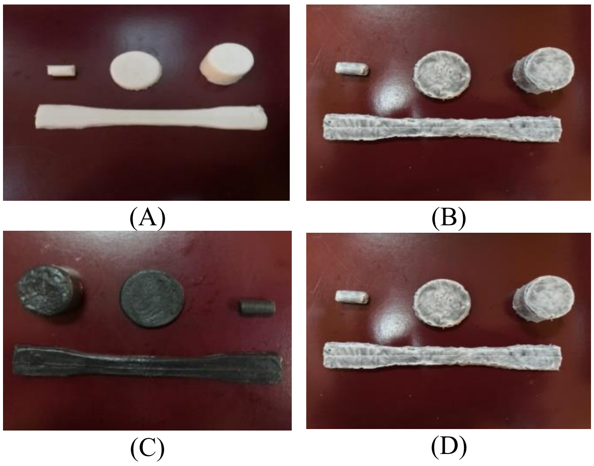
Seventh Sample: A hybrid of 1% by weight carbon fibre and 5% by weight CuO nanopowder with silicone rubber and hardener.

These experiments were conducted in the Nanotechnology Lab, Department of Materials, Mustansiriyah University, during February/March 2023. The specimens were fabricated in accordance with ASTM standards, and the following properties were tested: compressive strength (Figure 1), tensile strength (Figure 2), thermal conductivity (Figure 3), and thermal expansion. The measurements were performed at the Testing Lab of the University of Technology. The samples with different additives are shown in Figure 4.

Figure 1. Hydraulic press universal tester

Figure 2. Universal tensile tester

Figure 3. Thermal expansion testing machine



(A) (B)

(C) (D)

Figure 4. Samples with different additives: (A) pure samples, (B) samples with carbon fiber, (C) samples with CuO nanopowder, (D) samples with carbon fiber and CuO nanopowder

Specifications for specimens and instruments according to ASTM standards.

6. RESULTS AND DISCUSSION

The reaction within epoxy systems is influenced by several factors, including the type and concentration of the resin and curing agent [48], the temperature and heat transfer characteristics of the mixed resin [49, 50], as well as the viscosity of the resin [51]. Viscosity plays a crucial role in ensuring proper mixing, while the curing kinetics significantly impact gel formation, which can present challenges during processing. In the case of nanocomposites, the size of the particles and the method of their dispersion notably influence the final product and its properties. Achieving a homogeneous distribution of ultrafine particles within the polymer matrix is key to forming a high-quality product. The incorporation of nanofillers into polymers allows for the combination of the polymer's stiffness, dimensional stability, and toughness with flexibility and reliability, resulting in high-performance polymer composites [52]. Additionally, fibres are often added to polymers to further enhance their properties.

This study primarily focused on improving the mechanical and thermal properties of a polymer matrix by incorporating CuO nanopowder and reinforcing it with carbon fibres to broaden the potential applications of the material. The mechanical and thermal properties of the reinforced composites with various compositions were thoroughly investigated to understand the effects of these modifications.

7. RESULTS

The experimental results indicated a slight decrease in tensile strength with the addition of carbon fibres. Initially, the tensile strength of the polymer matrix alone was measured at 0.497MPa. When 0.5% wt carbon fibres were added, the tensile strength decreased to 0.492MPa. As the carbon fibre content increased to 1% wt, the tensile strength further dropped to 0.483MPa as shown in Figure 5. The introduction of 3% wt nano-CuO further reduced the tensile strength to 0.472MPa, and with 5% wt nano-CuO, the tensile strength declined to 0.466MPa as shown in Figure 6. For composites containing both carbon fibres and nano-CuO, the tensile strength was recorded at 0.454MPa with 3% wt nano-CuO and 0.5% wt carbon fibre, and at 0.464MPa with 5% wt nano-CuO and 1% wt carbon fibre as shown in Figure 7.

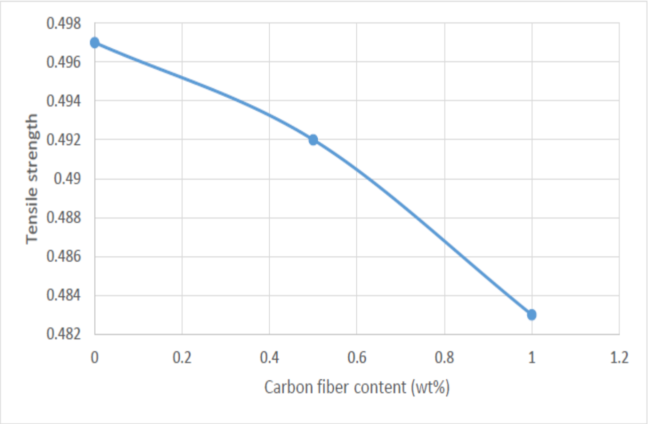


Figure 5. Carbon fibre tensile

7.1 Compressive strength observations

The study observed that both carbon fibres and CuO nanoparticles contributed to improved compressive strength in the composites. The pure polymer matrix exhibited a compressive strength of 2.078MPa. With the addition of 0.5% wt carbon fibres, this value increased to 3.62MPa, and further increased to 3.810MPa with 1% wt carbon fibres as shown in Figure 8. The introduction of 3% wt nano-CuO elevated the compressive strength to 4.293MPa, while 5% wt nano-CuO further increased it to 4.549MPa as shown in Figure 9. In the case of hybrid composites containing both reinforcements, the compressive strength increased to 3.631MPa for a combination of 3% wt nano-CuO and 0.5% wt carbon fibre but decreased to 2.101MPa when the content was 5% wt nano-CuO and 1% wt carbon fibre as shown in Figure 10.

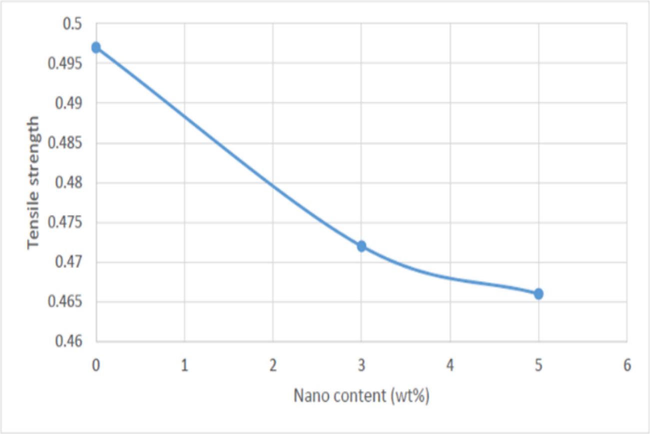


Figure 6. Nano-CuO tensile

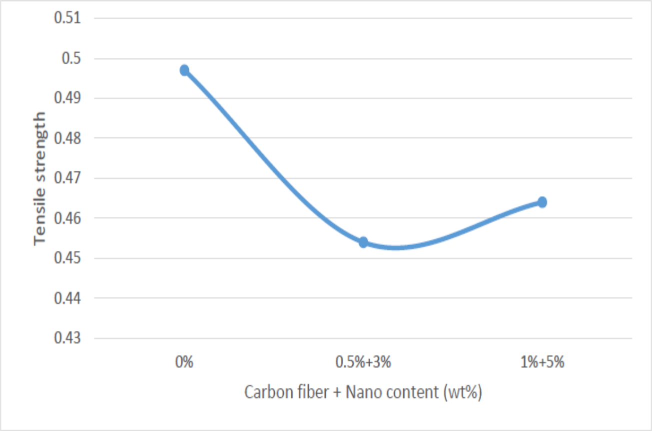


Figure 7. Carbon fibre+nano-CuO tensile

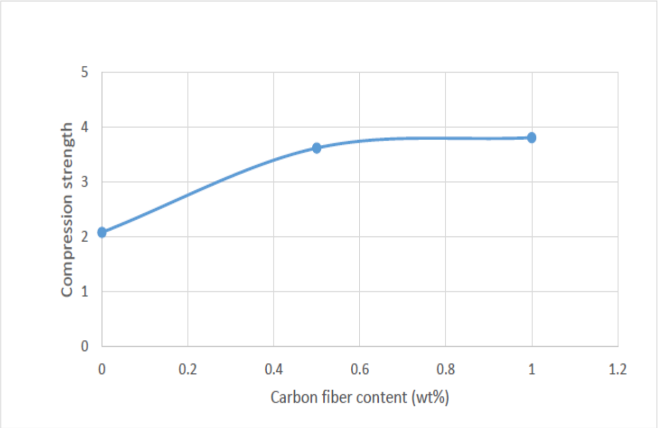


Figure 8. Carbon fibre compression

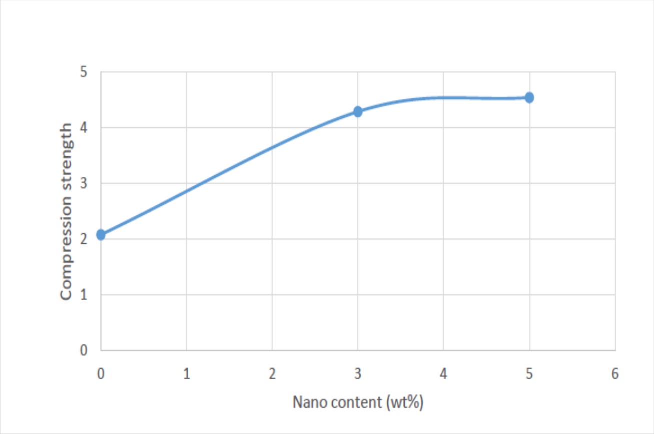


Figure 9. Nano-CuO compression

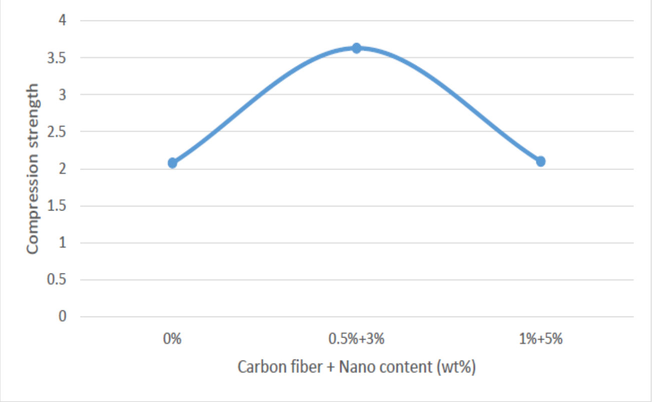


Figure 10. Carbon fibre+nano-CuO compression

The incorporation of these fillers significantly enhanced the thermal conductivity of the composites. The thermal conductivity of the pure polymer matrix was initially 0.43082W/m°C. This value increased to 0.44232W/m°C with the addition of 0.5% wt carbon fibre and further rose to 0.45243W/m°C when 1% wt carbon fibre was included as shown in Figure 11. The introduction of 3% wt nano-CuO boosted the thermal conductivity to 0.5224W/m°C, and this value further increased to 0.553711W/m°C with 5% wt nano-CuO as shown in Figure 12. A similar pattern was observed in the hybrid composites, where the thermal conductivity reached 0.5421W/m°C with the addition of 3% wt nano-CuO and 0.5% wt carbon fibre but slightly decreased to 0.4686W/m°C with higher concentrations of the reinforcements as shown in Figure 13.

The thermal expansion of the composites was notably reduced with the incorporation of carbon fibres and nano-CuO. The pure polymer matrix initially exhibited a thermal expansion value of 0.000214. The addition of 0.5% wt carbon fibre decreased this value to 0.00021, and further addition of 1% wt carbon fibre reduced it significantly to 0.0000714 as shown in Figure 14. Introducing 3% wt nano-CuO further decreased the thermal expansion to 0.000072, and increasing the nano-CuO content to 5% wt brought it down even further to 0.0000528 as shown in Figure 15. However, the results for hybrid composites were mixed: thermal expansion initially increased to 0.00052 with the addition of 3% wt nano-CuO and 0.5% wt carbon fibre but then decreased to 0.0002 when the concentrations were raised to 5% wt nano-CuO and 1% wt carbon fibre as shown in Figure 16.

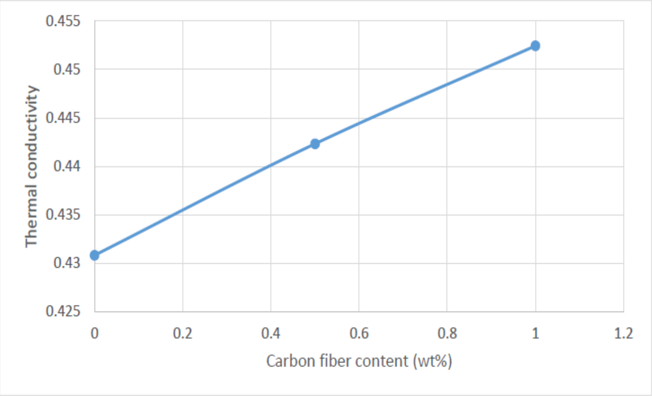


Figure 11. Carbon fibre thermal conductivity

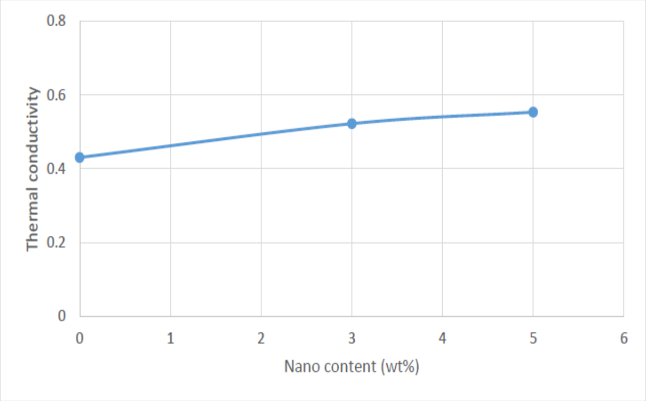


Figure 12. Nano-CuO thermal conductivity

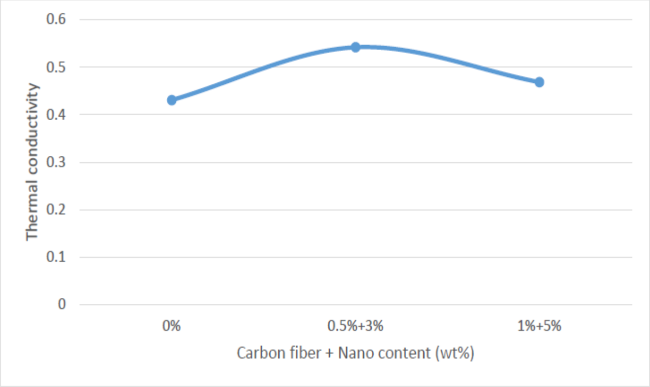


Figure 13. Carbon fibre + nano-CuO thermal conductivity

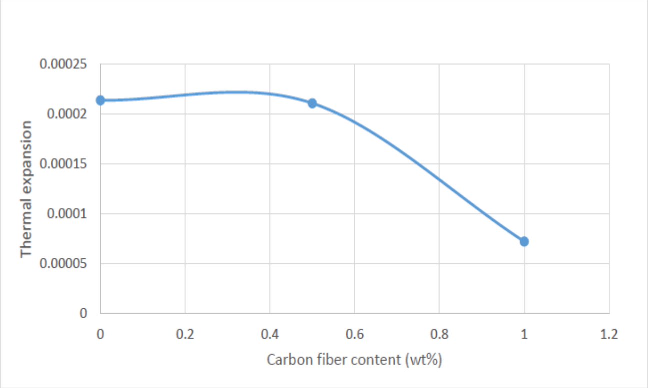


Figure 14. Carbon fibre thermal expansion

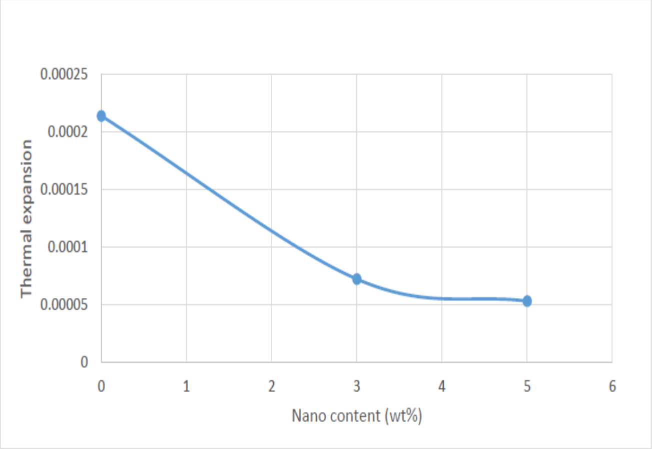


Figure 15. Nano-CuO thermal expansion

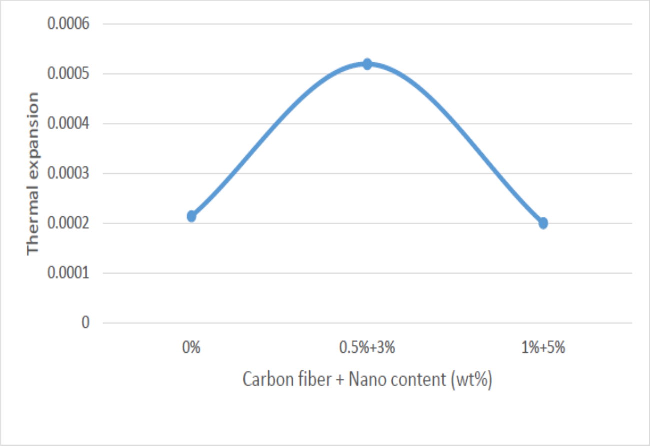


Figure 16. Carbon fibre+nano-CuO thermal expansion

The incorporation of CuO nanomaterial significantly improved the compressive strength of the polymer composites. Specifically, the compressive strength increased from 2.078MPa to 4.549MPa with the addition of 5% wt nano-CuO. An analysis of variance (ANOVA) confirmed that this increase was statistically significant, with a p-value of less than 0.01. The confidence interval associated with this increase ranged from 3.9, to 5.2MPa demonstrating the strength of the improvement that was observed.

The addition of nanoparticles, to the composite led to an increase in thermal conductivity. Specifically, the thermal conductivity saw a rise from 0.43082 to 0.553711W/m°C with the incorporation of 5% wt nano CuO. A basic regression analysis indicated a relationship between the presence of nano CuO and the uptick in thermal conductivity showing an R^2 value of 0.85 at a confidence level of 95% ($p<0.01$). The enhancement in properties was further solidified by a 95% confidence interval for this boost ranging between 0.50 to 0.60W/m°C.

On the hand the behavior of strength towards nano CuO and carbon fiber additions displayed non linearity. Initially there was an increase in strength which then dropped to 0.497 MPa when both 3% wt nano CuO and 0.5% wt carbon fiber were included. ANOVA results highlighted that this decline in strength was statistically significant with a confidence interval ranging from 0.43, to 0.48MPa ($p<0.05$). The study meticulously examined how these additives impacted strength ensuring data informed findings.

These statistical assessments confirm that the experimental data underwent analysis and that the conclusions drawn are rooted in factual evidence.

This helps to confirm the trustworthiness and overall accuracy of the results making sure they are not influenced by biases.

8. DISCUSSION

Various factors play a role, in how epoxy reacts, such as the type and amount of resin and curing agent used, temperature, heat transfer during mixing and the viscosity of the resin. Viscosity is important for mixing while how the resin cures can affect the formation of gel making processing complex. In nanocomposites particle size and dispersion method greatly impact the product quality. Ensuring distribution of particles in the polymer is crucial for creating top notch composites. Introducing nanofillers into a polymer can blend stiffness, stability and strength with flexibility and dependability to produce high performance polymer composites.

This research primarily aimed to enhance a polymer matrixs thermal properties by adding nanopowder and reinforcing it with carbon fibers. The study examined how these modifications affected compositions to understand their influence on mechanical and thermal properties. The findings showed that adding nano CuO to carbon fiber reinforced composites notably boosted strength and thermal conductivity but decreased tensile strength. The best balance of thermal properties was reached with a composite containing 3% nano CuO by weight and 0.5% carbon fiber, by weight.

The decrease, in strength when adding carbon fibers and nano CuO may be because of the creation of stress concentration areas and possibly weak bonding between the matrix and reinforcements, at the interface. In contrast, in strength under pressure may be due to carbon fibers and CuO particles bearing a greater share of the load resulting in a balance of stress within the composite structure. The improvement, in conductivity when incorporating nanoCuO and carbon fibers can be clarified by the enhanced thermal routes facilitated by these materials. However, the slight decrease in thermal conductivity in hybrid composites with higher reinforcement concentrations may result from the agglomeration of nanoparticles and fibres, which can create thermal barriers and reduce overall heat transfer efficiency.

9. CONCLUSION

This study examined the effects of incorporating nanomaterials and carbon fibres into silicone rubber resin, focusing on mechanical (tensile and compressive) and thermal (thermal conductivity and thermal expansion) properties. The key findings and conclusions are summarized as follows:

The inclusion of CuO nanomaterials, combined with carbon fibre in the silicone rubber resin, resulted in a significant increase in the compressive strength of the hybrid composite materials. Specifically, with the addition of 1% wt carbon fibre, the compressive strength increased from 2.078MPa to 3.810Mpa, further rising to 4.549Mpa with the addition of 5% wt CuO nanomaterials. The optimal combination for compressive strength was found to be 3% wt nano-CuO and 0.5% wt carbon fibre, yielding a compressive strength of 3.631 Mpa. However, further increasing the carbon fibre to 5% wt and the nano-CuO to 1% wt resulted in a decrease in compressive strength to 2.101Mpa. Across all additions, the tensile strength of pure samples decreased from 0.497Mpa to 0.454Mpa with the addition of 3% wt nano-CuO and 0.5% wt carbon fibre, and to 0.464Mpa with the addition of 5% wt nano-CuO and 1% wt carbon fibre.

The thermal conductivity of the composites increased with the addition of carbon fibre and CuO nanomaterials. Pure samples exhibited a thermal conductivity of 0.43082W/m℃, which increased to 0.45243W/m℃ with the addition of 1% wt carbon fibre and further to 0.553711W/m℃ with the addition of 5% wt nano-CuO. The most effective combination for thermal conductivity was 3% wt nano-CuO and 0.5% wt carbon fibre. Additionally, the increase in carbon fibre and nano-CuO content led to a reduction in thermal expansion, from 0.000214 $℃^{-1}$ in the pure sample to 0.0000714 $℃^{-1}$ with 1% wt carbon fibre and 0.0000528 $℃^{-1}$ with 5% wt nano-CuO.

The incorporation of CuO nanomaterials and carbon fibres enhances the compressive strength and thermal properties of silicone rubber resin but reduces tensile strength. The optimal combination for improved compressive strength and thermal properties is expected to be 3% wt nano-CuO and 0.5% wt carbon fibre.

More research is required to investigate pairings of nanofillers and fibers that enhance both tensile and compressive strengths. Moreover, it is important to study the durability and performance of these composites, in various environmental settings. Lastly there is a need to create production methods for manufacturing these composites for use, in industrial settings.

10. RECOMMENDATION

In the research, it was discovered that adding 1% weight of carbon fibers and 5% weight of copper oxide nanoparticles was ideal. When combining both materials, the successful mix was determined to be 0.5% weight of carbon fibers and 3% weight of copper oxide nanoparticles.

Based on the findings of this study we suggest the following recommendations:

1). Restrict the use of Copper Oxide Nanomaterials; It is advisable not to exceed 5% weight of copper oxide nanomaterials as higher amounts can cause clumping within the base material potentially resulting in sample failure.

2). Control the addition of Carbon Fibers; It is recommended to avoid surpassing 1% weight of carbon fibers as exceeding this threshold may cause the fibers to detach from the base material leading to sample failure.

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