Visual Abstract

Fractography and tensile studies on the effect of different carbon fillers reinforced hybrid nanocomposites

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ABSTRACT. The use of elastomers has become increasingly important in a variety of industries, including automotive, medical, and food packaging. The adaptability of elastomers to different mechanical stresses has made them a popular choice for these applications. However, the mechanical properties of elastomers can be further enhanced by adding suitable fillers. In this study, the effects of different carbon fillers, namely carbon black, carbon graphite, and carbon nanotubes, on the tensile strength of elastomeric materials were investigated. Different combinations of plain silicone with varying concentrations of CB, CG, and CNT fillers were prepared using a solution casting method. The concentrations of the fillers ranged from 5% to 15% with an interval of 5%. The tensile strength of each combination was measured, and the results showed that the maximum tensile strength was achieved with the combination of CNT at 15% loading. The results of this study highlight the importance of filler selection in enhancing the mechanical properties of elastomers. Carbon fillers, particularly CNTs, have shown to be effective in improving the tensile strength of elastomeric materials. This has important implications for various industries, particularly in the development of new materials for applications in automotive and medical fields.

The use of elastomers in the automotive industry has become increasingly important due to their ability to absorb mechanical shocks and vibrations. Elastomeric materials have also found applications in the medical field, such as in the development of artificial skin, blood pumps, drug delivery systems, and implants. The use of elastomers in food packaging has also become popular due to their ability to provide a barrier against oxygen and moisture.

The use of carbon fillers in elastomeric materials has the potential to significantly enhance their mechanical properties, particularly their tensile strength. This study provides valuable insights into the effects of different carbon fillers on the tensile strength of elastomers, which can help in the development of new materials for various industrial applications.

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INTRODUCTION

Carbon black is a commonly used filler in elastomers, primarily due to its low cost and availability. It can improve the mechanical properties of elastomers, such as their tensile strength, hardness, and abrasion resistance. Carbon graphite, on the other hand, is a high-performance filler that can enhance the mechanical properties of elastomers even further. It has been shown to improve the tensile strength, modulus, and fatigue resistance of elastomers.

Carbon nanotubes (CNTs) are another type of carbon filler that have gained significant attention due to their unique mechanical, electrical, and thermal properties. CNTs have high aspect ratios, high strength-to-weight ratio, and excellent mechanical properties, making them ideal candidates for enhancing the mechanical properties of elastomers. Studies have shown that the addition of CNTs to elastomers can significantly improve their tensile strength, modulus, and fatigue resistance [1].

In recent years, several studies have focused on investigating the effects of different carbon fillers on the mechanical properties of elastomers. These studies have shown that the type, concentration, and size of the carbon fillers can significantly affect the mechanical properties of elastomers. Therefore, it is important to carefully select the type and concentration of the carbon fillers based on the specific application requirements [2].

In this context, this study aims to investigate the effects of different carbon fillers, namely carbon black, carbon graphite, and carbon nanotubes, on the tensile strength of elastomeric materials. The results of this study can provide valuable insights into the effects of different carbon fillers on the mechanical properties of elastomers and can help in the development of new materials for various industrial applications. Carbon fillers, including carbon black, carbon graphite, and carbon nanotubes, have been widely investigated for their effects on the mechanical properties of elastomeric materials. Several studies have reported significant improvements in the tensile strength of elastomeric composites with the addition of carbon fillers. Carbon black is a commonly used filler in the rubber industry due to its high surface area and low cost. It has been reported to improve the tensile strength and tear resistance of elastomers when used in small concentrations (lesser than 10%) [3]. However, the tensile strength may decrease with increasing carbon black concentration due to the formation of agglomerates [4]. Carbon graphite is another filler that has been investigated for use in elastomeric composites. It has been reported to improve the mechanical properties of elastomers, including tensile strength and tear resistance, when used in concentrations ranging from 5% to 20% [5]. The high aspect ratio and good dispersion of carbon graphite particles contribute to the improvement in mechanical properties.

Carbon nanotubes (CNTs) have received significant attention as a filler for elastomeric composites due to their high aspect ratio, high mechanical strength, and excellent electrical conductivity. CNTs have been reported to improve the tensile strength and modulus of elastomers when used in concentrations ranging from 0.5% to 5% [6]. Higher concentrations of CNTs may lead to agglomeration and decreased mechanical properties [7].

Polymer nanocomposites (PNCs) are a class of materials that combine polymers with nanoparticles. The nanoparticles are usually inorganic and have at least one dimension that is less than 100 nanometers. These nanoparticles are often surface-modified to enhance compatibility with the polymer matrix. PNCs exhibit unique properties that are not found in conventional polymer composites, including enhanced mechanical strength, stiffness, thermal stability, and barrier properties. The addition of nanoparticles to the polymer matrix can also improve electrical conductivity, flame retardancy, and optical properties. The field of PNCs has attracted significant attention in recent years due to their potential for a wide range of applications, including automotive, aerospace, packaging, electronics, and biomedical engineering.

The properties of PNCs depend on a variety of factors, such as the type, size, and shape of the nanoparticles, their distribution within the polymer matrix, and the interactions between the nanoparticles and the polymer chains. The design and synthesis of PNCs can be tailored to meet specific performance requirements for a variety of applications, including packaging, automotive, aerospace, electronics, and biomedical engineering [8,9, 10].

Silicone/CNT nanocomposites have potential applications in a variety of fields, including electronics, aerospace, and biomedical engineering. For example, the high electrical conductivity of silicone/CNT nanocomposites makes them suitable for use in electromagnetic interference (EMI) shielding, while their biocompatibility and mechanical properties make them promising materials for medical implants and devices [11,12,13].

Studies have examined three different approaches to fabricating epoxy-based composite mold inserts and has revealed that a simple and economical method can be employed to produce such inserts. This process is particularly advantageous when utilized for intermediate tooling in the manufacture of high-volume products such as TV frames or vehicle bumpers, as it offers significant cost savings. The study has found that epoxy-based composite mold inserts can be created using a propeller technique at a reasonable cost, with a high success rate and a surface roughness that meets acceptable standards [14].

MATERIALS AND METHODS

The silicone elastomer polymer used in the study was supplied by Silicone Polymers Pvt Ltd., a company based in Bengaluru, in accordance with industry standards. The filler materials used in the composites were nanoscale carbon black, carbon graphite, and carbon nanotube powders, which were selected based on industry standards.
To create the silicon matrix for the composites, a liquid component kit was used, which included a monomer material (part A) and a curing agent. The monomer material was mixed with the silicone elastomer (part B) in a weight ratio of 10:1, following the supplier's instructions. A cross-linker was added to the monomer material to form the silicone polymer sample, and the mixture was evenly mixed with a mechanical stirrer for 45-60 minutes. The mixture was then degassed for 10-15 minutes in a vacuum chamber to remove any trapped air bubbles. The fluid was poured into a steel mold after degasification and allowed to cure for 36 hours at room temperature. Plain silicone samples for tensile testing were prepared using the same procedure, with the addition of CB, CG, and CNT particles to the silicone. Visual inspection was performed on all the samples, including the plain silicone, silicone with carbon black, silicone with carbon graphite, and silicone with carbon nanotube composites. The purpose was to identify any potential rips, bubbles, or flaws that could affect the materials' mechanical qualities. All samples that underwent mechanical testing had to be free of defects to ensure the consistency of the test results. The manufacturing process of silicone-based polymer nanocomposites typically involves the following steps and can be generalized.
Material selection: The first step in the manufacturing of silicone polymer composites is the selection of appropriate materials that will be used to reinforce the silicone polymer matrix. These materials can include fillers such as glass fibers, carbon fibers, and nanoparticles.
Mixing: The selected materials are then mixed with the silicone polymer matrix in a suitable mixing apparatus such as a banbury mixer, two-roll mill, or kneader. The mixing process helps to disperse the fillers uniformly throughout the silicone polymer matrix, improving the mechanical properties of the resulting composite.
Molding: The mixed material is then molded into the desired shape using various techniques such as compression molding, injection molding, or transfer molding. The molding process involves applying heat and pressure to the mixed material to transform it into the desired shape.
Curing: After molding, the composite is cured to achieve its final properties. The curing process involves subjecting the composite to high temperatures and pressures in an autoclave or oven, which helps to strengthen the bonds between the filler and the silicone polymer matrix [15.16].
Finishing: Finally, the composite is finished by trimming and sanding any excess material and applying any required surface treatments such as coatings or finishes.
Overall, the manufacturing of silicone polymer composites requires careful selection of materials, precise mixing and molding, and proper curing to achieve the desired properties. The resulting composites can be used in a wide range of applications where the unique combination of properties provided by the silicone polymer matrix and the reinforcing materials is required. Fig. 1 below shows the actual steps used in the assessment of polymer nanocomposites [17].

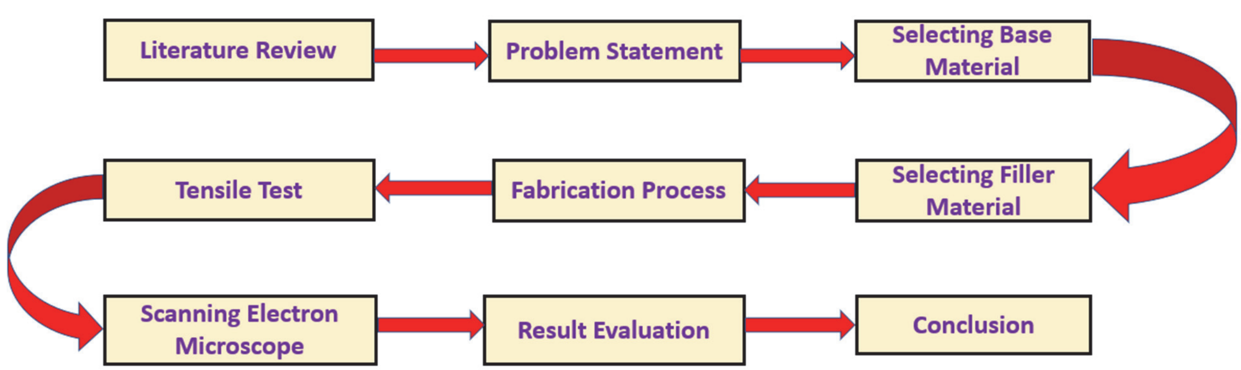

Figure 1: Sequence of the methodology.

Tensile Testing

Fig. 2 details the fabrication process for the composites composed of silicon, silicon CB, silicon CG, and silicon CNT. Samples were prepared for tensile testing and was carried out using a Universal Testing Machine from Dok System Inc. in accordance with ASTM-412 type C standards. The machine has a gauge length of 25mm, a speed of 500 mm/min, and an internal data monitoring programmer that is used to record the data. To prevent slippage and to provide adequate uniform pressure distribution across the composite samples, suitable gripping mechanisms were constructed on both sides of the test sample. Before the material was tested, the test apparatus was calibrated in accordance with the Universal Testing Machine guidelines.

Figure 2: Flowchart depicting materials, fabrication technique and samples used in current study.

RESULTS AND DISCUSSION

Powder Morphology

The unique physical and chemical properties of carbon fillers, such as carbon black, carbon graphite, and carbon nanotubes, give rise to distinct powder morphologies, which are characterized by their particle size, shape, and degree of porosity.

The fine, powdery nature of carbon black is due to the small, tightly packed spherical particles that make up its morphology. These particles are usually less than 100 nm in size and have a high degree of porosity, which is responsible for the high surface area to volume ratio of carbon black.

The morphology of carbon nanotubes is characterized by their long, thin, and cylindrical structure with a diameter of a few nanometers and a length of several micrometers or more. They can exist as either single-walled or multi-walled tubes, with the latter consisting of multiple concentric tubes. Due to their high aspect ratio, which means that their length is much greater than their diameter, carbon nanotubes have unique mechanical, electrical, and thermal properties.

The production process of composites involves the creation of aggregates when the reinforcing concentration is increased, which can be observed through Scanning Electron Microscope (SEM) examination. By examining images of the broken surfaces of the silicone, silicone with carbon black, carbon graphite, and carbon nanotube composites using

SEM, the particle distribution, fracture process, and interfacial bonding of the composite can be analyzed at a 100-micron scale.
Carbon graphite powder is made up of stacked layers of tiny flakes or platelets, which give it a morphology similar to that of graphite crystals. These platelets are usually a few micrometres in size and have a flat, hexagonal shape, contributing to the unique physical and chemical properties of carbon graphite.

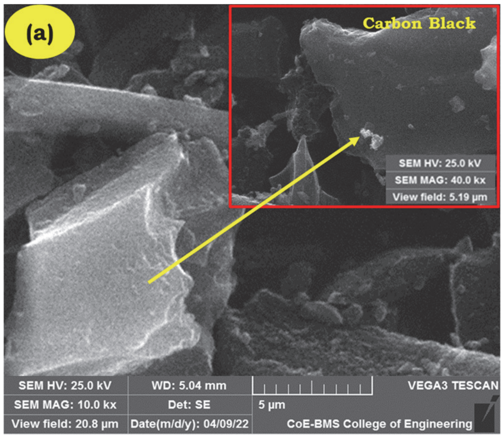

Figure 3(a): Powder Morphology of Carbon black at lower and Higher Magnification.

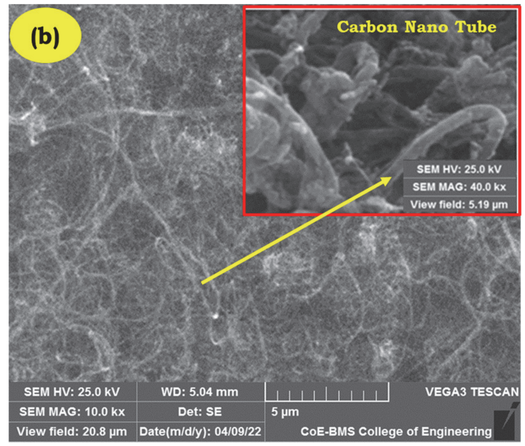

Figure 3(b): Powder Morphology of Carbon Nano Tube (CNTs) at lower and Higher Magnification.

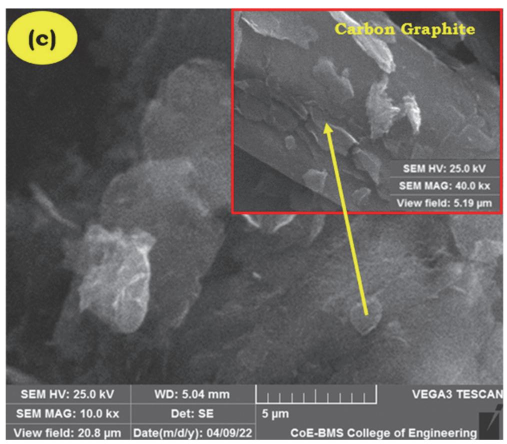

Figure 3(c): Powder Morphology of Graphene at lower and Higher Magnification.

Tensile test

Tensile testing is a widely used method for assessing the mechanical characteristics of materials, including their strength, elasticity, and ductility. Carbon fillers such as carbon black, carbon graphite, and carbon nanotubes are commonly added to silicone to enhance its mechanical properties.
To conduct a tensile test on carbon-filled silicone, a thin strip or rectangular bar of the material is usually prepared and clamped at both ends in a testing apparatus. The apparatus then gradually applies a force to the material, causing it to stretch and deform until it eventually breaks. During the test, various parameters are measured, such as the load applied to the material, its deformation under load, and the resulting stress and strain. These measurements can be used to calculate different mechanical properties of the material, such as its tensile strength, Young's modulus (which indicates its stiffness), and elongation at break (which measures its ductility) [18].
The addition of carbon fillers to silicone can significantly alter the material's mechanical properties. For instance, carbon black is often used as a reinforcing filler, which can enhance the silicone's tensile strength and stiffness. Carbon graphite is another popular filler that can increase the material's thermal conductivity and reduce its coefficient of thermal expansion. Carbon nanotubes, on the other hand, possess unique mechanical characteristics and a high aspect ratio that can greatly boost the material's stiffness and strength, as well as improve its electrical conductivity and thermal stability.
In summary, tensile testing is a useful method for evaluating the mechanical properties of carbon-filled silicone materials, such as those containing carbon black, carbon graphite, or carbon nanotubes. By measuring various parameters during the

test, it is possible to assess the material's strength, elasticity, and ductility, and to optimize its properties for a particular application.

Material	Width (mm)	Thickness (mm)	CSA (sq.mm)	Peak load(N)	Elongation at break (%)	Tensile Strength (N/mm^2)
Plain Silicone	5.5	2.58	14.19	35.17	288.16	1.81
Carbon Black (5%)	5.5	2.10	11.55	45.72	281.04	2.07
Carbon Black (10%)	5.5	2.00	11.00	46.97	310.00	2.36
Carbon Black (15%)	5.5	2.20	12.10	59.04	275.56	3.07
Carbon Graphite (5%)	5.5	1.90	10.45	62.14	275.80	3.34
Carbon Graphite (10%)	5.5	2.45	13.48	66.64	324.60	4.04
Carbon Graphite (15%)	5.5	2.60	14.30	70.81	241.72	4.64
CNT (5%)	5.5	2.40	13.20	61.43	251.56	4.52
CNT (10%)	5.5	2.60	14.30	72.33	275.08	5.42
CNT (15%)	5.5	2.45	13.48	81.49	215.04	5.92

Table 1: Data obtained based on Hooke's law assumptions.

The study investigated the impact of carbon black, carbon graphite, and carbon nanotubes on the tensile strength of plain silicone. The findings, which were plotted on a graph, revealed a direct relationship between the filler composite composition and the maximum strain of the sample. Specifically, higher percentages of CB, CG, and CNT nano-composites led to increased maximum strain.

Tab. 1, which is based on Hooke's law, presents the Young's modulus of pure silicone and its composites with varying percentages of CB, CG, and CNTs. The table also displays the failure load, ultimate tensile strength, and elongation at failure of the composites. The results show a direct correlation between the filler content of the composites and their Young's modulus.

Interestingly, the highest tensile strength was observed for the composite with 15% CNTs, while the tensile strength of composites with higher percentages of CNTs decreased. This decrease in tensile strength at higher CNT percentages may be attributed to the clumping of CNTs, resulting from their agglomeration. Moreover, the tensile strength of the composite with 15% CNTs was found to be higher than that of the CB and CG composites.

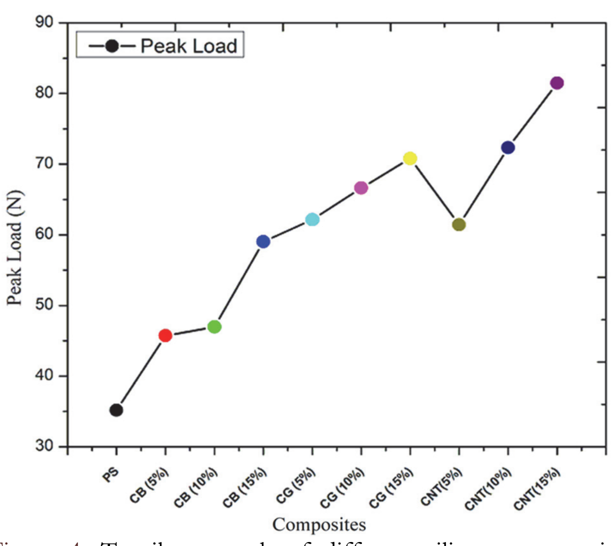

Figure 4: Tensile strength of different silicone composite with change in % of filler

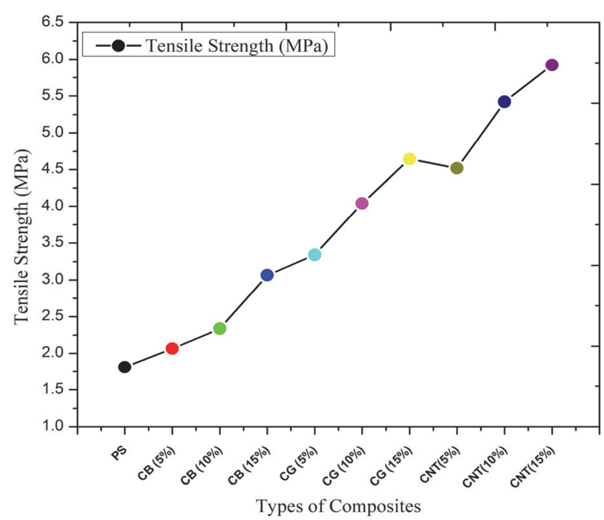

Figure 5: Peak load of different silicone composite with change in % of filler

The results of these studies can provide insights into the optimal combination of carbon fillers and polymers to use in composite materials for specific applications. They can also help identify any limitations or trade-offs associated with using different types and amounts of carbon fillers in composite materials. Ultimately, these studies can help advance the development of stronger, more durable, and more versatile composite materials for a wide range of industrial and commercial applications.

Fractography

As the amount of filler in the matrix grew until 15% reinforcement, the tensile strength of the composites increased, suggesting an increase in silicon's carbon content. Additionally, compared to other filler levels, the increased strength produced with 15% carbon nanotubes may be attributable to good interfacial bonding between the CNTs and Silicone. Additionally, the particles aggregate as more reinforcement is added, which lowers the tensile strength.

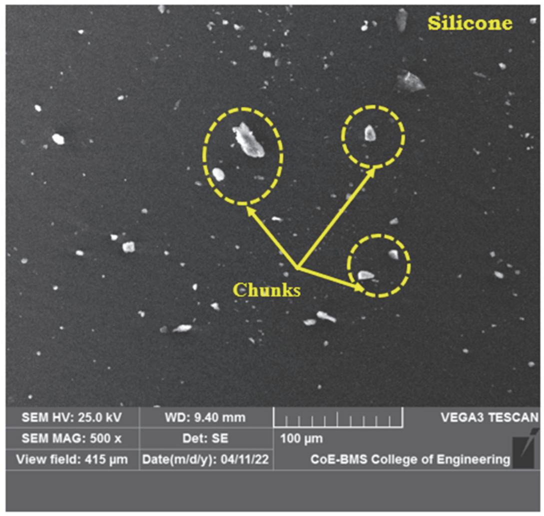

Figure 6: Fractography of plain silicone.

Fig. 6 depicts the fractography of pure silicone displaying chunk sized Si and C grains leading to ductile fracture. Similar observations were made by few researchers [19]. Fractography of plain silicone-based composites involves examining the fracture surfaces of these materials to understand the mechanisms of failure and identify any defects or weaknesses in the material.

Silicone-based composites are widely used in a variety of applications, including medical devices, automotive parts, and consumer products. These materials typically consist of a silicone polymer matrix filled with various types of fillers, such as silica or carbon black, to enhance their mechanical properties.

Fractography of plain silicone-based composites involves preparing fractured samples of the material and examining their surfaces using various techniques, such as scanning electron microscopy (SEM) or optical microscopy. By analyzing the fracture surfaces, researchers can gain insights into the underlying mechanisms of failure, such as crack propagation or delamination.

Fractography can also reveal any defects or weaknesses in the material, such as voids or inclusions, that may have contributed to the failure. This information can be used to optimize the material's composition or manufacturing process to improve its performance and durability.

Additionally, fractography can be used to evaluate the effectiveness of different filler types and concentrations on the mechanical properties of the material. For example, researchers may compare the fracture surfaces of composites with different filler types to determine which types provide the greatest resistance to crack propagation or other modes of failure.

Overall, fractography of plain silicone-based composites provides valuable information about the material's mechanical behavior and can help guide the development of more advanced and durable composite materials for various applications.

Fig. 7 depicts the fractography of silicone reinforced with carbon black. Fig. 7 (a) shows fractography of silicone reinforced with 5% carbon black displaying chunk sized Si and C grains leading to brittle fracture. Fig. 7 (b) shows fractography of silicone reinforced with 10% carbon black displaying chunk sized Si and C grains along with cracks at few places leading to brittle fracture. Fig. 7 (c) shows fractography of silicone reinforced with 15% carbon black displaying chunk sized Si and C grains and protruded pattern at few places leading to brittle fracture. Overall, it can be analysed that Si-composites reinforced with 5%, 10% and 15% carbon black display brittle fracture. Similar observations were made by few researchers [20,21].

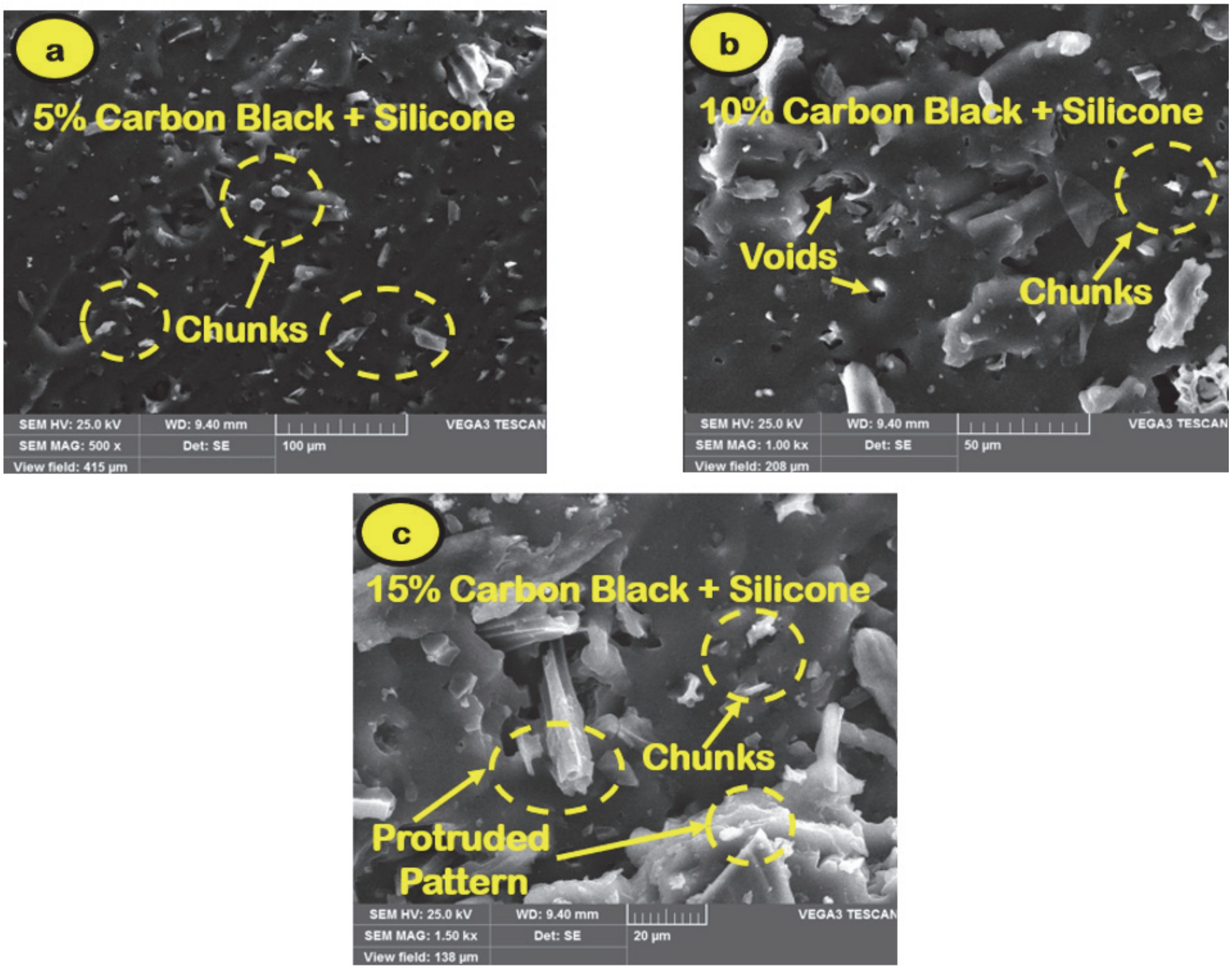

Figure 7: Fractography of silicone reinforced with carbon black.

Fig. 8 depicts the fractography of silicone reinforced with carbon nanotube. Fig. 8 (a) shows fractography of silicone reinforced with 5% CNTs displaying chunk sized Si and C grains leading to brittle fracture. Fig. 8 (b) shows fractography of silicone reinforced with 10% CNTs displaying chunk sized Si and C grains along with cracks at few places leading to brittle fracture. Fig. 8 (c) shows fractography of silicone reinforced with 15% CNTs displaying chunk sized Si and C grains and protruded pattern at few places leading to brittle fracture. Overall, it can be analysed that Si-composites reinforced with 5%, 10% and 15% CNTs displays brittle fracture. Similar observations were made by few researchers [21-22].

Silicone and CNT composites are of particular interest due to their potential use in a wide range of applications, including electronics, energy storage, and biomedical devices. The addition of CNTs to silicone can improve the mechanical properties of the composite, such as its strength, stiffness, and toughness.

However, when the concentration of CNTs in the composite exceeds a certain threshold, the material may become prone to brittle fracture. This is because the CNTs, which are highly stiff and strong, can act as stress concentrators and lead to the formation and rapid propagation of cracks in the material [22].

Overall, understanding the mechanisms of brittle fracture in silicone and CNT composites is critical for the development of safe and reliable composite materials for various applications. By optimizing the composition and processing conditions of the composite, it may be possible to reduce the risk of brittle fracture and improve the overall mechanical performance of the material [23,24].

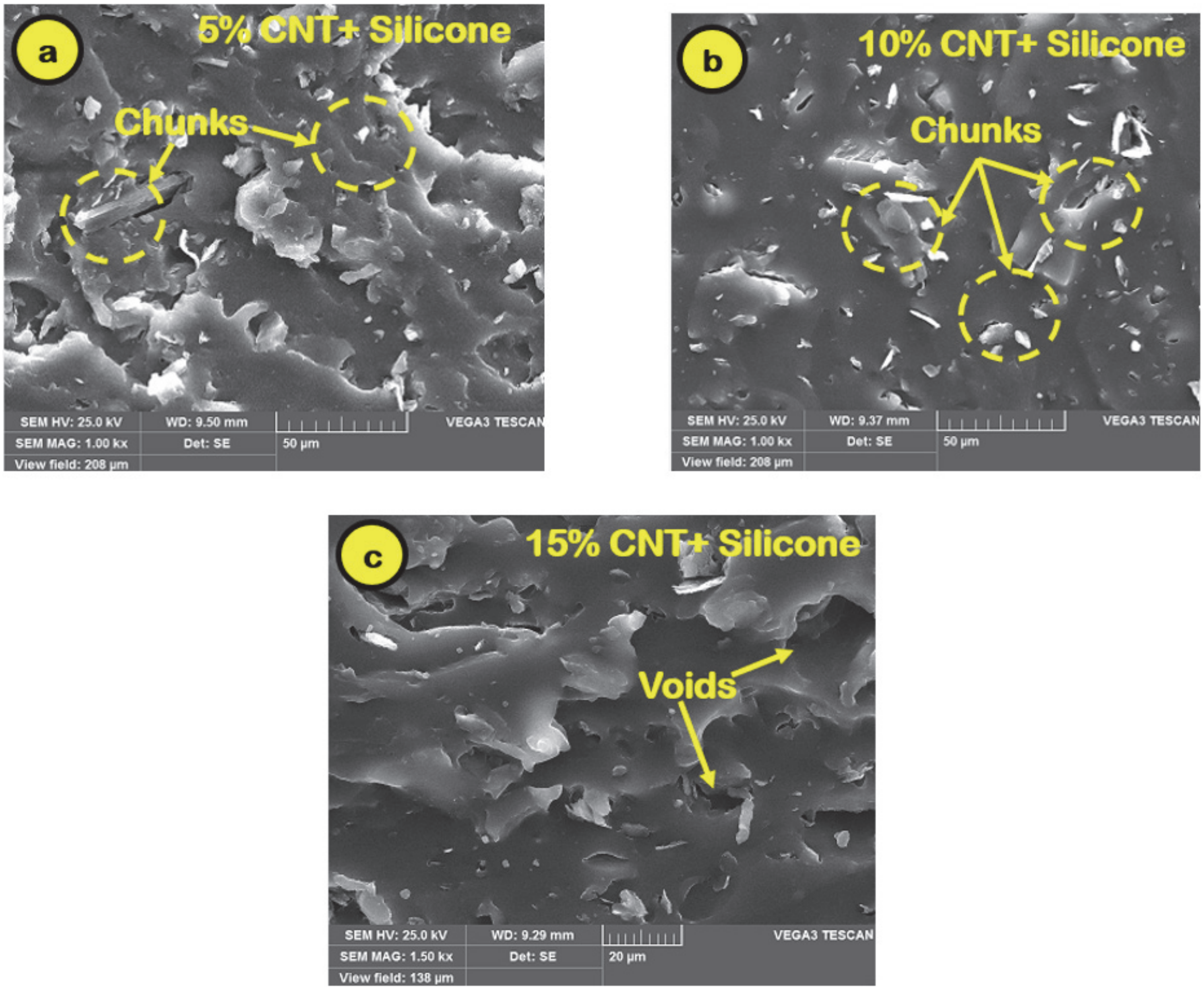

Figure 8: Fractography of silicone reinforced with carbon nano tube.

Based on the fractography shown in Fig. 9, it can be concluded that the silicone composites reinforced with 5%, 10%, and 15% carbon graphene all display brittle fracture behaviour. The fractography in Fig. 9(a), (b), and (c) all exhibit chunk-sized silicon and carbon grains, with some cracks and protrusions in the material.

These observations are consistent with those made by other researchers who have studied the mechanical properties of silicone composites reinforced with carbon graphene. The addition of carbon graphene to the silicone matrix can improve the strength and stiffness of the composite, but when the concentration of carbon graphene exceeds a certain threshold, the material can become prone to brittle fracture [25,26].

In particular, the chunk-sized grains seen in the fractography of the composites indicate that stress concentrations may have formed around the carbon graphene particles, leading to the formation and rapid propagation of cracks in the material. The presence of cracks and protrusions in the fractography further supports the conclusion that the composites underwent brittle fracture [27,28].

Overall, the fractography of silicone composites reinforced with carbon graphene provides important insights into the mechanical behavior of these materials and can guide the development of stronger and more durable composites for various applications.

Effect of fillers on the tensile strength of elastomers

Elastomers' tensile strength can be significantly affected by the addition of fillers. Elastomers can have fillers added to them to change their characteristics and improve performance in a variety of applications. The tensile strength of elastomers can be significantly affected by the choice of fillers, including carbon black, carbon nanotubes and carbon graphite. The reinforcement that fillers give to the elastomer matrix has a significant impact on tensile strength. Fillers function as physical impediments inside the elastomer structure, preventing polymer chains from moving freely and boosting the resistance to deformation. As a result of the reinforcement mechanism, the elastomer is less likely to stretch and break under applied loads, improving tensile strength.

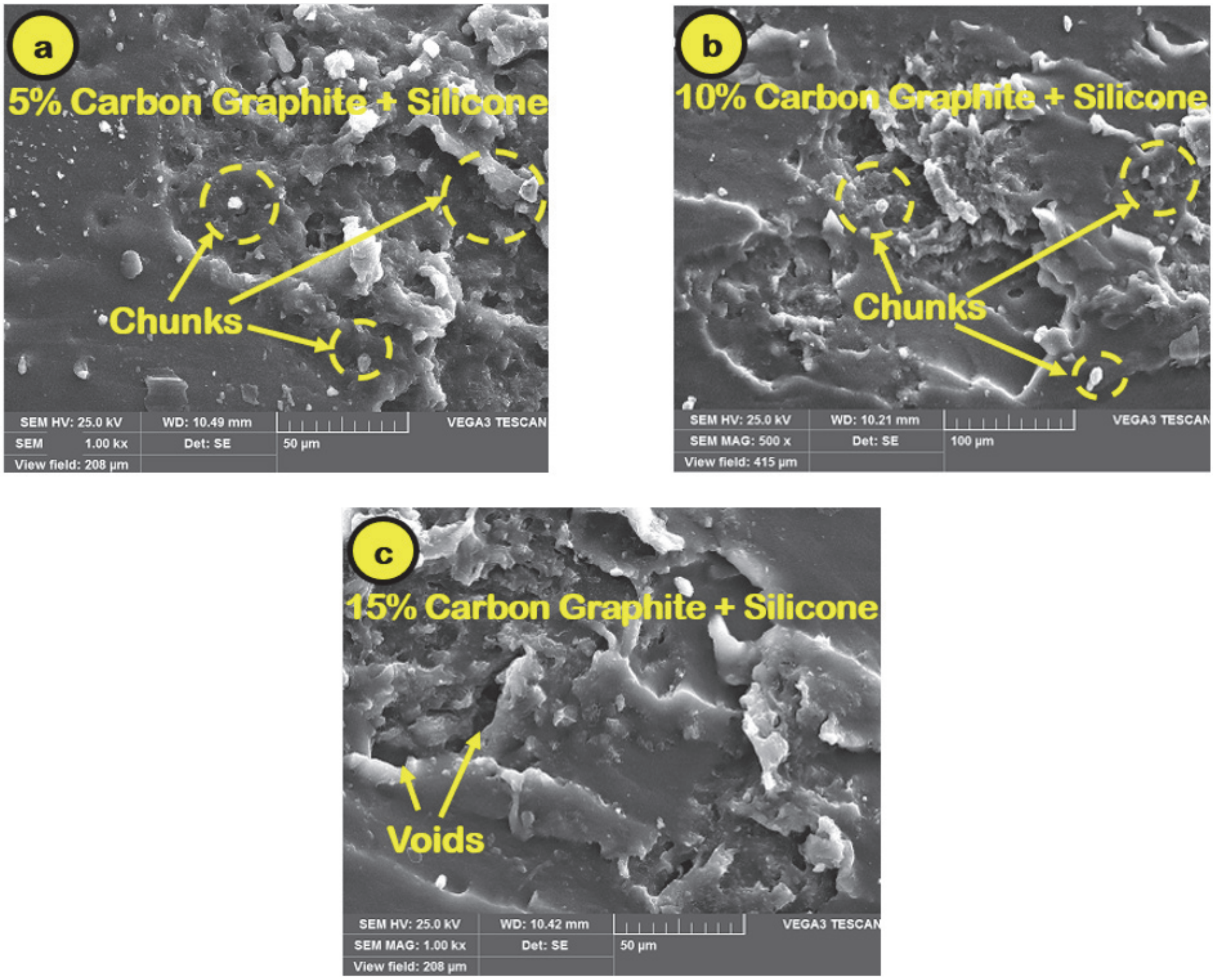

Figure 9: Fractography of silicone reinforced with carbon graphite.

The reinforcing impact of fillers is significantly influenced by their form, size, and surface area. High aspect ratio fillers have a greater surface area and better interfacial interaction with the polymer matrix, like carbon black or carbon nanotubes. The load transmission and stress distribution inside the elastomer are improved as a result of greater filler-polymer bonding. The elastomer's tensile strength consequently rises.

Achieving the best tensile strength also depends on the dispersion of fillers inside the elastomer matrix. A homogeneous distribution of fillers is ensured via uniform dispersion, enabling effective load transfer throughout the material. Agglomeration or inadequate dispersion can cause weak spots to form inside the elastomer, reducing the tensile strength of the material as a whole.

The tensile strength of elastomers is also influenced by the concentration or loading number of fillers. Up until a particular point, referred to as the percolation threshold, increasing the filler content typically results in an improvement in tensile strength. Beyond this point, additional filler addition could cause the elastomer to become stiffer and agglomerate, decreasing its tensile strength.

The tensile strength of elastomers can be affected differently by various kinds of fillers. For instance, carbon black is a frequently used filler that provides elastomers with significant reinforcement, increasing their tensile strength.

It is important to note that the individual application requirements should be taken into account while choosing fillers. The impacts of tensile strength on other desired qualities like flexibility, abrasion resistance, and scratch strength need to be balanced with the various combinations of features that different fillers offer.

Elastomers' tensile strength can be substantially impacted by the addition of fillers. The reinforcement offered by fillers, together with elements including filler size, form, dispersion, loading level, and interaction with the polymer, all help to increase tensile strength. It's essential to comprehend how fillers affect elastomer qualities in order to modify materials to fulfil particular application requirements and enhance performance.

Material	Strain in %	Hardness in Shore
Plain Silicone	287.2	40.26
Carbon Black (5%)	185.42	36.74
Carbon Black (10%)	183.45	38.29
Carbon Black (15%)	180.33	41.77
Carbon Graphite (5%)	342.65	37.44
Carbon Graphite (10%)	300.15	40.23
Carbon Graphite (15%)	247.83	44.21
CNT (5%)	392.46	38.44
CNT (10%)	351.66	42.56
CNT (15%)	317.22	47.12

Table 2: Data on Material Strain and Hardness

Tab. 2 provides the shore hardness and strain of respective materials at various weight percentages. In comparison to other levels, CNT reinforcement at a 15% concentration has the highest observed hardness value. Hardness and material strain are crucial mechanical characteristics that shed light on how different loading situations affect a material's behaviour and performance. Hardness indicates a material's resistance to indentation or penetration, whereas strain describes the deformation that a material experiences when subjected to applied stress.

Realizing how strain and stress interact is essential for comprehending how materials behave. When a material is forced by an external force, it deforms and experiences strain. The ratio of a material's new length or shape to its previous length or shape represents the way strain is quantified. It offers details on the degree of deformation and the substance's capacity to endure external forces without sustained impairment or failure.

Depending on the material composition, microstructure, and processing circumstances, the connection between material strain and hardness can change. Higher hardness ratings are typically found in materials that are capable of handling significant strains without major deformation or damage. In materials with excellent strength and good resistance to plastic deformation, this is frequently seen.

Conclusions

The methodology involved in the preparation of composite samples using plain silicone and different percentages of carbon black, carbon graphite, and carbon nanotubes was successfully attained. The composite materials were found to exhibit significant improvements in tensile strength compared to plain silicone. The experimentations were conducted to determine the tensile strength of each composite material with varying percentages of carbon fillers, including carbon black, carbon graphite, and carbon nanotubes.

The results showed that as the concentration of each carbon filler increased, the tensile strength of the composites also increased. Specifically, the highest tensile strength was observed in the composite with 15% carbon nanotubes, which had a tensile strength of 5.92 N/mm^2. Similar trends were observed for carbon black and carbon graphite composites.

Inclusive, the methodology used in this study demonstrated the effectiveness of using carbon fillers to improve the mechanical properties of elastomeric materials. In conclusion, the use of different carbon fillers such as carbon black, carbon graphite, and carbon nanotubes has been shown to have a significant impact on the tensile strength of elastomeric materials. The addition of these fillers has been found to enhance the mechanical properties of elastomers, making them more suitable for a wide range of applications in various industries, including automotive, medical, and food packaging.

Among the three fillers, carbon nanotubes have been found to have the most significant effect on the tensile strength of elastomeric materials, with a maximum tensile strength of 5.92 N/mm^2 observed in the 15% CNT composite.

With a 47.12 Shore number, CNT reinforcement at a 15% concentration has the highest reported hardness value when compared to other levels. However, the optimal concentration of each filler may depend on the specific application and the desired properties of the final material. Overall, the use of carbon fillers in elastomeric materials provides a promising approach to develop materials with improved mechanical properties, which can lead to innovative solutions for various industries.

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