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Advanced Ceramics Progress

## Original Research Article

# Investigation of the Impact of Graphene Nanostructure on the Mechanical Properties of Tires Compounds

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## ARTICLE INFO

## ABSTRACT

## Article History:

Received 14 November 2022  
 Received in revised form 21 November 2022  
 Accepted 29 November 2022

## Keywords:

Graphene  
 Tensile Strength  
 Rubber Compound  
 Stress and Strain

Numerous researchers have shown interest in the new technique of adding various nanoparticles to elastic materials in an attempt to improve their properties. Physical qualities such as wear resistance, strength, thermal properties, tear limit, and elastic fracture were improved as a result of the atomic scale bonds between the nanoparticles and elastic compounds. These characteristics will in turn lead to high-quality and market-friendly products that can compete in international markets. According to the literature, various nanoscale materials including graphene, calcium carbonate (CaCO<sub>3</sub>) nanoparticles, aluminum nanoparticles, diamond nanoparticles, nanoclays, and zinc oxide nanoparticles have been widely used in the rubber industry. Development of significant CaCO<sub>3</sub> nanoparticle structures has continued to date. Carbon nanotubes are another type of nanoscale that can be employed in the rubber industry. In this paper, the effect of graphene on the mechanical properties of rubber compounds was studied due to the significance of incorporation of graphene into the composites, especially into the rubber compounds. The obtained results demonstrated that mechanical properties including tensile strength, wear resistance, and elongation percentage could be easily enhanced by adding graphene to rubber materials. The authors hope that these enhanced compounds will be applicable to the industrial production.


<https://doi.org/10.30501/acp.2022.369482.1111>

## 1. INTRODUCTION

The tire industry manufactures a wide variety of tires, including various sized riding tires, motorcycle tires, truck tires, tractor tires, and bicycle tires. Tire tread, grooves, ridges, layers, tire collars, etc. are the basic parts of a tire. Each part of the tire (rubber) is manufactured for a particular purpose with unique properties. In recent

years, the characteristics of tires have been significantly improved by adding various nanoparticle combinations. Due to the atomic-scale bonds that exist between the nanoparticles and elastic compounds, the presence of nanoparticles not only enhances the physical properties of the rubber compounds but also increases their wear resistance, strength (improves mechanical properties), thermal properties, and tear and fracture limits [1-3].

Please cite this article as: Jeddi, K., Sattari F., Mortazavi S. Z., Mirershadi, S., "Investigation of the Impact of Graphene Nanostructure on the Mechanical Properties of Tires Compounds", *Advanced Ceramics Progress*, Vol. 8, No. 4, (2022), 42-47. <https://doi.org/10.30501/acp.2022.369482.1111>

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These factors come together to produce a high-quality marketable product that can compete on international markets. Numerous nanometer materials such as calcium carbonate ( $\text{CaCO}_3$ ) nanoparticles, calcium oxide nanoparticles, alumina nanoparticles, diamond nanoparticles, nanoclays, and fullerenes have reportedly found widespread applications in the rubber industry. However, according to the literature,  $\text{CaCO}_3$  nanoparticles have recently gained in popularity [4]. Due to the atomic-scale bonds that exist between the nanoparticles and elastic compounds, the presence of nanoparticles enhances the physical properties of rubber compounds. Carbon nanotubes and graphene are two more significant nanostructures that can be used in the rubber industry. In the following, some of the characteristics of graphene will be examined.

Pure carbon and graphene atoms are arranged in a regular hexagonal structure, much like graphite but with one-atom thickness, to form graphene. Graphene, one of the carbon allotropes, has a single-sheet structure composed of atoms joined together by strong bonds to form a honeycomb-like crystal network. Graphene is the thinnest, yet strongest, known material discovered so far [5-9]. In this structure, the carbon-carbon bond is 1.42 Å long. One square meter plate of graphene weighs just 0.77 g, making it a lightweight substance. A graphite sheet or crystal is formed of several graphene sheets that are bonded together and are arranged on top of one another at the distance of 3.35 Å. Theoretical physicist Philip Wallace first investigated the theory of graphene in 1947. He made attempts to comprehend the complex electrical characteristics of the three-dimensional graphite at a time when graphene had not yet been given a name. The term graphene, first coined in 1962 by Hans-Peter Boehm, is a combination of the words graphite and its suffix. They employed a transmission electron microscope to examine the single-layer carbon plates; however, graphene had not been yet produced until the 21<sup>st</sup> century when Professor Andre Geim and Konstantin Novoseloff in cooperation with their research group from the University of Manchester succeeded in separating single layers of graphene using adhesive tape in 2004 and won the Nobel Prize in Physics in 2010. The Massachusetts Institute of Technology selected graphene as one of the top ten technologies owing to its unique features and the extensive studies conducted on it. Additionally, a scientific journal named it the top-notch scientific achievement of 2009. Graphene is currently the thinnest yet most resistant material in the world. Although it is highly transparent due to its thinness, the smallest gas atom, helium, cannot pass through it due to its high density [10-12].

Single-layer, double-layer, and multi-layer graphene have potential applications in different industries. The hardest and thinnest material ever created by humans is called graphene. Its thinness, which is equal to the thickness of a carbon atom, allows light to pass through

it despite its dense structure. Additionally, ease of preparation, conductivity (it is even more conductive than copper), and capacity of graphene to transmit heat and electricity make it a new option to be used in optical screens and computer components. This substance is even harder than diamond with considerable resistance to pressure that causes a disintegration 200 to 300 times greater than that of steel. Owing to its highly desirable lightness and flexibility, graphene is described as a super material which is expected to bring about a revolution in the electronics sector in the future [13]. One of the characteristics that distinguishes graphene from other materials and makes it particularly effective as a reinforcing component in composites is its impressive mechanical properties. The stability of the  $\text{Sp}^2$  bonds that make up the hexagonal network and resist all types of in-plane deformations are other outstanding mechanical characteristics of graphene [14-16].

## 2. MATERIALS AND METHODS

A variety of techniques have been employed so far to analyze the investigated graphene including Scanning Electron Microscopy (SEM), Diffusion Reflectance Spectroscopy (DRS), and X-Ray Diffraction (XRD), to name a few, and to evaluate the properties of the crystal structure and determine the network parameters. The following procedure was considered to create the principal compound of 980 KN (2 kg) in a laboratory tank with a nominal capacity of 2.5 liters using a combination of rubber, carbon black, chemicals, oil, and other materials (Table 1). A ram used for pressurization and consist mixing was employed in conjunction with a laboratory mixer with a volume of 5.2 liters that was made by Samak Iran. The ram is pneumatically operated that works at the pressure of 5 bar. The task of pressurizer is to provide uniform mixing in the mixer chamber. The chemicals, oil, and soot are loaded into the hopper after being weighed and then, the feed door located above the hopper is utilized to feed the materials. The rubbers are poured into the funnel in the first step. Chemicals, carbon, and oil are introduced to the funnel once the temperature reaches 100 °C, with the exception of the chemical curing agents. The temperature serves as the decisive factor of the test. Once the compound was thoroughly mixed and the temperature reached 140 °C, KN compound was discharged until the compound age (rest) time was passed.

Once the compound reached its age period, the curing chemical agents were added. Since there was not enough graphene in the lab, 100 g of the initial compound was used. A relatively small laboratory mill was utilized because it was unable to produce 100 g of the chemical in a 2.5-liter beaker. Then, KN compound was softened on the mill as the working technique. Then, in accordance with the instructions given in Table 2, graphene was

added to the compound in varying amounts (in the first step, 0.5 g of graphene), and the mixture was thoroughly mixed on a mill (two mills). Next, the curing agents were added to the nano compound, and after 24 hours of aging

time, 70 g of the nano compound was baked in a special mold in a laboratory baking press for 30 minutes at the temperature of 155 °C.

**TABLE 1.** Quantities of chemicals required to produce master batch compound or KN

Trade name of chemical substances	Chemical name	The amount of substances (g)	The amount of substances (wt. %)
SBR1500	Butadiene Starene Rubber	377.2	12.041
PBR1220	Poly Butadiene Rubber	506.5	6.592
SBR1712	Oily Rubber Butadiene Styrene	474.7	15.153
CARBONN375	Carbon	718.4	22.932
AROMATIC OIL	Aromatic oil	188.5	6.017
ZNO	Zinc Oxide	359.2	11.466
IPPD Antioxidant	N-Diparaphenylene isopropyl amine	269.4	8.600
STEARIC ACID	Stearic acid	359.2	11.466
TMQ Antioxidant	Polymerized 2,2,4-Trimethyl – 1,2- Dihydroquinoline	269.4	5.733

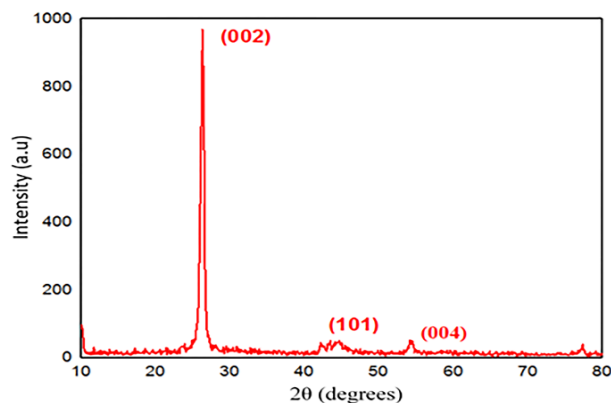
**TABLE 2.** The fraction of chemicals required to produce the final composition of graphene

Baking Factors and Graphene	Weight of chemical compounds, Graphene	Weight of chemical compounds, Graphene	Weight of chemical compounds, Graphene	Weight of chemical compounds, Graphene
Master Batch (MB)	98.665	98.181	97.701	96.756
CBS Accelerator	0.632	0.629	0.626	0.620
Sulfur	0.637	0.634	0.631	0.625
PVI Anti scorch	0.065	0.065	0.064	0.064
Graphene	0	0.491	0.977	1.935

Following the compound baking step, four samples were created using a punch machine in the shape of dumbbell-shaped strips so that the tests could be performed on the strips. The tensile, wear, and hardness tests are considered the necessary mechanical testing.

### 3. RESULTS AND DISCUSSION

The XRD method was employed to characterize the synthesized graphene and examine the crystal structure properties and establish their lattice parameters. Figure 1 displays the X-ray diffraction spectrum of the synthetic graphene.



**Figure 1.** Graphene's X-ray diffraction spectrum

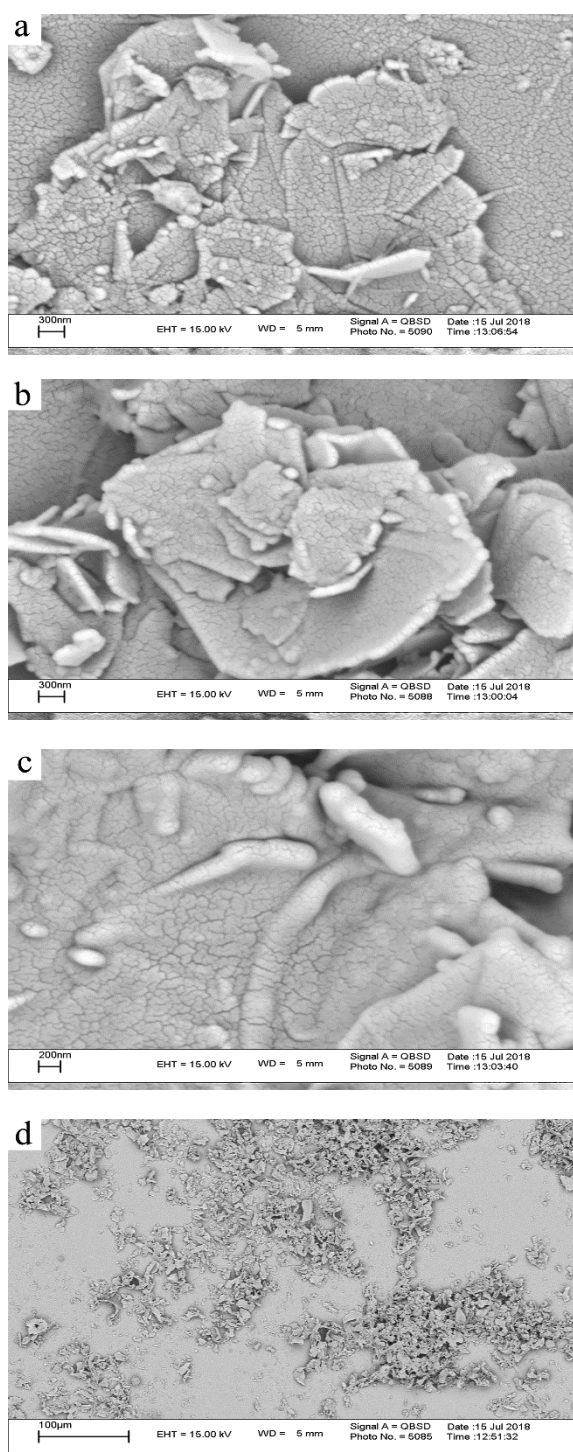
According to the data analysis, the peaks that appear at the angles of 26.3, 43.5, and 54.3 degrees, respectively, refer to the plates with the Miller indices (002), (101), and (004). The observed results, which are consistent with the findings supported by reliable scientific journals, demonstrate that a graphene structure with a lattice constant of 3.34 Å has formed [17–18].

Figure 2 depicts the images captured from the surface of the created graphene samples at different magnifications by scanning electron microscopy that helps examine the surface morphology of the graphene thin layer sample and confirm the creation of graphene nanosheets. As observed in the images, the surface of the created graphene is quite wide, and the folds and bends suggest that the graphene is single-layered.

The energy gap of the graphene nanosheets was calculated using the diffusion reflection method. As a result, to determine the energy gap, first, diffuse reflection spectroscopy, capable of measuring the powder samples, was used to determine the reflection spectrum in terms of the wavelength of light.

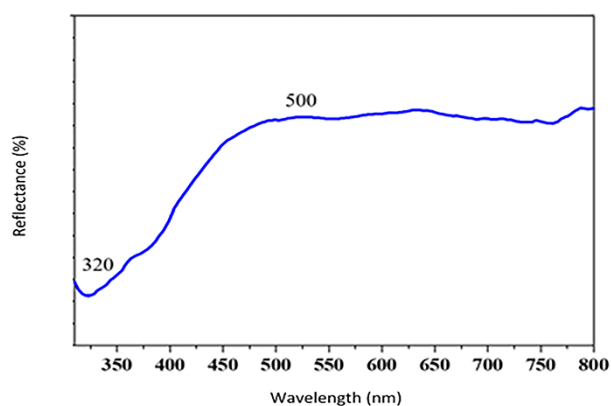
In the diffusion reflectance spectroscopy, the spectrophotometer measures the intensity of the light reflected from the sample and compares it with the that of the light reflected from the surface of the reference sample.

The spectrum in Figure 3 depicts the transition of electrons from the valence band to the conduction band as a result of incident photon energy, the cause of light intensity at the relevant wavelength to drop. In other



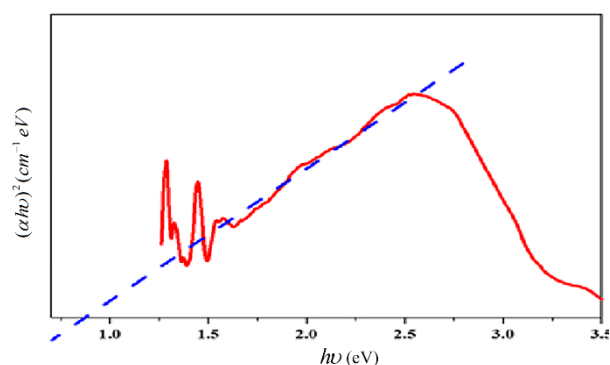
**Figure 2.** Scanning electron microscope images of graphene nanoparticles magnified by 300 nm in (a), 300 nm in (b), 200 nm in (c), and 100 micrometers in (d)

words, there is a decrease in the ratio of the transmitted to the reflected light. As shown in the graphene sample, the amount of light reflection decreased with a decrease in the wavelength of the incident photon from 500 nm to 320 nm.



**Figure 3.** The graphene nanostructure's reflection spectrum as a function of the light's incident wavelength

Graphene thin layer energy gap was calculated using Mott and Davis's theory, where the  $(\alpha h\nu)^2$  curve was drawn in terms of photon energy ( $h\nu$ ). To be specific, the reflection coefficient  $R(\lambda)$  is considered to derive the absorption coefficient  $\alpha(\nu) = (1 - R)^2 / 2R$ , and the energy gap was then simply calculated by drawing a tangent line on the linear portion of the graph produced from  $(\alpha h\nu)^2$  in terms of energy [19]. Based on Figure 4, the energy gap for this two-dimensional structure was calculated as approximately 0.8 eV by drawing the tangent line on the graph in the linear region.

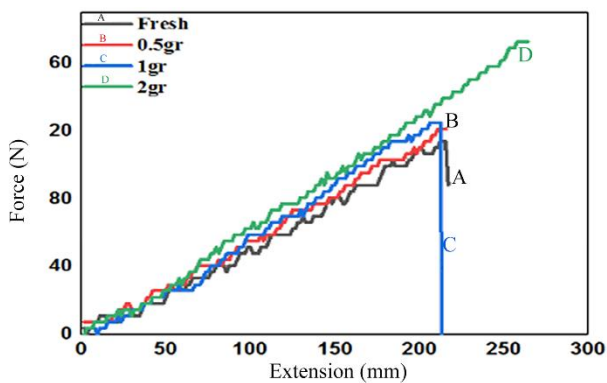


**Figure 4.** The curve of changes of  $(\alpha h\nu)^2$  in the two-dimensional graphene nanostructure in terms of photon energy ( $h\nu$ )

Following that, the impact of graphene on the mechanical characteristics of the compound was examined in terms of its tensile strength, tearing force, and elongation. This examination in turn had a positive impact on the compound, as shown in Figure 5.

Particularly, an increase in the length, tearing force, and tensile strength were all greatly improved by graphene, which accounts for 1.935 wt. % of the material. As the graphene weight increased, the tear force roughly increased proportionally. In diagram (a) attributed to the compound without graphene, the sample is subjected to





**Figure 5.** Compound tension diagram with different amounts of graphene in terms of force-tension

the maximum force of 114 N; in other words, the force imposed at the point of rupture was 114 N, and the displacement was 215.54 mm. In addition, the values of stress, strain, and length increase were obtained as 11.4 MPa, 7.18 dimensionless, and 718 %, respectively. Diagram (b) shows a compound containing 0.491 % graphene by weight and the relevant applied force, displacement or stretching, stress, strain, and length increase. In this diagram, the values of the applied force, displacement or stretching, stress, strain, and length increase were obtained as 121.4 N, 215.56 mm, 12.14 MPa, 7.18, and 718.53 %, respectively.

The applied force in diagram (c), which represents the compound containing 0.977 % by weight of graphene, is 125.1 N, and the values of displacement or stretching, tension, strain, length increase, and modulus are 212.46 mm, 12.51 MPa, 7.08, 708 %, and 1.69 N/mm<sup>2</sup>, respectively. In diagram (d), the values of the applied force, displacement, stress, strain, elongation, and modulus in the compound containing 1.935 g of graphene were obtained as 172.9 N, 264.06 mm, 17.29 MPa, 8.88, 880.2 %, and 1.96 N/mm<sup>2</sup>, respectively. The obtained results are presented in Table 3.

**TABLE 3.** The values obtained from the graph of compound tension with different amounts of graphene in terms of weight percentage

Graphene in weight (%)	0	0.491	0.977	1.935
Force (N)	114.0	121.4	125.1	172.9
Tensile (mm)	215.5	215.5	212.4	264.1
Tension (MPa)	11.4	12.1	12.5	17.2
Strain	7.2	7.2	7.1	8.8
Increased length (%)	718.04	718.5	708.0	880.2
Modulus (MPa)	1.5	1.6	1.7	1.9

The A SHORE equipment from Bareiss, Germany, was used to conduct the hardness test, the results of which are given in the following. The reference sample, containing no graphene, yielded 62 ShoreA. In addition, 2, 1, and 0.5 g of graphene yielded ShoreA64.5, ShoreA65, and

ShoreA64, respectively, in the samples constructed at various levels of graphene presence.

The wear test was completed in two minutes using a wear instrument developed by Bareiss in Germany. The results for the rubber compound containing the nanographene substance are reported in Table 4, and the wear test samples are displayed in Figure 6. The wear test result for graphene with the weight percentages of 0.491 and 0.977 is 80 %, while that for the graphene with the weight percentage of 1.935 is 65 %. Finally, for the reference sample, which is our initial compound without graphene, the result is 145 %

**TABLE 4.** The degree of wear in compounds with a graphene weight fraction

The amount of Graphene in compound	The amount of wear (%)
Without nano	145
0.491	80
0.977	80
1.935	65



**Figure 6.** Examples of baked mixtures for a hardness test

#### 4. CONCLUSION

The current research aims to examine the impact of graphene nanostructure on the elastic compounds, and a summary of the obtained results will be given in the following. The tensile strength, tearing force, and elongation were examined to determine the impact of graphene on the mechanical properties of the compound, and the results showed that graphene had a positive impact on the compound, which was also confirmed in the relevant diagram. Particularly, an increase in the length, tearing force, and tensile strength were all greatly intensified by the presence of graphene, especially the one with the weight percentage of 1.935 %. As graphene weight increased, the tear force was proportionally raised. In the reference compound that contained no graphene, the greatest force imposed on the sample, the amount of force applied at the moment of rupture, was 114 N, and displacement was 215.54 mm. In addition, the values of stress, strain, and length increase were obtained as 11.4 MPa, 7.18 without dimension, and 718 %, respectively. The displacement or amount of tension in the compound with the weight percentage of 0.491 was measured as 215.56 mm, applied force as 121.4 N, stress

as 12.14 MPa, strain as 7.18, and length increase as 718.53 %. The modulus of the compound with the weight percentage of 0.977 was 1.76 N/mm<sup>2</sup>. The values of the applied force, displacement or amount of tension, stress, strain, was and length increase were measured as 125.1 N, 212.46 mm, 12.51 MPa, 7.08, and 708 %, respectively. In the compound with an applied force of 172.9 N and the displacement or tension of 264.06 mm, the stress value of was obtained as 17.29 MPa, strain as 8.88, length increase as 880.2 %, and modulus as 1.96 N/mm<sup>2</sup>, respectively. The results from wear and hardness tests showed that the strength of the elastic compound could be greatly enhanced by adding graphene nanostructure.

## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the management and personnel of the Artaville Tire Ardabil factory for their cooperation and assistance.

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