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An Investigation on The Effect of Carbon Nanoparticles on The Properties of Carbon Brushes

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HIGHLIGHTS

- In this paper, we report on the production process for new composite material based on a metal matrix consisting of nanoparticles as an additive for improving and developing the performance of carbon brushes. We believe that this work should be of interest to readers in the areas of material science and engineering.

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ABSTRACT

The demand for carbon brushes with specific properties and improvements in production economics in recent years has led to increased interest in metal-graphite composites. Metal matrix composites are considered excellent materials to obtain properties superior to those of the constituent phases and meet the specific requirements of material application. In the present study, we suggested a new composite material by utilizing nanomaterials to improve the properties of metal-graphite composite material usually used as carbon brushes. This has been achieved by adding different percentages of 0.1-0.5wt % of carbon nanotubes, carbon nanospheres, or both to the metal matrix composite. The samples were prepared by powder metallurgy technique. The XRD results gave a sharp line and indicated a high crystalline structure and little amorphous, which improved the conductivity performance of the composite produced within the structure of this work. The density measurement chart results showed an increase in the amounts of the carbon nano additives leading to a decrease in the density of the sample. The investigation of nano additives on hardness showed that increases in the additive led to reduced hardness. On the other hand, the resistivity values have reduced gradually when there is an increase in the amounts of the carbon nano additives, especially on the CNT, which gives better results than CNS, which we obtained the resistivity value =(0.32 Ωcm), Comparing with commercial-grade containing free of nano additives (1.3Ω cm).

1. Introduction

The invention of electrical brushes is back in the last century in England. It had stages in development since then, accompanied by the motors and the clusters of copper wires, as was the form of the earliest brush. The motors, modified to provide higher power and higher performance, had made primitive brushes. After that, carbon brushes were invented, composed of carbonic material, solid lubricant, resin binder, and additives. [1]. The demand for carbon brushes with specific properties and improvements in production economics in recent years has led to increased interest in metal-graphite composites. Metal matrix composites are considered excellent materials to obtain properties superior to those of the constituent phases and meet the specific requirements of material application [2]. In the last twenty years, the world has witnessed an increase in a tendency toward the improvement of new materials due to the progress of technology and continuous demands for new devices; the requirements for the very suitable type of reinforcement and matrix that pushed for a new standard of working that formed new conditions which appealed a need to expand its useful applications in many industries fields. In a certain way, the metal matrix composite has new potential thanks to the developments in nano-size scale materials. That is why the relationship between the properties, components, and the production route is essential [3]. The unique features that exist in carbon nanomaterials, e.g., physical,

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mechanical, optical, chemical, and thermal properties, jointly with good stability, high conductivity, and biocompatibility, have made these materials, e.g., carbon nanospheres and carbon dots, vital for the next generation of structural, energy, and bioengineering materials. Metal matrix composites have been applied in several applications, including in the transportation, aeronautics, marine, and defense sectors. These composites have exhibited the ductile and tough performance of a matrix despite the high elastic modulus of the reinforcing particles [4]. Recently, many research investigations have been conducted to improve the engineering materials by making them stronger, stiffer, and more wear-resistant than the present commercial materials. Metal matrix composites are considered excellent materials for obtaining properties superior to those of the constituent phases [5].

The powder metallurgy method is considered the most popular method for the metal matrix composites MMCs preparation of reinforced [6]. The P.M is more economical than several other fabrication methods because no operation is involved in casting or melting in its stages. This method has several advantages over diffusion bonding [7]. Silicon carbide, mica, zircon, and graphite are some of the popular reinforcement materials employed as additives [8]. Graphite is a popular reinforcement for metal matrix composites that can be used as a solid lubricant and renders the composite self-lubricating [9.10]. Due to its solid lubricating property, the graphite particulate phase has a wide range of applications requiring increased wear resistance, such as engine bearings, pistons, piston rings, cylinder liners, etc.[11]. Graphite, an effective lubricant additive, provides some extra properties to the composite, such as anti-corrosion, high-temperature endurance, and self-lubrication, which results from its laminar structure [12]. Under sliding conditions, owing to the transfer of the graphite embedding its matrix into the tribo-surfaces and to the formation of a thin film of graphite that obstructs direct contact between the pairing surfaces, the metal-graphite composite becomes self-lubricating. This lubricating film is formed because shearing graphite particles are placed just below the sliding surface of the composite. This graphite-rich lubricant film decreases the magnitude of the shear stress transferred to the material underneath the contact area, reducing the plastic deformation in the subsurface area, prohibiting metal-to-metal contacts, and acting as a solid lubricant between the two sliding surfaces [13]. Much work has been published on the reinforcement of metal matrix composites with different materials. However, much less has been published about using nanomaterials as a reinforcing material for improving the properties of metal graphite composites. Therefore, this study investigated the use of carbon nanoparticles for improving the properties of metal-graphite carbon brushes. Our results demonstrate that carbon nanotubes and carbon nanoparticles will add to the main constituents of conventional brushes and will improve their performance properties.

2. Materials and Methods

2.1 Materials

The graphite was supplied from Glentham Life Sciences (U.K). The study also utilized a high-purity copper supplied by Oxford Lab Fine Chem LLP (India). The Molybdenum disulfide and novolac phenolic resin, which were used as binder materials, were supplied by Fluka AG (Switzerland). Also, a high-purity carbon Nanospheresre supplied by Nano shell LLC (India) and carbon nanotubes with a purity of 98 % were produced in the laboratory using a homemade arc discharge apparatus. The electrodes in the system were high-purity graphite rods purchased from Lufa Group (China). Table 1 shows the mixture components of the composite used in the experimental work. Also, Table 1. shows several of the Mechanical Properties that distinguish these components.

2.2 Methods

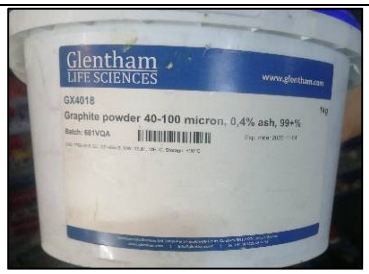
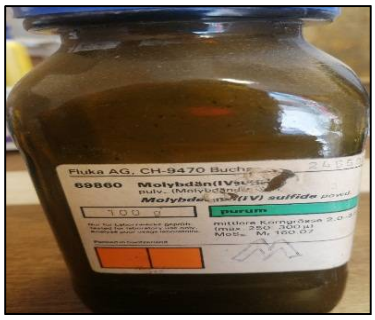
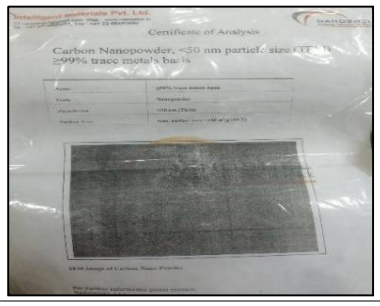
2.3 Preparation of Carbon Nanotube by Arc Discharge Method

The first step includes carbon nanotubes synthesized in the laboratory by arc discharge technique to obtain defect-free CNTs, which is considered the most popular method in this field Which had successfully produced in this study 98% pure carbon nanoparticles in the form of tubes at a range of (40 -70) nm to be added then to the mixture.

The apparatus used in the present study is locally produced and have dimensions with a length of 472mm and a diameter of 243mm. It has a chamber made of stainless steel. It has a design that manually facilitates the easy control of the gap distance between the two electrodes and is surrounded by a copper pipe coil with a length of 28 cm and a wall thickness of about 0.3 cm. By the high accuracy process of cutting and machining high purity graphite rods, the two graphite electrodes used in this study are made with a diameter and length of 85 mm and 8 mm, respectively, for the anode. And the length of 20 mm and diameter of 25mm for the cathode. The providing DC is supplied by power supply type Makita model 950 Arc. Figures 1-2 show the parts of the apparatus and the parts of the arc discharge system. Electrical discharge of the graphite electrodes in the plasma of an arc consumption during the burning in an inert gas atmosphere like nitrogen is the core of the method, which starts by placing the electrodes in the chamber with a sealed gate get evacuation by the rotary pump and set until a vacuum of −1000 mbar was reached. Then filled with nitrogen gas and reevaluated several times. Finally, N_2 (110 mbar) was added into the chamber to employ as a buffer. Due to these procedures, the chamber stabilized, and the arc discharge was created by modification of the anode manually.

The igniting of the arc started by setting the reference point across an approximately 0.3mm gap, turning on the power from the supply, and letting the two electrodes touch each other before reversing it to the previous reference point. The high accuracy manual controlling is necessary to compensate for the backlash of the lead screw when the anode is continuously consumed. By switching off the power supply, the arc is stopped. The soot deposition can be observed on the top surface of the cathode and the chamber floor was also filled. The synthesized carbon nanotube CNT has been done by arc discharge technique using homemade apparatus Figure 1 followed the procedure used by “Mohammed et al.” [14].

Table 1: List of the mixture ingredients

Materials title	photo	Particle size	source
Graphite powder		106 micron	Glentham Life Sciences/ United Kingdom
Copper powder		75 micron	oxford laboratory reagent /Indian company
molybdenum disulfide powder		75 micron	Fluka AG/ Switzerland Company
Phenolic resin type novalac		75 micron	Fluka AG/ Switzerland Company
carbon nanosphere powder		≤ 50 nm	nanoshel llc / Indian company

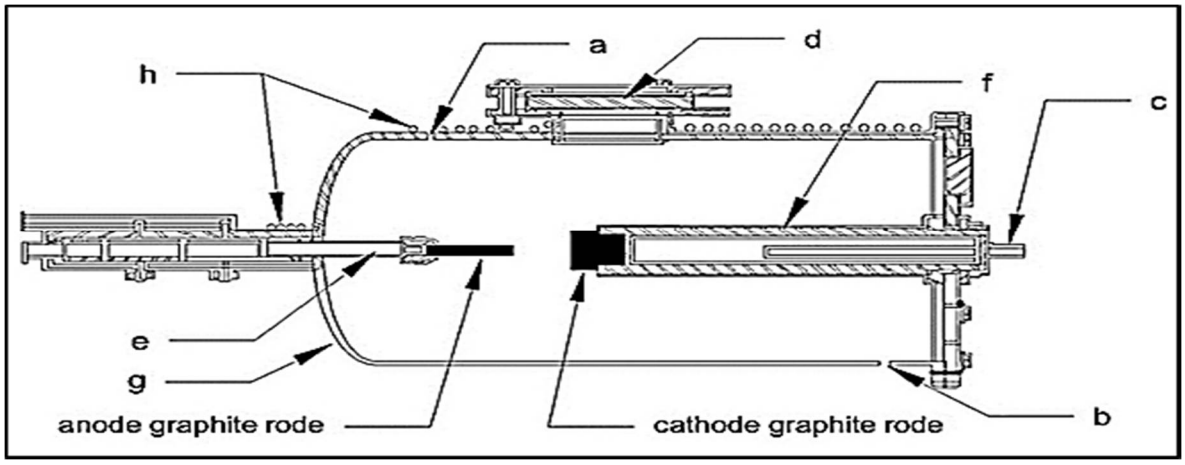


Figure 1: Graphical diagram for the arc discharge device: (a) the vacuum way out, (b) gas entry, (c) the inlet and outlet for cathode coolant water, (d) quartz sealed vision window, (e) pure copper shaft coated by nickel, (f) pure copper tube separated from the chamber, (g) chamber of stainless steel, (h) copper cooling water pipes

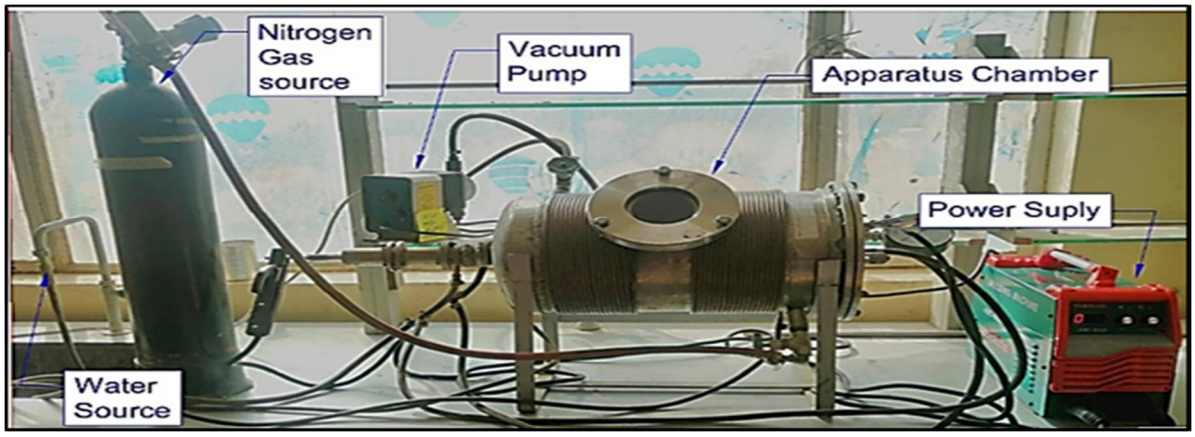


Figure 2: The system parts of the arc discharge method

2.4 Preparation of Composite Samples by Powder Metallurgy Method

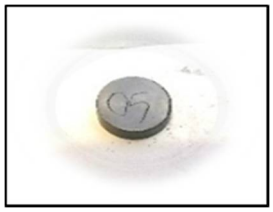
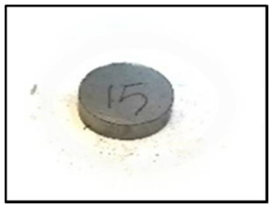
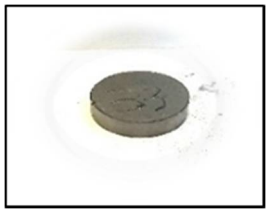
The main components of the composite samples that are usually used as carbon brushes in industry consisted of (59% wt. graphite + 30%wt copper) accordingly. In addition, the study suggested adding novolac, a form of the polymer obtained from mixing the phenols and formaldehyde work as the binder material. The study has also proposed adding MOS_2 as a lubricating factor to the mix of powders due to its good mechanical properties and well flame resistance, which are attributed to the highly aromatic structures and its layered structure and low coefficient of friction [15]. In the present study there were four composites have fabricated into G1, G2, G3, and G4, as shown in Table 2 below:

The first step in preparing composite samples was to remove the humidity from the graphite, which was accomplished by heating the graphite powder in an oven bench thermostatic dryer type (Laboao, China) for 120 minutes at 110□ C continuous stirring. Next, the dried graphite was ground and then sieved by an electrical shaking sieve machine to the grain size of 60 µm. After being ground by a ceramic mortar, the novolac resin was added to the mixture and carefully blended to ensure better homogeneity and good binding between the components. Next, MOS_2 powder with a particle size of 75 µm was added to the mixture and combined with the other components using a ceramic ball mill for 4 hours to eliminate the agglomeration and to ensure good homogenization of all materials within the mixture [14-16].

The first sample consisted of 59% wt. graphite + 30%wt copper + 10%wt novolak + 1%wt MOS_2. After carefully mixing, 1 g from the mixture was transferred to the steel mold shown in Figure.2 and subjected to a hydraulic press up to 2.5 Ton/cm^2. After removing the mold, the green samples were cured in an oven at 150□ C for 2 hours, then heat-treated in a muffle furnace up to 550□ C at a heating rate of 10□ C/min in an oxygen-free atmosphere. The furnace was left to cool overnight, and the sample was labeled G1. The sample was kept in a desiccator for further characterization tests. In the second sample G2, CNTs of various percentages i.e., 0.1, 0.2, 0.3, 0.4, and 0.5 wt. % was added to the powder mixture of G1, which took the code 00 to prevent the sample from mixing in the furnace vessel, and the other samples took their codes according to their additives percentage ie.01, 02, 03, 04, 05, respectively as marks on the upper surface of each sample. Next, sample G3 was prepared by adding CNs at different percentages, i.e., 0.1, 0.2, 0.3, 0.4, and 0.5 wt. % to the powder mixture of G1, and as well they took the codes sequence of 11, 12, 13, 14, and 15; whereas, in the G4 sample, both CNTs and CNs were mixed in equal amounts and took the code 33, and then each was added at different percentages, i.e., 0.1, 0.2, 0.3, 0.4, and 0.5 wt. % to the powder mixture of G1. From each powder mixture, i.e., G2, G3, and G4, 1 g was taken and poured into a steel mold (see Figure 3 a and b), pressed at

2.5 Ton/$Cm^{2,}$ and then heat-treated as was sample G1. After preparation, the samples were subjected to various tests to investigate nano additives' effect on the properties of normal commercial carbon brushes. Table 3 shows the list of devices utilized during the powder metallurgy procedure.

Table 2: The chemical composition of the composites

Composite Number	Composite Symbol	Composite Photo	Composite Composition
1	G1		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) Blank Sample
2	G2		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.5% C.N.T
3	G3		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.5% C.N.S
4	G4		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.3% C.N.T + 0.3% CNS

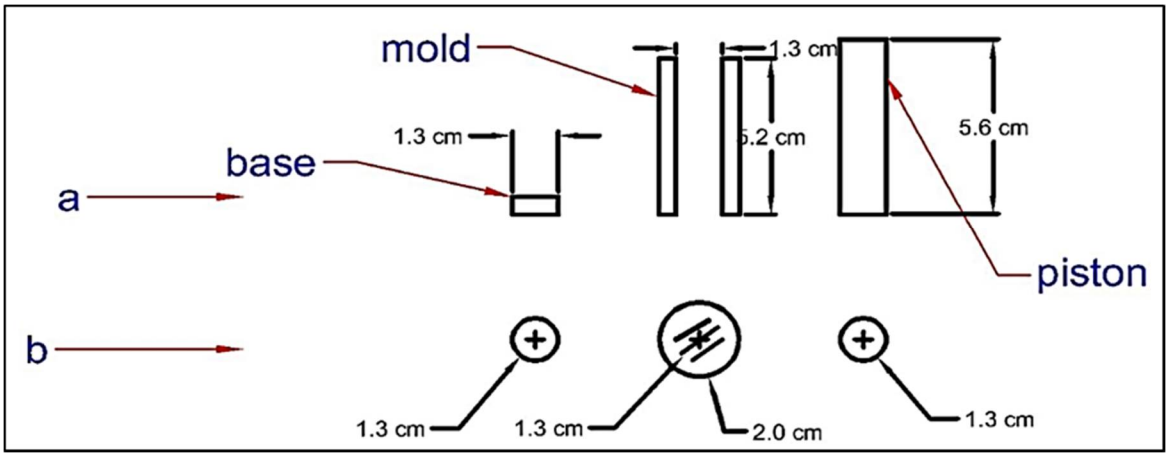


Figure 3: (a) Side view of the samples in the mold section, and (b) Front view of the samples in the mold section

Table 3: The devices that have been used in the powder metallurgy method

Device title	origin	photo	Purpose
shaking sieve	Retch German company		To get the wanted fine particle size
4 digits electronic sensitive scale	Adam Equipment, Inc./united states		To ensure precise amounts of elements in the mixture
Milling ball	capco company / U.K		Ensure better mixing for the powder contents
Metal mold	Local workshop produced		To form the shape of the wanted sample
Electrical Press	MEGA /Spain company		To apply a force works to stack the powder particles inside the mold
oven	Bench thermostatic drier/ china		to get dryness for the graphite and hardening for the samples after the mold pressing
High-temperature furnace	carbolite shefeld England company		To accomplish the sintering process

3. Results and Discussion

The morphology of the samples was analyzed by Scanning Electron Microscopy (SEM), and the tested samples were analyzed using an X-ray diffractometer (XRD). The SEM images of the carbon nanotubes prepared by the arc discharge method

are shown in Figure 1, where well-defined carbon nanotubes (CNTs) can be observed. After measuring several sizes of diameters, the average external diameters of the carbon nanotubes were 55 nm. The aspect ratio (the length to diameter ratio) was ~50. The diameter of the CNTs > 10 nm refers to the formation of the multiwall carbon nanotubes (MWCNTs).

The white pieces on the top of the tubes indicate the catalyst particle on which the CNTs were grown. The photo shows that the catalyst nanoparticles have detached and moved to the head of the growing nanotube, shown in Figure 4 "tip-growth"; in such a case, the carbon nanotube's diameter might depend mainly on the catalyst particle diameter. The results agree well with those "Purohit et al." [17].

We found that the production of CNTs depended on the gas pressure inside the chamber and the electric current applied to the system. According to our optimization of a 75-amp current at 260 bar, N_2 gas produced more CNTs deposits on the cathode of the arc chamber.

The SEM images of composite specimens revealed different structures due to the variation in their composition. For example, Figure5 represents the SEM of the G1 sample, which mostly consisted of graphite and copper.

CNTs are obvious in the SEM image of the G2 sample. The G3 sample presented in Figure 6 under SEM is clearly shown in Figure 7 CNSs can be easily identified in the SEM image and seem to be distributed homogeneously, as indicated by an arrow, with an average particle size of 38.08 nm. On the other hand, the SEM image of the G4 sample can be shown in Figure 8, accompanied by the CNTs and spread inhomogeneously. The structure shows a uniform distribution of nanosphere particles in composite This homogeneity increases the electrical conductivity and reduces the resistivity. And that has given a satisfy requirements for the produced brushes.

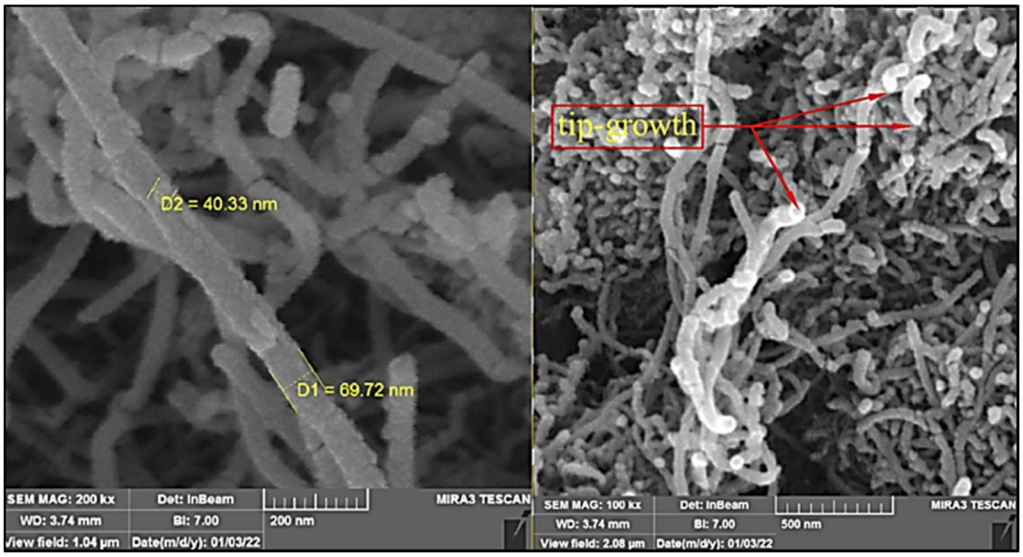


Figure 4: (98% Pure CNTs prepared by the arc discharge method

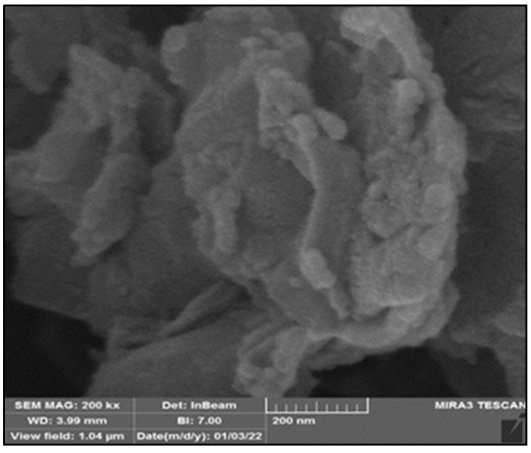


Figure 5: SEM image of the G1 sample

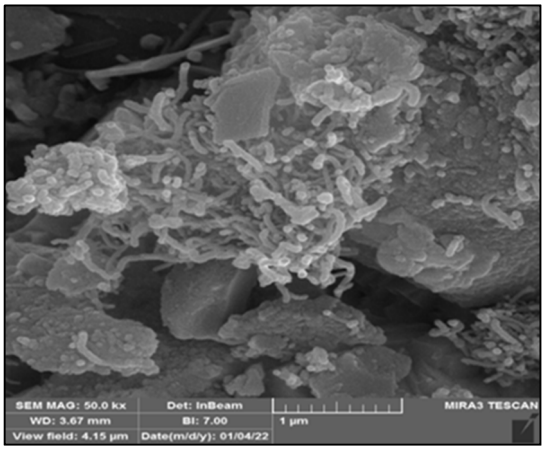


Figure 6: SEM image of the G2 sample containing CNTs

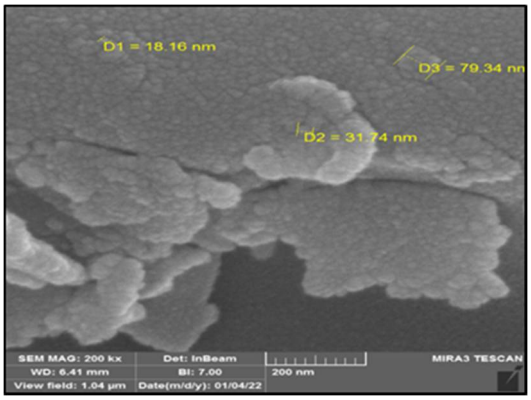


Figure 7: SEM image of the G3 sample

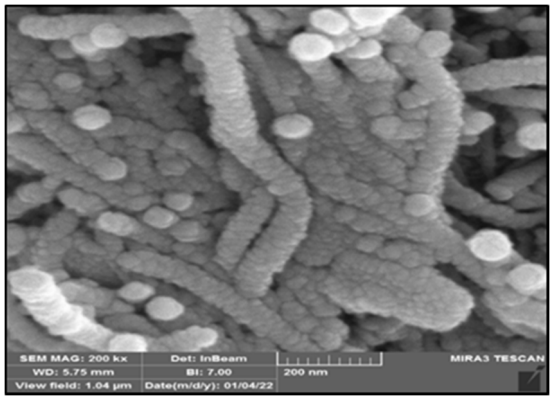


Figure 8: SEM image of the G4 sample

The crystalline structure of the XRD pattern is illustrated in Figure 9. It shows that the binder seems to be completely converted to carbon. The structure is homogeneously graphite, and the binder had decomposed into carbon or was partially graphitized within the structure. The graphite main peaks were located at 2theta = 26.530 for the (hkl) line (002), and Cu was obser The XRD result shown in Figure 10 also displays a peak for the line (004) at 2theta = 54.80, which may be attributed to the line (004) of the CN nanoparticles. The structure shown in the XRD shows sharp lines and may indicate a highly crystalline structure with little amorphous material. This will improve the conductivity performance of the composite produced within the scope of work. In this study, the glass apparatus used the mercury displacement method to measure the density. All of the 12 samples were immersed in mercury. With the pressed by the cover, some mercury was scattered out of the container, and its volume was equal to the volumes of the samples. ved at 2theta = 43.4 for the line (111); the CNT peaks usually overlapped the graphite peaks.

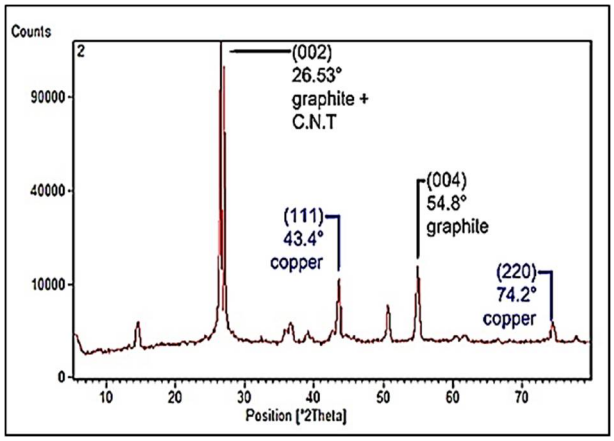


Figure 9: XRD pattern of G2 sample

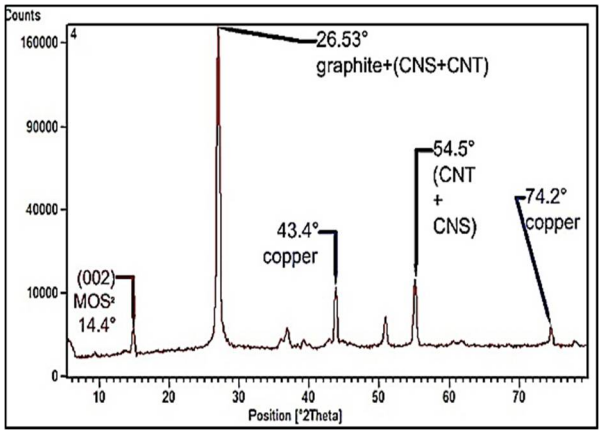


Figure 10: XRD pattern of G4 sample

Then the density was calculated by calculating the volume by the mercury mass and density. Finally, the mercury collection by a dish is weighed by an electronic balance with 4 digits. To reduce error, the study has taken the average of several measurements in each sample.

The laws that have been used in the mathematical formulations are:

$$V = \pi r 2 \quad (1)$$

The density P can be calculated from the following relationship

$$P = \frac{m}{v} \quad (2)$$

V: volume (m3),Π: constant ratio (3.14),R: sample radius (cm),H: sample high (cm), P: density (g/cm3),M: mass (g)

Eq. (1) is known as the volume Law for cylindrical shapes.

Eq. (2) is known as density Law.

Increasing the number of nanoparticles leads to a decrease in the sample density, as shown in Figures 11-12, which represent the densities of the samples as a function of the CNTs and CNSs percent, respectively. In both cases, the density decreased. This may be attributed to the nanomaterials' low weight and the sponge-like behavior of the nanoparticles within the composite structure.

Shore D Hardness is considered a standardized test that measures the depth of penetration for a specific indenter. It has a sharp indenter 30-degree angle and a rounded tip with a radius of 0.1 mm. it is convenient for thermoplastic materials [18]. The test method used in the measurement of hardness for the present study is Shore D scale which is used for hard materials and is measured based on ASTM D-2240 standard, and the devise type is Shore D durometer Th210 from TIME Group Inc Chinese company. Shore Hardness measures are usually dimensionless. It has a range between 0 and 100. The higher number represents the harder material.

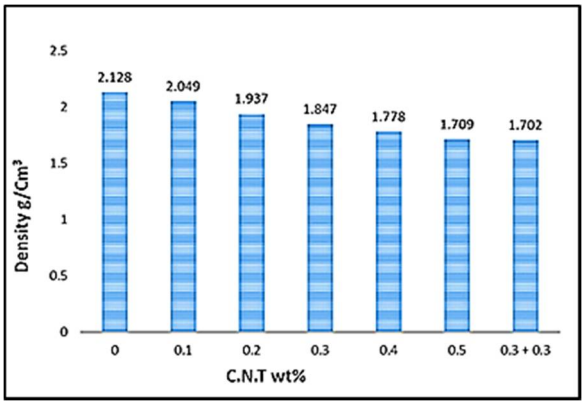


Figure 11: Density of the G2 sample as a function of the CNTs%

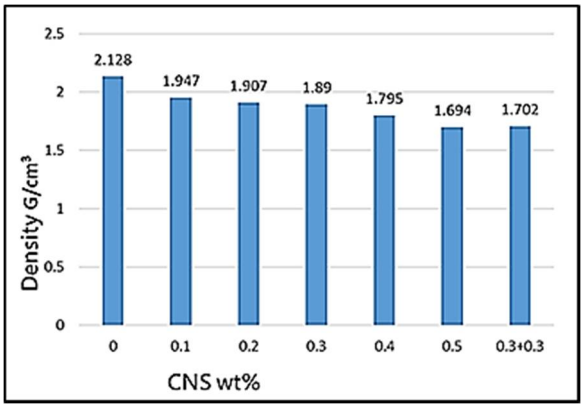


Figure 12: Density of the G3 sample as a function of the CNS%

The Shore D hardness test indicates the capability of the material to resist scratching and abrasion. Figures 13 and 14 show the effect of adding CNTs or CNs on the Shore D hardness. The hardness of the G1 sample without additives was 50. As the number of nano-additives increased, the hardness decreased stepwise until it reached 0.5%. After that, it dropped slightly above 0.5%, reaching 42.5 with a 0.5% carbon nanotube. It has a clear effect on the hardness that decreases due to the tendency of nanoparticles to partial agglomeration that makes pores between the composite ingredients, which is the most difficult issue facing any study dealing with nanoparticles where it requires using advanced techniques to have a perfect homogenization of components within the structure of the composite mixture.

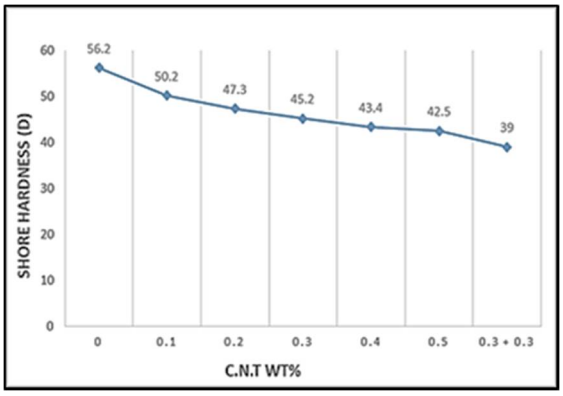


Figure 13: Effect of the addition of CNTs on the hardness of the G2 sample

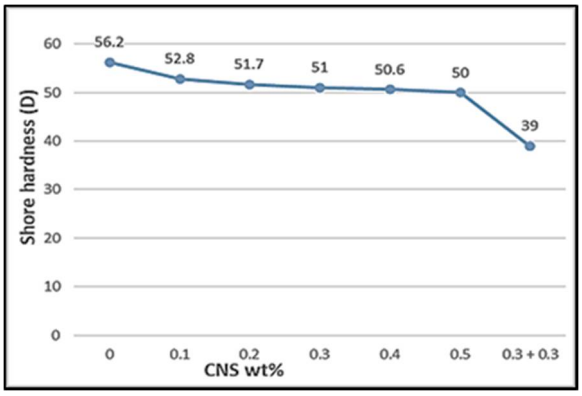


Figure 14: Effect of the addition of CNSs on the hardness of the G3 sample

Similar behavior was obtained with the addition of CNs. Accordingly, we recommend not increasing the nano-additive content above 0.5% because it may significantly affect other properties. The hardness values seem relatively stable between 0 and 5% nanomaterials. These values agree with the hardness of commercial products type - electro graphitic brush grade L, which has a hardness value of 35 [19].

If a probable different Voltage between the two electrodes is measured. And a stable current (I) that passed through a cylindrical sample was known. Then we can give the resistivity (ohm-cm) of the sample by:

$$\rho = \frac{V\,A}{I\,L} \tag{3}$$

$$\text{Or } \rho = \frac{R\,A}{I} \tag{4}$$

Where: ρ: resistivity; R: Resistance (ohm); A: Sample cross-sectional area (m2); L: Length of the sample (cm)

Eq. (3) and Eq. (4) are resistivity Laws. In the present study, the direct measurement of the resistivity was carried out using an odometer type (Pros kit® MT-12700) made in India. The resistivity values decreased gradually with an increase in the amounts of the carbon nano-additives, especially for the CNTs, which demonstrated better results than the CNSs, as shown in Figures15 and 16, respectively. Additionally, the resistivity values equal 0.32 Ωcm compared with a commercial grade of 1.3 Ωcm and contained no nano-additives. Therefore, a significant improvement in the resistivity value was obtained, indicating the intense effect of the nanoparticles on improving the properties of carbon brushes. In this case, the operational performance of the carbon brushes improved due to the reduction in the resistivity, which led to an increase in the electrical conductivity, as shown in Figures 17 and 18. Also, the current density while reducing the friction heating.

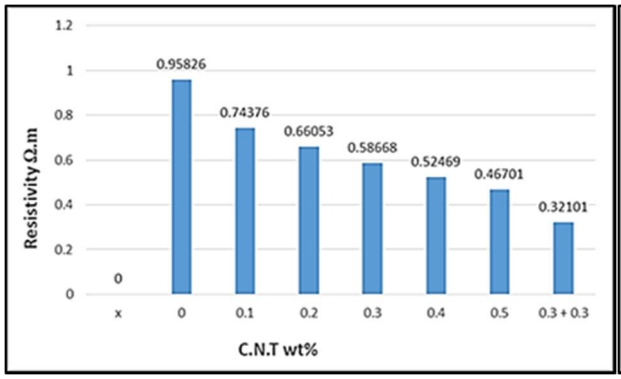


Figure 15: Resistivity of the sample G2 as a function of the CNT wt. % additive

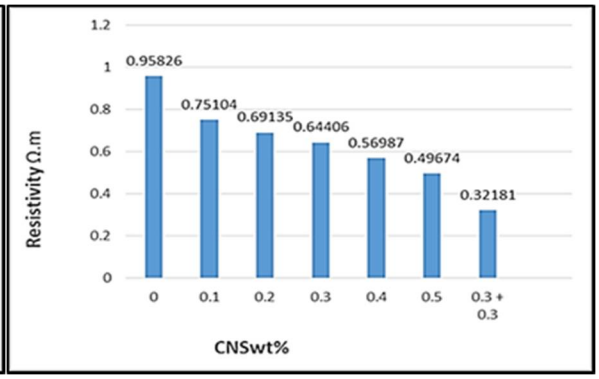


Figure 16: Resistivity of the sample G3 as a function of the CNS wt. % additive

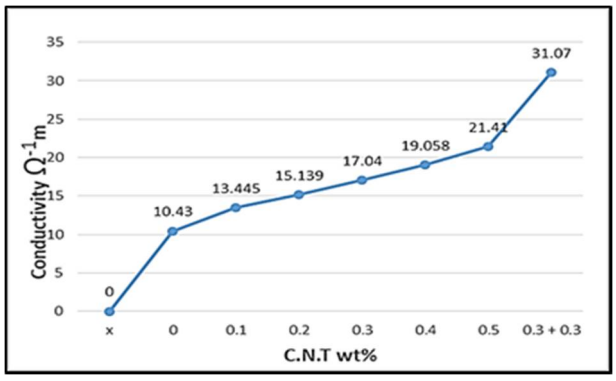


Figure 17: Conductivity of G2 composite as a function of CNT wt. % additive

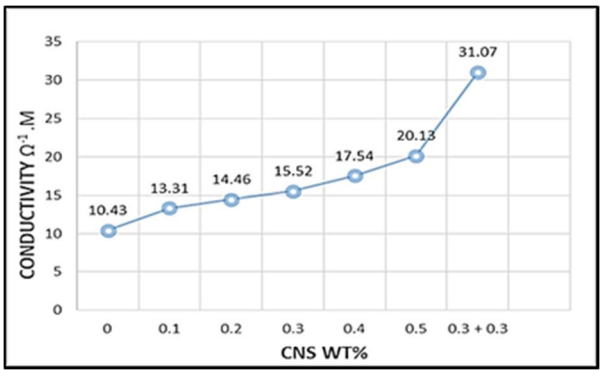


Figure 18: Conductivity of G3 composite as a function of CNS wt. % additive

The results of the wear tests are shown in Figures 19-20. We observed a small increase of 0.05 g/cm wear per 0.1% of nano-additives in the wear value as the nano-additives increased, which may be attributed to the tendency of nanoparticles toward partial agglomeration with each other or due to changes in the porosity that might result from resin decomposition and gas liberation. These can be eliminated or reduced to a minimum by the functionalization of the nanoparticles and by using an ultrasonic technique to create perfect homogenization of the components within the composite mixture or by using a hot pressing technique to prepare the samples. The results of all experimental work that investigated the mechanical and chemical tests has summarized in Table 4 below.

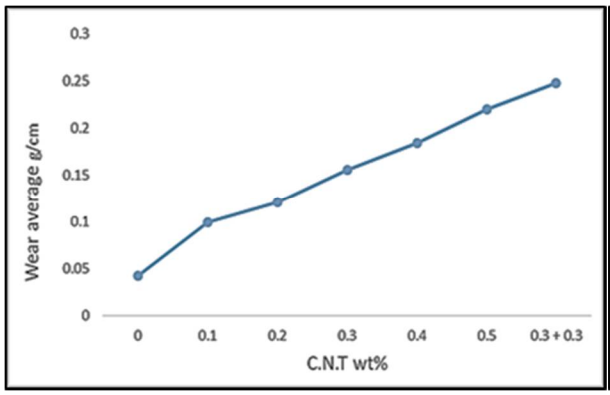


Figure 19: Average wear of the G2 sample as a function of the CNT wt. % additive

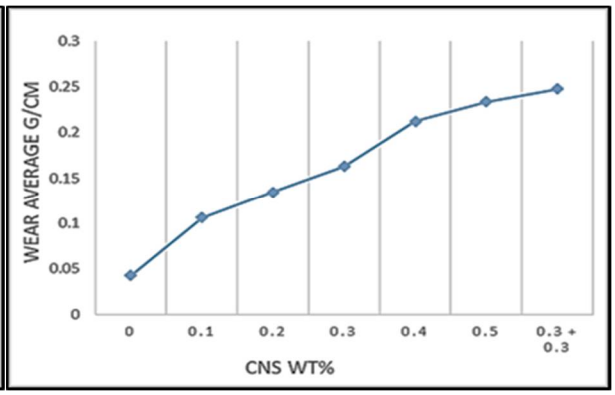


Figure 20: Average wear of the G3 sample as a function of the CNS wt. % additive

Table 4: List of the results of the test

S. .no	S. code	S.photo	S.composition	Density Gm./cm 3	Hardness Shore(D)	Resistivity Ω.m	Conductivity Ω-1.m	Wear Gm./cm
1	00		(59% graphite + 30% copper + 10% novolac + 1% MOS_2)	2.128	56.2	0.95826	10.43	0.04246
2	01		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.1% C.N.T	2.049	50.2	0.74376	13.445	0.09907
3	02		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.2% C.N.T	1.937	47.3	0.66053	15.139	0.12031
4	03		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.3% C.N.T	1.847	45.2	0.58668	17.040	0.15569
5	04		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.4% C.N.T	1.778	43.4	0.52469	19.058	0.18400
6	05		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.5% C.N.T	1.709	42.5	0.46701	21.41	0.21939
7	11		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.1% C.N.S	1.947	52.8	0.75104	13.31	0.10615
8	12		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.2% C.N.S	1.907	51.7	0.69135	14.46	0.13446

Table 4: Continued

9	13		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.3% C.N.S	1.890	51	0.64406	15.52	0.16315
10	14		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.4% C.N.S	1.795	50.6	0.56987	17.54	0.21231
11	15		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.5% C.N.S	1.694	50.0	0.49674	20.13	0.23354
12	33		(59% graphite + 30% copper + 10% novolac + 1% MOS_2) + 0.3% C.N.T + 0.3% C.N.S	1.702	39	0.32101	31.07	0.24769

4. Conclusions

From the present work, the following can be concluded:

1) The carbon nanotubes have been successfully prepared with a high yield at 75 amp current across the electrodes, a 5-min reaction time, and 260 MB nitrogen gas pressure.
2) The resistivity decreased as a function of the CNTs and CNs reaching a minimum value, i.e., 0.32 Ωcm. This improvement will enhance other properties, such as electrical and thermal conductivity while reducing surface contact and friction heat.
3) There was a slight increase in the wear of the nanoparticle samples. However, this result can be considered normal due to the high weight of 1 kg used during the wear test, more than the pressure of ordinary loading on carbon brushes during their work performance.
4) The sharp peaks observed in the XRD results indicate the highly crystalline structure of the prepared samples, which may indicate that the samples possess high conductivity due to their structure.
5) Properties are beneficial for use as a synthetic electrical carbon brush. Moreover, by adding carbon nanoparticles, its conductivity properties increased. On the other hand, its mechanical properties can be increased by eliminating or reducing the tendency of nanoparticles to partially agglomerate to a minimum value. This can be done by using the ultrasound technique to have a perfect homogenization of components within the structure of the composite mixture.
6) The study has revealed that when there is an increasing percentage of Nano-additive particles above 5 percent, there is an apparent effect on the value of the hardness. Therefore, the study recommends not to exceed this limit because this will affect the other properties, including the value of wear and density. According to the experiments, the combination of composite G4 had the best results in the mechanical and electrical properties.
7) The study has suggested that the Optimum combination that works under conditions of low current density, scratch, and abrasion is the combination of composite G4, which contains 59% wt. graphite + 30%wt copper + 10%wt novolak+1%wt MoS2 and additives of 0.3%wt Carbon nanotube (CNT) and 0.3%wt Carbon Nano sphere (CNS). That combination has greatly improved the resistivity value, indicating the intense effect of the nanoparticles on improving the properties of carbon brushes. In this condition, the working performance of the carbon brushes improved due to the reduction in resistivity, which increased the electrical conductivity and the current density while reducing friction heating. On the other hand, the hardness values seem stable in this percentage, which agrees well with the hardness of commercial products.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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