Effect of Mixing Methods and Black Conductive Fillers on Properties of Natural Rubber Composites

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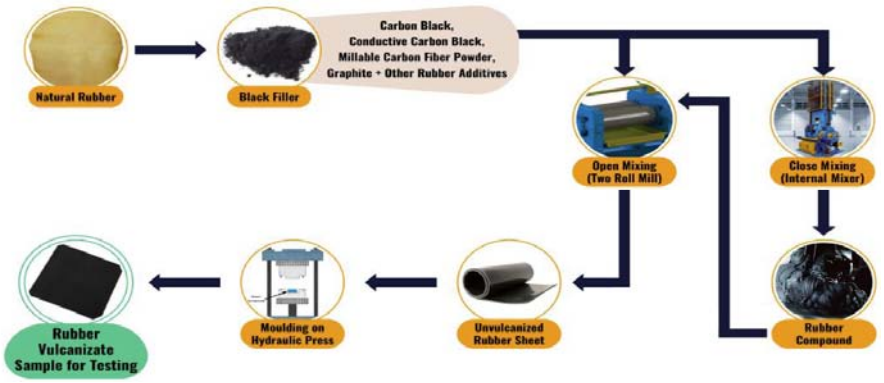
Abstract: Carbon black, graphite, carbon nanofibers, carbon nanotubes, and metal fillers increase composite conductivity in natural rubber, which is electrically insulating. Depending on dispersion, conductive filler lowers insulating material resistivity. These materials are frequently used for electromagnetic/radio frequency interference (EMI/RFI) shielding, conductive flexible seals gaskets, and conductive mats used to prevent electrostatic damage to electronic devices. These elastomers could be used to make flexible solar cells or mechanical-to-electricity devices. Temperature, mixing time, shear rate, and cross-linking during vulcanization affect rubber electrical conductivity of composite. To study shear rate effects, vulcanizate of Natural Rubber-based composites filled with carbon black, millable carbon fiber powder, and synthetic graphite powder was prepared by open mixing (two roll mill) and close mixing (internal mixer). We compared how shear rate affects cure, stress-strain, and volume resistivity of conductive filler-based Natural Rubber composites. Increment in clearance of two roll mill during addition of rubber additives along with rubber of reduced the shearing force resulted in less dispersive and distributive mixing and stagnant points due to band formation on roll surface compared to intermix where compound movement had no stagnation point and long wings pushed material axially and two nogs pushed material in other chamber. Compared to two roll mill samples, the compound reached every point of the mixing chamber for best homogeneity, reducing cure time and improving stress-strain and volume resistivity.

Keywords: Mixing, conductive fillers, natural rubber composites, cure characteristic, stress-strain properties, volume resistivity.

1. INTRODUCTION

The advancement of technology across multiple industries, along with the rapid expansion of electrical and electronic applications, has led to a progressive increase in the need for electrically conductive higher molecular weight polymer, typically functions as an insulator. The electrical resistivity of rubber matrices typically ranges about 10^{15} ohms. Electrical conductivity can be conferred to rubber materials by integrating conductive fillers such as carbon blacks, carbon fibers, conductive metal particles, graphene, or



Schematic Presentation of Natural Rubber Composites based on black Conductive Fillers

polymeric materials, whose potential uses are continually expanding. Rubber, a category of high conducting polymers like polyaniline (as detailed in Table **2**) into commercial rubber products through various methods, including solution mixing, latex incorporation, dry blending, or melt processing are utilized to prepare conductive rubber composites [1, 2].

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Table 1: Classification of Conductive Polymeric Composites (CPC) Materials According to their Resistivity Value and Applications [3]

Resistivity (Ω.cm)	Polymer Composite	Application
10^{14} -10^{12}	Insulating	Insulator
10^{10} -10^{6}	Electrostatic Dissipative	Antistatic Material: Fuel Tanks, Mining Pipes, Antistatic storage containers, Electrostatic paintable compound, electronic connectors, microscopic housing material etc.
10^{4}-10	Conductive	Sensors and EMI shielding: self-regulated heating elements, strain sensing materials, electronic noise device, over current protector, organic liquid sensing device etc.
10^{-2} -10^{-4}	Highly Conductive	Conductors: Metal replacement, conducting adhesive and coating, bipolar plates, resistors, thermoelectric materials, busbars, etc.

Conductive Rubber Composites (CRC) are extensively utilized for various applications, including electrostatic charge dissipation, touch control switches, pressure-sensitive sensors, and conductive parts within diverse devices for electricity and electronics [3-6] as shown by the values for resistivity in Table **1**.

The natural rubber has limited properties. To increase the value of natural rubber modification is needed. One of the fillers is carbon black. Carbon black is the most prevalent conducting component utilized in rubber matrices. It offers both excellent conductivity and effective strengthening to the rubber matrix by increasing tear resistance, abrasion resistance, and high breaking stress [7-10].

The abundance of active sites on the surface of carbon black (CB) renders it compatible with various rubber types, promoting strong interactions with both elastomeric and non-polar rubbers, including Natural Rubber (NR) and Styrene Butadiene Rubber (SBR) [11], without requiring surface modifications. Conversely, silica is employed as a reinforcing filler for both standard and specialty rubbers to manufacture non-black products. For numerous applications, high conductivity is the primary requirement, whereas the mechanical quantities of the system may be a minor concern [12-15].

The basic rubber of Conductive Rubber Composite (CPC) typically consists of compounds like silicone, fluoro silicone, or EPDM (ethylene propylene diene

Table 2: Conductive Fillers Their Merits and Demerits [3-6]

Fillers	Merits	Demerits
Carbon Black	Having Smaller Aggregates, higher structure, less volatile, relatively cheaper	Higher percolation threshold (requires higher filler loading), at high loading particles tend to slough
Carbon Fiber	Higher Strength and modulus, low linear coefficient of thermal expansion, lighter than steel	Bundling and debonding effects, poor dispersion and distribution
Carbon Nanofibers	Improved electrical conductivity at relatively low level of loading (Low percolation threshold)	Dispersion and distribution difficulties, agglomerates, higher cost compared to conventional filler
Carbon Nanotubes	Low percolation threshold, unlike other fillers improved mechanical properties of composites	Dispersion and distribution difficulties, agglomerates, quite expensive
Graphite	Light weight alternative to metal, CNT and CNF, relatively cost effective	Poor filler matrix adhesion
Graphene	Excellent electrical properties	Very Expensive
Metallic Fillers	Least electrically resistance materials, ideal choice as a conducting filler	Processing at higher filler loading is challenging due to their high density and poor dispersion, formation of nonconductive oxide layers that reduces conductivity
Conjugated Polymers (Polyaniline)	Excellent electrical properties, good environmental stability and economic importance	Inherently insoluble, infusible and difficult to process due to their strong intermolecular interaction, their use as conductive filler is till under development stage

monomer). The selection of a particular rubber is contingent upon its distinctive features, which are dictated by the desired environment and application. The primary goal of the presented experimental work is to evaluate the replacement of specialty elastomers with natural rubber in order to achieve the required electrical conductivity through the inclusion of conventional conductive additives such as carbon black, vulcanXC 72R, milled carbon fiber powder, and graphite without necessitating any surface modification of fillers like carbon nanotubes, graphene, reduced graphene oxide, carbon nanofibers etc. This methodology aims to produce cost-effective products, such as conductive seals and gaskets, while maintaining mechanical properties through a batch mixing process. Batch mixing is conducted using both a rill mill and an internal mixer. The impact of mixing methods on the characteristics of conductive natural rubber composites is examined and compared.

2. MATERIALS AND METHODS

2.1. Material

Natural Rubber (RSS-1X) was procured from Raman Enterprise, Gujarat, and utilized as received. Commercial synthetic grade graphite with an average particle size of less than 20 µm was procured from Otto Chemie Pvt. Ltd, Maharashtra. Milled carbon fiber powder (density 1.65-1.75 g/cm³, electrical resistivity 1.5 x 10^{-3} Ω/cm, average particle size 500 microns, draw ratio 1.50:1) was sourced from Poojan Fibers, Gujarat, India. Additional components such as activators zinc oxide and stearic acid, processing aid aromatic oil, the antioxidant 6PPD N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine, vulcanizing agent Sulphur, and accelerators including Cyclohexyl Benthiazyl Sulfenamide (CBS) and Tetramethyl Thiuram Disulphide (TMTD) were used as received without further purification for compounding.

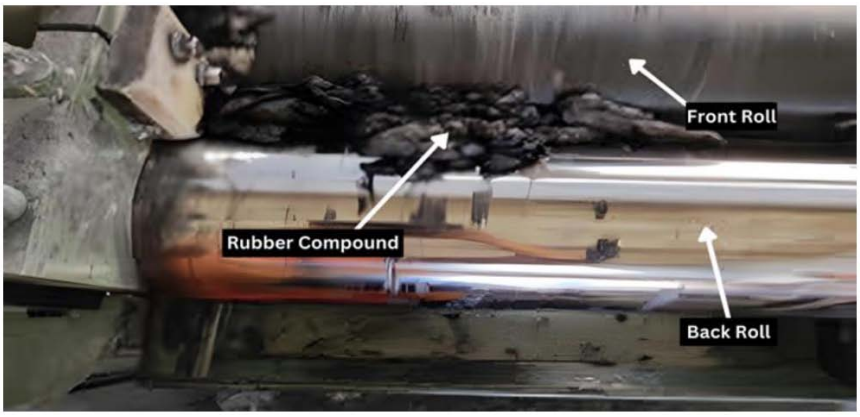
2.2. Compounding and Mixing

The compounding of natural rubber, expressed in parts per hundred rubber(phr), together in order with various black fillers and rubber additives, is presented in the table below. The total filler dosage was maintained at 50phr, while the other chemicals remained consistent across all four formulations. The incorporation of carbon fiber enhances the mechanical properties of the composite; nevertheless, a large amount of carbon fiber elevates its permeability. Likewise, graphite functions as a solid lubricant, and its increased dosage leads to enhanced tack and diminished mechanical characteristics. To circumvent the constraints of these fillers, carbon black (20phr) was utilized as a secondary filler with milled carbon fiber powder and synthetic graphite powder as primary fillers.

The method for the preparation of rubber composites is essentially contingent upon the type of rubber, its initial state, and the characteristics of the

Table 3: Formulation and Additives used for Open Mixing and Close Mixing in Preparation of Natural Rubber Composites (NRC)

Ingradients	Parts per Hundered Rubber			
	Sample-A	Sample-B	Sample-C	Sample-D
RSS-1X(NR)	100	100	100	100
Zinc Oxide(ZnO)	5	5	5	5
Stearic Acid(SA)	2	2	2	2
Styrenated Phenol	1	1	1	1
Carbon Black(N-330)	50	-	30	30
Vulcan XC 72R	-	50	-	-
Millable Carbon Fiber	-	-	20	-
Synthetic Graphite Powder	-	-	-	20
Aromatic Oil(710)	15	15	15	15
TMT	0.5	0.5	0.5	0.5
CBS	1.5	1.5	1.5	1.5
Sulphur	2.5	2.5	2.5	2.5



(**a**)

(**b**)

(**c**)

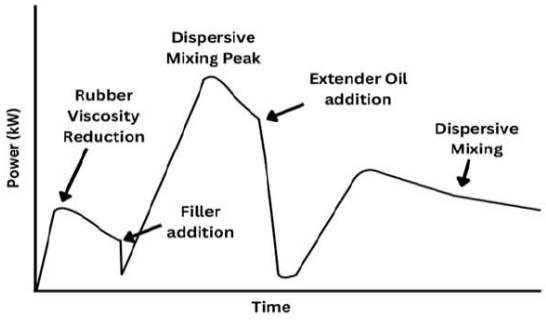
(**d**)

(**e**)

Figure 1: (**a**) NR/Conductive filler mixing on two roll mill (**b**) Sample-A NR/N-330 Composite (**c**) Sample-B NR/ VULCANXC72R (N-770) Composite (**d**) Sample-C NR/CCF Composite (**e**) Sample-D NR/CGP Composite.

selected fillers. Dry mixing is a process utilized for the preparation of NR composites. This study involved dry mixing followed by two mixing methods: open mixing using a two-roll mill and closed mixing using an internal mixer to produce conductive natural rubber composites. Open mixing was conducted using a two-roll mill (10" x 24", Indian Expeller, Gujarat, India). Natural rubber was masticated in a mill with a friction ratio of 1:1.15 until band formation occurred on the front roll. Sequential addition of zinc oxide, stearic acid, various black conductive fillers, aromatic oil, and curatives like CBS, TMTD, and sulphur were carried out for all four compositions (Table **2**). Mixing (Figure **1a**) occurred for 15 minutes at a temperature kept below 60°C to 70°C, leading to an evenly distributed mixture that was eventually sheeted through a 2mm nip adjustment, as depicted in Figure **1b**, **1c**, **1d**, and **1e**.

Close mixing was conducted in a Poly Lab Rheomix 0S (Thermo Electron, Germany) internal mixer (intermeshing rotor geometry) for all four compositions as given in Table **3**, applying the following parameters: temperature of 60°C, rotor speed of 40 rpm, and a total mixing duration of 5 minutes. Raw natural rubber was masticated for one minute in an internal mixer. For the final four minutes, mixing was conducted by shearing rubber and other ingredients between the rotors. Shearing enabled the breakdown of rubber, known to



(**a**)

(**b**)

Figure 2: (**a**) Power/Time Curve (Mixing Cure observed in intermix), (**b**) NR/Conductive filler mixing in intermix. Sample- A, Sample-B, Sample-C, Sample-D.

as viscosity reduction, along with the incorporation, dispersion, and distribution of fillers and other ingredients (Figure **2a**), following to extensive mixing. The produced compound (Figure **2b**) was kept at room temperature for 24 hours for maturation.

2.3. Rheumatic Measurement and Vulcanization Process

5 x 5 cm Natural rubber composite samples, around five g, were made for both closed and open mixing batches (Figures **1b**, **c**, **d**, **e** and **2b**), and afterwards placed between two PET (Mylar) films for the evaluation of rheological properties. The vulcanization parameters were determined based on the rheometric curves obtained from measurements taken with an Oscillating Disk Rheometer (ODR 2000, Alpha Technologies, USA) in accordance with ASTM D2084 [16]. The curing isotherms and cross-linking kinetics were measured at 150°C. The increase in torque was calculated from the curing curves as follows:

$\Delta M = M_{max} - M_{min}$

M_{max}- maximum of torque moment [dNm]

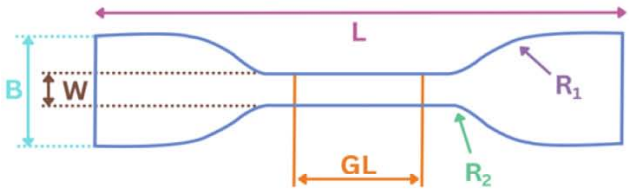
M_{min}- minimum of torque moment [dNm]

Total eight samples, prepared via close mixing and open mixing, were vulcanized at 150°C using an electrically heated hydraulic press (Mon Tech, Germany, ASTM D3182 [17]), in accordance to the optimum cure time (t_{c90}) calculated from rheometric data. The vulcanizates (square slab) generated through this method have an average thickness of 2.5 mm.

3. TESTING AND CHARACTERIZATION

3.1. Hardness Measurement

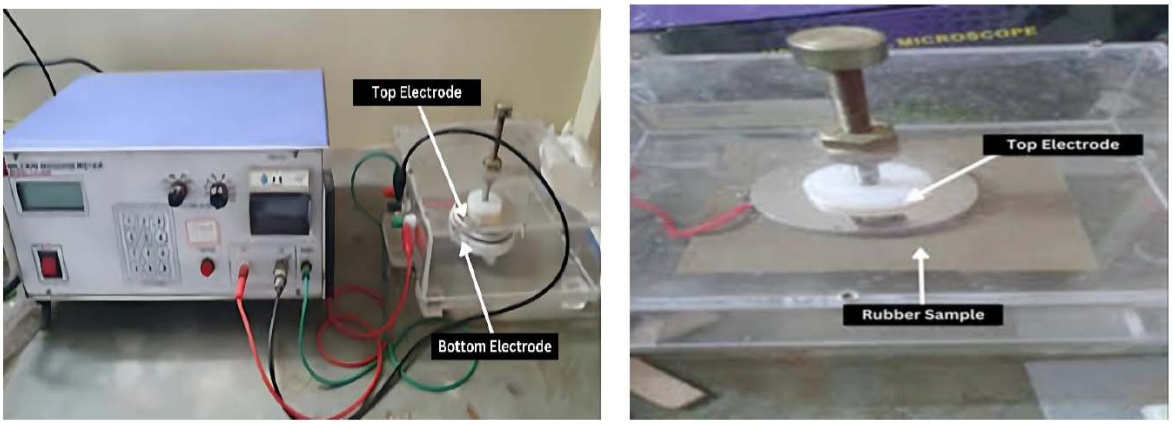
The apparent hardness of each composite sample was measured using a Shore-A Durometer according to ASTM D-2240 [18].Three button die specimens of each compound were made through molding, and data



(**a**)

(**b**)

Figure 3: (**a**) ASTM Die-A used to prepare test specimen (**b**) Test Specimen prepared to check stress-strain properties [20]



(**a**) (**b**)

Figure 4: Experimental setups for volume resistivity measurement (**a**) without sample (**b**) with sample.

were obtained at three different places on each sample, having the average value reported as the hardness measurements.

3.2. Stress-Strain Measurement

Tensile testing was carried out using a Universal Tensile Testing Machine according with ASTM D 412 [19].

Three dumbbell-shaped test specimens from each compound were made using a dumbbell die cutter. The dumbbells, shown in Figure **3a**, were taken from each NR composite sheet sized 150 mm x 150 mm x 2 mm. The specimens were elongated at the ambient temperature (25 ± 2°C) at a crosshead speed of 500 mm/min. The mean tensile characteristics for each composite was determined from three specimens.

3.3. Volume Resistivity Measurement

The volume resistivity test for each sample was carried out on the electrode assembly, as depicted in Figure **4a** and **4b**, according to ASTM D-257 [21], utilizing a vulcanized rubber sheet (150 mm x 150 mm x 2 mm) at the ambient temperature (25 ± 2 °C).

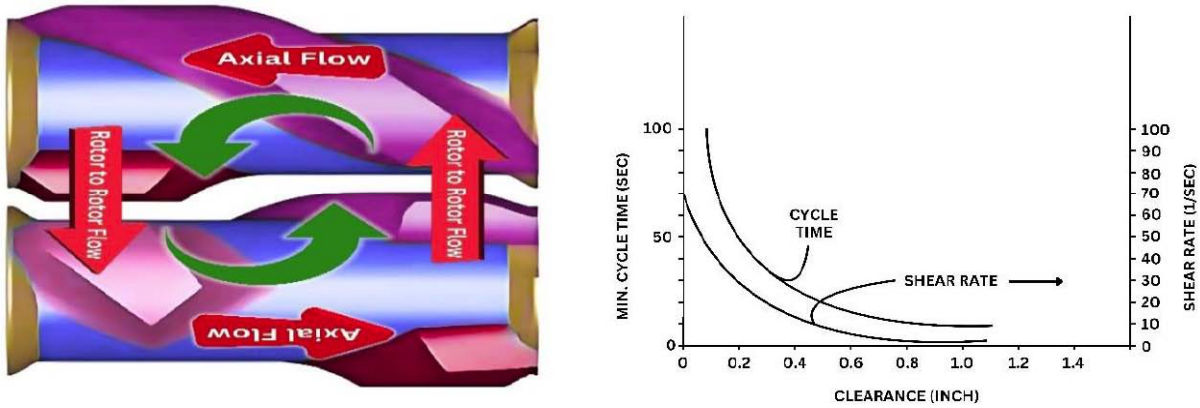
4. RESULT AND DISCUSSION

4.1. Mixing Behaviour

The rubber mixing operation is a composite operation that involves multiple steps and stages, involving viscosity reduction, incorporation, dispersion, and distribution. When a charge of extremely elastic rubber is introduced into a mixer, it must be swiftly transformed into a condition that allows for the incorporation of particle additives. This phase is referred to as viscosity decrease. As the viscosity and flexibility of rubber the material may promote the flow of additives, hence integrating and enclosing them inside a rubber matrix. Incorporation and distributive mixing normally take place simultaneously, with the latter commencing as soon as the incorporated additives are ready for distribution. The two mixing types involve subdivision, in which the additive volumes are progressively reduced due to the exponential mixing mechanism shown in Figure **5a** (rotor-to-rotor flow). Folding flows (material exchange) also facilitate exponential mixing, as do the separation and recombination of flow streams in various patterns. Conversely, the laminar flow observed in a two-roll mill is highly inefficient for achieving an acceptable uniform distribution of additives throughout a rubber mix, leading to suboptimal properties of the rubber mix. In this study, although the mixing caused by asymmetric milling (following the friction ratio), the mixing efficiency remains considerably insufficient due to the presence of closed streamlines and a lack of material exchange across the nip length, accompanied by a reduction in shearing force with increment mill clearance Figure **5b** resulted all samples of inferior in properties than samples prepared through intermix.

4.2. Cure Characteristics

The crosslinking of rubber is an essential step to attain the three-dimensional structure and optimum characteristics of the vulcanizate; thus, the effect of mixing methods and different conductive fillers on the curing behaviour is investigated. Tables **4** and **5** present the curing characteristics of the NR-based conductive composites. The scorch time (ts_2), induction time (ts_5), cure time (tc_{90}), and torque values (M_L and M_H) are given in the table below.



(**a**) (**b**)

Figure 5: (**a**) Exponential Mixing observed in Internal Mixer, (**b**) Relationship between Mill Clearance and Shear Rate.

Table 4: Rheometric Measurement of Samples Prepared through Open Mixing

Type of Filler	$ts_{2\,(min)}$	$tc_{10\,(min)}$	$tc_{50(min)}$	$tc_{90(min)}$	M_L	M_H	ΔM
N-330	2.08	2.01	2.28	2.5	6.2	19	13.4
Vulcan XC 72 R	2.63	2.56	2.92	3.28	6.5	20	13.5
Milled Carbon Fiber	3.28	3.3	3.65	3.9	4.9	18.7	11.8
Synthetic Graphite Powder	2.98	2.95	3.26	3.48	5.7	17.2	10.5

Table 5: Rheometric Measurement of Samples Prepared through Close Mixing

Type of Filler	$ts_{2\,(min)}$	$tc_{10\,(min)}$	$tc_{50(min)}$	$tc_{90(min)}$	M_L	M_H	ΔM
N-330	0.79	0.77	1.05	1.76	2.21	17.96	15.75
Vulcan XC 72 R	1.57	1.56	1.93	2.09	3.43	22.7	19.27
Milled Carbon Fiber	0.89	0.85	1.19	2.55	1.29	14.16	12.87
Synthetic Graphite Powder	1.24	1.18	1.5	2.37	1.38	13.5	12.12

As expected, the minimum torque (M_l) of carbon black as primary filler compounds (sample A and Sample B) prepared by both mixing methods increases constantly in by virtue of the hydrodynamic effect and filler-filler and filler-polymer/rubber interactions and making the compound viscous. Torque difference (ΔM) is indirectly related to crosslink density, which is higher in case of vulcanXC 72 R indicates restriction of the rubber molecules from the occlusion of the rubber into the carbon black aggregates. The compound exhibiting high amount of occulated rubber is characterized by low mobility and thus high viscosity. It can be assumed that the sulphur crosslinking system was partially absorbed onto the outer surface of the milled carbon fiber powder, which resulted in a slower curing process. In case of graphite powder slight fall in torque compared to carbon value is due to plasticizing effect of graphite structure [22].

4.2. Hardness

The effect of different conducive fillers and their dosages on the hardness of NR composite is shown in Figure **6**. In comparison with NR/Carbon Graphite composites, NR/vulcanXC 72R composites have a higher hardness, suggesting that the carbon black is strongly organized. Graphite is defined by its high aspect ratio and several flat layers of hexagons. Just 2% of the total energy exists within these flat layers, which is barely enough to form a bond. Thus, the graphite's softness, slickness, and superb lubricating properties are all the result of these layers' ability to slide over one another [20].

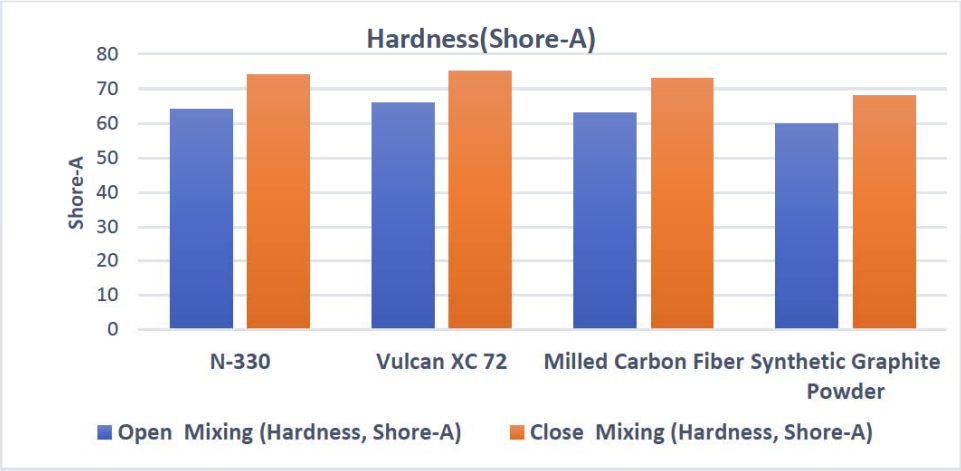


Figure 6: Effect of mixing method and conductive fillers on Hardness of Natural Rubber Composites.

Given this, it's not surprising that vulcanXC 72R is harder than NR/carbon graphite composite. Composites' toughness is enhanced by carbon fibers shaped like ribbons or with glassy carbon structures. Milled carbon fiber may have a little lower hardness than carbon black, which could be because of agglomeration. However, the high rate of shear observed during close mixing has enhanced filler dispersion, leading to samples with greater hardness compared to open mixing.

4.3. Tensile Stress-Strain Properties

Figure **7** shows the impact of mixing methods and various conductive additives on the tensile strength of natural rubber composites. Typically, all degrees of carbon black enhance rubber properties, resulting in increased tensile strength, rip strength, and abrasion resistance. Carbon black particles coalesce during formation to form carbon black aggregates, which are the true primary unit of carbon black. The quantity of primary particles and the extent of branching in the carbon black aggregate dictate its structural level, which directly influences many critical in-rubber properties. In this case, expanding the structure of carbon black improves modulus, hardness, electrical conductivity, and dispersibility, but simultaneously elevating compound viscosity. Carbon Black N330, an outstanding Abrasion Furnace (HAF) grade, possesses a medium structure and surface area, giving great durability, ease of processing, and remarkable tensile strength capabilities. The improved dispersibility of the NR/N-330 composite brings about superior stress-strain (elongation at break) qualities. Conversely, vulcanXC 72R has smaller particle sizes than N-330, that results in difficulties in dispersion and a tendency of particles to slough at higher loadings. Material hardens, leading to reduced flexibility of chains. A decline in stress-strain value is noticed. Tensile strength is influenced by factors like inhomogeneity, the physical structure of the polymer, and its molecular orientation. The incorporation of filler material into the polymer matrix adversely affects these variables, resulting in a reduction in tensile strength, as demonstrated in the case of NR/Millable. Carbon Fiber powder composites exhibit non-uniform dispersion of carbon fiber powder due to the significant entanglements of their elongated tubular and fibrous structures; in contrast to carbon black, fibers also enhance the reinforcing of rubber [23], [24]. The NR/graphite composite has the lowest stress-strain characteristics due to inadequate adherence of graphite particles to the rubber matrix. The spherical morphology of carbon black enhances its stress-strain capabilities relative to other fillers. Distributive mixing occurred simultaneously with dispersive mixing in the internal mixer, which has facilitated the separation of agglomerate fragments post-fracture, resulting in superior reinforcing and enhanced stress-strain properties compared to close mixing.

4.4. Volume Resistivity

The majority of elastomers are dielectrics, having low conductivity (less than 10−11 S/m, which corresponds to resistivity between $10^{\wedge 12}$ Ω.cm and $10^{\wedge 14}$ Ω.cm). The use of diverse conductive fillers may significantly enhance their conductivity through the formation of percolation routes inside the elastomer matrix created by the conductive filler. The variation in conductivity with a progressive increase in conductive filler indicates a very narrow loading range, wherein a minor increase in filler results in a significant rise in conductivity or a reduction in resistance. At this

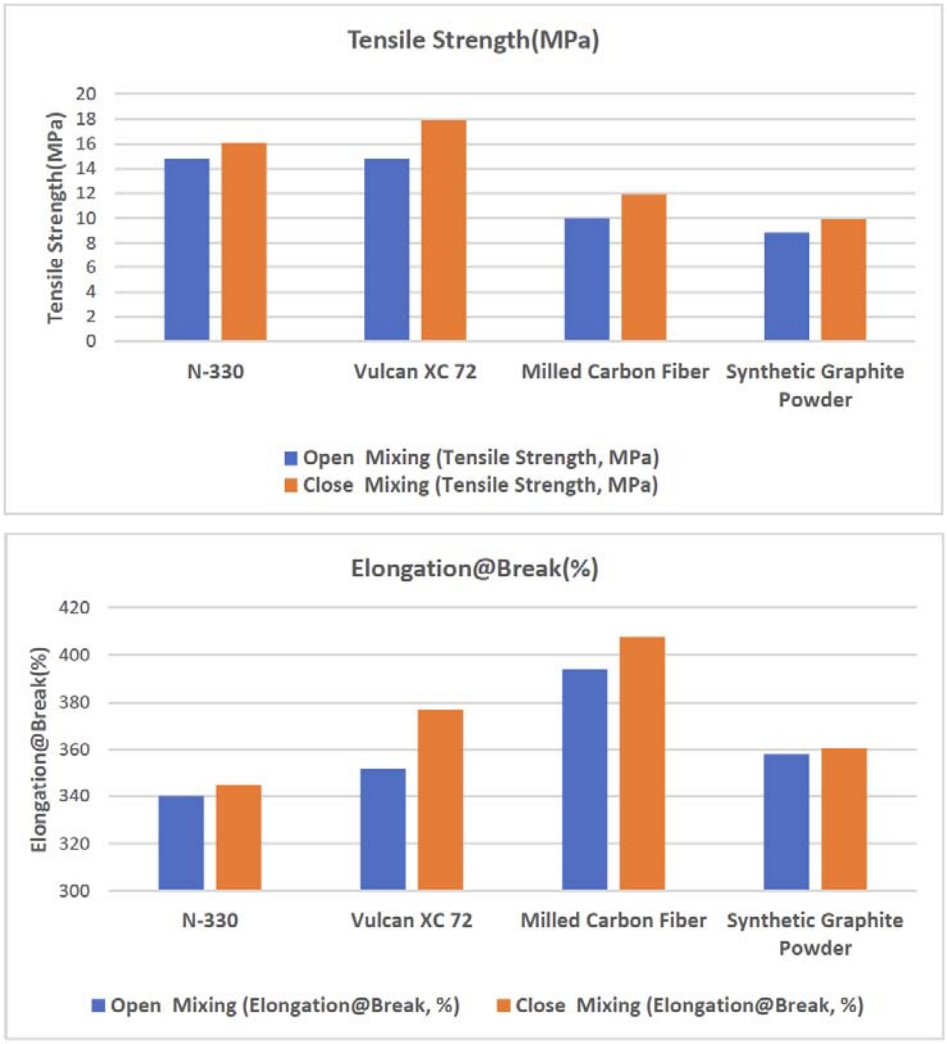


Figure 7: Effect mixing method and conductive fillers on stress-strain properties of NR Composites.

concentration, the insulating rubber matrix transforms into a conducting one, and this crucial quantity of filler required to create a conductive composite is termed the percolation threshold [24], [25]. During this crucial phase, electrons are efficiently moved through the polymer via hopping or quantum tunnelling, resulting in a significant improvement in electrical conductivity by several orders of magnitude. This significantly expands the application domains of elastomer composites. Figure **8** shows the volume resistivity values of various NR/filler composites.

The observed variations in volume resistivity among the composites (Sample-A and Sample-B, correlating to each mixing process) is due to the difference in the size of carbon black particles and their specific surface area. The specific surface area (BET) of furnace carbon black N 330 is 75 m²/g, while that of vulcanXC 72R is 250 m²/g. The diminutive particles of vulcanXC 72R, with their elevated specific surface area, facilitate the establishment of conductive channels, even at reduced filler concentrations, which is essential for enhanced conductivity. Furthermore, the abundance of active sites on the surface of carbon black renders it compatible with various rubber types, facilitating strong interactions with both elastomeric and non-polar rubbers, such as natural rubber (NR) and styrene-butadiene rubber (SBR), without requiring surface modifiers. The incorporation of 30 phr of carbon fiber powder does not result in a notable alteration in conductivity values. This may be attributed to bundling and debonding phenomena, as well as the agglomeration of carbon fiber powder. The dosage of milled carbon fiber is determined to be below the percolation threshold. Furthermore, it can be inferred that the orientation of the carbon fiber within the composite is perpendicular to the current flow, resulting in poor conductivity; however, close mixing enhances conductivity ($4.91 \times 10^{\wedge s}$ Ω.cm), transforming the insulating rubber matrix into an electrostatic and

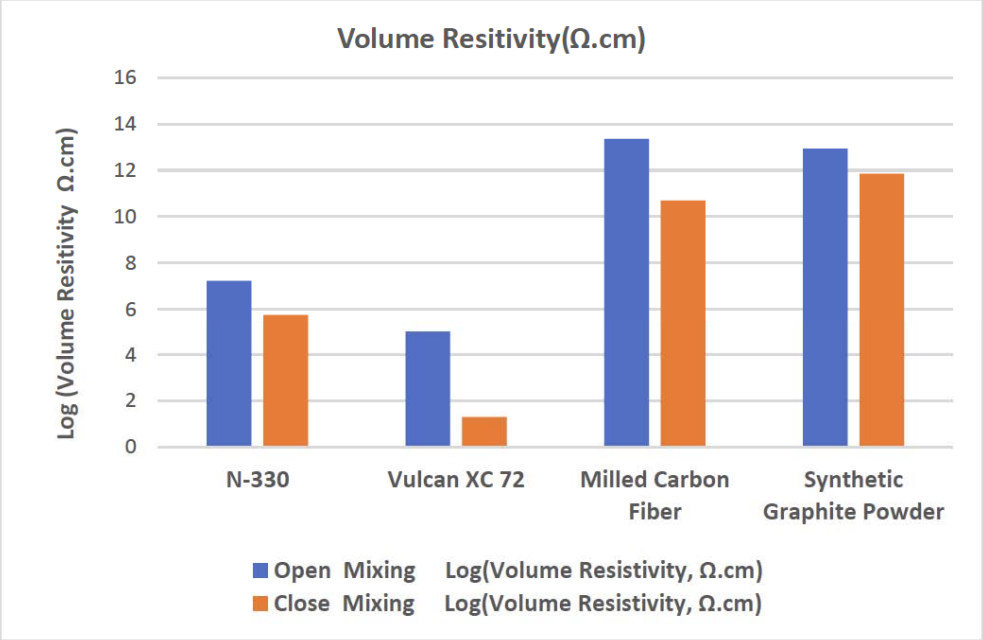


Figure 8: Effect of mixing method and conductive fillers on Volume Resistivity of NR Composites.

dissipative material. Graphite manifests as a stratified substance in its bulk form. The elevated surface energy of graphite particles facilitates their aggregation into clusters. To utilize graphite effectively as a filler, it is essential to separate and disseminate its layers inside a polymeric matrix. The current study indicates that the absence of conductive pathways, resulting from the lack of a rubber-graphite interphase, led to no significant enhancement in conductivity, even with thorough mixing.

5. CONCLUSION SCOPE OF WORK

Regardless of having remarkable elasticity and reversible deformability, unmodified natural rubber (NR) has restricted applications due to its undesirable characteristics, including durability, electrical conductivity, thermal conductivity, and heat resistance. This limitation is addressed by incorporating various conductive fillers into natural rubber. In the current study, natural rubber composites were synthesized using different mixing methods with varying dosages of conductive fillers, and their effects on cure characteristics, stress-strain properties, and volume resistivity were analysed. The minimum torque of all compounds consistently increases throughout all four samples due to the hydrodynamic impact and interactions between fillers and between fillers and the polymer/rubber. The minor reduction in torque value for graphite powder is attributable to the plasticizing impact of its structure. The enhanced dispersibility of the NR/N-330 composite results in superior stress-strain (elongation at break) properties. Conversely, vulcanXC 72R has a smaller particle size than N-330, resulting in challenges in dispersion and a tendency for particles to slough at higher loadings. The smaller particles of vulcanXC 72R, due to their elevated specific surface area, facilitate the development of conductive channels, even at reduced filler concentrations, which is essential for enhanced conductivity. The incorporation of carbon fiber powder is not demonstrate a substantial impact on electrical conductivity. The dosage of milled carbon fiber is under the percolation threshold. Due to the absence of an intercalated structure of graphite within the rubber matrix, surface modification of graphite, such as ultrasonication, should be performed prior to its incorporation into the rubber matrix. Overall, close mixing provides superior conductivity characteristics for the natural composite compared to two-roll mill mixing.

Apart from the present experimental work, still few more samples can be prepared by changing the dosage (phr) of chosen filler especially vulcanXC 72R where with the present dosage we could make the sample conductive ($0.1x10^{\wedge 6}$ Ω.cm). though open mixing and also better than this ($0.2x10^{\wedge 2}$) through close mixing. Some Specialty fillers like metal powders, graphene oxide, reduced graphene oxide and carbon nanotubes can be added in small proportion along with existing fillers by keeping their compatibility in mind to prepared products like sensors, conductors and EMI Shielding.

DATA AVAILABILITY STATEMENT

All data are mentioned in the body of manuscript, tables and figure.

AUTHORS CONTRIBUTIONS

Anal Bhatt: Conceptualization, Methodology, Investigation, Writing, Original Draft Preparation, Data Curation, Data Analysis

Omprakash Mahadwad: Supervision, Reviewing, Correspondence

Parimal Parikh: Guidance and assistance in carrying out experimental work

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CONFLICT OF INTEREST

The authors do not have any conflict of interest.

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LIST OF ABBREVIATIONS

CRC = Conductive Rubber Composite

N-330 = Normal High Abrasion Furnace Black

CCF = Carbon and Carbon Fiber

CGP = Carbon and Graphite Powder

MDR = Moving Die Rheometer

ZnO = Zinc Oxide

Phr = Parts Per Hundred Rubber

SBR = Styrene Butadiene Rubber

DEG = Diethylene Glycol

TMTD = Tetramethyl Thiuram Disulfide

CBS = Cyclohexyl Benthiazyl Sulfenamide

RSS = Ribbed Smoke Sheet

EMI = Electromagnetic Interference

PET = Polyethylene Terephthalate

LIST OF SYMBOLS

M_I = Initial Torque Value

M_L = Lower Torque Value

M_H = Highest Torque Value

t_2 = Scorch Time

t_5 = Induction Time

t_c = Cure Time

t_{c90} = Optimum Cure

Ω = Ohm

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