



Review Article

Investigation the conductivity of carbon fiber composites focusing on measurement techniques under dynamic and static loads

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ABSTRACT

Carbon fibers (CFs) have been extensively investigated in several applications because Carbon fibers have unique characteristics in comparison to other materials. CFs have superior qualities for example as high mechanical strength, Young's modulus, tenacity, and thermal conductivity when reinforced with other composites. Dynamic load measurements are highly conductive than static load measurements. Conductive carbon yarn fibers are much better than all other fiber structures in terms of conductivity. The conductivity of carbon fiber has proven that this is the best material for the aircraft industry because of its many advantages. This study project is systematic and provides the latest technology that uses the reformed conductivity of carbon fibers. The focus of the present study is a review of an assortment of studies related to conductive nanofibers. It has been established that a correlation exists among the factors that show a dynamic character in the uses adopted for these conductive nanofibers. This paper examines the morphology, structure and composition, electrical conductivity, and mechanical, and electrochemical attributes that inform the use of these conductive nanofibers which have enabled these fibers to be used in various applications.

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1. Introduction

1.1. General background

Thermal conductivity is a fundamental thermal property for evaluating the heat-transfer characteristics of fine fibers such as carbon, metallic, and non-metallic. It's difficult to measure the thermal conductivity of fine fibers due to its small diameter [1,2] and is usually estimated by measuring a composite specimen comprised of a bundle of fibers. The complicated

impact of glue material with a composite structure yields thermal conductivity values that are far from the value of a single fiber.

The addition of carbon fiber fillers to thermoplastic resins enhance the composite's the resistance and the electrical conductivity as well as viscosity. While, using technology, a single type of carbon fiber filler is supplementary to achieve the preferred conductivity, which allows the material to mold into a bipolar uniform plate. Different amounts of PAN-polyacrylonitrile-based carbon nanofibers (CFs) could be added to liquid crystal polymer to form SWNTs fiber composites, which then can be tested for electrical/ionic conductivity and other properties [3].

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Nomenclature

ABS	acrylonitrile-butadiene-styrene
ACFC	activated carbon fiber cloth
AFI	amniotic fluid index
AgNO ₃	silver nitrate
Al ₂ O ₃	aluminum oxide
AOT	aerosol OT (surfactant)
BMI	bismaleimide
BN	boron nitride
Br	bromine
C ₂₀	n-eicosane
CAP	cellulose acetate propionate
CB	carbon black
CCFs	continuous carbon fibers
CFs	carbon fibers
CFME	carbon fibers microelectrode
CFRC	carbon fibers-reinforced carbon
CNTs	carbon nanotube
Cr	chromium
1D CNTs	one-dimensional CNTs
CNY	carbon nanotube yarn
CPC	conducting polymer
CPSA	camphorsulfonic acid
CRF	carbon-reinforced fiber
DBSA	4-dodecylbenzenesulfonic acid
DEHS	diethylhexylsebacate
DMA	dynamic mechanical analysis
DMF	dimethylformamide
DMSO	dimethyl sulfoxide
EB	emeraldine base
ECA	electrically conductive aggregates
EDC	ethylene dichloride
EG	ethylene glycol
EMI	ethyl-methylimidazole
EVA	ethylene vinyl acetate
FSa	ferrous saponite
FeCl ₃	iron trichloride
GF	graphene foam
GNP	graphene nanoplatelet
GPC	gel permeation chromatography
HCl	hydrochloride acid
HDPE	high-density polyethylene
IL-FCM	ionic liquid-functionalized carbon material
LDPE	low-density polyethylene
LiCF ₃ SO ₃	lithium trifluoromethane sulfonate
LiClO ₄	lithium perchlorate
LiCoO ₂	lithium cobalt oxide
LiFePO ₄	lithium iron phosphate
Li ₂ S	lithium sulfide
LTEG	low-temperature expandable
MEK	methyl ethyl ketone
Mg ₂ C ₆₀	fullerene polymer
MWCNT	multi-walled carbon nanotube
Ni-Cp	nickelocene
ODA	octadecylamine
P ₂ S ₅	phosphorus pentasulfide

PA6	polyamide 6
PAA	poly(acrylic acid)
PAM	polyacrylamide
PAN	polyacrylonitrile
PANI	polyaniline
PBMA	poly(n-butyl methacrylate)
PBO	poly(p-phenylenebenzobisoxazole)
PBX	polymer-bonded explosives
PC	propylene carbonate
PCM	phase change material
PDLLA	poly(D,L-lactide)
PDMS	polydimethylsiloxane
PEDOT	poly(3,4-ethylenedioxy)
PEKK	polyetherketoneketone
PEO	polyethylene oxide
PET	polyethylene terephthalate
PHA	polyhydroxy amide
PHB	polyhydroxybutyrate
PLA	poly-DL-lactide
PMDETA	pentamethyldiethylene triamine
PMMA	poly(methyl methacrylate)
PP	polypropylene
PPP	polyparaphenylene
PPS	polyphenylene sulfide
PPTA	phenylene terephthalamide
PPy	polypyrrole
PS	polystyrene
PS-co-DVB	poly(styrene-co- divinylbenzene)
PSS	poly(4-styrene sulfonic acid)
PTFE	polytetrafluoroethylene
PTH	polythiophene
PU	polyurethane
PVA	polyvinyl alcohol
PVC	polyvinyl chloride
PVDF	polyvinylidene fluoride
PVDF-HFP	polyvinylidene fluoride- hexafluoropropylene
PVP	polyvinylpyrrolidone
SBS	styrene-butadiene-styrene
SCC	self-compacting concrete
SDBS	dodecylbenzene sulfonate
SEM	scanning electron microscopy
SFG	semiconductor fiber graphite
SHM	structural health monitoring
SiC	silicon carbide
SMA	styrene-maleic anhydride
SPLE	solid polymer electrolyte
SWCNT	single-walled carbon nanotube
THF	tetrahydrofuran
UPR	unsaturated polyester resin
UV	ultraviolet
VBTMA	vinylbenzyltrimethyl ammonium
VDF	vinylidene fluoride
VDWF	van der Waals forces
VGCFs	vapor-grown carbon nanofiber
ZrO ₂	zirconium dioxide

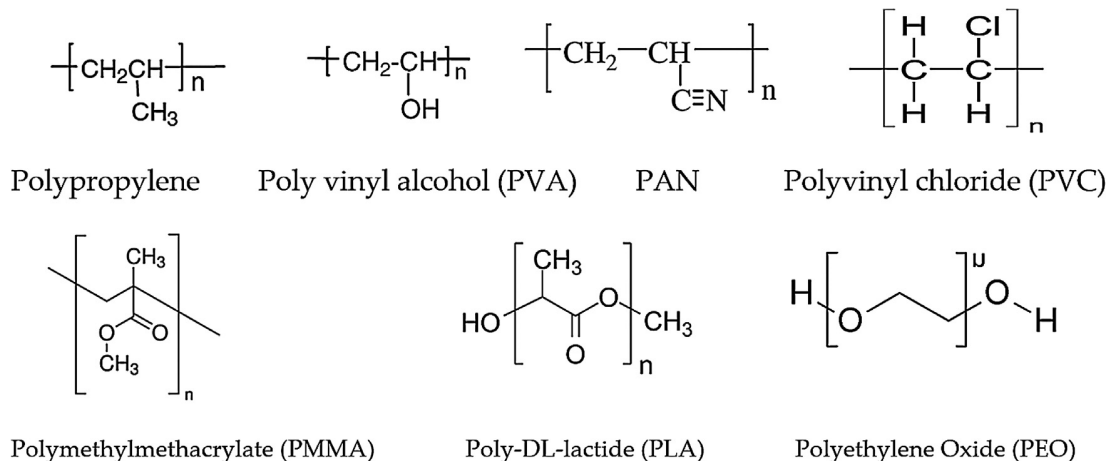


Fig. 1 – Shows the most common polymeric chemical that is sure to provide good conductive carbon fibers.

The most recent investigations of the electric CFs conductivity of carbon nanofibers composites have been directed to involving experimental applications of conductive carbon fibers, and other studies on the resistivity of SWNTs/CFs have been restricted to conductance and resistivity. Carbon fibers are anisotropic and have an ideal direction of turbostratic graphite crystals. The resistivity of SWNTs/CFs ought to be anisotropic, and bulk CFs measurements do not afford much detail about their applications in carbon fiber-reinforced composites [4,5]. The discussion here emphasizes on the investigation of the ionic, the thermal, electrical, and ionic conductivity of CFs and their associated composites.

1.2. Properties and classification of conductive carbon fibers

Nanofibers/CFs are the strongest fibers for reinforcing polymeric (Fig. 1) matrices. High-performance-grade CFs have a tensile strength that exceeds 6 GPa and tensile modulus that exceeds 600 GPa. They also have a low density, averaging from 1.8 to 2.0 g/cm³, and the highest specific stiffness and strength. Most CFs are obtained from PAN-based copolymer precursors and exhibit a turbostratic crystalline structure. CFs obtained from mesophase pitch have the high strength/thermal conductivity as well as high electrical conductivity, hence making them appropriate for electrostatic and electromagnetic interference shielding [6].

Table 1 shows a general summary of some properties and the conductivity of carbon fibers. The characteristics of CFs include considerable physical strength and lightweight, good vibration damping, toughness, high dimensional stability and low-slung abrasion, CFs electrical conductivity, X-ray absorptivity, the resistivity of fatigue, self-lubrication, extraordinary damping ability, electromagnetic CFs properties, and chemical inertness with high resistant to corrosion. The arrangement of CFs carbon fibers is the based on its features (ultra-high modulus, Young's modulus, intermediate level of modulus, low behavior modulus, and super-high mechanical tensile strength), precursor nanofibers materials (polyacrylonitrile, pitch, mesophase pitch, rayon-based, and initial gas-phase

grown), and temperature of the final heat treatment (high, intermediate or low) [7,8].

1.3. Structure and composition of conductive carbon fibers

Nanofibers/CFs have at least 92 weight percentage (wt%) of carbons in their composition. The Carbon fibers are stacked in microscopic crystals that are less associated parallel to the stretched axis of the carbon fibers [13]. This crystal arrangement creates the carbon fiber CFs tough with respect to its dimension size. The atomic structure of CFs resembles that of graphite, with films of carbon atoms that are organized to assume a regular hexagonal arrangement [7]. The only modification is in the interlocking of the films since graphite is crystalline and has its sheets regularly stacked parallel to one another. The intermolecular forces between films are weak shorting range electrostatic attractive (VDWF) that make graphite indulgent and hard. Based on the precursor used in producing carbon fibers, it could be turbostratic or graphitic/have a hybrid CFs structure with both turbostratic and graphitic parts. The turbostratic type of CFs has films of carbon atoms pleated haphazardly or lined together. CFs obtained from PAN are turbostratic [14]. After heat treatment, Carbon fibers derived from mesophase pitch are graphitic at temperatures more than 2000 degrees Celsius. Turbostratic-derived CFs are having high mechanical tensile strength, and it' has been derived CFs and having a high Young's modulus and thermal conductivity [13].

While carbon fibers have been in existence for quite some time, Carbon fibers/Nanotubes with tailor-made tensile strength and high modulus have been made the nanofibers from a precursor have yet to be developed [15]. There is a lack of comprehension on by what means the structure, polymer arrangement, crystallitant size, crystallinity, and arrangement of a specific precursor polymer translate into the ultimate CFs [16]. Through the electrospinning process, it has become possible to successfully fabricate randomly oriented as well as electrically aligned conductive nanotube/nanofiber of decomposable poly-DL-lactide-(PLA)

Table 1 – Standard properties, thermal conductivity, and classification of conductive carbon fibers.

Conductivity measurement	Standard type carbon fibers	Experimental methods	Thermal conductivity (W/mK)	[Reference] [Year]
Ionic carbon fiber	PAN/HCl	Dopant/counterion	8–70	[9] [2012]
Electrical carbon fiber	PU and wet spun	Matrix, processing method	0.19	[10] [2000]
Thermal carbon fiber	Carbonized PAN	Heat treatment	0.20	[11] [2015]
Electrical carbon fiber	PAN-based	Blending	5	[12] [2018]

with inserted multi-walled carbon nanotubes (MWCNTs). Researchers assert that not using electrical stimulation results in the creation of better cell proliferation in aligned poly-DL-lactide with MWCNTs nanotube/nanofiber meshes.

Use of the electrospinning method has been found to lead to the better growth of osteoblasts beside the axis of ranged nanofibers. Electrical stimulation of randomly oriented nanofiber meshes significantly promotes the elongation of osteoblasts, while in the case of ranged nanofiber meshes, the encouragement enhances the elongation along the nanofiber route [17]. Research has been done on a load-bearing supercapacitor developing mesoporous carbon with coated nickelocene (Ni-Cp) core-shell Nanowires grown up straight on the (CFs) carbon fibers material as well as a microphase disconnected structural polymer electrolyte used to embed the ionic liquid. Studies have been done on a bicontinuous structural polymer electrolyte whereby the polyethylene oxide micro-domains are covalently connected to cross-linked polystyrene-co-divinylbenzene (PS-co-DVB) micro-domains, thus allowing an exceptional mixture of ionic conductivity and very high mechanical strength. These attributes indicate the significant contribution to the reliability of the structural electrolyte [18].

The use of carbon fibers has been encouraged because they offer vital reinforcement materials that advance high-performance composites, providing a means of reducing weight on structural components as well as the carbon footprint. However, it follows that using carbon fibers is associated with a considerably high cost, which limits their use. It has become imperative that to enhance using of the carbon fibers, their price must be reduced. Optimization of a fiber structure via processing is another aspect that authors support. Structural evolution, chemical reactions during carbonization, and properties development during processing are additional issues that require further research [19]. Several strategies are used when it comes to the fabrication of composites place special emphasis on the solution towards the processing and melt mixing in situ polymerization. Overall, both covalent/non-covalent modifications of polystyrene (PS) with CNTs, are commonly used in improving spreading and compatibility of the polystyrene/CNTs composites. It becomes imperative to assess the electrical response impact of the diverse variables involved in their fabrication, including the CNTs processing with the type and content of the method as well as the temperature employed. It becomes clear that CNTs are dynamic when it comes to the improvement of the material performance of polystyrene composites used in industries [20].

1.4. Fabrication and experimental techniques

The structure, as well as the polymeric composition of the precursor, carbon fibers, affects their properties. Even though the processes for CFs production are similar, the different processing conditions have different precursors require to accomplish the desired performance. CFs are processed using the precursor fibers controlled Stabilization pyrolysis. These precursor fibers undergo stabilization process at 250–450 °C in air through an oxidation process. Stabilization process fibers are formerly treated with at approximate 1000 °C in chemically stable atmospheric conditions to eliminate hydrogen, oxygen, and nitrogen. This phase is referred to as carbonization process. The carbonized fibers are then graphitized step at higher temperatures reach to 3000 °C to attain a high carbon contented and a high modulus in the carbon fibers [21]. The properties acquired in the carbon and graphite nanofibers are artificial by several factors, such as crystallinity in polymer distribution, molecular polymer positioning, carbon content, and a number of failures [22]. The relative inert chemically inactive surfaces of carbon and graphite fibers are treated to enhance composite matrix of the adhesion. Fig. 2 illustrates the process of fabrication for highly conductive or medium-conductive carbon fiber.

1.5. Conductive nanofiber morphologies

Electrically conductive polymers have been established as exhibiting the conducting polymer has physical/chemical properties such as the metals organic polymers and the electrical properties. (poly (3,4-ethylenedioxy:PSS) is that tends to appeal superior attention because it exhibits electrochemical, thermal, and oxidative stability [24], thus making it an excellent candidate for numerous applications in areas that encompass flexible electrodes, electrochemical displays, nanocomposites, and transistors. The aspect of the ethylene glycol has incorporation of some organic solvents, dimethyl sulfoxide or sorbitol in the aqueous spreading of (poly (3,4-ethylenedioxy:PSS) tends to improve the conductivity of these thin films [24]. Authors have established that the effects of different solvents on the morphology of fiber, such as the addition of ethylene glycol (EG) and dimethyl sulfoxide (DMSO) to the rotating dopes, led to the transformation of (poly (3,4-ethylenedioxy: PSS) chains from a random to a stretched coil configuration. It's not only increased the conductivity by enhancing the interchange interaction among the PEDOT chains, but it further enhanced the carbon fibers orientation image [24].

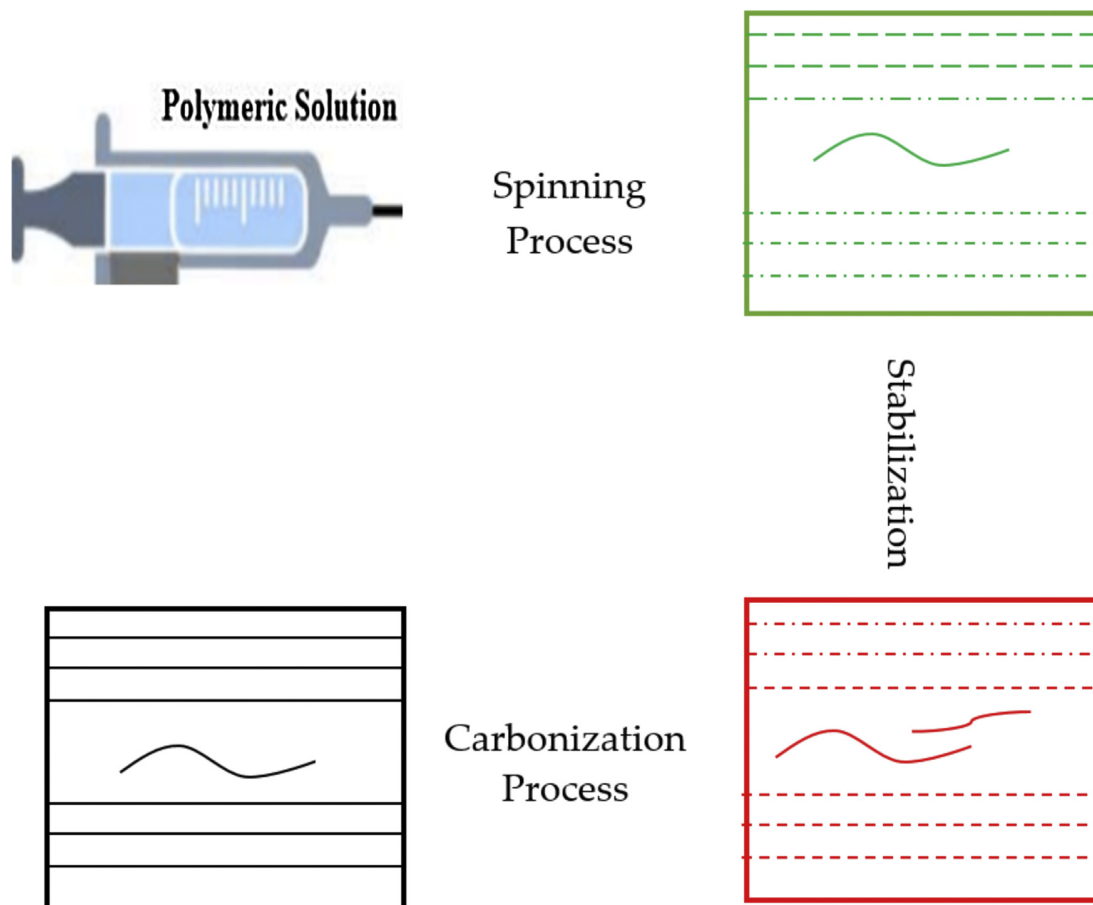


Fig. 2 – The fabrication process of conductive carbon fibers [23].

Fig. 3 (a) shows the morphology and arrangement of conductive carbon yarn fibers yarn, illustrating that conductive yarn will help researchers ensure that the fiber orientation is well arranged. Fig. 3 (b) shows a single-walled conductive carbon fiber following a carbonization process at 850°C. There has been increased attention in polyaniline (PANI), a conducting polymer with unique electronic and optical properties, which make it an appropriate candidate for possible application in sensors and electronic devices in an assortment of fields. Most attention has been directed at synthesizing PANI with nanostructures such as nanorods and nanofibers since nanostructured PANI sensors respond better than conventional polymerized sensors. Overall, surfactants are the best candidates for the template synthesis of PANI with nanostructures since they are able to guide the polymerization of aniline with a specific orientation [26].

Fig. 4 (a) shows the SEM morphology and a cross section using Scanning Electron Microscopy (SEM) image of a conductive CFs composite, clearly indicating the arrangement and size of the fibers. Fig. 4 (b) shows an SEM image of a CFs with condition of conductivity polydimethylsiloxane (PDMS) matrix showing connecting MWCNTs magnified at 200nm. The fabrication of nanotubes using the electroplating method has attracted significant attention because of its versatile maneuverability in the production of controlled

fiber structures, orientations, porosity, and dimensions. While these processes appear to be straightforward, the strategies involved as well as impacts on orientation, structure, and mechanical/thermal properties are issues of concern [28,29]. Overall, it has been established that both size and tensile properties of the fibers have an impact on the overall structure [30].

2. Investigation of carbon fiber conductivity

Carbon fibers have relative thermal, electrical, and ionic conductivity characteristics. Carbon fibers and other carbon-based materials are being investigated to replace other traditional heat-conducting materials. They conduct heat especially well with the addition of graphite and diamond. The heat conductivity in carbon fibers varies with chemical composition, type of wood, crystalline structure, methods of measurement, alignment of fibers, temperature gradient, and type of precursor materials. Carbon fiber takes various forms, making it difficult to state its conductivity without an explanation, and its heat-conducting property is not explicitly shown in heat-conductivity tables. Carbon fiber conductivity depends on the carbon content and level of carbonization, both of which tend to increase the thermal conductivity [31].

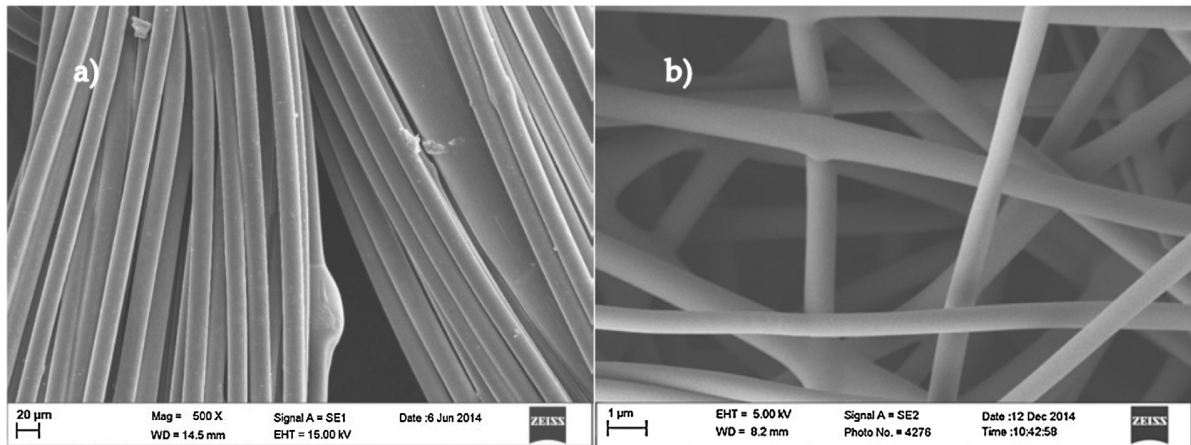


Fig. 3 – Conductive carbon yarn fibers: (a) morphology and arrangement [25], and (b) single-walled carbon fibers.

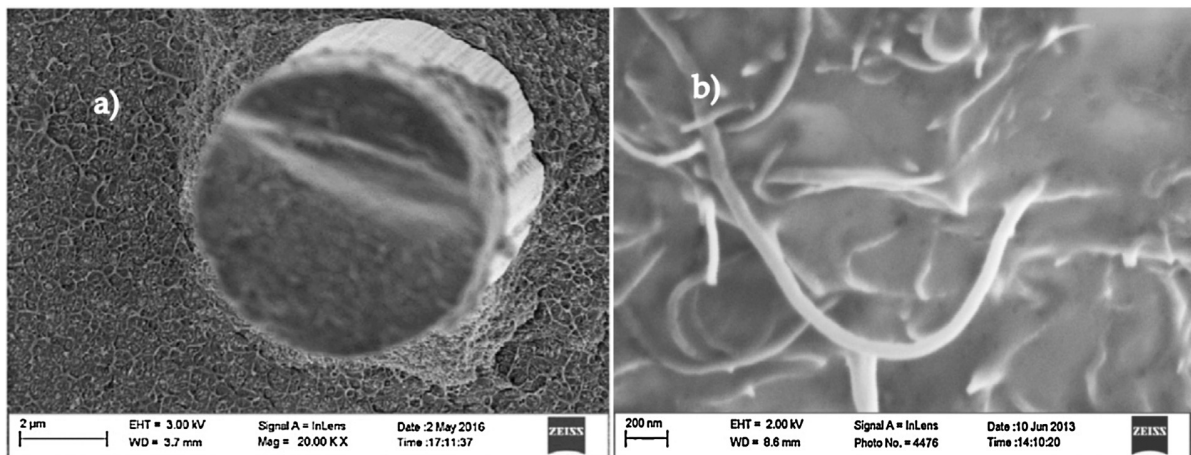


Fig. 4 – SEM micrographs: (a) cross section of conductive carbon fiber composite, and (b) conductive PDMS matrix showing connecting MWCNTs [27].

The main component of carbon fiber is carbon, and its molecular structure is similar to graphite. Thus, it behaves like metal because its electrical conductivity is extremely high. Carbon fiber is not used alone but rather mixed with reinforcing materials such as epoxy resin, metal, and ceramics. Most carbon fiber products have electrical conductivity. Carbon fiber also generates electricity in a magnetic field, which is a property of electrical conductors [32,33].

2.1. Electrochemical and mechanical characterization

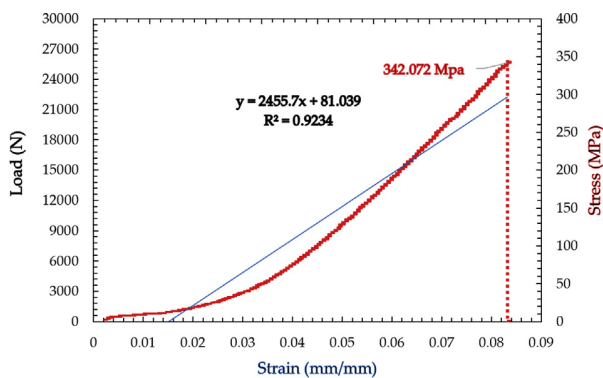
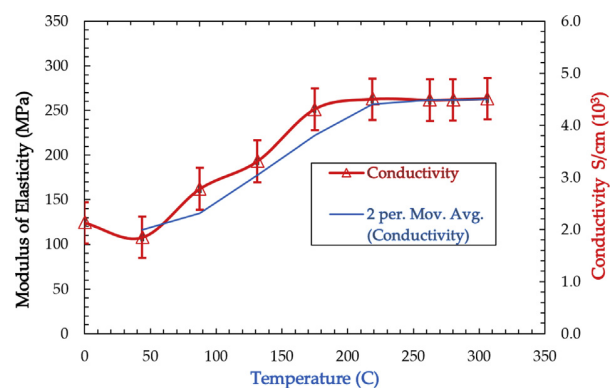
There has been an increase in the attention paid to heat-dissipation challenges. Traditionally, polymeric products have been used extensively as an electronic packet material because of their exceptional mechanical attributes, low cost, and ease of processing. In most instances, adding ceramic fillers to polymers results in the creation of highly thermally conductive carbon fibers composites, which is a great approach [34]. Nevertheless, it follows that the limited electron spectrum does not match between monomers polymer resins and ceramic phases (inorganic) immensely weakens the efficiency of the quantized lattice vibration wave [35]. By orienting

fillers in the heat-flow direction, it becomes possible to attain an improved thermal conductivity of the polymer composite [36]. Table 2 shows the mechanical properties of some conductive carbon nanotube (CNT) composites involving amine, and MWCNTs—using two mechanical tests: dynamic mechanical analysis (DMA) and tensile test.

Due to the high axial-load Young's moduli and high aspect ratio, it follows that CNTs, irrespective of whether they are multi-walled or single-walled, exhibit potentially of polymer composites has excellent mechanical reinforcing fillers. The progress of high performance polymer and CNTs composites is delayed by the inability to attain a homogenous spreading of CNTs in the polymer matrices as well as strong interactions, which impact the load transference from the polymer matrix to the CNTs. It is claimed that the weak connections existing between the inner/outer tubes of the MWCNTs end up limiting the stress behaviour transferred from the outer walls to the inner walls [57,58]. Also, the weak interactions between SWCNTs that are prevalent in a polymer-matrix end up distressing the productivity of the CNTs. Overall, the use of an adequate amount of Nimesulide (at least 9%) has been established as necessary to attain a good dispersion of MWNTs

Table 2 – Mechanical properties of some conductive CNTs composites.

Type of CNT	Tensile strength (%)	Young's modulus (%)	Storage modulus (%)	Mechanical test	[Reference] [Year]
PMMA and MWCNTs	100	50	90	DMA and tensile test	[37] [2005]
PBMA and MWCNTs	84	40	83	DMA and tensile test	[38] [2007]
MWCNTs	75	40	200	DMA and tensile test	[39] [2005]
SWCNTs	55	80	400	DMA and tensile test	[40] [2004]
SWCNTs	–30	10	10	DMA and tensile test	[41] [2005]
SWCNTs	–20	15	80	DMA and tensile test	[42] [2004]
MWCNTs	23	39	150	DMA and tensile test	[43] [2007]
Amine and MWCNTs	20	0	75	DMA and tensile test	[44] [2006]
MWCNTs	162	214	45	DMA and tensile test	[45] [2004]
SWCNTs	20	15	30	DMA and tensile test	[46] [2006]
MWCNTs	75	0	88	DMA and tensile test	[47] [2003]
SWCNTs	15	40	60	DMA and tensile test	[48] [2005]
MWCNTs	10	100	100	DMA and tensile test	[49] [2002]
MWCNTs	–70	600	900	DMA and tensile test	[50] [2002]
MWCNTs	23	39	150	DMA and tensile test	[51] [2007]
MWCNTs	110	110	0	Tensile test	[52] [2004]
CNTs	670	470	0	Tensile test	[53] [2009]
SWCNTs	31	93	0	DMA and tensile test	[54] [2003]
PAN and MWCNTs	75	72	0	Tensile test	[55] [2005]
Phenoxy and MWCNTs	440	230	0	Tensile test	[56] [2007]

**Fig. 5 – Engineering stress-strain curve for conductive PAN-derived carbonized nanofiber composite [60].****Fig. 6 – PAN conductivity of carbon fibers lines behavior during uni-axil load [60].**

within a composite [59]. Fig. 5 shows the stress-strain curve for a conductive PAN-derived carbonized nanofiber composite. As can be seen, the stress value is approximately 342 MPa with R^2 equal to approximately 0.9 versus the maximum strain value of 0.85 mm.

From the time that CNTs were discovered in 1991, interest in them has increased because of their exceptional in CNTs of the electrical and mechanical properties. However, the common organic solvents and polymeric matrices follow that the inflexibility and chemical inertness of CNTs make it problematic for them to dissolve or disperse them in the manufacture of useful articles. When it comes to mechanical properties, it has been known that the use of improving load transfer can be attained via the covalent bonds or non-covalent connections that are prevalent between the nanotubes functional groups on as well as the polymer matrix [61,62]. Fig. 6 shows the results of testing the mechanical properties of PAN carbon fibers using the dynamic load measurement test. Here the conductivity value is about 4.5×10^3 S/cm, and the stress value is about 290 MPa.

2.2. Electrospinning process and technique

The emergence of nanotechnology in nanoscale materials has resulted in researchers studying the properties. Electrospinning technique is an electrostatic fibers producing technique that has high versatility and potential for applications in adverse fields [63–67]. It is applied in tissue engineering, bio-sensors, filtration materials, coiled dressing, drug delivery, and mobilization. Electrospinning helps to create electrospun fibers, whose diameters range in size between tens of nanometers to a few micrometers [68–71].

The process of electrospinning includes the application of high-voltage to a liquid droplet, which charges the body of the liquid and stretches the droplet as a result of the electrostatic repulsion counteracting the surface tension. A stream of liquid is generated from the surface at a critical-points. Doubt, if the liquid molecular consistency is high, then the liquid stream does not break and a charged liquid is formed. As the jet dries and as the charge travels to the surface of the

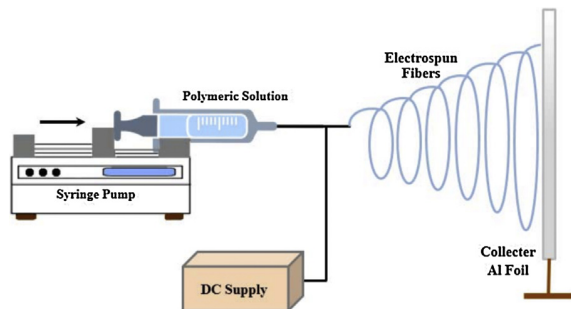


Fig. 7 – Schematic view of the nanofiber preparation process [60,77].

fiber, the flow changes mode. The jet is expanded through electrostatic repulsion caused by small bends in the fibers until it is dropped on the grounded accumulator. The fibers thinning and elongation from bending instability creates the establishment of uniform fibers with the size of the nanometer scale diameters [72–76].

Fig. 7 is a schematic drawing of the electrospinning process involving the use of a charge in electrical to obtain fine fibers from a liquid form. So, the electrical charge of the applications of a high voltage at grounded collector begun with a liquid droplet, then the liquid develops exciting, and then the electrostatic repulsion responds the liquid's surface tension causing the liquid stream to explode from the surface until it is deposited on a grounded collector.

Electrospinning can be accomplished through both needleless and needle-based techniques [78]. Needle-less electrospinning begins with a transfer of polymer solution to an open vessel where fibers are produced from a still or rotating platform. This process allows for mass production. Fiber morphology and quality are not well controlled, and the raw materials used are limited, thereby limiting versatile fiber production. For needle-based electrospinning, the initiating polymer solution is stored in an air-tight closed reservoir that reduces and prevents solvent evaporation. This method allows various materials to be processed. One of the significant advantages of the needle-based electrospun process is the high flexibility in the processing of changed structures such as core-shell and multi-axial fibers [79,80]. This technique also has the advantages of being a continuous process, being cost-effective, and producing controllable diameters [81].

2.3. Carbon fiber thermal conductivity

The thermal properties of CNTs, considering specific heat, CTE Coefficient of thermal expansion, diffusivity, and thermal conductivity, are crucial parameters in studying the behavior of carbon and carbon composites. Individual carbon nanotubes have good properties, including high thermal and electrical conductivities. These properties, combined with a high characteristic ratio and low-density, have produced interest in the possible to create high performance, CNTs nanomaterials. The heat dissipation is the most serious challenges in high performance electronics, and thermal conductivity of Carbon nanotubes has increased interest in their use for thermally managing high-power electrical alliances. Table 3 shows the

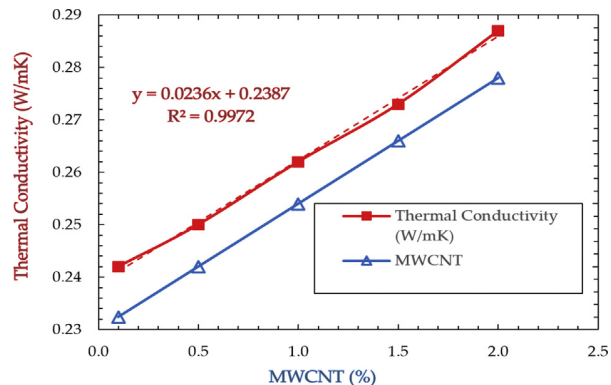


Fig. 8 – Thermal conductivity vs. aspect ratio of MWCNTs composites (%) [102,103].

weight percentage and the composition of various thermally conductive carbon fibers, including weight percentages of the element composition, fabrication theories, and thermal conductivity values.

Research has shown that carbon fiber composites are thermally conductive. The thermal characterization has the highest value of thermal conductivity per/the density unit amid another materials. Similarly, they reach high toughness and mechanical strength that rises with considering temperature. Fig. 8 showing the thermal conductivity and aspect ratio of MWCNTs composites.

The thermal conductivity of SWCNTs can be valued when the average temperature improved, and the heat generated rate is measured for similar systems [104]. The electrical conductivity of SWCNTs has been measured using a similar method as used for measuring thermal conductivity, the four-point contact method [105].

2.4. Carbon fiber electrical conductivity

Nanocarbon fibers composites have low plane electrical conductivity. It is appropriate to enhance the properties of the composite electrical conductivity for various applications. There has been major progress in increasing the electrical conductivity of polymer materials [106]. Carbonaceous particles including carbon black, CFs, CNTs, and graphene particles have been used to increase the electrical conductivity of composites. Table 4 shows the chemical composition of various electrically conductive carbon fibers, including weight percentages of the element composition, fabrication theories, stationary/dynamic measurement values, and electrical conductivity values.

A conductive silver nanoparticle coating improves the electrical conductivity of carbon fiber-reinforced plastics for aircraft lightning protection. In one study, colloidal nanoparticles were applied and sprayed on the surface of carbon fibers and then made larger using epoxy resin to form a carbon fiber-reinforced plastic specimen [119]. The electrical resistance value was then converted to electrical conductivity, which was found to increase by four times that of ordinary reinforced plastic [120].

Figs. 9, 10 and 11 show three factors affecting conductivity behavior when AC power is supplied: resistance, voltage, and

Table 3 – The weight percentage and chemical composition of various thermal conductive carbon fibers.

Element composition/Weight percentage			Fabrication theory	Thermal conductivity W/(m.K)	[Reference] [Year]
Epoxy resin	Carbon fibers (Δ wt%)	Glass fiber	Coating and body reinforced	18 ± 3–0.02	[82] [2016]
PAN	Dimethylformamid(DMF)	MWCNTs	Electrospinning, stabilization, carbonization	0.14–0.5	[83] [2014]
Ethyl-methylimidazole (EMI)	Epoxy resin	MWCNTs	Synthetic procedure	1.3	[84] [2009]
Nickel powders	Carbon fibers (Δ wt%)	Epoxy resin	Filler loading	8.2	[85] [2014]
CNTs	Epoxy resin	N-icosane (C20)	Vacuum impregnation and dispersal	0.27	[86] [2017]
N-tert-Butyl-2-benzothiazole-sulfenamide	Rubber (Δ wt%)	CNTs (5 wt%)	Mill process	0.267	[87] [2015]
Polyamide-6	None	Graphene foam GF (2 wt%)	Synthesized process	0.847	[88] [2016]
None	Epoxy resin	BNNs	Coating and heat treatment	3.13	[89] [2017]
None	GF	PMMA	Backfilling and molding process	0.35–0.70	[90] [2015]
Low-temperature expandable graphite (LTEG)	EG (60 wt%)	Polyamide 6 (PA6)	Melting process	21.05	[91] [2014]
None	Ultrathin graphite	Phase change materials (PCMs)	Dispersing and filling process	3.5	[92] [2014]
4-bromobenzene (PBX)	CNTs	Graphene nanoplatelets (GNPs)	Hybrid fillers	1.4	[93] [2017]
Polyvinylidene fluoride (PVDF)	Polyvinyl chloride (PVC)	MWCNTs + silicon carbide (SiC)	Blending and filling process	1.8	[94] [2013]
Polyhydroxy butyrate (PHB)	Boron nitride (BN)	Aluminum oxide (Al ₂ O ₃)	Melt blending process	1.79	[95] [2017]
Epoxy resin	GNPs	MWCNTs	Filler loading	0.33	[96] [2017]
One-dimensional CNTs (1D CNTs)	PVDF	GNPs	Filer and blending process	2.06	[97] [2016]
None	Polybenzimidazole	CNTs	Core-shell electrospinning	1.94	[98] [2013]
None	Epoxy resin	BN	Self-assembly and infiltration	1.81	[99] [2017]
Epoxy resin	Polymer composites	SWCNTs	Filler-matrix process	2 × 10 ⁻⁷	[100] [2012]
Poly (vinylpyrrolidone) (PVP)	Polyacrylamide (PAM)	Poly(acrylic) acid (PAA)	Blending process	0.12–0.38	[101] [2016]

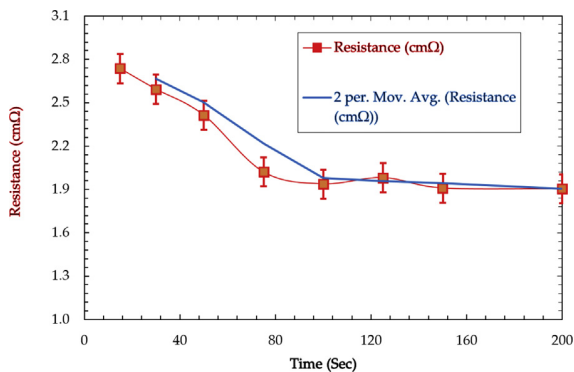


Fig. 9 – Resistance vs. time changes for conductive PAN-carbonized fibers [60].

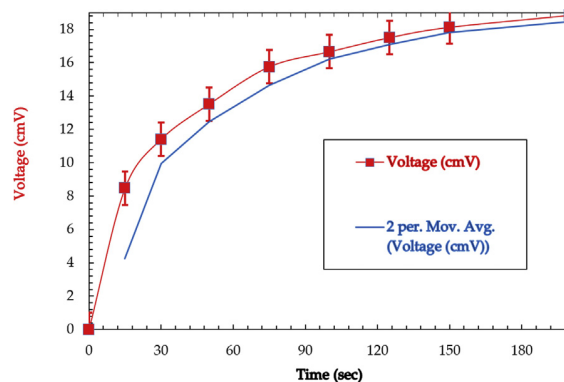


Fig. 10 – Voltage vs. time changes for conductive PAN-carbonized fibers [60].

Table 4 – The chemical composition of various electrically conductive carbon fibers.

Element composition/Weight percentage			Fabrication theory	Static/ Dynamic measurement	Electrical conductivity (S/cm)	[Reference] [Year]
PVC (Δ wt%)	Carbon black (CB) (Δ wt%)	Not mentioned	Ultrasonication and speed mixing	Dynamic (tensile test)	9.9210×10^{-3}	[4] [2016]
Polyether ketoneketone (PEKK) (60 wt%)	Meta linkages (40 wt%)	Silver nanowires	Annealing and slow cooling	Static (film stacking)	$1.5 \times 10^{-1} \pm 0.001$	[107] [2016]
CNTs (4 wt%)	Silver (46 wt%)	Embedded polypropylene (PP)	Extruding, water bath, and quenching	Dynamic (tensile test)	$4.1-7.2 \times 10^{-2}$	[108] [2017]
PEO (4 wt%)	Polypyrrole (PPy)	Diethylhexyl sebacate (DEHS) (3 wt%)	Electrospinning and blending	Static (two-point method)	$4.910 \times 10^{-8} - 1.2 \times 10^{-5} - 3.5 \times 10^{-4}$	[68] [2006]
PPy	APS	4-dodecyl benzenesulfonic acid (DBSA)	Electrospinning and synthesizing	Static (four-probe technique)	0.2–0.5	[79] [2005]
PPy	Iron	Sodium di-2-ethylhexylsulfo succinate (AOT) (99 wt%)	Electrospinning and heating	Static (four-probe technique)	14	[109] [2007]
Silver nitrate (AgNO_3) (Δ wt%)	PAN (Δ wt%)	PPy (Δ wt%)	Chemical coating	Static, four-probe technique	1.3×10^{-3}	[110] [2008]
PAN-gelatin	Camphorsulfonic acid (CPSA)	Ethylene dichloride (EDC)	Electrospinning and coating	Dynamic (tensile test)	0.021	[111] [2006]
PVDF	PMMA	Polytetrafluoro ethylene (PTFE)	Coating and heat treatment	Static (two-probe technique)	3.09	[32] [2011]
CNTs	Copper	Silver	Blending and coating	Static (four-probe resistivity meter)	$9.5 \times 10^{-5} - 6.633$	[112] [2015]
PAN (20 wt%)	DMF (80 wt%)	CFs	Electrospinning, stabilization, and carbonization	Dynamic (tensile test) and static (four-probe technique)	$2.13 - 4.52 \times 10^3$	[60] [2015]
PPy	Iron trichloride (FeCl_3)	PEO	Electrospinning and vapor polymerization	Static (paw method and four-probe technique)	10^{-3}	[113] [2005]
Polyurethane (PU)	PPy (5 wt%)	DMF	Electrospinning and mixing	Dyanmic (tensil test)	$7 \times 10^{-7} - 1.4 \times 10^{-6}$	[114] [2012]
Polyethylene terephthalate (PET)	PP	MWCNTs	Coiling speeds	Dyanmic (tensil test)	0.8862	[115] [2016]
DMF	Carbon nanotube yarn (CNY)	PAN	Carbonization and heat treatment	Dyanmic (tensil test)	66.4 ± 13.2	[116] [2018]
CNCs	PS	Poly(D,L-lactide) (PDLLA)	Electrospinning and filling	Dyanmic (tensil test)	5.8×10^{-4}	[117] [2013]
CNTs	DMF	SWCNTs	Dispersion and electrospinning	Dyanmic (tensil test)	54	[118] [2009]

current. Both elastic and wearable engineering strain sensors tend to change the existing mechanical deformation into electrical signals that used in several applications as soft robotics. Highly conductive flax-based yarns have been generated using a simple, cost-effective, environmentally friendly. Emphasis has been on the use of a new coating strategy via the integration of an ultra-sonication bath (DIGTECH 100 W, 60 Hz) in the coating because it offers continuous uniform dispersion with higher energy for chemical as well as mechanical bonds between the sodium dodecylbenzene sulfonate functionalized carbon fibers particles and the surface of yarns [121].

Fig. 12 shows the behavior curve of conductive Pan carbon fibers testing the resistance versus current. Electrically conductive textiles have been produced via wet/melt

spinning, conductive polymer PANI, and fiber coating conductive (carbon black) electrically, metal powders, or intrinsically conductive polymers [122]. Other than these electrically conductive materials, it is evident that carbon nanotubes are excellent electrical conductors [123]. Their unusual atomic structure and exceptional electrical, electromechanical, mechanical, and chemical properties have created them useful. Some of the attributes that emerge with CNTs is the direct result of the coating technique, which is practical but can result in highly conductive yarns. It is also apparent that the electrical conductivity of polyvinyl alcohol) (PVA)/CNTs-coated yarns varies depending on the substrates. Researchers argue that short carbon fibers are used in the form in cement-based materials of admixtures within the objective

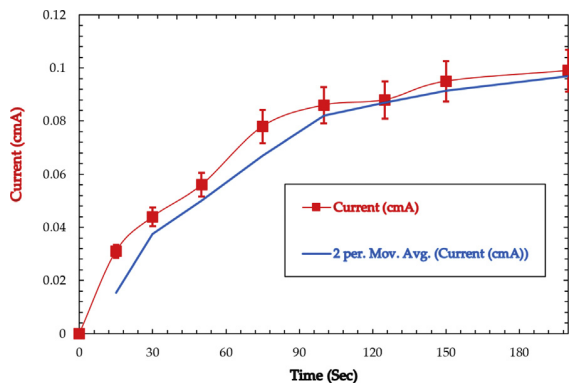


Fig. 11 – Current vs. time changes for conductive PAN-carbonized fibers [60].

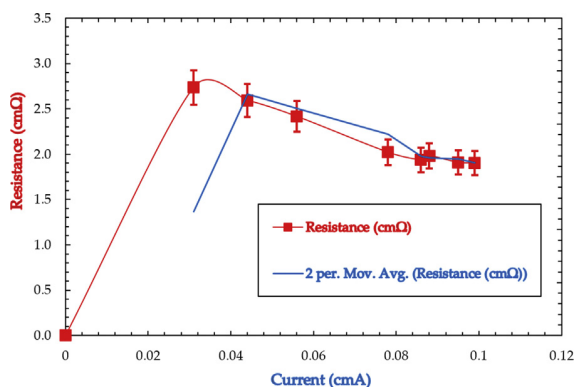


Fig. 12 – Resistance vs. current changes for conductive PAN-carbonized fibers [60].

of decreasing the drying decrease and enhancing the flexural durability [124]. Those instances where fibers conduct electricity, they are found to offer non-structural meanings including self-sensing, self-heating for deicing, and electromagnetic reflection in cases that address electromagnetic interference shielding. Researchers' prevailing assertion is that the effectiveness of the fiber admixture in cement-based materials relative to the improvement of structural and efficient properties is massively affected by the level of fiber spreading [124]. It follows that the realization of a fibers dispersion high degree is specifically vital when the fiber volume fraction is minimal. Thus, the idea follows that with low fiber volume fractions, it becomes possible to decrease material costs, enhance workability, reduce air voids, and further enhance the comprehensive stress.

While the mechanical attributes of fibers are more significant that the electrical conductivity in concrete applications, researchers contend that electrical conductivity can better imitate the extent of fiber dispersion than mechanical elements. In those instances where the fiber fraction of volume is lower than the threshold of percolation, the degree of fiber spreading is higher, leading to the enhanced conductivity of the composite [124]. These attributes are attained as the result of the relatively extended length of the conduction path within the matrix in the cases of deprived fibers spreading. Thus, the fibers have superior electrical conductivity over the matrix,

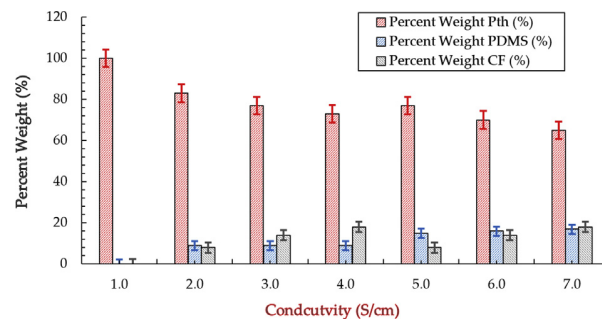


Fig. 13 – Electrical conductivities of PDMS/CFs/Pth composites [126].

and volume fractions below the filtration beginning to make the electrical conductivity of the cement materials impart on fibers filtration degree.

Fig. 13 provides the weight percentages of three conductive materials: PDMS, CFs, and polythiophene (Pth). According to Liu et al., carbon nanotubes display an assortment of excellent thermal, mechanical, and electrical properties that offer promise for an extensive range of applications [125]. Due to the high electrical conductivity, low density, and decent mechanical attributes, CNTs have indicated that they are capable of replacing expectable metals in most cabling applications. Moreover, the single CNTs have demonstrated ultra-high electrical conductivity that reaches 106 S/cm. However, this figure has been found to drop significantly in most CNTs fibers, which is likely attributed to the challenges in controlling CNTs fiber morphologies.

The electrical conductivity evident in CNTs fiber is associated with the intrinsic properties of CNTs, contact surface resistance, interline spacing, the orientation of the CNTs, and impurities inside the CNTs fiber. The many properties of CNTs could be enhanced by changing their diameter and type, along with monitoring the number of impurities and damage in fibers. According to the authors, CNTs fibers containing pure metallic single-walled CNTs would indicate electrical conductivity that is as high as that of SWCNTs [127].

One of the simplest and most effective methods in the production of highly conductive polymer composites has been demonstrated by the combination of inside the polymer-matrix a conductive hybrid filler. When the hybrid filler is comprised of both macro/nanosized particles composed, the nanosized conductive fillers that fill the tunneling phase allow for electron transport and significantly improve the electrical conductivity of the polymer composites [128].

2.5. Carbon fiber ionic conductivity

The discussion about carbon fiber ionic conductivity is based on CFs-reinforced material as the specimen [129]. The electrical conduction of CFs-reinforced with a fiber volume fraction contains several electrons among ions in the space. The fibers disturb on both factor the electronic/ionic conduction. Also, the ozone handling the surface of fiber improves the ionic side conduction. The use of latex provides a comparatively superior ionic conductivity, and (silica fume) provides a high electronic

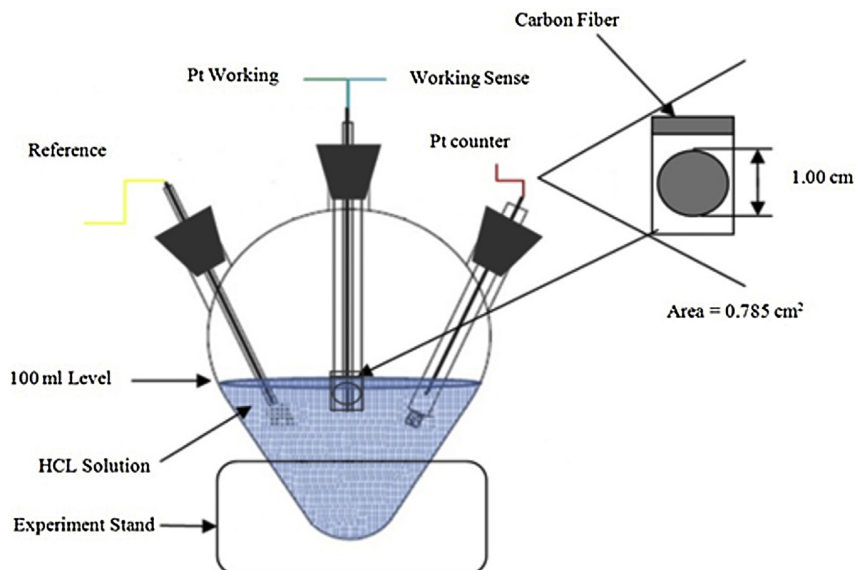


Fig. 14 – Experimental electrochemical setup (Gamry Instruments) for measuring ionic conductivity [60].

conductivity [130–134]. Fig. 14 shows the experimental setup of a Gamry Instruments Potentiostat/Galvanostat, ZRA, Reference 600, used to characterize the ionic conductivity of PAN nanofibers.

The conductivity values of the polymeric fibers were calculated using the resistance obtained from a slope of the I-V plot.

$$\sigma = \frac{L}{RA} \quad (1)$$

Where “A” is the area of the film and “L” is the thickness of the film. Generally, ionic conductivity increases with increasing temperature. In the dry state, electronic process conduction is extra substantial than the ionic process conduction, and in the wet stage, when saturation occurs, ionic conduction controls. The conductivity of wet ionic ratio than to the conductivity of dry ionic is enhanced by the treatment the surface of the fiber and is high when latex is applied. Then, the wet ionic conductivity is more elevated than dry ionic conductivity when latex theorem is used but is lower than dry conductivity when (silica fume) is existing [130–134]. Table 5 shows the chemical composition of various ionic conductive carbon fibers, including weight percentages of the element composition, fabrication theories, and ionic conductivity values.

Scientists assume the domination of the ionic conduction in CFs-reinforced because as an ionic conductor, cement is the matrix. Resulting, the thermal and electrical properties of CFs-reinforced shows that its holes are the major carriers, and the p-type character increases with the use of bromine (Br)-intercalated carbon fiber in the cement. Controversy exists over the electron and hole conduction and ionic conduction in CFs-reinforced.

Figs. 15 and 16 show the important factors of temperature and concentration of materials while performing a conductivity test on carbon fiber composites. An electrical contact in the status of an ionic conductor does not permit all electrons to

move from using the metal wire linked with an outside electrical circuit to a sample [151]. Ionic can not move in metals and hence could not move in a circuit. Metals allow the flow of electrons but not ionic. Hence, a configuration comprised of a specimen and an external circuit (metal) can help in the study of a specimen’s ionic conduction. Electrons can move through the specimen and also the exterior metal-wire circuit, whereas ionic moving is sluggish and more incomplete than the flow of electrons [152]. Fibers are electronic conductors, but they affect both electronic/ionic conduction. The special treatment of the fibers surface to enhance the ionic conduction; for example, latex provides a comparatively high ionic conductivity, and (silica fume) provides a relatively high electronic conductivity [130–134].

2.6. Chemical and physical activations

Substantial research has been performed on the absorption properties of activated carbon, but the information about its performance is limited. The discussion here will focus on pitch-based or polyacrylonitrile-based carbon fibers that have been activated by physical/chemical methods [154]. Activated CFs are characterized by static adsorption approaches based on the specific surface area, the volume of micropore, volume of mesopore, uptake of water, and hexane inlet [155,156]. With steam or carbon dioxide. They can be obtained by physical activation. Hydroxides are good activating materials, but the research on the use of potassium hydroxide and sodium hydroxide is limited. In one experiment, carbon fibers has been activated with the surface area were obtained after chemical activation with potassium hydroxide, and both agents had different behaviors [155]. The sodium hydroxide agent developed activated carbon fiber with the highest porosity, and potassium hydroxide developed carbon fiber with narrow micro-pore size distribution. For comparison of the results obtained from physical activation, some of the activated carbon fiber was prepared using carbon dioxide.

Table 5 – The chemical composition of various ionic conductive carbon fibers.

Element composition/Weight percentage			Fabrication theory	Ionic conductivity (mS cm ⁻¹)	[Reference] [Year]
Cellulose acetate propionate (CAP) (6 wt%)	PMMA	PEG/gel permeation chromatography (GPC)	Dopping and stirring	8.1×10^{-4} – 4.4×10^{-4}	[135] [2016]
PAN	PMMA	DMF	Electrospinning and soaking	1.02 to 3.31 3.31 to 5.81	[71] [2015]
Polyvinylidene fluoride-hexafluoropropylene (PVDF-HFP) (16 wt%)	DMA	Kynar Flex	Electrospinning and soaking	4.21–5.92 to 6.45–7.21	[76] [2008]
PVDF (90 wt%)	PEO (10 wt%)	DMA	Dopping and stirring	4.9×10^{-3}	[67] [2015]
PVA	Polyvinyl	PVDF	Solution casting	2.7×10^{-3}	[136] [2014]
Nanosilica	Vinylbenzyltrimethyl ammonium (VBTMA) (99 wt%)	Pentamethyldiethylene triamine (PMDETA)	Nanoparticle synthesis polymerization	0.40	[137] [2014]
Propylenecarbonate (PC)	Poly(epichlorohydrin-ethyleneoxide)	DMF	Solution casting	5.8×10^{-4}	[138] [2012]
CNTs	Ethylene vinyl acetate (EVA)	PS	Dispersion and melt mixing	50	[139] [2018]
Bismaleimide (BMI)	Chromium (Cr)	MWCNTs	Grinding and mixing	0.1	[140] [2011]
Carbon	Pristine (pure) Li+	Lithium iron phosphate (LiFePO ₄)	Heat treatment	5×10^{-5}	[141] [2007]
Emeraldine base (EB)	DBSA-doped polyaniline	wt% VDF	Electrospinning, doping, and blending	1.0 ± 0.3	[74] [2016]
(SFG)	Carbon	Lithium cobalt oxide (LiCoO ₂)	Milling	0.005	[142] [2014]
Carboxylic acid	PEO	PAA	Doping and layering	10^{-5}	[143] [2012]
Supercritical carbon dioxide (ScCO ₂)	Ferrous saponite (FSa)	P(EO/EM)	Dispersion and freezing	6.5×10^{-7}	[144] [2012]
Pt/g-Al ₂ O	Pt/CeO ₂	Carbon	Doping and deposition	0.75	[145] [2006]
Reduced graphene oxide (RGO)	Ionic liquid-functionalized carbon material (IL-FCM) (10 wt%)	CB	Oxidization and acid functionalization	10^{-7}	[146] [2015]
Salts and lithium acetate	Methanol	ScCO ₂	Mixing process	2×10^{-4}	[147] [2001]
Anthracene-tetrahydrofuran (THF) ₃	Carbon	Fullerene polymer (Mg ₂ C ₆₀)	Pelletizing and vacuum processing	0.5×10^{-4}	[148] [2013]
ScCO ₂	Lithium trifluoromethane sulfonate (LiCF ₃ SO ₃)	PEO	Mixing and dissociation process	1.8×10^{-5}	[149] [2002]
Zirconium dioxide (ZrO ₂)	Carbon/phosphorus pentasulfide (P ₂ S ₅)	Lithium sulfide (Li ₂ S)	Mixing process	2.1×10^{-5}	[150] [2014]

Findings show how to prepare carbon fiber with a higher porosity using chemical activation methods rather than physical activation methods [132].

Fig. 17 shows a heat treatment furnace used to carbonize fibers and convert them to carbon nanofibers. In one study that assessed the physical and chemical activation of carbon fibers and their adsorption properties, it was reported that the chemically activated carbon fibers failed to continue the fibrous nature of the pre-carbonization fibers. The performance of the fibers in humid conditions remains poor for both physically and chemically has been activated CFs carbon fibers. As well as the fibers physically has been activated pitch-based carbon fibers show decent performance against hexane, but at high

degrees, their performance is poor. Chemically activated PAN-based carbon fibers, when subjected to dry conditions, take less time to reach the maximum breakthrough concentration [155,156].

2.7. PAN electrospun fibers as strain sensors in structural health monitoring applications

Highly moveable and sensitive strain sensors for human body motion monitoring are in great demand in response to any reactions [157]. Electrospun carbon nanofibers that have been fixed in a polyurethane matrix have been used as strain sensors. The piezoresistive properties and strain-sensing

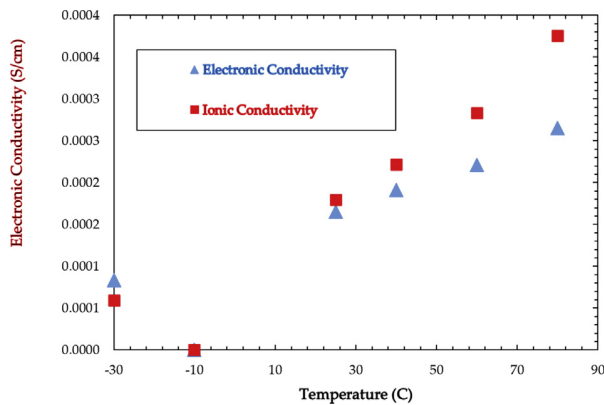


Fig. 15 – The electronic and ionic conductivity of three LiFePO₄ samples [178].

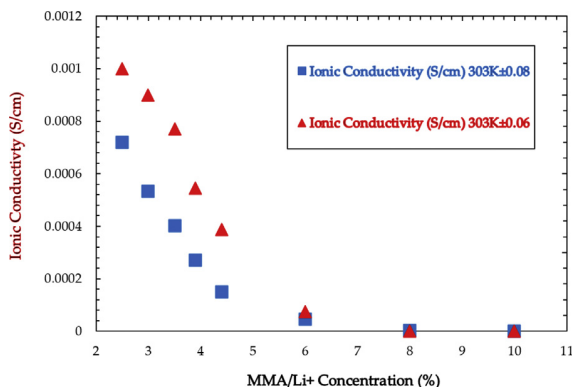


Fig. 16 – Ionic conductivity for different salt concentrations of plasticized MMA-lithium perchlorate (LiClO₄) electrolytes [153].

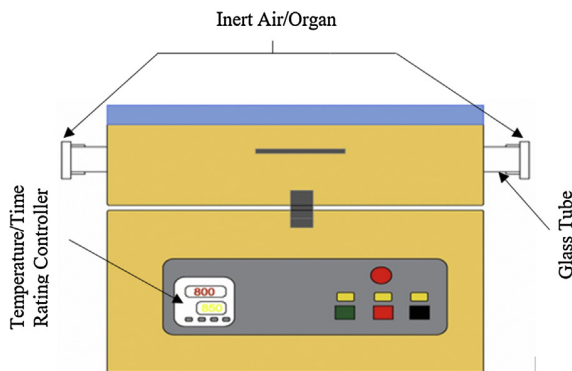


Fig. 17 – Heat treatment furnace used to carbonize fibers and convert them to carbon nanofibers [60].

mechanism of electrospun carbon-nanofiber sensors have been widely discussed in the literature. This type of sensor has high stretching and strain reach 300%, the high sensitivity of the gauge factor in the stretch and release cycles [158]. Again, the bending of the hand, wrist, or moving elbow can be noted by the sensor resistance change, which shows that the electrospun carbon nanofibers strain sensor has talented

applications in flexible and wearable strategies for use in human motion monitoring.

Fig. 18 shows the locations of various sensors located in an airplane structure. Structural health monitoring (SHM) is a method of applying a damage identification approach for all types of infrastructures to estimate the prevailing health conditions in real time and deliver an estimated of the remaining service life of the structures [159]. The purpose of SHM is to monitor the damage in infrastructures by embedding a non-destructive/destructive assessment system into a structure and taking preventive measures before catastrophic failure [157,160,161].

Electrospun nanofibers have unique properties such as extremely high surface area, lightweight, nano-porous features, and design flexibility for particular physical and chemical [163]. In contrast to other nanofiber fabrication techniques, electrospun is straight, multipurpose, and effective of cost for the nanofibers production from materials such as polymers, polymer blends, sol-gels, suspensions, and composite [164]. Electrospun nanofibers and other nanowebs exhibit unique properties that make them applicable in the fields of membranes, biotechnology, textiles, sensors, energy, electronics materials, and the environment [165,166]. In the process of electrospinning, a high-weight of the molecular polymer and high solution absorptions are used, since entanglements and touching between the chains of polymer and uniform nanofibers produce.

2.8. Experimental measurement techniques

The electrical and mechanical characteristics of carbon microfibers could be characterized using various techniques. Carbon microfibers are commonly used as fillers in the composite to evaluate their mechanical and electrical properties [167]. The electrical resistivity, density of mass, and Young's modulus can be determined using simple laboratory procedures. The mechanical Young's modulus is defined by measuring the resonance occurrence of CFs-based cantilevers.

Fig. 19 shows the differences between two techniques for measuring the surface of a carbon fiber composite: a four-point probe contact and a two-point probe. For electrical measurements, the two-terminal resistance between surface contacts separated by an increasing distance can be measured.

The density of the mass of CFs carbon fibers is determined by measuring the mass of a given two factors such material and volume. However, the mixture of the small proportions of CFs with their low values of density of mass makes it challenging to determine the mass of single carbon fiber using laboratory equipment. This limitation can be addressed by using carbon fibers that are supplied in bundles of thousands of individual fibers, the diameter of which is provided by the manufacturer [167]. Fig. 20 illustrates the main purpose of this research by showing a comparison of measurement techniques for static and dynamic Ppy/APS, PAN/DMF, PVDF/PMMA, and dynamic carbon/methyl ethyl ketone (MEK) materials. It is clear that the dynamic load measurement test is much better than the static load measurement test. Fig. 21 summarizes this research work and shows the conductivity value of PAN carbon fibers as a weight percentage.

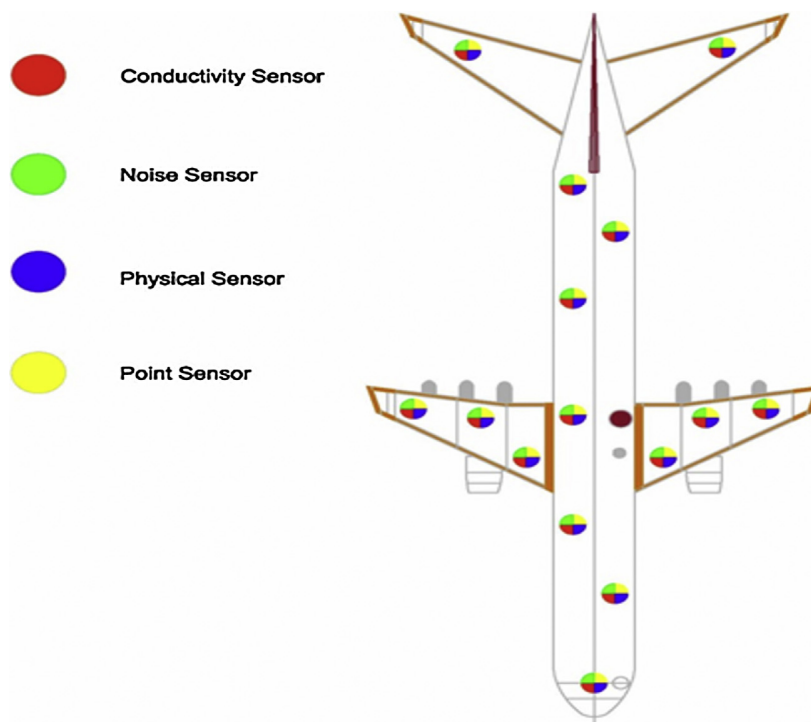


Fig. 18 – Use of composite materials in the manufacture of Boeing 787-B [60,162].

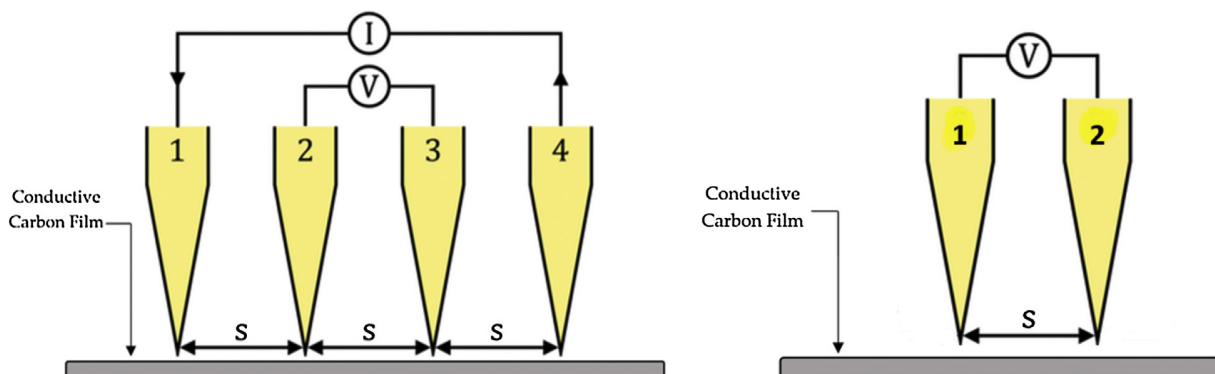


Fig. 19 – Surface measurement techniques: four-point probe (left) and two-point probe (right) [162].

2.9. Single-walled conductive carbon nanotubes

CNTs performance a fundamental role in nanotechnology because of their exceptional structural, mechanical, and electronic properties. SWCNTs are unified cylinders that comprise a graphene layer and have unique electronic properties that change expressively with a vector of chiral, the parameter indicating how a graphene sheet is rolled to form a CNTs [168-170]. SWCNTs have a high electrical conductivity that displays either a metallic or semiconductor behavior. The thermal and electrical conductivities of CNTs are high in comparison to other conductive materials. SWCNTs depend on feedstock materials to manifest their high theoretical conductivity; hence, it is necessary to improve the bulk conductivities of SWCNT ribbons and wires [170,171].

Fig. 22 shows that carbon nanotubes offer an assortment of unique properties that indicate they have huge promise for use in nanoelectronic applications. As can be seen here, at point 2.59 cmΩ, the optional resistivity of the materials dropped down, and at point 1.85 S/cm, their conductivity started increasing.

The high electrical conductivity of quantum wires offers the greatest possible solution for on-chip interconnected metals as well as transistors for future integrated circuits. The one of the challenges in the fabrication of CNTs has been the desire to control whether they are metallic or semiconductors. This challenge is resolved by using the hybrid functional B3LYP in demonstrating the furthestmost precise cohesive energies, ionization capabilities, and electron affinities for a specific range of molecules [164]. One evident attribute is that the

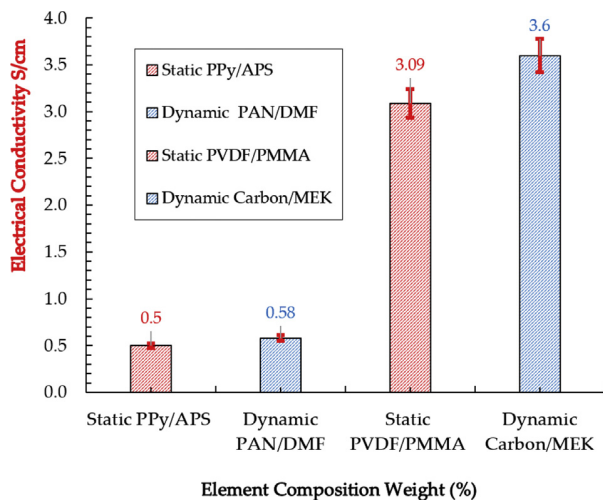


Fig. 20 – The comparison of carbon fibers conductivity (static and dynamic load measurements).

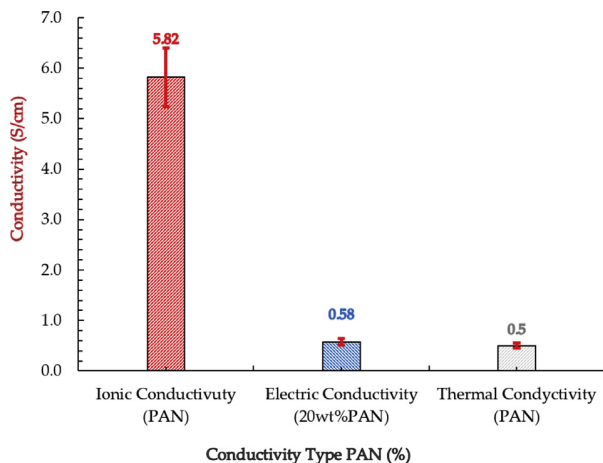


Fig. 21 – The comparison of PAN conductivity carbon fiber from several studies.

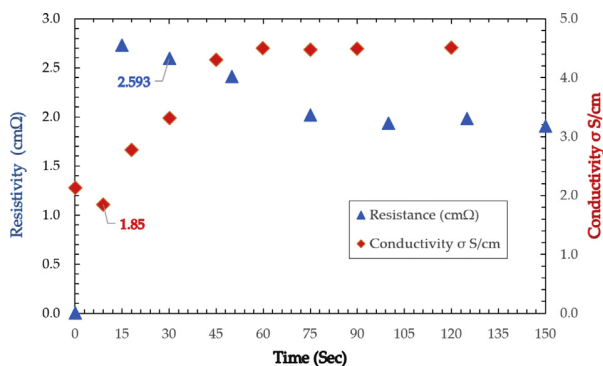


Fig. 22 – Changes in resistance and conductivity vs. time of SWCNTs [77,172].

crystallization behavior indicates that the nucleation of SWCNTs in composites has led to their encapsulation by styrene maleic anhydride (SMA). The implication here is the fact that it resulted in the elongation of breaks in the composites, which is attributable to enhanced adhesion of interfacial between Polyamide 6 and the styrene-maleic anhydride-modified SWCNTs [173].

Additional assessment of the use of single-walled CNTs revolves around the desire to incorporate active functionality into textiles, which has encouraged a significant amount of effort to produce smart textiles, especially electronics. On the electrical attributes of CNTs that are attached to textiles via van der Waals forces as well as hydrogen bonding, with the objective of enhancing their conductivity. Thus, organic molecular anions are extensively used in the dispersal of nanotubes in the water via the formation of adducts with the CNTs. Moreover, SWCNTs are non-covalently being functionalized with dye and consequently dispersed in water while the cotton yarn is treated with poly. The resulting mixture, when immersed into the SWCNT dispersion, leads to the self-assembly of SWCNTs onto the yarn because of electrostatic forces that occur between the functionalized CNTs and the yarn [174]. Single-walled nanotubes fall into the classification of either semiconductors or metals, the choice being dependent on their conductivity, which in turn is based on their nanotube bonding configuration, or chirality [175]. Carbon nanotubes have not yet found a universal application in electronic devices, aside from their electronic properties. Han and Final assert that this has to do with the electronic properties that relate to chirality [176]. They assert that there has been an achievement in the separation of SWCNTs based on their connectivity, thus enriching the distribution of nanotubes with a precise conductivity.

Tang et al. claimed that the assessment of both magnetic and transport attributes of SWCNTs that are embedded in a crystal matrix of zeolite (AFI) indicates that at temperatures below 20 K and 4-angstrom that hold superconducting tendencies manifest an anisotropic Meissner outcome [177]. They further established that these carbon nanotubes had been found to pass a supercurrent between the connecting that leads due to their accuracy. The fact that single-walled nanotubes are formed inside ordered channels of an AFI implies that they are well-aligned and consequently uniform in size. Following the assertion that SWCNTs are isolated from one another, they end up making an ideal 1D CNTs system.

According to Grujicic et al. [178], the reduction in the electronic size and mechanical devices into a nanometer length scale makes the conductivity of thermal for the materials progressively relevant. This is based on the assertion that the operations of such devices could predominantly demand that substantial quantities of heat be dissolute in a tiny region. On the assessment of chirality, the authors establish that this has an impact on the lattice part of the conductivity of thermal in SWCNTs. Considering the scale of the band gap alone, it should be established that the electronic band structure, electron-electron as well as phonon of electron scattering, has an impact on the electronic contribution to thermal conductivity. However, the assessment of lattice thermal conductivity can vary by more than 20 percentage, which can also affect

electronic thermal conductivity [176]. Thus it follows that the thermal conductivity of specific SWCNTs in nanoprobe can vary significantly from one to another.

2.10. Carbon fiber electric resistivity

Overall, the growing demand for effective heat dissipation in electrical as well as electronic devices has made it imperative for engineering materials to be designed with improved thermal conductivity. Also, concerning higher thermal conductivity, improved electrical resistivity could be considered necessary for those applications where materials come into contact with electrical components as leads and wires [179–181]. It follows that ceramic fillers, including boron nitride, aluminum oxide, silica, and aluminum nitride, are used to improve the conductivity of thermal for the polymer matrices as well as maintain their electrical insulating attributes.

$$R = R_c \times A_o \quad (2)$$

$$A_r = \frac{R - R_o}{R_o} \quad (3)$$

Where the contact resistance presented (R_c) is existing in the overlapping area measured A_o , so the amplitude resistance presented (A_r) and R_o is the initial of measured resistivity value. Further studies reveal that reinforced of cement with short CFs carbon fibers has the capability of establishing its strain owing to the impact of strain in the resistivity of the electrical [182]. In this case, resistivity increased upon tension because of the slight fiber pull-out associated with the opening of the crack and decreasing compression following the minimal fiber push-in related to the closing of the crack [183]. Additionally, resistivity variations in directions that are opposite the direction of the stress offer valuable insight into this attribute that has an impact on the piezoresistive effect. Thus, it becomes imperative that scientific and technological issues assess the resistivity in directions that are not associated with the direction of stress [184].

Table 6 shows the effect of temperature on carbon fiber conductivity, which allows researchers to find appropriate material for future research work. Overall, the carbon nanotube-based polymer composite is comprised of materials of multifunctional, which is adding to their function of basic for the physical and the mechanical attribute enhancement make it possible to sense through electrical methods. Conductive composites are mainly found automotive has been significant applications, also electronics, aircraft, and other industries [185]. Due to the electrical elements of CNTs, the aspect ratio is high along with their propensity to create percolated networks in matrices of viscous are extremely low content; they are very effective candidates for the modification of thermosetting matrix components [186,187]. The electrical conductivity of CNTs is directly connected to the strain of macroscopic functional to the material as well as the internal damage that accrues during service [185]. Changes in electrical resistance owing to the applied strain on CNTs composites are attributable to variations in the configurations of the CNTs

conductive network as well as the changes of dimensions for the nanotubes because of their deformation [185].

Traditionally, concrete has been found to be a brittle material characterized by low tensile strength and low strain capacity, which leads to low resistance to cracking. To improve these properties, concrete reinforced with fiber has been developed [219,220]. The use of fiber here is intended to enhance the tensile strength, toughness, flexural strength, and impact strength, thus changing the failure mode through the improvement of post-cracking ductility and controlled cracking. These fibers can additionally exhibit a strong impact when it derives to the electrical properties of the composite in those cases where the added fibers have highly conductive attributes compared to the matrix [219,221–223].

The assessment of interfacial attributes that exist between the fiber and the matrix, as well as the investigation of the relationship between tensile attributes of SWCNTs specimens and the resistance ratio of electrical, reveals some unique attributes. This assessment indicates that, based on the linear relationship, due to the transfer of stress from the reinforcing matrix to the fiber, the SWCNTs ends up breaking first. In this case, the stress delivery along the CFs predicts that the carbon fibers tend to fracture along the tensile lines [224]. In this research, it is evident that carbon black and fibers filled polymer composites of conductive have found applications in numerous high-technology applications comprised of a polymer matrix and fine elements of conductive such as carbon black, aluminum fibers, and carbon fibers as the main reinforcing materials [225,226]. The main challenge associated with the production of conductive polymer composites is in finding reproducible conductivity because the conductivity of electrical along with attributes of mechanical are strongly impacted by the mode of the additive of conductive, the mode of dispersion, and the state of the conductive fiber breakage [225]. Thus, it becomes imperative to choose a standard processing condition for the manufacture of these composites with reproducible properties for a specific conductive filler-polymer system. In the case where the embedded fillers are conducting, this leads to the production of materials whose behavior will be like that of conductive polymer composite [225].

The aspect of sensing the strain as well as structure damage is vital for load assessment, operation control, regulation of the structural vibration, and resulting evaluation of the structural health [227]. Engineering Strain curve rather than engineering stress curve is a measure that impacts a structure, although strain is caused by the application of stress [227]. Furthermore, stress and strain are linked in the elastic rule via the elasticity modulus. The maximum conventional approaches for engineering strain and sensing encompass of damage embedding or attaching a sensor as a sensor of fiber optic, a piezoelectric sensor, along with an acoustic sensor [227]. The less-conventional method is that of self-sensing, which is reached by assessing the electrical resistivity of the structural material, so long as the resistance continues is changing could be correlated with the strain or defect. Sensor. The assessment of resistance encompasses the predominant electrical surface contacts uses along with a meter [225]. The use of a carbon fiber polymer-matrix is recommended because the CFs are the middle in resistivity and the polymer-matrix is completely not conductive, while the composite of

Table 6 – Electric resistivity values of conductive carbon fibers.

Element composition/Weight percentage	Resistivity (Ωcm)	Temperature Range ($^{\circ}\text{C}$)	[Reference] [Year]
0–30 PAN-based CFs	10^{14}	120.6–124.4	[188] [2016]
0–45 styrene-butadiene-styrene (SBS)/PANI/DBSA	9 ± 4	100	[189] [2005]
SiC CFs	10^{-1} – 10^2	800–1350	[190] [2011]
20–80 carbon fiber-reinforced carbon (CFRC)	200–2580	50–300	[191] [2006]
Epoxy carbon-reinforced fiber (CRF)	1.80^{-3} – 2.10^{-3}	100–140	[192] [2005]
10–20 activated carbon fiber cloth (ACFC)	0.19–0.74	20–200	[193] [2016]
PH1816P-3	44–3700.11	500–1300	[194] [2013]
35 CB co-filled with MWCNTs	20–100	20–120	[195] [2012]
2.5–4 PA6/5 MWCNT	10^3	240–260	[196] [2009]
0.5 CRF/2 (ECA)	734	23–105	[197] [2017]
SWCNTs	82306–304370	1618–22,142	[198] [2017]
CNT fibers	0.8–1.9	–64 to –224	[199] [2015]
9–16 CFs	1.8–12.8	20–120	[200] [2004]
Oxidized ACFC)	0.05–0.45	20–220	[201] [2009]
0.5–0.75 continuous carbon fiber (CCFs)/0.5–0.75 self-compacting concrete (SCC)	200^2 – 2500^2	–15–20	[202] [2013]
3–10 CB	5–15	20–220	[203] [2005]
3 vapor-grown carbon nanofiber (VGCFs)/unsaturated polyester resin (UPR)	$0-8.2^2$	20–200	[204] [2008]
9–10 CNTs-PEEK composite	—	20–140	[205] [2011]
0–10 vanadium dioxide (VO_2)/LDPE-PP	7–12.5	20–150	[206] [2017]
2–5.2 high-density polyethylene (HDPE)/2–5 CB	10^1 – 10^4	20–200	[207] [2007]
PAN-based	3.8×10^{-3}	90–140	[208] [2002]
CFs	0.005–0.3	—	[209] [2015]
CNT/PEEK	10^{-4} – 10^{-5}	380	[210] [2013]
CFRP	0.2–1.5	—	[211] [2016]
PAN	2800	—	[212] [2017]
2 acrylonitrile-butadiene-styrene (ABS)	1.32^4 –0.037	23–150	[213] [2000]
P-100 + Br composite	440–580	567– 687	[214] [1991]
CFs	852–2240	–244.15 to –206.15	[215] [2018]
Polyparaphenylene (PPP)	10^{-10^5}	740–680	[216] [2004]
CFs	0.003	21	[217] [2016]
CFs/epoxy composite	1.9×10^{-3}	—	[218] [2015]

resistivity is sensitive to the orientation of the fibers, which is impacted by the damage or engineering strain on the composite [227,228].

Carbon fibers have been incorporated into materials that have been established as a mode of increasing the efficiency of fuel and minimizing the impacts of climatic variation. Their role is linked with being lightweight and increasingly used in the aerospace industry and the manufacture of turbines for wind generation. However, it follows that while carbon material offers significant promise, it has limitations, such as high electrical conductivity, which presents a risk to electrical equipment [229]. This challenge has been resolved via some interventions, as carbon manufacturers have been applying a layer from any size to the freshly manufactured fibers. This layer is made of an aqueous suspension of low molecular weight polymer of a similar type as the expected mix [229]. This size layer serves several functions, such as fibers that can easily be handled and formed into different shapes and products. It additionally serves as some intermediate layers between the resin/fibers in the ultimate composite [230].

The tensile strength of carbon fiber is a vital measure when it comes to the consideration of the application of the ultimate composite product. The increased emphasis to recycle

composite material will enhance the desire to design a classification system of recycled fibers. The determination of the tensile strength makes it imperative that the user knows the tensile force that is to be applied as well as the areas to which the force will be applied [231]. Thus, the use of an electrical impedance measurement technique makes it possible to assess the diameter of individual carbon fibers. The information obtained through this measurement can then be used in identifying the precise number of carbon fibers that are present in a bundle.

2.11. Conductive carbon fiber temperature and weight percent ratio

Progress in diverse scientific and technology fields offers the creation of new materials that meet the expected properties. Some of the attributes that are emphasized in these materials include conductivity, strength, hardness, and heat resistance, among others. Overall, it becomes evident through this assessment that temperature dependencies of electrical resistivity are characterized by a situation where temperature inflection shifts towards the high-temperature composites that have graphene nanoplatelets [232]. This finding implies that there

exists greater impact of direct contact between the filler particles and that it does deviate from the model of effective electrical resistivity. Conversely, the contribution of tunnel conductivity is evidenced by the significant increase in the conductivity of electrical in the microwave range.

Most studies that are accessible in the area of characterization electrical of the CFs polymer matrix concern nondestructive assessment as well as damage sensing in composites [233]. The overall objective has been in the assessment of changes in electrical resistance as well as an electrical field that emanates following the deviations in resistance of electrical and the consequent electrical field that is occasioned by mechanical damage [234,235]. When using electrical characterization tests, it becomes evident that electrical resistance is reduced following an increase in the magnitude of the electric current. It also becomes evident that electrical resistance is reduced following an increase in the plies number that are in the composite laminate and that electrical resistance is a composite function layout [234]. Overall, temperatures in electrified composites tend to increase in tandem with a magnitude as well as the period of the current of electric and the resistance of contact at the junction for the composite-electrode.

Traditional sensing strategies can be undertaken through the use of either an embedded or attaching sensor, which leads to an increase in the cost, or the reduction of durability and consequent deterioration in the performance of the composite. This challenge can be resolved if the composite material uses an intrinsic sensor. A new technique for assessing interfacial attributes as well as curing elements and residual stresses involves the measurement of electrical resistivity for different conductive steel and carbon-reinforced composites [236]. The emphasis here is on how conductive carbon and steel fiber-reinforced composites respond to temperature changes and applied load. An increase in temperature and the modulus as well [237].

2.12. Multi-walled conductive carbon nanotubes

Multi-walled carbon nanotubes have several rolled layers of graphene. They are not well defined related to single-walled carbon nanotubes, due to their complexity and variety of structural [238,239]. However, MWCNTs have advantages over SWCNTs including mass production ease, lower the cost per unit, and enhanced stability of thermal and chemical. The electrical and mechanical properties of SWCNTs can transformation due to defects of structural for the carbon-to-carbon bond, resulting in breakage [240]. However, the properties of MWCNTs can be well preserved by modification of the surface by exposing the outer wall to chemical modifiers [241]. Multi-walled carbon nanotubes are electrically conductive and also have high thermal conductivity [238,239]. The use of cellulose grafting enhances the mechanical and electrical properties of MWCNTs and composite fibers [242]. The new biosensor of glucose amperometric is based on the conductor position of platinum nanoparticles onto the surface of multi-walled CNTs polyaniline nanocomposites as well as glucose oxidase of the immobilizing using covalent interface, and here an absorption effect has been developed. In this case, MWCNTs-polyaniline nanocomposites were synthesized in situ polymerization and consequently characterized by microscopy of

electron, Fourier transforms infrared spectroscopy, and ultraviolet (UV) and visible UV absorption spectra. The process of the electrode modification was investigated via SEM as well as cyclic voltammetry along with optimization of the environmental condition using a glucose biosensor assessment based on detailed chronoamperometry [243].

The covalent modification of MWCNTs using low weight polyhydroxy of molecular is meant to improve the solubility and adhesion of interfacial for MWCNTs in the polymer matrix. This method advances the strategies on how MWCNTs can be employed in the fabrication of microscopic functional as high-performance films or fibers. PHA allows the formation of a thermally superior stable polymer via an additional ring closure in the polycondensation at elevated temperatures. Overall, having demonstrated that increased conductivity can be attained in poly(p-phenylenebenzobisoxazole) (PBO)-MWCNTs composite films as well as the inner core of composite films, although it becomes evident that the outer surface of the fibers does not indicate an increase in conductivity following the addition of MWCNTs.

Kuan et al. have established some unique facts relative to the assessment of multi-walled thermal conductive nanotubes [244]. One of these attributes is that the insulator conductor transmission occurs following the addition of small amounts of MWCNTs in polystyrene-MWCNTs composite systems [245]. Kara et al. also found that optical percolation processes for polymer-CNTs thin film composites can be established by using optical transmission systems. Furthermore, they established that the percolation of the electrical threshold, the point of optical transparency, has disappeared. These attributes imply that the loss in transparency of the optical indicates the start of electrical conductivity, which increases and further saturates in completely opaque composite films.

Multi-walled carbon nanotube yarns have been produced through electrospinning from the sides of vertically aligned MWCNTs displays of 500 μm [246]. In the assessment of their conductivity of electrical, it was confirmed that the electrical conductivity of MWCNTs tends to be decreased by increasing their diameter [246]. This trend is associated with structural variations existing between small-large diameter yarns, principally regarding decreased CNTs migration lengths. The authors further assert that a decrease in the twist angle of the yarns results in their reduced alignment with a larger diameter. Investigations by Jakubinek et al. [246] have established that the smaller-diameter yarn exhibits superior electrical and thermal conductivity than the larger-diameter yarn.

The past few decades have seen development in the production of conducting polymer composites (CPCs) due to their exceptional thermal, mechanical, and electrical properties. This type of composite is prepared via fixing fillers of conductive as carbon nanofibers, metal powder, carbon black, and carbon nanofibers into polymers. Compared to traditional metal-conducting materials, CPCs have been found to have corrosion resistance, lightweight, and adjustable resistivity [247]. It follows that their capacitance, resistance, dielectric constant, and volume have the capability to change, depending on environmental conditions, which makes them excellent electromagnetic shielding materials [248].

A greater number of turns in the preparation of carbon nanotube yarns would lead to an increase in the radial grip, which would make the yarn tighter, thus enhancing its properties of physical. Yao et al. established that the fibers of outer on a larger-diameter yarn tend to be more lightly bound and thus less effective when it comes to contributing to the overall yarn properties. Conduction and stress properties have thus been established as being more uniform across smaller-diameter yarns [249].

Yao et al. also established and functionalization that the covalent of CNTs permits groups of function to be differently attached to the tube caps as well as defective sidewalls [249]. They found that the caps exhibit a semi-fullerene structure, which is vital for the reaction of functionalization to occur. Furthermore, the chemical reactivity of CNTs is strongly impacted by the occurrence of damages, including pentagons and vacancies, which result in a localized increase of reactivity of chemical for the graphic nanostructures.

Overall, the authors demonstrate that MWCNT's can be directly functionalized with octadecylamine to create superconductive, superhydrophobic thin films. It becomes evident that the amination procedure does not demand the use of destructive chemicals, which is in complete contrast to traditional routes for activating MWCNTs, such as oxidation treatment via the use of strong acids or mineral, which can disrupt the pi-stacking structure and consequently decrease the electrical conductivity of MWCNTs.

Li et al. examined the conductivity of PEDOT/PSS thin films doped with diverse MWCNTs, focusing on their role as a favorable enhancement in composite films [250]. They assert that the increased conductivity, in this case, is possibly due to two effects, including π - π interactions and the channel effect. The π - π interactions between the theophany rings of the poly(3,4-ethylenedioxy) backbone and MWCNTs, along with the electronic density transfer, take place from the poly(3,4-ethylenedioxy) to the MWCNTs in PSS/ poly(3,4-ethylenedioxy), whereby the changes become more localized on the PEDOT chains [250]. The latter is found to emanate from the creation of some favorable MWCNTs channels in the poly(3,4-ethylenedioxy)/PSS matrix. The two attributes exhibit the possibility of aiding the charge transport as well as enhancing the conductivity of the conductivity films.

2.13. Conductive carbon nanotube yarns

Carbon nanotubes have great potential in replacing conventional metals because of their significant mechanical, electrical, thermal, and non-oxidizing properties. Their density and thermal conductivity are high in comparison to metals such as copper. Their properties have made them essential in the medical, electronics, and antenna applications [251,252]. The use of carbon nanotubes in yarns has been shown to exhibit frequency-independent resistive conduct and benefits various applications such as ultra-wideband and wireless body area networks [253,254]. The conductivity of electrical a carbon nanotube yarn depends on the properties, loading, and aspect ratio of the CNTs. Other factors include the twist angle and conductive network characteristics [255,256].

A method of fabricating a superior conductive CNTs and the graphene hybrid yarn has been established. The process

starts with displays of vertically aligned MWCNTs that are transformed into long MWCNTs sheets by sketch [253,254]. Graphene flakes are dropped on the MWCNTs sheets through the electrospun process to form the structure of composite that is changed into yarn nanofibers by using the twisting technique. The materials setup are then characterized by microscopy of the electron, and electrical and mechanical measurements. The electrical conductivity of the composite MWCNTs-graphene yarns is more than 9 S/m [255], which is the percentage within 400–1250 percentage higher than the conductivity of electrical for the natural MWCNTs yarns or graphene sheet, correspondingly [253,254]. This increase in conductivity is due to the increase in the state's density close to the Fermi level and a decrease in hopping distance [257].

In assessing the impact of solution conductivity on polystyrene fibers using DMF as the solvent, it becomes evident that different results received from DMF solvent from diverse suppliers exhibit slightly different solution conductivities. Additionally, polymer solutions prepared with the same polystyrene absorption exhibit different conductivities, which impact the morphology of the polystyrene fibers obtained under otherwise similar electroplating conditions. Overall, it has been shown that solutions with higher conductivity produced bead-free fibers from lower polymer concentrations, which are an indication that solution conductivity plays a vital part in the production of uniform polystyrene fibers [258].

The conductivity of thermal for polyacrylonitrile-based carbon fibers occurs via phonons that travel through the medium. Material that has regular atomic structures displays high conductivity of thermal because of the fast-traveling photons via the regular coupling structure. Furthermore, the regular structure of atomic of the material as a polymer exhibits low thermal conductivity due to the complex structural attributes. The thermal conductivity in a unitary polymer change formed by covalent bonds as phonons travel fast through the covalent bonds. Conversely, a thermal conductivity that exists between the nondiverse con-covalent bond chains as van der Waals forces are significantly slow, due to phonon reflection as well as scattering phenomena between the chains [259,260].

According to Jakubinek et al. [248], recent years have seen an increase in nanotube assemblies in a high density of packing, as well as aligned configurations, offering the promise of superior strength as well as transport attributes in microscopic materials. Kim et al. sought to assess the effects of thermal conductivity in free-standing carbon nanotube strands, CNTs yarn-like polymer composite fibers, and CNTs yarn-like fibers [261]. The conductivity of thermal valuations was made using T-type experimental configurations that employed a Wollaston wire hot probe inside a scanning electron microscope. The conductivity of thermal was presumed from an analytical model that associated the drop in spatially averaged temperatures of the wire to thermal contact resistance as well as the thermal conductivity of the sample [248]. It was established that the higher the thermal conductivity associated with the increased stiffness, the lower CNTs-CNTs boundary struggle as well as CNTs alignment along the length of the fiber, which occurred as the result of fiber pulling during the manufacturing process.

Bradford and Bogdanovich sought to demonstrate that CNTs yarns could be utilized along with old-style carbon fibers

to produce three-dimensional (3D) braid performed [262]. The CNTs yarns tested during this study were extremely multifaceted systems of electrically conductive routes entrenched in the epoxy, and that was resulting composite's electrical conductivity had magnitudes greater than those of conventional composites created from the lower volume dispersals. While the authors established that the electrical conductivity of the hybrid 3D-braided CNTs composites was much higher than that of fiberglass, the integration of carbon nanotubes with the CFs pulls resulted in creating an insignificant enhancement of in-plane electrical conductivity.

Abot et al. examined the variations in resistance of the electrical in DC mode, which was studied as a purpose of engineering strain level in CNTs yarns [263]. They asserted that negative piezo resistance is evident in CNTs yarns, which exhibit a parabolic variation in the deformation phase. This assertion is supported by the fact that the subsection of CNTs yarns to tension leads to nanotubes being transported nearer together, thereby dropping the gap between them and consequently the electrical resistance following the reduction of the artificial resistance. Overall, the reduction in resistance of electrical by minimizing the interfacial contact resistance of nanotubes in the CNTs yarn acts as the dominant factor in the piezo resistance response of this yarn.

2.14. Applications of conductive carbon fibers

Carbon fibers are the strongest fibers, with extremely high thermal and electrical conductivity, thereby making them fine applications in electrostatic and electromagnetic interference shielding [264–267]. They are also used for construction antennas and microwave circuits by exchanging the metal with carbon fiber composites [268–270]. Conductive carbon fiber-graphite concrete material has been proposed recently for engineering floor heating. Carbon fiber finds such uses due to its high strength and the modulus, resistance to high temperature, resistance to acidic and alkali corrosion, good conductivity, and flexibility [271–275]. Fiber-reinforced composites such as fiberglass have been used in the aircraft industry due to their high modulus and less weight [276–281]. CFs is also used for making sporting goods such as tennis rackets, golf clubs, hockey sticks, and archery arrows and bows. They are also employed in the manufacture of wind turbine blades and the automotive industry [282–286]. In the contemporary world, most applications of conductive carbon fiber electrodes revolve around the sensors for neurotransmitters. Carbon fiber microelectrodes (CFMEs) have an assortment of advantages, which have advanced their use. One of these advantages is that they are physically compatible and not toxic to cells. Another advantage is that their electrochemistry has been effectively characterized, and they exhibit good electrochemical attributes [287–289]. Also, these carbon fibers employed in electrodes are fewer than 20 mm in radius, which makes them amenable for implantation and result in fewer engineering tissue damage defected and compared to other larger predictable electrodes [290,291]. The conducting fibers, as well as yarns, have been seen as an essential component of the next-generation wearable electronics that have been seen to seamlessly incorporate electronic function into one of the

most versatile as well as widely used modes of manufacturing textiles [292–295].

Further studies reveal that electrically conductive textile coatings, which represent a group of latest established composites, the studies have an applications assortment ranging from static charge dissipaters, sensors, and fillers to electromagnetic interference shields [296,297]. One-dimensional conducting polyvinyl alcohol has been established as a promising non-metal that can be used the applications of a biosensor in solution-processable microfluidic devices because of its hydrophilic attributes, which means that PVA fibers exhibit a good affinity for solutions and thus are desirable materials for detecting the critical contained in solutions [298,299]. Polypropylene is one of the major importance used polymers, offering a balance among strength, chemical resistance, and modulus. PP has a low density, fiber forming capability, low cost, and easy processability, thereby making it suitable for use in the automobile, packing, and textile industries [300]. Its excellent strength-to-weight ratio associated with the carbon fibers along with its exceptional mechanical attributes has increased the use of PP in an assortment of applications in the aerospace, transport, and sports sectors. Also, the quantum wires described as the high electrical conductivity of it's the highest probable solution for on-chip intersect metals for integrated circuits in future [301].

From these studies, it is evident that conductive carbon fibers have numerous applications in the contemporary world. Their physical properties, as well as manufacturing technologies, address both the technical and economic effects of their use in protecting airplane structures [302]. Their incorporation into the cement matrix enhances the flexural strength and tensile ductility, and their ability to adjust electrical conductivity makes them highly advantageous applications, especially in the military [303]. According to Katunin [301], other applications of carbon fibers involve formulations that are planned for utilization in conductive material adhesives because of their high mechanical strength attributes and in the composite of structural panels. The replacement of metal for weight savings and corrosion resistance, making them ideal components for aerospace, medical, and electronics applications [304,305].

An additional application for carbon fibers is in solid polymer electrolytes (SPEs), which have been receiving major attention due to the role as conductors of ionic in diverse electrochemical parts, such as flash memory, solar cells were dye-sensitized, supercapacitors, and the devices of electrochromic [306,307]. Furthermore, carbon nanotubes are believed to act as one of the most hopeful materials owing to their exceptional properties [308]. The inclusion of CNTs even in tiny quantities has shown significant improvement in a product's mechanical, thermal, and electrical conductivity [309–317]. They have a huge range of applications including electromagnetic shielding, fuel emission, gas sensing, and actuation [318].

3. Summary and conclusions

Carbon fibers CFs is one of the most significant materials in today's world due to its superior characteristics of being strong, with high modulus, high tenacity, resistance to high

temperatures, and high thermal and electrical conductivity, when reinforced with other composites. CFs exist in various classifications based on the strength of nanofiber materials and final heat-treatment process temperature. The researchers could be fabricated using standard procedures to obtain the desired type of composite material with unique characteristics in comparison to metals. The important characteristics of carbon fibers discussed in this paper are its thermal, electrical, and ionic conductivity, which have enabled them to be applied to various electrical and thermal appliances. Because electrical devices are becoming slimmer and more integrated, the aspects of electrical conductivity and have become central to the design of these devices. Electroplating methods have been found to offer versatile maneuverability in the production, orientation, porosity, and dimensions of controlled fiber structures. In applications, it is evident that low density offers a fiber-forming capability, the cost is low, and the processability is much easy, thereby making CFs appropriate for use in the automobile, packing, and textile industries. While this study has highlighted an assortment of issues and ways that inform the use of conductive CFs, it is evident that further studies are needed to enhance the effectiveness of these applications. In this study, we have established that the increasing interest in conductive CFs has led to an enhancement in the ways that these components can be used. From this assessment of different studies and properties of conductive CFs, it can be concluded that significant issues related to their electrical and thermal conductivity make them unique. Some of their attributes have made it evident that the enhancements to conductive CFs are associated with the densification as well as purification of the post treatments. It has also been established that the superior electrical attributes along with the flexibility of conductive carbon fibers have demonstrated a likely possibility that they will replace conventional metal wires for use in future.

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