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Electrical Behaviour of Glass/ Carbon- Phenolic Conductive Hybrid Composite Woven Used In Electrostatics Precipitator Filter

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Electrical behavior of hybrid conductive composites made of phenolic resin, graphite woven, glass woven and graphite nano powder has been studied for the first time in the present research to apply as collecting plates in electro static precipitators. To this purpose, two types of four-layer composites smeared with phenolic resin by different amounts of graphite nano powder then produced at 120ºC and 200 bars with proper curing cycle. Finally, electrical resistivity of all the plates undergoing impact loading after different rapping cycles was measured by means of a repetitive rapping tester system particularly manufactured for this task. This study performs changes in mechanical behavior of the samples and their effects on electrical resistivity which can be so effective to choose the proper composite as the collecting plate in electro static precipitators.

Keywords: Electrostatic Precipitators (ESP);Electrical resistivity, Collecting plate; conductive composite; Carbon woven; Glass woven; Phenolic resin; residual strength; Residual Modulus

1. INTRODUCTION

Colleting plates as the main components in electro static precipitators are to collect the dust on their surface in the form of "dust cake". Discharge electrode as negative electrode and collecting plate as positive electrode are applied in ESP. Therefore, collecting plate as grounded electrode should be conductive to make a proper high voltage circuit and collect the dust. In industries with low corrosion environment, mild steel (simple carbon steels like St37 and/or St12) usually used to facilitate the construction while corrosion resistant steels for industries with high corrosion environment and lead, super duplex and super austenitic steels for industries with acid corrosion environment are suitable materials [1]. Recently, applying conductive polymer composites based on thermosetting resins including phenolic, epoxy, ester and etc. combinations have been also taken in to consideration. Material characteristics to construct the collecting plates of ESP are [1, 2]:

1. Electrical resistivity of these plates should be less than 0.1 Ω-cm and not to be less than this value during the operation. The materials applied in these plates must desirably sustain electrical properties against cycle impacts.

2. Tensile strength of these plates should be at least 100 MPa. In addition, their residual tensile strength obligatorily not to be reduced from this value in practical situations.

3. It is necessary the plates could withstand the temperature range 100-120ºC and their electrical properties should not be reduced from this amount under practical situations.

Collecting plates have a great influence on reducing volume, weight and cost of electro static precipitators. Thus, a proper material selection is so important in efficiency and final price of ESP.

In spite of acceptable results for applying metal combinations as the collecting plates in industries with ignorable corrosion and non acidic environment, metal combinations except lead did not perform adequate results for industries with acid corrosion environment. Moreover, lead is not cost effective because of its heavy plates so nowadays conductive polymer composites can be introduced as another candidate for collecting plates.

Compared with many light metals (e.g. Aluminum), polymer composites are light materials which can make accessible particular advantages such as low mass to elasticity modulus ratio up to 50%. On the other hand, if material properties like electrical properties are also considered it will be important to note the materials added to the composite for example, carbon fiber of reinforced polymer composites has relatively low conductivity 0.1-1 Ω-cm in the direction of plate's length and approximately 10 Ω-cm along the thickness [3, 4]. Furthermore, according to the results of some investigations different additives such as carbon combinations including soot, graphite and coke or conductive metal particles as the conductive component of polymer multi-system can be utilized to improve electrical conductivity of polymer composites [5, 6]. Considering other researches, nano-powders and carbon nano-tubes CNTs in the hybrid form with available advanced composites can represent a new solution. Carbon nano-tubes can enhance multiple properties of composites with minimum weight besides their electrical properties [7-9]. With regard to strong carbon-carbon bonding and low defective atomic structure of carbon nano-tubes and graphite nano powder, these materials have several special properties like higher mechanical stiffness and strength, (comparable or higher) thermal and electrical conductivities than metals [10]. Therefore, both conductive components have been utilized due to achieve higher electrical conductivity for hybrid composites in the present study. In comparison with metals, conductive polymer composites are lighter, more corrosion resistant and able to optimize polymer combinations for particular aims. It is possible to obtain individual composites with adequate and controllable conductivity for collecting plates by adding proper amount of conductive particles to polymer composites.

There has been a lack of research on mechanical behavior of carbon and glass fibers reinforced polymer composites under repetitive impact loading in recent years. Jang et al (1991, 1992)'s investigation is the most notable one in studying impact fatigue behavior of composites which was done on graphite, aramid and multi-layer glass fiber reinforced epoxy composites under single and repetitive impacts[11,12]. Furthermore, Roy et al [13,14], Whisleret al [15] Zahidet al [16], and Azouaoui [17], research was done by constructing a particular pendulum impact machine and applying impact loading on the Kevlar, glass and carbon fiber reinforced composites. Since these studies weren't done on conductive composites, their electrical behavior was ignored. Cho et al did a few studies concerning changes in electrical resistivity of multi-layer composites to construct composite bipolar plates under static loading [18].

Mechanical behavior of polymers under repetitive loading has been investigated by many different researches since polymeric matrices form a main component in a composite. Moreover, they studied the effect of alternating impacts on polymer surfaces in terms of energy besides the effect of impact number on mechanical behavior of polymers. They found that under impact fatigue the cracks initiate in the lower surface of the planar polymer samples where the stress reaches to the maximum point. Reduction in mechanical properties is expected as glass and/or carbon fibers reinforced polymer composites grow. Furthermore, these composites probably behave similarly under repetitive impact fatigue. Therefore, impact fatigue has been studied to evaluate mechanical behavior of glass and/or carbon fibers reinforced composites under impact loading. Fundamental mechanism of failure has been realized according to the fracture point analysis. So, changes in electrical properties (electrical resistivity of the composite) has been investigated in the present research after studying previous researches and electrical properties of two series of composites under impact loading. Investigating the changes in electrical properties can be considered as a way to find out the damages produced along the composite piece and utilized as a defects monitoring in aerial industries, aircrafts, etc [10].

2. EXPERIMENTAL

2.1. Material

The hybrid nano composites of this study were improved, including three fundamental components: advanced fiber fabric (with high amount: ~50%), polymer matrix and graphite nano powder with different percentages. In the present research, two types of fabrics; one type with carbon fiber having Young's modulus (231 GPa), tensile strength (4.53 GPa) and fracture strain (1.5%), "Torayca" product and the other one with glass fiber (S-glass) having Young's modulus (86 GPa), tensile strength (4.58 GPa) and fracture strain (0.01%), "Hexcel" product were used as the reinforcement material in phenolic conductive composites. Both mechanical and electrical properties of these two fabrics are represented in table (1). The applied phenolic resin was resol resin with a density of 1.21 g/cm3 under commercial name "Resitan IL800", the Rositan Company's product. The specification of this resin is given in table (2). In addition, the applied graphite nano powder was the Merck Company's product with a density of 2.2 g/cm3 (at 20°C) and particle size less than 70μm and typical particle thickness of 0.5 μm. Cobalt naphthalene and N-N dimethyl aniline were utilized as catalyst, accelerator and promoter, respectively.

Table 1. Specifications of the woven fabric applied as the reinforcement in providing hybrid nano composite.

Typical Property of a filament of Fiber	Glass Fiber	Carbon Fiber
Tensile Strength	4.585 GPa	3.75 GPa
Tensile Modulus	85.5 - 86.9 GPa	231 GPa
Density	2.48 - 2.49 g/cc	1.76 g/cc
Elongation at Break	5.4 %	1.6%
Poissons Ratio	0.22	0.3
Electrical Resistivity of Carbon Fiber	9.05e+10 ohm-cm	18.0e-4 ohm-cm
Dielectric Constant	5.1 - 5.34	
Thermal Conductivity of Carbon Fiber	-	5 W/mK
Velocity of sound, m/s	5850	-

Table 2. Specification of the resol applied as the reinforcement in providing hybrid nano composites.

specification of the resol	
Viscosity (mPa.s)	600-800
Percent of Solid(%)	75±3
Density(g/Cm^3)	1.21±0.02
Resol Type	IL800

2.2. Sample preparation

Two constructed composite families investigated in this study are: (1) four layer hybrid resol phenol composites reinforced with different percentages of graphite nano powder and carbon fabric (abbreviated PRWC), (2) four layer hybrid resol phenol composites reinforced with different percentages of graphite nano powder and carbon fabric in two external layers and glass fabric in two inner layers (abbreviated PRWCG) all constructed as a plate with 200 mm length, 20 mm width and 2 mm thickness. For this purpose, resol phenol was completely mixed with different amount of graphite nano powder (5%, 10%, 15% and 20%) by means of a Brabender Pl2200 blender with a velocity of 60 rmp for 30 min. and finally accelerator, promoter and catalyst (each of them 1%) were added to the mixture. Then, by use of hand lay up method glass and carbon fabrics with similar fiber amount were soaked in the blended resin and molded. At the end, thermal press curing was done after molding at 200 bar pressure and 120°C temperature for 10 minutes.

2.3. Design and manufacture of impact fatigue tester pilot

A particular impact fatigue tester pilot was designated and constructed in order to exert side impact on the sample. This impact tester pilot was constructed in five rows; each includes 5 plates (totally, it is capable to do experiments for 25 plates). Parameters like impact energy, rapping velocity and rapping cycle numbers can be controlled in this pilot. The components of the pilot are: 1- disc rapping hammer with simple two strap arm, 2- rapping bar including two parallel straps which connected to the anvil at the end and impacts on the plates with the contrived pieces. 3- Motor, pulley and strap are used to make rotary motion in hammers shaft. 4- Hammers shaft including a bar being attached to hammers arm. 5- The whole structure of the pilot. In this tester pilot, a horizontal rotating shaft which coupled to a gearbox motor (with external rotation 36 rpm and power 0.25 KW) through pulley and strap make the mounted impacted hammers rotate around the shaft axis. These hammers with an h-long arm impact the anvil by its gravity. Then, the anvil connecting to planar samples impacts to all the plates. So, an impact with the same energy applies on the plates in each motor rotation the hammer rotates again after each impact, goes up and impacts the sample till it's damaged. In addition, shaft rotation numbers is recorded by a censor to record all the imposed impacts. Compared with the conventional impact testers which used to examine fatigue in composites based on Charpy Impact Tester (Sarkarand Glinn ،(1971), Maityand Sarkar (1992)) much more cycles besides studying the effect of wave propagation caused by the impact through the plate can be available with the designed and manufactured impact tester of this work because it applies side impacts (plates thickness) on the plates. (In previous testers, the damage was made exactly in the region of the plate that the impact directly applied and the whole sample was not considered). In the connections of composite plates, all the plates' connections are similar, at top, snag-formed and it's avoided to screw the plates.

In the experiments, hammer mass, m, is 400 g and the length of hammer arm from rotation center to hammer mass center equals 50 mm. The hammer releases with a primary velocity of V=0.2 m/s and at 180° relative to the anvil. Therefore, impact energy of the hammer (E) before applying impact on rapping is given by equation 1.

$$E = 0.5mV^2 + mgh \qquad (1)$$

2.4. Measurement of electrical resistivity of samples

Volume electrical resistivity of the samples was measured with direct method and according to standard ASTM D257-99. On the other hand, surface resistivity of the samples was gained using two-probe technique according to standards ESD STM 11.11/11.12 and ASTM D257 besides four-probe technique according to ASTM F390-98. These measurements were done by JPS 303D Dual DC Power Supply, manufactured by Afzar Azma, and two multimeters manufactured by Hioki Company.

2.4.1. Measurement of volume electrical resistivity through direct method

This method is a very simple and economic method (because it just needs two probes and one multimeter). But measured data were utilized more to compare with volume resistivity [19]. In this technique, two electrodes are connected to the two ends of the sample from one side in order to measure the resistivity be means of a multimeter. Then specific electrical resistivity will be obtained having sample dimensions. Main problems of this method causing inaccurate measurement in determining the conductivity are resistivity of electrodes contacts with the sample in addition to measuring the human error.

2.4.2 Electrical resistivity of samples by two-probe measurement

Although two-probe technique is simple and cheap (because two probes are only needed) interpretation of the measured data is difficult [20]. In this method, two electrodes are connected to the sample to determine its specific resistivity having the resistivity and dimensions of the sample. The main problem of two –probe is resistivity of electrodes contacts with the sample which leads in inaccurate measurements [20]. According to figure (1), two - probe has two contacts which used as both current and voltage connections. It is necessary to have total resistivity of the circuit considering equation 2 to obtain electrical resistivity of the sample.

$$R_T = \frac{V}{I} = 2R_W + 2R_C + R_{DUT} \qquad (2)$$

Where, R_w: probe or wire resistivity, R_c: contact resistivity, R_{DUT}: device resistivity.

Wires are utilized to construct electrical connections which are more conductive than the sample. In such these cases, wires resistivity is ignorable in comparison with sample resistivity while contacts resistivity are normally considerable and this matter makes limitation for two-probe method [20].

Due to low current in applied multimeter the measured resistivity is less precise. So two-probe measurement was used for bulky samples. Copper tapes were utilized as contacts with the sample which attached at both ends of the samples. Circuit of figure (1) was then established and since there is possibility of temperature increase for the sample after applying voltage on two sides of the sample, the temperature effect on the sample can be preventable by applying the voltage discretely.

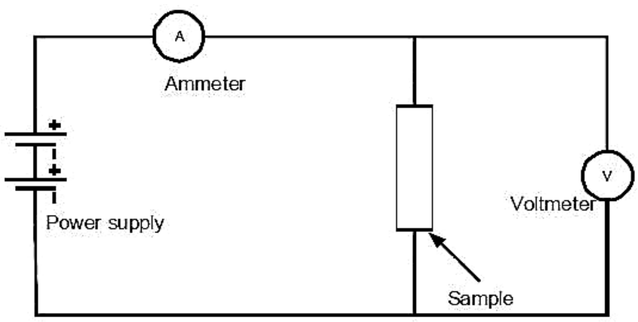


Figure 1. Schematic diagram for resistivity measurement with two-probe method

Electrical resistivity is specified from diagram IV and repetition in all samples. The polarity of all samples was varied during the experiment and because the resistivity was almost similar it can be resulted that there was no preferred direction in sample structure.

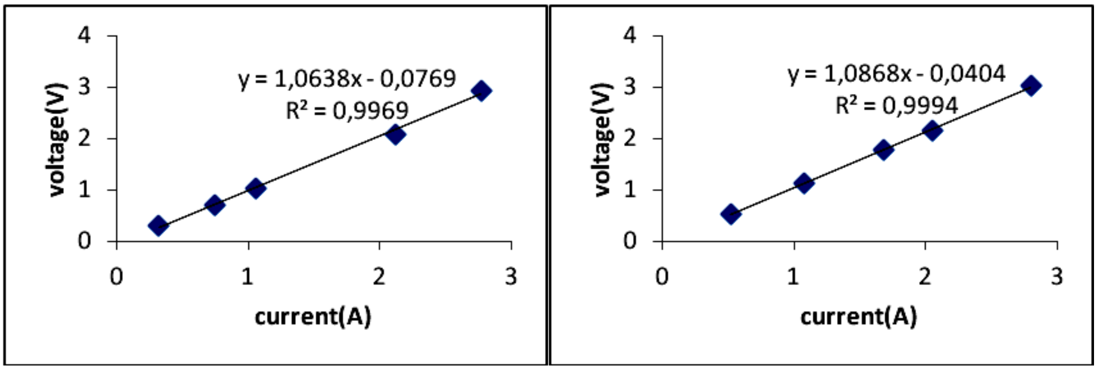


Figure 2. V-I diagram with variation in samples polarity

For example, the diagram of figure (2) shows that the samples are Ohmic or in other words shows that resistivity is independent of voltage. Applied voltage didn't exceed the ultimate value for all samples and normally they heated up rapidly at this voltage. As seen in the diagrams of figure (2), electrical resistivity of the sample measured in both polarities was equal that can imply that sample is non-diode (non-linear).

2.4.3 Electrical resistivity of samples by four-probe measurement

Although four probes or four contacts are used to determine electrical resistivity of samples and current path is as same as two-probe technique as shown in figure (3), voltage is obtained by two added contacts. The current passing the voltage path is very low however it still includes R_W and R_C because of enormous electrical impedance of voltmeter (around $10^{12}\Omega$ or more). Therefore, voltage drop around R_W and RC are extremely small that can be ignored. As a result, the measured resistivity is so close to the sample resistivity[20].In measuring electrical resistivity of composite samples with four-probe technique, contacts distance was considered 2 to 5.5 cm according to the sample dimensions (length: 20 cm and thickness: 1.5mm). Copper tape was utilized to attach the contacts at proper distances.

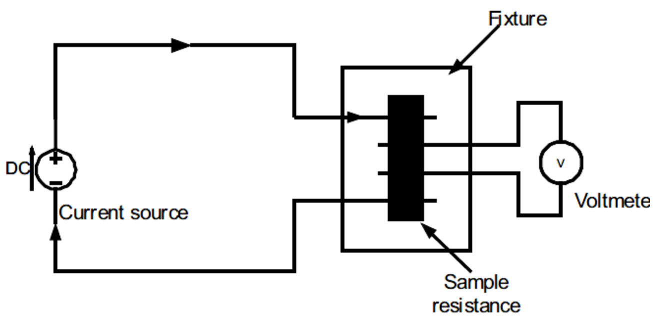


Figure 3. Schematic diagram for four-probe measurement.

The power supply was similar in both methods but in four-probe measurement it was set at 30 mA then positive and negative polarities were connected for some minutes to avoid current variation so power supply performed as a current supply. Another precaution is related to the temperature. Since sample temperature has no effect on its resistivity, after voltage variation voltmeter was hold and power supply was put on standby in order to prevent heating sample and connections through passing current. The later precaution was observed in two-probe measurement.

The connections with composite samples are shown in figure (4) for both two-probe and four-probe techniques. The two contacts at the end (black and red colors) are related to two-probe measurement while two inner contacts (yellow and red colors) are just for four – probe measurement. Dimensions and distances are precisely given in table (3).The contacts at the end are only belong to measuring by two – probe method while both inner and outer contacts are related to four – probe measurement.

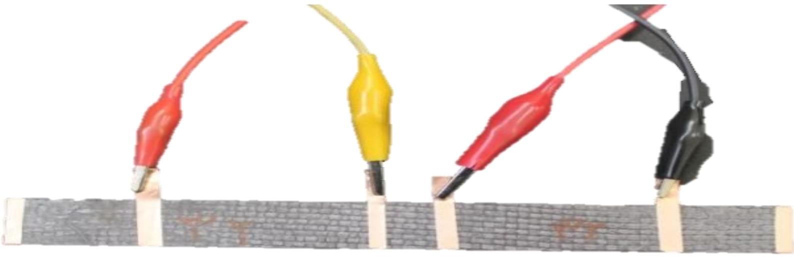


Figure 4. Connections with composite samples to measure electrical resistivity

Table 3. Dimensions and distances applied in measuring electrical conductivity of composite samples

Type	Two point probe method	Four point probe method
Space Probes (mm)	195mm	S2=20mm , S1=S2=55mm
Length of Samples(mm)	182mm	195mm
Cross-Section Samples(mm^2)	30 mm^2	30 mm^2
Surface Resistance (Ω-cm)	$\rho = R\frac{A}{L} =$ 0.0165R	$\rho = \frac{\pi}{\ln(2)} t \frac{V}{I} = 4.532 t \frac{V}{I}$ ρ =0.6798R

2.5 Tensile test

Two constructed composite families investigated in this study are: (1) four layer hybrid resol phenol composites reinforced with different percentages of graphite nano powder and carbon fabric (abbreviated PRWC), (2) four layer hybrid resol phenol composites reinforced with different percentages of graphite nano powder and carbon fabric in two external layers and glass fabric in two inner layers (abbreviated PRWCG) all constructed as a plate with 200 mm length, 20 mm width and 2 mm thickness. For this purpose, resol phenol was completely mixed with different amount of graphite nano powder (5%, 10%, 15% and 20%) by means of a Brabender Pl2200 blender with a velocity of 60 rmp for 30 min. and finally accelerator, promoter and catalyst (each of them 1%) were added to the mixture. Then, by use of hand lay up method glass and carbon fabrics with similar fiber amount were soaked in the blended resin and molded. At the end, thermal press curing was done after molding at 200 bar pressure and 120°C temperature for 10 minutes. Figure (5a) and Figure (5b) respectively illustrates the layer composites PRWC and PRWCG.

According to ASTM D3039 tensile tests were done with the samples (length: 200 mm, width: 20 mm, thickness: 1.5 mm) for both hybrid composite families (PRWC & PRWCG). The samples were prepared through end-taps connection of epoxy- glass fabric composites and attached with special glue. This process resulted in more available area for the samples to do tensile tests.

Tensile tests of the samples were done bySTM-150 series Santam universal testing machine with pneumatic Wedge grip and STt-100D series Santam Extensometer with approximately constant cross velocity 2mm.min-1 and at room temperature.

(a) (b)

Figure 5. Four-layer hybrid nano composite samples, (a) PRWC and (b) PRWCG

3. RESULTS AND DISCUSSION

3.1 Tensile resistivity results of investigated composite families

Fatigue is known as the responsible for most defects in composites. According to the experiments fiber reinforced polymer composites, glass and/ or carbon woven fibers and etc., are encountered to changes and reduction of mechanical properties under repetitive impacts. So, designers have paid attention to this issue. These structures are often fluctuated because of successive dynamic loads. This matter leads in delamination and defect in composite components such as background phase (matrix) and/or reinforcement phase under material fatigue.

To this purpose, mechanical properties of two composite families were compared by doing tensile test on all samples under impact loading in impact tester after passing different rapping cycles. The results of tensile tests for all samples of these two families are given in Table (4). Table (4) also indicates the results obtained for mechanical properties of samples like elastic modulus, tensile strength and fracture mode in tensile test of each hybrid composite family. According to these results, hybrid composites of both families show significant increase in mechanical properties by adding graphite nano powder. The highest tensile strength belongs to PRWCG family with 20% graphite nano powder (almost 238.4 MPa) while PRWC family has the highest amount of tensile modulus (60 GPa).

Considering these results, graphite nano powder shows an acceptable compatibility with phenolic matrix and glass and carbon fiber reinforcements. This compatibility and increase in mechanical properties of background matrix and probably in interface adherence of components consequently enhance mechanical properties of composites of these two families.

Moreover, comparing mechanical properties of the samples of the same family and with a same hybrid combination under different rapping cycles it was shown mechanical properties of all composites noticeably reduced with increasing number of rapping cycles under impact loading. Simultaneous reduction of strength, stiffness and toughness of both families because of composite fatigue was observed. Finally, all composite samples were suffered delamination failure in rapping cycles over 2*106. Therefore, samples have a strength limit against delamination in these values. Since non-delaminated samples endured near 50% of rapping cycles (50%-N) for residual mechanical properties in rapping cycles below 106, mechanical properties like tensile strength, elastic modulus and stiffness of both PRWCG and PRWC families can be compared for both main samples and 50%-N through tensile test. Although noticeable reduction of the properties was occurred in these samples but under loading composites still sustained fatigue without any damage and delamination. Reducing behavior in mechanical properties such as residual modulus and strength are approximately equal for both composite families. Differences in values of residual mechanical properties are represented in table (4). Composites of PRWCG family without graphite nano powder indicated more reduction in the properties compared with other composites. This matter may be referred to high fiber fracture particularly glass fiber and delamination of composite layers through matrix separation and/ or cracking.

Table 4. Results of tensile tests of the composites

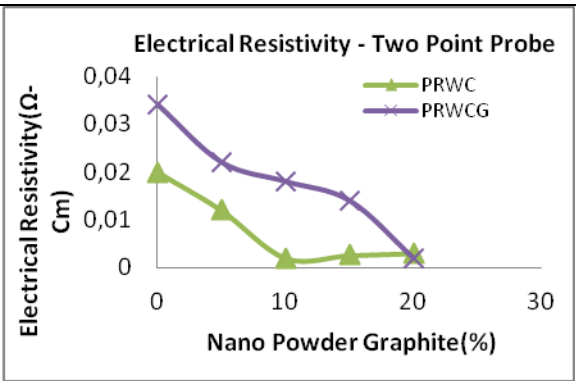
Composite	Residual Tensile Strength (MPa)	Percent reduction in strength (%)	Residual Modulus (GPa)	Percent reduction in strength (%)	Failure Modes
PRWC					
Before impact	153.1	0	30	0	DGM
After 2.0E+05 impact	130.7	14.6	19	36.6	DGM
After 1.0E+06 impact	80.5	47.4	10	66.6	DGM
After 2.0E+06 impact	72.9	52.4	7	76.6	EGM
PRWCG					
Before impact	139.2	0	30	0	MGM
After 2.0E+05 impact	107.6	22.8	10	66.6	MGM
After 1.0E+06 impact	71.4	48.7	5	83.3	MGT
After 2.0E+06 impact	38.4	72.4	2	93.3	MGT
PRWC (with20% Nano powder Graphite)					
Before impact	211.9	0	60	0	DGM
After 2.0E+05 impact	138.5	34.6	26	56.6	DGM
After 1.0E+06 impact	81.6	61.5	8	86.6	DGM
After 2.0E+06 impact	69.9	67	5	91.6	DGM

PRWCG(with20% Nano powder Graphite)					
Before impact	238.4	0	38	0	MGM
After 2.0E+05 impact	164.8	30.9	24	36.8	MGM
After 1.0E+06 impact	110.9	53.5	9	76.3	MGM
After 2.0E+06 impact	69.6	70.8	7	81.6	MGT

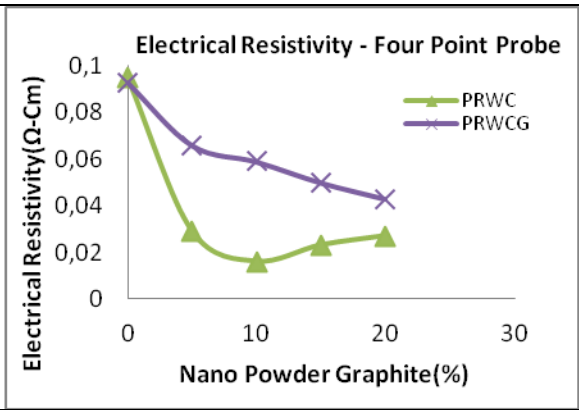
In rapping experiments, samples of different families under distinct rapping cycles were endured fatigue but they weren't fractured or delaminated. So, as seen in table (4) in rapping cycles below 2000000 impacts mechanical properties of the samples with hybrid fabric (glass and carbon) shows more reduction in comparison with other samples about 72% for residual strength and 92% for modulus. Another sample of this family indicates a reduction of around 71% for residual strength and 82% for modulus by adding 20% graphite nano powder. Besides, fracture mode of different samples tested by tensile test according to ASTM D3039-00 is classified in table (4). All parts of the samples were examined after tensile test and the fracture accuracy was investigated through cutting and / or lamination in the interface of laminates. Some samples indicated a fracture close to the gages as mentioned in ASTM D3039-00. So, all distinct fracture modes are considered valid and used to calculate modulus and tensile strength of tested samples.

3.2. Comparison of electrical resistivity between two composite families

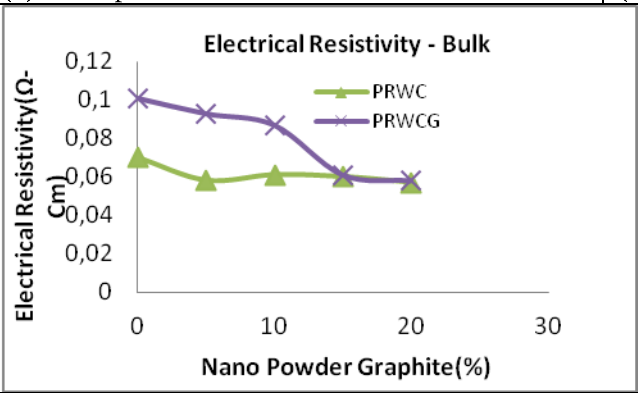
The results of the electrical resistivity obtained by direct, two–probe and four–probe measurements for both composite families of this research, carbon fabric reinforced hybrid phenol resol composite family with different amounts of graphite nano powder (PRWC) and glass and carbon fabric reinforced hybrid phenol resol composite family with different amounts of graphite nano powder (PRWCG), illustrated in the diagrams of figure (6). According to the three diagrams of these figures, Increase in nano powder amount added to hybrid composite cause reduction in surface and volume electrical resistivity of both composite families. But this resistivity reduction is not uniform and linear with various percentages of graphite nano powder. It means that reduction behavior is not the same in two families. Surface electrical resistivity shows a notable drop and then remains constant in carbon fabric reinforced hybrid phenol resol composite family with a certain amount of graphite nano powder (about 10%)while volume electrical resistivity varies insignificantly. In hybrid phenol resol composite family reinforced by carbon fabric in superficial layers and glass fabric in inner layers and with different amount of graphite nano powder, reduction pattern in surface electrical resistivity is similar with the first composite family but it keeps on reducing in higher amounts. Moreover, reduction in volume electrical resistivity of PRWCG samples is noticeable as compared with PRWC ones. This point is predictable with regard to the material of inner woven layers (glass). Slight reduction in electrical resistivity indicates that both composite families left behind their conductivity threshold having conductive fabrics before adding conductive powder, in addition, graphite nano powder is only capable to enhance conductivity.



(a):Two-probe measurement



(b): Four-probe measurement



(c): Direct and reverse measurement

Figure 6. Effect of graphite nano powder on surface electrical resistivity of PRWC and PRWCG

This matter can be so effective in many applications particularly in ESPs. According to many researches, conductivity threshold value varies depending on conductive additive type, background polymer type and process conditions [21-25]. Another important point is the similarity between electrical behaviors of two curves given in figures (6a), (6b) and (6c) with insulating to conducting behavior of insulated polymers which become conductive by adding additives. So, the effect of adding conductive nano powder to both conductive and insolated composites is seen while in previous researches the effect of conductive additive to insulated polymeric background showed an intensive increase in conductivity up to several orders of decimal. In present study, increase in conductive nano powder added to the composites conducted with conductive fabric follows the similar insulating to conducting behavior of insulated polymers and shows conductivity increase only in lower range.

3.3. Studying electrical resistivity variations of composites under impact loading

Considering the fractured samples in tensile tests after rapping by different rapping cycles, damage occurrence in background matrix besides its development up to fabric reinforcement phase simultaneously cause reduction in mechanical properties like strength and stiffness. Therefore, it is considered that samples sustain damage and its development in different rapping cycles. So, these damages effect on other composite properties as electrical properties of these materials. The investigation results on electrical behavior of two distinct hybrid phenol resol composite families, one composite reinforced by carbon fabric (PRWC) and the other one reinforced by glass and carbon fabrics (PRWCG), under impact loading with two different amounts of graphite nano powder are illustrated in figures 7, 8 and 9.

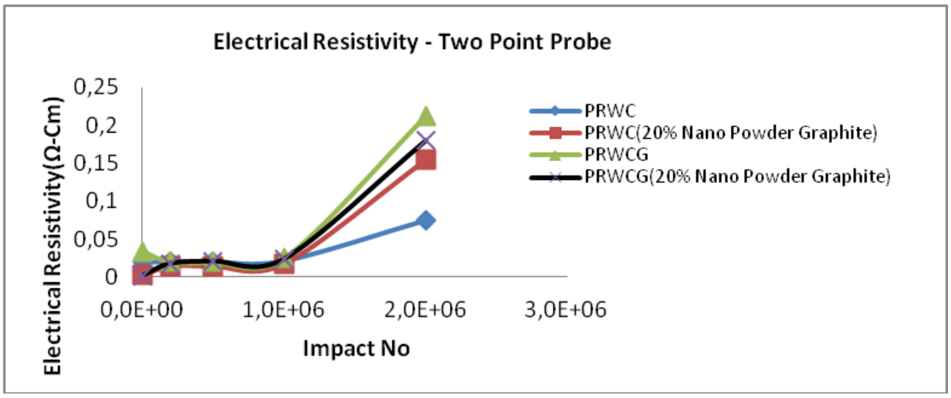


Figure 7. Impact effect on surface electrical resistivity of PRWC and PRWCG (Two-probe measurement)

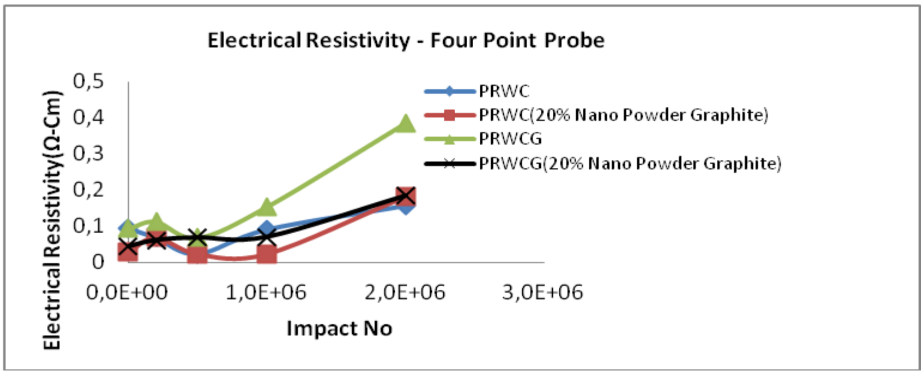


Figure 8. Impact effect on surface electrical resistivity of PRWC and PRWCG (Four-probe measurement)

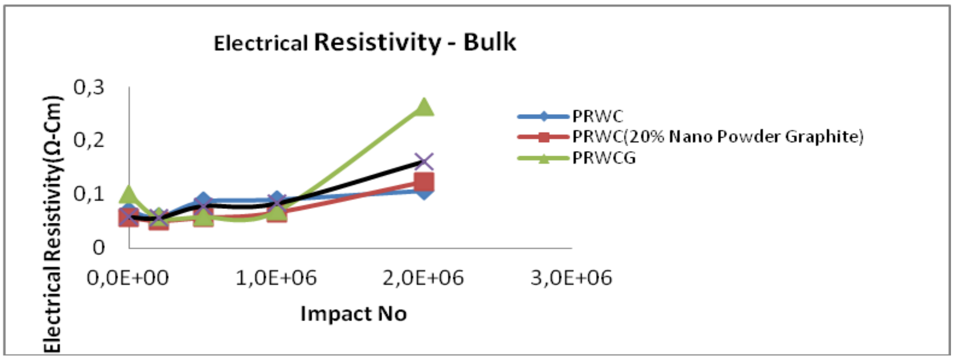


Figure 9. Impact effect on surface electrical resistivity of PRWC&PRWCG (Direct measurements)

According to these figures, all four composite samples behave so similarly and frequently in slight reduction and increase of electrical resistivity under repetitive impacts below 1000000 impacts. After this value, electrical resistivity of the samples increases around 2000000 impacts. This similar electrical behavior of all distinct composite samples implies similar events in composites fatigue tested under repetitive impacts.

4. CONCLUSION

The results of present research in studying two aspects of mechanical and electrical behaviors of two composite families and the effect of mechanical behavior on electrical properties of composites reveal that:

Hybrid composites of both two families show significant increase in mechanical properties and electrical conductivity by adding graphite nano powder as the maximum amount of tensile strength (about 238.4 MPa) is related to PRWCG with 20% graphite nano powder and the maximum tensile modulus (60 GPa) is for PRWC. Non-linear and non-uniform variations occur in both surface and volume electrical resistivity by changing the amounts of graphite nano powder that reducing behavior in electrical resistivity of two families is relatively different. Surface electrical resistivity noticeably drops at first in carbon fabric reinforced hybrid phenol resol composite family with a certain amount of graphite nano powder (about 10%) and then it becomes constant. Impact fatigue behavior of two composite families with graphite and/or glass fabric reinforced resin is observed in rapping cycles up to 2*106 impacts. In the same rapping cycles, both composite families give similar gradual reducing behavior for mechanical properties. Cycle rapping reveals mechanical behavior changes with creating cracks in phenolic matrix through the contact stresses which produced because of the impacts. Fatigue damage initiates due to the failures by unifying and propagating along the interface of composite layers. The cracks caused by cycle impacts enhance in size and number which leads in strength and stiffness dissipations till these cracks develop and make damages in composites. Tested samples of composite family with dominant fabric properties show higher fatigue properties. PRWCG composites without graphite nano powder indicate more reduction in properties compared with other composites which can be referred to the high fiber fracture particularly glass fiber and delamination of composite layers through matrix separation or crack. Finally, while mechanical properties like strength and stiffness are reduced the produced damages effect on the other composite properties including electrical properties. The results of studying electrical behavior of two different families of hybrid phenol resol composites, one composite reinforced by carbon fabric (PRWC) and the other one reinforced by glass and carbon fabrics (PRWCG), under impact loading with two different amounts of graphite nano powder show very similar and frequent behavior in slight reduction and enhance of electrical resistivity until representing electrical resistivity increase after 2000000 impacts. This similar electrical behavior of four different composite samples indicates occurrence of similar events in fatigue composites tested under repetitive impacts.

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