Examination Of Electrical Behaviour Of Unidirectional Epoxy-Carbon Fiber Composite Under Tensile Load By Experimental Method.

Prathmesh Chopade, Mahesh Pradhan

Abstract: Composites are modern materials which are currently used in almost all areas of technology. Because of the versatile behaviour of composites, analysis of composites is required to be done. In this work a unidirectional epoxy-carbon fiber reinforced composite was subjected to tensile load. While loading, the electrical resistance measurement is done using Kelvin's four-wire method. Electrical contacts were made by epoxy-silver adhesive on the specimen. Connecting wires were attached with the epoxy-silver adhesive. The results obtained during tensile test were analysed to study the mechanical and electrical behaviour of the composite and their correlation which could be helpful in predicting the performance of composite materials.

Keywords: Composites, Tensile loading, Mechanical and electrical behavior

1. INTRODUCTION

Carbon-containing polymer composites are widely distributed in various fields, mainly in the aerospace, military, automotive and engineering industries. Composites have outstanding properties such as light weight, high strength, flexibility and the ability to customize directional strength. Among the many composites available, an epoxy carbon fiber composite is preferred because of its versatility. With increasing use of the composite, the aspect of reliability and monitoring of the composite has been widely studied. Carbon fiber composite materials shows electrical conductivity. It implies that the material itself might be applied for self-sensing without need of any additional sensors needed to monitor its structural health [1]. Even though carbon fiber composites being self sensing, it is necessary to perform a comprehensive study to check electrical and mechanical behavior of the composite and establish the relationship between them if any. The change in electrical resistance in composites is mainly associated to deformation, delamination and percolation [2]. Recently extensive research is being made to study the behaviour of carbon-fiber composite electrical characteristics with respect to stress and strain occurred. Methods with two wires and Kelvin's four wires are popular for recording the electrical resistance characteristics of composites, whereas Kelvin's four wire method is preferred because of its high accuracy [3]. Work has been done to determine the electrical resistance behavior of multilayer multidirectional carbon fiber composites with respect to deformation [2]. The strain sensitivity (gauge factor) was found to be −35.7 to −37.6 for the longitudinal resistances[4]. A study was made of the effect of carbon nanotubes on the mechanical and electrical properties of composites, which are compared with carbon fiber, glass reinforcement and other polymers [5].

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The influence of various fillers, such as CNT, carbon black, on polymers, including polypropylene, styrene butadiene and PEEK, on their electrical resistance characteristics with deformation is carried out to establish a connection between them [3]. Carbon nanotubes (CNTs), MWCNTs (Multi Walled Carbon Nano-Tubes), CB (Carbon Black), CFs (Carbon Fibers) can be used as conducting reinforcements [3]. CNTs, CB can also be used as fillers to improve mechanical properties of composites. Silver paste electroplated with copper can form electrode for electric wire contact [6]. Silver paste, conducting adhesive copper tape, brass lugs are preferred in the researches performed [7][2][8].

2. Experimental Process

A composite sheet was manufactured by hand layup and heat curing technique followed by waterjet cutting. Tensile test was performed as per ASTM D-638 standard on a unidirectional epoxy-carbon fiber composite with volumetric ratio of 60% carbon fiber-40% epoxy and 6 layers. Tensile test was performed on UTM and for the electrical resistance measurement, Kelvin's four wire method was used to indirectly measure the electrical resistance behavior at constant current. Constant current supply was given using regulated DC power supply and voltage change is measured and logged using Arduino controller. Using the fundamental relation the resistance of the specimen was measured.

A. Manufacturing of Epoxy Carbon Fiber unidirectional composite sheet

A composite sheet manufactured in Diamond Crafts Industries, Bhosri MIDC, Pune. Carbon fibers supplied by Hindoostan Technical Fabrics ltd. with 3K unidirectional fiber tow and 160 GSM. A mould of 350X350 mm was used to put 6 layers of composites and epoxy by hand lay-up technique with volumetric ratio of 60% carbon fiber-40% epoxy. Epoxy was made of Araldite MY-740, 100 pbw (Parts by weight), Hardeners HY-918, 85 pbw and Accelerators DY-062, about 2.5 pbw. Initially compression moulding was performed by pressing the mould between two hot surfaces of about 110^0C temperature for about 10 minutes. To prevent the sticking of epoxy with the upper and lower mould plate, a BOPP (Biaxially Oriented Poly Propylene) layer was placed to cover the sheet. To provide the high strength, post curing was performed at about 150^{0}C for about 2 hrs. The pressure was kept 2.94 MPa through the processing.

Fig. 1. *Compression moulding of epoxy-carbon fiber sheet*

B. Waterjet machining of Epoxy Carbon Fiber composite sheet

The epoxy carbon fiber composite sheet was cut by Water Jet Machining method at Kakade Lasers, Narhe, Pune. Cut was made along the carbon fiber direction for a unidirectional tensile test specimen. Specimen was cut according to ASTM D-638 standard. A water jet machine made by Shuttle Water Jet, China, was used to cut the composite sheet under a water pressure of 50,000 psi (about 345 MPa).

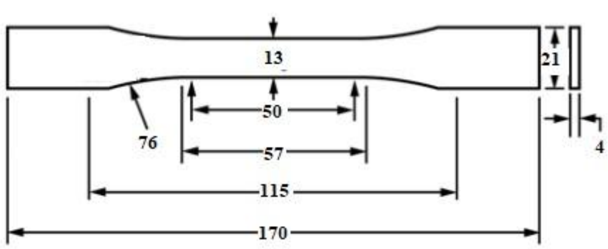

Fig. 2. *ASTM D- 638 Specimen dimensions[9]*

C. Specimen Preparation

The specimen was polished with a sand paper to remove the upper epoxy layer. Epoxy-Silver paste adhesive with resin and hardner used was provided by Coatex Industries, Pune, having surface resistance less than 1Ω per square cm. Fine strips of adhesive were made with the help of brush on the gauge length and 5mm apart the gauge length so as to get 4 strips of which 2 at longer distances were for constant current supply and remining 2 on gauge length were for voltage measurement. Copper wires were then attached on the specimen. Another layer of epoxy-silver adhesive was applied on the wires. Specimen was allowed to dry for 6 hrs. To avoid the dislocation of the wires, adhesive tape was applied on the contacts.

Fig. 3. *Specimen of epoxy-carbon fiber composite*

D. Power supply and voltage measurement

Aplab single channel regulated DC power supply was used under constant current (CC) mode as a constant current supply. The supply was capable of providing maximum 32 V DC under the maximum allowable current of 2 A. The applied current for the specimen was 0.12 A and the maximum allowable voltage was set to 12 V. Arduino Uno of 10 bit ADC was programmed and connected to read the voltage changes occurring in the specimen under constant current as per the principle of Kelvin's four wire method. The Arduino had resolution of 1mV for measurement of voltage variations.

E. UTM Tensile Test

Tensile test was performed at Praj Metallurgical Lab, Kothrud, Pune on UTM manufactured by Star Testing Systems, India, Model No. STS 248. Gradual displacement of 5mm/min was applied. In the tensile test the stress was recorded with the data acquisition system present in the machine and extensometer was used to measure strain. Values of voltage change were taken with the Arduino Uno using its inbuilt ADC and internal reference voltage of 1.1V under constant current supplied by Aplab single channel DC power supply.

Fig. 4. *Tensile test setup*

The UTM maximum load 100kN. The grip used was of range 0 to 7mm flat.

F. Stereo Microscopy

Stereo microscopy was performed at Praj Metallurgical Lab, Kothrud, Pune with stereo microscope manufactured by Wuzhou New Found Instrument Co. Ltd., China of model number XTL 3400E with the magnification of 20X. Stereo microscopy was used to study the lamina structure of the unidirectional epoxy carbon fiber composite specimen along the length of carbon fibers. The images obtained are stored in computer and studied.

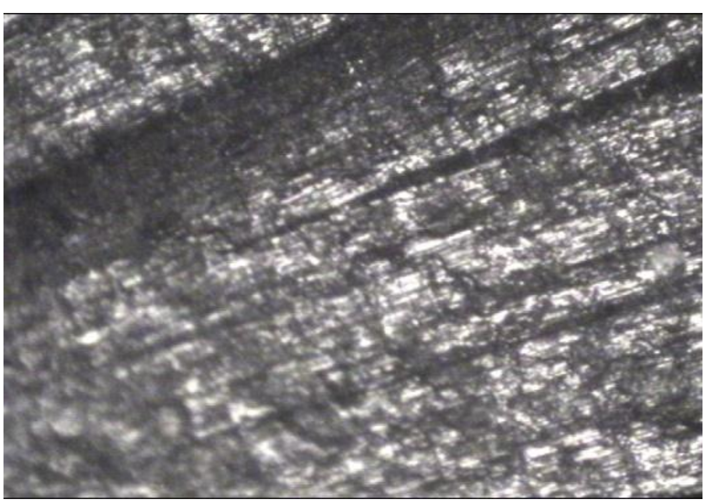

Fig. 5. *Microscopic structure under 20X magnification before loading*

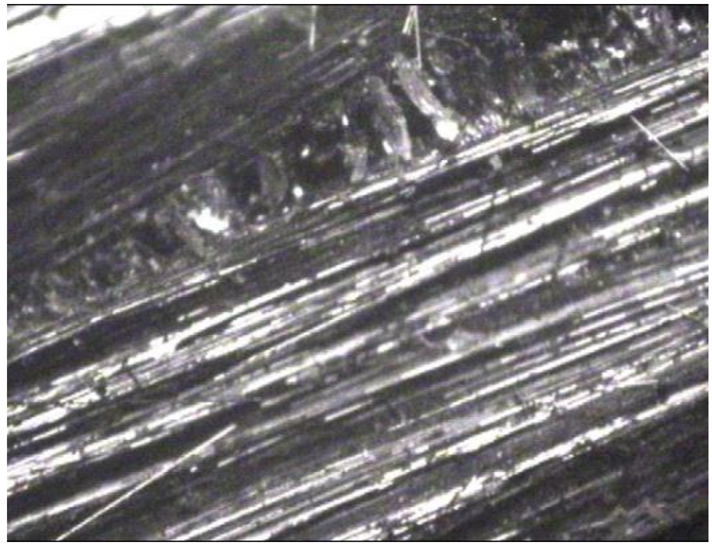

Fig. 6. *Microscopic structure under 20X magnification after loading*

3. RESULT AND DISCUSSION

The stress-strain behavior of the specimen was recorded until the first cracking sound occurred so as to prevent permanent damage to the extensometer. While loading the specimen, Arduino was implemented to measure the voltage behavior under constant current. Resistance was then calculated with the outputs.

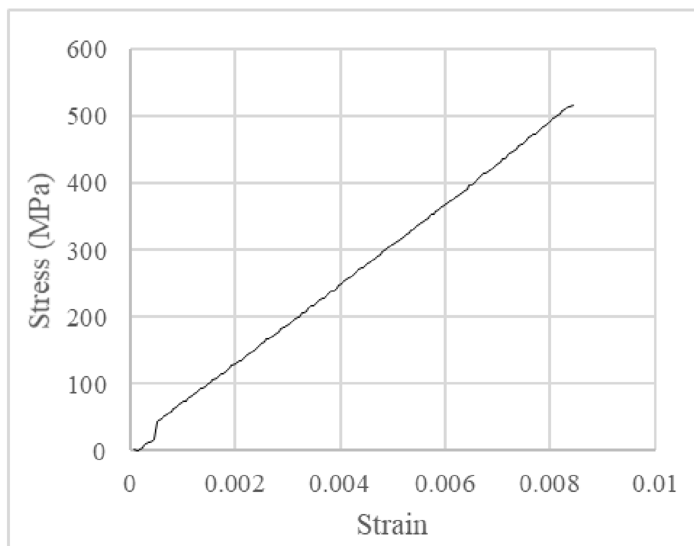

Fig. 7. *Stress-strain curve obtained for unidirectional epoxy-carbon fiber composite. The peak stress before the cracking of the specimen was found to be 516.49 MPa.*

G. Stress-Strain relation

The peak stress before the cracking was found to be 516.49 MPa whereas strain associated with the stress was 0.00843. Fig.7 shows the stress-strain relation occurred with the tensile loading in unidirectional epoxy-carbon fiber composite specimen.

H. Electrical Resistance vs Stress-Strain relation

The electrical resistance vs stress-strain relation obtained in the specimen is represented graphically. Fig. 8 shows the electrical resistance-stress relationship. The electrical resistance increased initially upto certain level and then decreased suddenly. Further a small increase was observed in the electrical resistance which further reduced near the cracking of the specimen. This behavior of the specimen indicates the possibility of monitoring its mechanical health with respect to its electrical behavior. Fig. 9 is the electrical resistance-strain relationship obtained which also shows similar behavior because of stress-strain dependability.

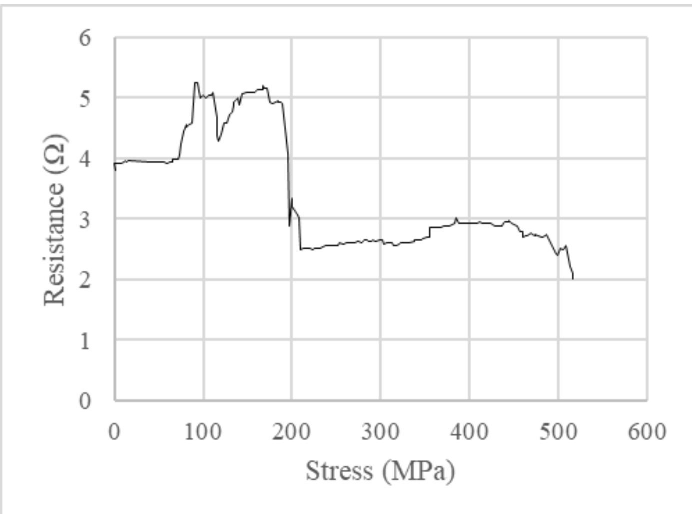

Fig. 8. *Electrical Resistance-stress curve*

The trend obtained in the results was more close as that found by Xiojun Wang and Chung[4]. On the other hand, Joaquin Rams, Maria Sanchez et al.[5] experimentally found the relation to be more linearly increasing than that of decreasing. The possible reason behind the increase and drastic decrease of electrical resistance could be the inherent anisotropic electrical behaviour of composite material or contact loosening[10]. The gauge factor is related with the change in resistance with original resistance and strain as

$\Delta R/R_0 = GF*$□

where □ is strain $\Delta R/R_0$ is ratio of resistance change to original resistance and GF is gauge factor. Fig. 10 shows the $\Delta R/R_0$ vs □ graph thereby giving the average gauge factor.

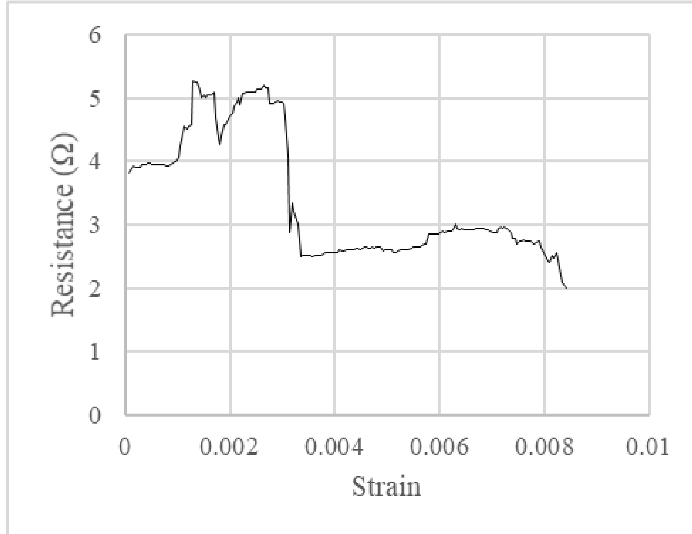

Fig. 9 *Electrical resistance-Strain curve*

Gauge factor is an important aspect for the purpose of self-sensing and structural health monitoring of the composite. It shows the feasibility of using the composite material itself for monitoring its health. The gauge factor of unidirectional epoxy carbon fiber composite specimen under study with 6 laminas and 60-40 volumetric ratio of carbon fiber to epoxy was found to be -37.895. The results were found similar to the research of Xiojun Wang and Chung[4] in which the gauge factor of epoxy-carbon fiber composite specimen in longitudinal direction was found to be -37.6.

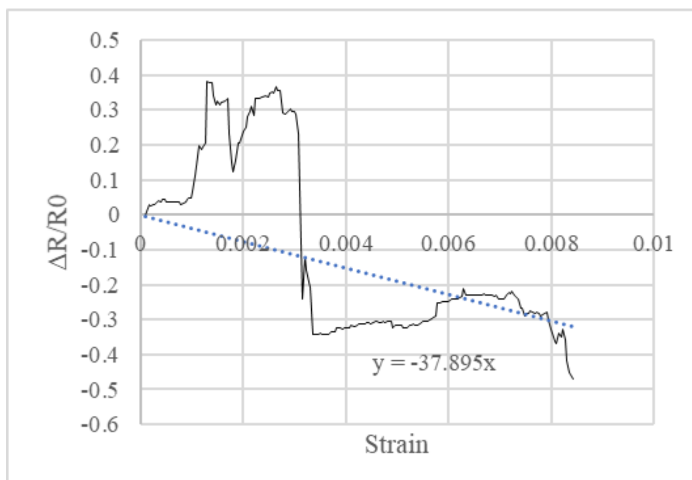

Fig. 10 *$\Delta R/R_0$ vs □ (Slope shows GF)*

Fig. 5 and Fig. 6 shows the stereo microscopic images of the specimen along the carbon fiber direction before and after loading. Stereo microscopy of the specimen after loading showed significant stretching and overlapping of the carbon fibers inside the laminate. Before loading the specimen, discrete layers of epoxy between the carbon fiber fabric might be the hindrance for the electrical conduction since the electrical resistivity of the epoxy is as high as 10^9 Ω-mm. On contrary the electrical resistivity of carbon fiber is as low as $1.7*10^{-2}$Ω-mm. With the application of load the carbon fibers were stretched and overlapped each other hence it could be the reason of significant current conduction thereby decreasing the overall electrical resistance of the specimen.

4. Conclusion

As expected, the unidirectional epoxy-carbon fiber composite exhibited high strength in the direction of the applied force, reaching a stress of 516.49 MPa and associated strain of 0.00843 before the cracking was observed. The electrical behavior of the composite showed an initial increase and a sudden drop in the electrical resistance of the specimen. The average gauge factor of the specimen was found to be -37.895. Under stereo microscopy, the carbon fibers were found to be stretched and overlapped after loading thereby suggesting it to be one of the reason for electrical resistance drop. The other reasons behind the electrical behavior could include material properties, contact loosening and electrical anisotropy. Therefore, the results shows the mechanical and electrical behavior of unidirectional epoxy-carbon fiber composite with epoxy-silver paste adhesive electrodes subjected to tensile load. This behavior suggests the possibility of monitoring the specimen with its electrical resistance change.

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