The 4th International Conference
″Advanced Composite Materials Engineering ″
COMAT 2012
18- 20 October 2012, Brasov, Romania

ELECTRICAL RESISTANCE CHANGE IN CFRP COMPOSITES WITH DIFFERENT FIBRE VOLUME FRACTION UNDER TENSILE LOADING

[1]I. Dumitrascu, [1]P.D. Barsanescu*, [1]V. Goanta
[1]"Gheorghe Asachi" Technical University of Iasi, Faculty of Mechanical,
Department of I.M.M.R, Iasi, Romania, *e-mail: paulbarsanescu@yahoo.com

Abstract: *Carbon fibers have high electric conductivity, while the matrix surrounding them is an insulator. Carbon fibers can be represented in materials as some resistors. If a fiber breaks, the current can not pass through this fiber. Thus the electrical resistance material will increase because the current will have to find another route. In this study, the electrical resistance change method is used. Two type of cross-ply laminate composites is used in this study: carbon fibre reinforced polypropylene and epoxy matrix. First, the composites production and set-up used is presented. Then, tensile tests on the laminate are performed. The influence of fibre volume fraction on the measurements is examined. It may be concluded that the volume fraction of fibres has a some influence on the resistance change. If the fibers volume fraction is higher, the contact between fibre is greater and the resistance is lower, but during the test, its value increases with applied load.*
Keywords: *Composites, CFRP, Carbon Fiber, Electrical resistance change*

1. INTRODUCTION

Carbon fiber reinforced polimer-matrix composites (CFRP) have become in recent years the basic material used in many engineering areas where high mechanical properties (i.e. stiffness, strength, etc.) and light weight is necessary. In general, CFRP is formed intro laminated structures made from unidirectional prepreg or woven fabric sheet, positioned in different stacking sequences. To detect internal damage like matrix cracks or delamination is very difficult because this damage is not visible from the outside of structure.
Several NDT techniques (e.g. ultrasound, radiography, thermography, acoustic emission, etc.) have been developed for structural health monitoring and detected of damage in composites structure. However, these techniques require expensive equipment, extensive human involvement and often, inspected structure must be switched off. Fiber optic sensor or piezoelectric senzor is a "sesitive" materials used for health monitoring of composites structures [1-4]. One disadvantage of using them it is their tendency to compromise the structural integrity of the host components.
Electrical resistance change method (ERCM) is of great interest as an in-service structural health monitoring system for CFRP [5-11]. This method is employed to detect the internal damages of CFRP like matrix cracking [5,6], delamination [7,8,9] or fiber breakages [10,11]. The electrical resistance change method does not require expensive instruments. Since, the method adopts a reinforcement carbon fiber it self as a sensor, and it does not requre additional sensors except for electrodes to make contact with carbon fibers in the CFRP structures. Therefore this method is called "self-sensing method", and the basic principle is that the damages due to carbon fiber breakage or delamination in the laminate will cause an increase in electrical resistance, resulting in voltage change in the damaged region. To measure resistance, a current is introduced in the materials through the electrodes and the voltage is measured. In literature, there are two measurement techniques [5-17]: (i) the two-probe technique, which means that the voltage is measured on the same electrodes where the current is introduced; and (ii) the four-probe technique, where the first two contacts are needed for the current injection and the voltage is measured with the other two. The first technique is mostly used in tests in which current is introduced by bonding electrodes on opposites edges or on the surface of the sample. They provide a better contact with carbon fibers in the edges of the samples [17]. Most research on the use of electric resistance change method was performed on unidirectional composites, and this is because current flows more easily in the direction of fibers and measured resistance is much higher [12-17]. In transvers to the fiber and in the specimen thickness direction, the current will flow with more difficulty because the fiber is isolated of the resin and are coated with agents for interface strength improvement. In this case the transverse and thickness conduction can only be

achieved via fibre to fibre contact from many longitudinal paths. This means that transverse resistivity will also be a function of fibre volume fraction as well as the number and area of contact points [7,18].

In multidirectional laminates the present of different orientations of fibers in the lamina can complicate the conduction proces of current. Thus, in this investigation the effect of differing fibre orientations and the fiber volume fraction on the electrical resistance change in multidirectional laminates will be investigated.

2. MATERIALS, EQUIPEMENT AND METHOD

2.1. Raw Materials

Two types of unidirectional CFRP prepregs were used:

- Unidirectional prepreg carbon fiber/polypropylene (CF/PP), namely CarbostampTM UD tape, produced by Soficar (France), with a nominal ply thickness of 0.25 mm. The carbon fibres used were T700 (made of Toray), with the following tensile properties: modulus of 230 GPa, strength to failure of 4900 MPa, density 1.80 g/cm3 and strain to failure of 2.0 % and filament diameter 7 µm.
- Unidirectional prepreg carbon fibre/epoxy (CF/Epoxy) type Q-1112 product by TohoTenax Europe GmbH, with a nominal ply thickness of 0.15 mm. The carbon fibres is STS 40 24K, modulus of 230 GPa, strength of 4240 MPa, density 1.77 g/cm^3 and strain to failure of 1.75 % and filament diameter 7 µm.

2.2. Production of plate laminates composites

The stacking sequence used for production of the plates laminate composites were $[(0,90),\overline{0}]_s$ for CF/PP and $[(0,90)_2,\overline{0}]_s$ for CF/Epoxy. The carbon fiber/polypropylene cross-ply laminates were fabricated with the hot pressing machine Zenith 2 (Pinette Emidecau Industries). A mold was designed for 25 mm width samples. The slender channels of the mold provided the individual samples, avoiding cutting the samples from the moulded plates. This was a countermeasure against the fact that sticky thermoplastic polymer, especially PP, makes it impossible to cut the samples with a water-cooled diamond saw. Therefore, 5 layers were cut from the prepregs into the length and width as needed for the objective samples. Thickness of the coupons was controlled by spacers at the both edges of the slender channels between upper and lower mould. The cut plies were stacked in designated stacking sequences and filled into the mould. Then, the mould was placed into the hot-pressing machine and immediately heated up. When reaching the designated temperature of 165 °C, the mold is pressed under 3 bar for 10 min. Then, the mold was cooled down to temperature of curing polymer (50 °C) and after that, removed from the machine.

To produced the carbon fiber/epoxy cross-ply laminates CF/Epoxy, the prepregs were cut into sheets with dimensions 300 mm by 300 mm. Nine such prepregs were stacked one on top of the other and cured at 90°C for 60 min followed by a post curing step at 130°C for 90 min. The laminates were produced in an autoclave at vacuum of -0.68 to -0.70 bar.

The fiber volume fraction of composites is 48% for cross-ply CF/PP and 71% for cross-ply CF/Epoxy, and was determined by matrix digestion method, described in ASTM D3171-99 [19], using sulphuric acid/hydrogen peroxide.

The cross-ply CF/PP samples have not required cutting from composite plate, because their are already resulting to size recommended in ASTM D3039 [20], from the manufacturing process. The cross-ply CF/Epoxy samples were cut from the composite plate to size recommended in ASTM D3039, with a water-cooled diamond saw machine.

The size of samples were 260 mm length, 25 mm width and around 1.3 mm thickness, see Figure 1. Tabs made of glass fiber woven/epoxy prepregs stacked in $[\pm 45^o]_{2s}$ direction, with 2 mm thickness, were cut to size 40 mm length and 25 mm width (without taper) and bonded to the sand-blasted surface of the samples, using Araldite 2011TM epoxy glue.

2.3. Equipment

The tensile test were performed on a testing machine Instron 8801 with a load cell of 100 kN and hydraulic grips. Tensile tests were done according to ASTM D3039 [20]. The test was displacement controlled with a speed of 1 mm/min. For measuring the electrical resistance, a multimeter Agilent 34401 A was used. The measured data of the instrument were recording to the computer via data cable type RS-232. Using the Agilent IO Control program, we could control time (of 1 sec.) in which the multimeter to perform two measurements.

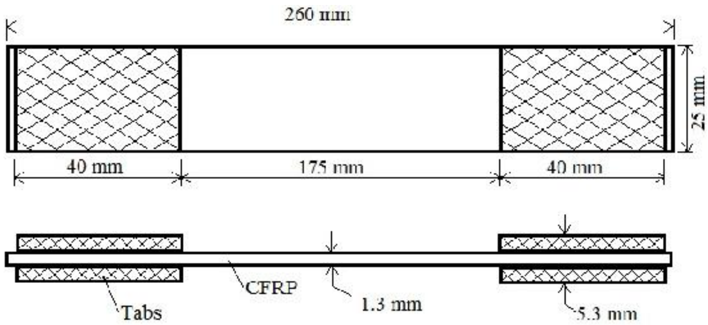

Figure 1: Dimension of the tensile samples used and bonded tabs

2.4. Method

These tests were performed to confirm the electrical resistance change during tensile loading in the fiber direction. In order, to measure the resistance, a DC current of 10 mA is introduced in the samples and the voltage is measured using data acquisition system. To eliminate any electrical contact between samples and the Instron machine, the tabs made GFRP composites was used. In this study, the two-probe technique is used. To provide a good contact between electrodes and carbon fibers, the edges of the samples was polished. After polished, the electrodes were attached to the edges of the samples through silver paste. To protect the electrode, they were covered with epoxy resin. In Figure 2., is represented an example of the sample with bonded electrodes on the edges used for this study.

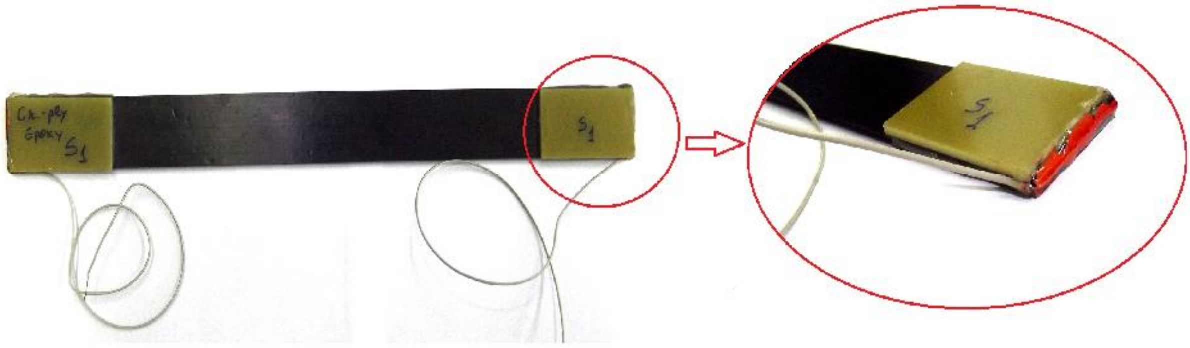

Figure 2: Sample prepared with electrods for electrical resistance measurement

3. RESULTS AND DISCUTION

Electrical resistance values vs strain and stress-strain diagrams are show for cross-ply CF/PP in Firure 3. and for cross-ply CF/Epoxy in Figure 4. Before starting the test, initial electrical resistance R_0 of each sample tested, after she was clamping the test machine, was recorded. So, for cross-ply CF/PP, R_0=5.466 Ω and the failure stress of specimen was 941 MPa and for cross-ply CF/Epoxy, R_0 =0,820 Ω and the failure stress of specimen was 1223 MPa. As show in these figures, for both materials, the electrical resistance increase with increase of applied tensile strain. The lower values of initial resistance obtained for cross-ply CF/Epoxy, is a consequence of the high volume fiber which provides a larger area the current flowing. Electrical resistance values measured for cross-ply CF/PP, remain relatively close in most of the test and after ε =1.6 %, the values increase suddenly. This suggests that in the samples the damage like delamination or fibres break growth and the end of the failure of sample is close. Not the same thing is observed for cross-ply CF/Epoxy. Even if the electrical resistance values recorded are much lower, they grow steadily during of the test. Same results were obtained by I De Baere [21] but for materials reinforced with fabrics. Contrast to cross-ply CF/PP, sudden increase of resistance values is observed for these materials close to the end of the test, which means that the damages growth and the end of the failure of sample is close.

In Figure 5. and Figure 6. the evolution of electrical resistance change function of the strain for the two types of materials is shows. Can observe that for cross-ply CF/ PP the evolution of electrical resistance change can be divided in two separate phases: a "steady state phase", where the increase of $\Delta R/R_0$ are small and fluctuate to positive to negative values, and an "end of life" phase, where the growth suddenly increases (from ε =1.6 %, and onward). Pentru cross-ply CF/Epoxy, as show in Figure 6., the the electrical resistance change increases whit the increase of strain. This increase, compared to cross-ply CF/PP, is almost linearly, which means the piesoresistivity, which represent electrical resistance change of material, is positive and constant.

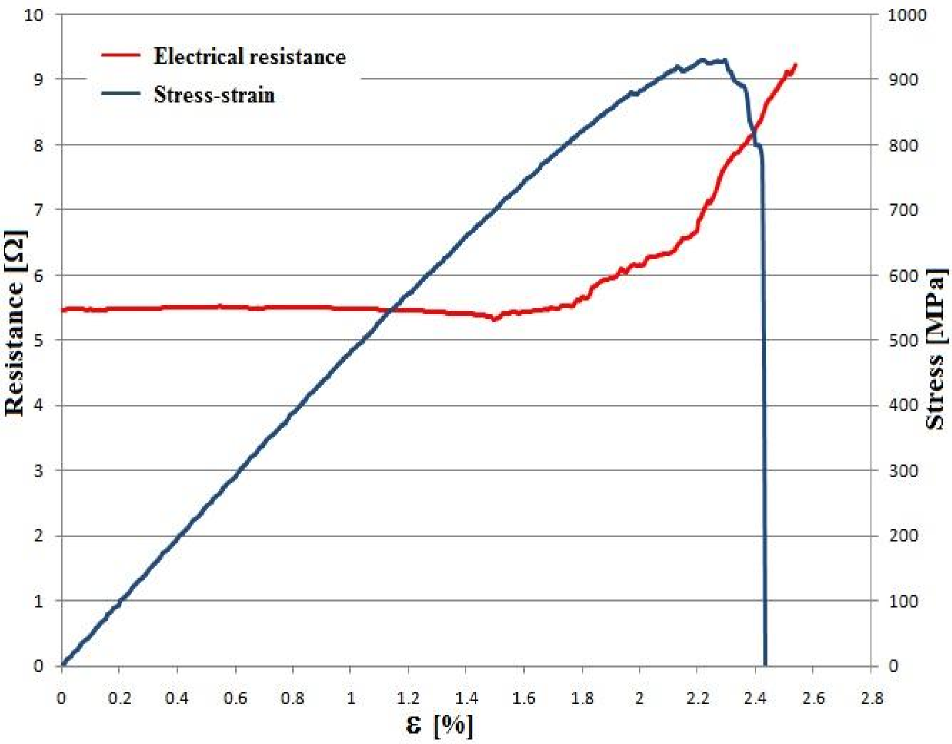

Figure 3: The evolution of resitance vs strain (red) and stress-strain diagram (blue) for cross-ply CF/PP

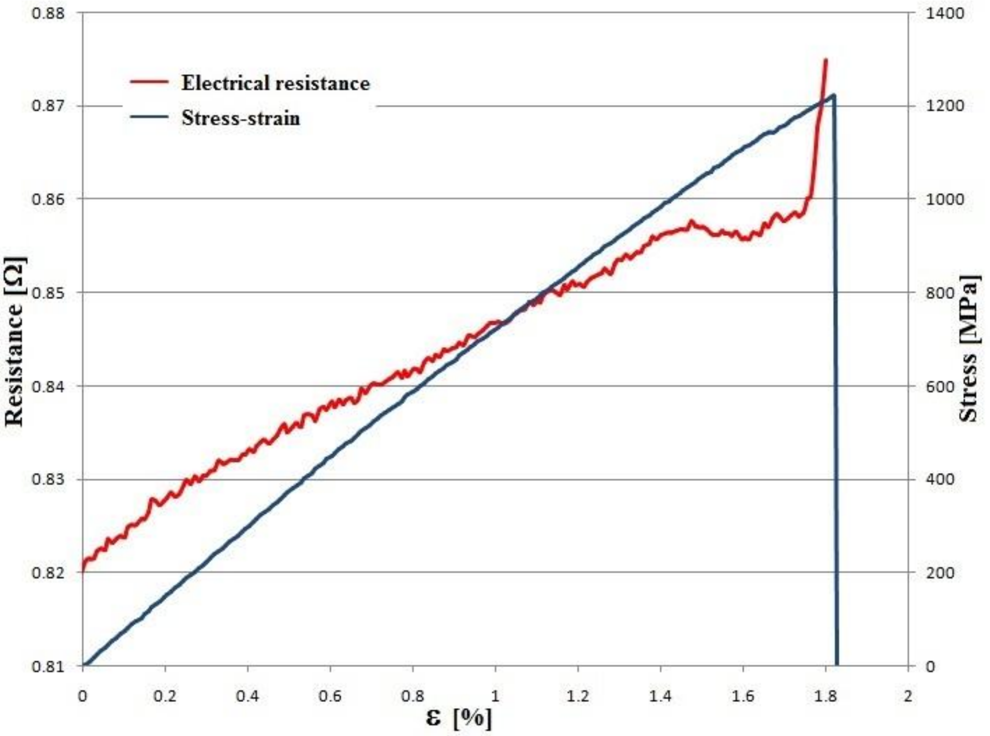

Figure 4: The evolution of resitance vs strain (red) and stress-strain diagram (blue) for cross-ply CF/Epoxy

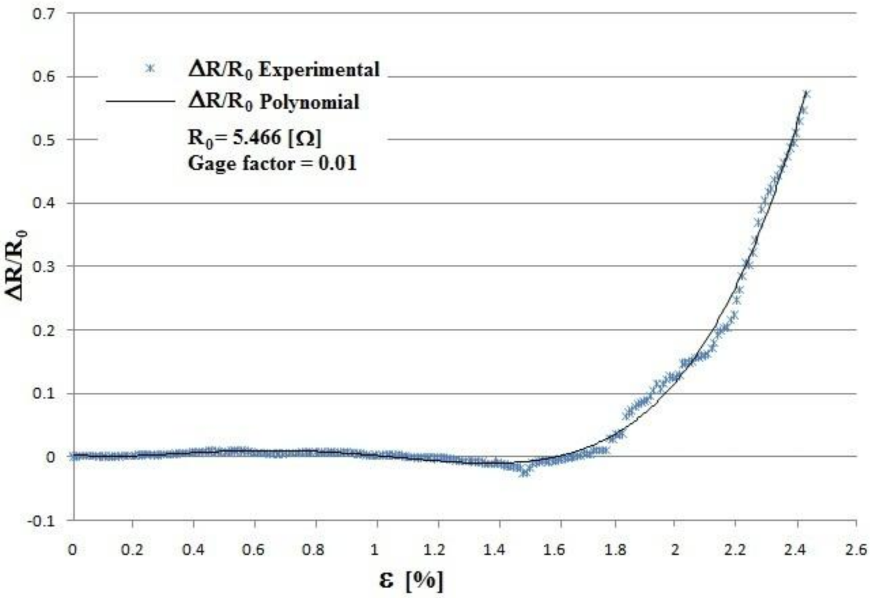

Figure 5: The evolution of electrical resitance change vs strain for cross-ply CF/PP

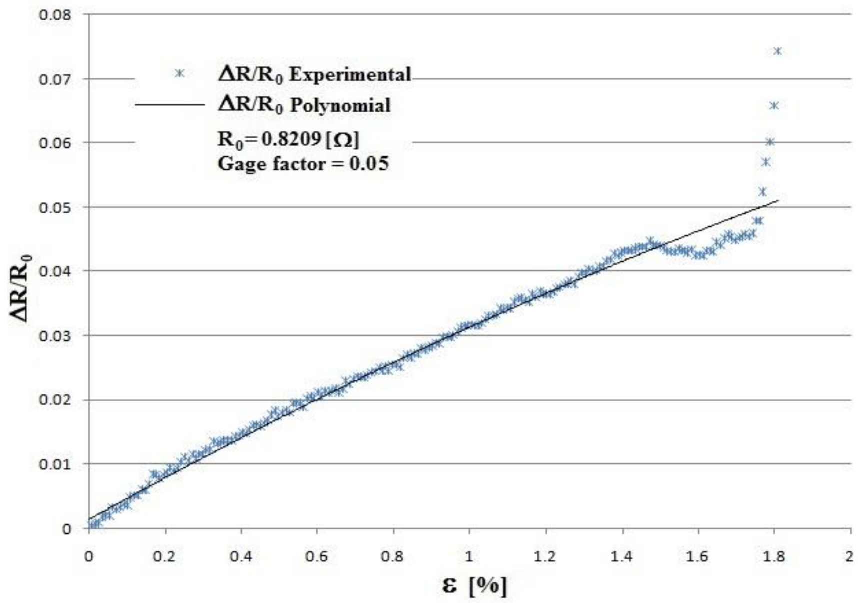

Figure 6: The evolution of electrical resitance change vs strain for cross-ply CF/Epoxy

4. CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

- The electrical resistance in both types of materials with different fiber volume fraction increases with applied load. For CFRP composites with lower fiber volume (cross-ply CF/PP), this increase is insignificant till to the value of 1.6% of strain, but, after that, the electrical resistance increases pronounced. Not the same thing was observed for cross-ply CF/Epoxy, where electrical resistance increases steadily with increasing of strain.
- The electrical resistance change in cross-ply CF/PP in the first part of the tensile are small and fluctuate to positive to negative values which meant that in inside of materials no major changes of the circuits through which the current flows, occur.
- Constant increase of change of electrical resistance in cross-ply CF/Epoxy composite, where the volume of fiber is higher, represents the constant interruption of contacts between fibers, leading to the number reducing of circuits in which current flows.
- Increased resistance to the end of the test as a result of damage (delamination or fiber breakage), suggests that this method can be used successfully for predicting the end of life of carbon-reinforced composites.

ACKNOWLEDGMENT

This paper was realized with the support of EURODOC "Doctoral Scholarships for research performance at European level" project, financed by the European Social Found and Romanian Government.

REFERENCES

[1] De Waele W., Degrieck J., De Baets P., Moerman W. and Taerwe L., Feasibility of integrated optical fibre sensors for condition monitoring of composite structures—part II: combination of Bragg-sensors and acoustic emission detection, Insight 45:542-546, 2003.
[2] Kuang K.S.C., Kenny R., Whelan M.P., Cantwell W.J., Chalker P.R., Residual strain measurement and impact response of optical fibre Bragg grating sensors in fibre metal laminates, Smart Materials and Structures 10(2):338–46, 2001.
[3] Imai S., Tokuyama M., Hirose S., Burger G.J., Lammerink T.S.J., Fluitman J.H.J., Thin-film piezoelectric impact sensor array fabricated on a Si slider for measuring head-disk interaction, IEEE Trans Magn 31(6.1):3009–11, 1995
[4] Haywood J., Coverley P.T., Staszewski W.I., Worden K., An automatic impact monitor for a composite panel employing smart sensor technology, Smart Materials and Structures 14(1):265–71, 2005.
[5] Omagari K., Todoroki A., Shimamura Y., Kobayashi H., Detection of matrix craking of CFRP using electrical resistance changes, Key Engineering Materials 297-300, pp 2096-2101, 2005.
[6] Todoroki A., Tanaka M., Shimamura Y., Kobayashi H., Effects with a matrix crack on monitoring by electrical resistance method, Advance Composite Materials., Vol. 13, No. 2, pp. 107–120, 2004.
[7] Wang X., Chung D.D.L., Sensing delamination in a corbon fiber polymer-matrix composites during fatigue by electrical resistance measurement, Polymer Composites 18(6), pp.692-700, 1997.
[8] Ueda M., Todoroki A., Shimamura Y., Kobayashi H., Monitoring delamination of laminated CFRP using the electric potential change method (application of normalization method and the effect of the shape of a delamination crack), Advance Composites Materials 13(3–4):311–24, 2004.
[9] Todoroki A., Tanaka Y., Shimamura Y., Delamination monitoring of graphite/epoxy laminated composite plate of electric resistance change method, Composites Science and Technolgy 62(9):1151–60, 2002.
[10] Kaddoour A.S., Al-Salehi F.A., Al-Hassani S.T.S., Electrical resistance measurement technique for detecting failure in CFRP materials at high strain rate, Composites Science and Technolgy 51(3):377–85, 1994.
[11] Schueler R., Joshi S.P., Schulte K., Damage detection in CFRP by electrical conductance mapping, Composites Science and Technolgy 61(6):921–30, 2001
[12] Gordon D.A., Wang S., Chung D.D.L., Piezoresistivity in unidirectional continuous carbon fibre polymer matrix composites: single lamina composite vs 2 lamina composite, Composite Interfaces, 11:95–103, 2004.
[13] Xia Z., Okabe T., Park J. B., Curtin W. A., Takeda N., Quantitative damage detection in CFRP composites: coupled mechanical and electrical models, Composites Science and Technology 63 :1411–22, 2003.
[14] Todoroki A, Samejima Y, Hirano Y and Matsuzaki R. Piezoresistivity of unidirectional carbon/epoxy composites for multiaxial loading, Composites Science and Technology 69: 1841–1846, 2009.
[15] Todoroki A, Yoshida J., Electrical resistance change of unidirectional CFRP due to applied load, JSME International Journal Serie A, vol.47, nr.3, pp.357-364, 2004.
[16] Park J.B., Okabe T., Takeda N., New concept for modeling the electromechanical behavior of unidirectional carbon-fiber-reinforced plastic under tensile loading, Smart Materials and Structures 12:105–14, 2003.
[17] Angelidis N., Wei C.Y., Irving P.E., The electrical resistance response of continuous carbon fibre composite laminates to mechanical strain, Composites Part A, 35:1135–47, 2004.
[18] Todoroki A., Tanaka M., Shimamura Y., Measurement of orthotropic electric conductance of CFRP laminates and analyssis of the effect on delamination monitoring with an electric resistance change method, Composites Science and Tehnology 62(5):619-28, 2001.
[19] ASTM Standard ASTM D3171 - 11, "Standard Test Methods for Constituent Content of Composite Materials", ASTM International, West Conshohocken, PA, 2011.
[20] ASTM Standard D 3039/D3039M-08, " Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials", ASTM International, West Conshohocken, PA, 2008.
[21] De Baere I., Van Paepegem W., Degrieck J., The use of rivets for electrical resistance measurement on carbon fibre-reinforced thermoplastics, Smart Material and Structures 16, pp.1821–1828, 2007.