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Mechanical Engineering

Elixir Mech. Engg. 76 (2014) 28437-28441

ISSN: 2229-712X

# An experimental investigation on the tensile behavior of carbon fiber reinforced aluminum matrix composites at low temperatures

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ARTICLE INFO

**Article history:**

Received: 3 September 2014;

Received in revised form:

27 October 2014;

Accepted: 11 November 2014;

**Keywords**

Tensile,

Carbon fiber,

Automobile,

Ships aircraft.

**ABSTRACT**

Carbon fibers have been considered as so important reinforcements for aluminum alloys in manufacturing advanced composite materials. Composite materials have been used in automobile, ships aircraft, sports goods and so on. This study discussed the experimental results on tensile strength and modulus of three samples, at different orientations and constant volume fraction of 60% of carbon fibers reinforced aluminum matrix composites at low temperatures. Several experimental tests have been carried out at longitudinal (0°) and transverse (90°) directions of composite specimens using an environmental test chamber with a universal testing machine. Thermo-mechanical tensile loads at strain rate of (0.0015 $s^{-1}$) were applied to carbon fiber/Aluminum laminates at room temperature (RT=23 $^{0}$C, zero $^{0}$C, -15 $^{0}$C and -30 $^{0}$C). The results indicated that low temperatures have a significant effect on mechanical properties i-e tensile and modulus. It was found that the tensile strength for sample $S_1$ reduced as the temperature decrease for both directions while $S_2$ didn't effect by low temperatures in transverse direction but the strength was reduced at -30 $^{0}$C by 10% compared to RT in longitudinal direction. It was also observed that for $S_3$, the tensile strength was reduced at -30 $^{0}$C for both directions. The modulus of the three samples was increased as the temperature reduced. The experimental results also indicated that the strength and modulus for the three samples are higher in longitudinal laminates compared to transverse laminates at low temperatures.



## Introduction

In recent year, carbon fiber reinforced composite materials have been currently employed, particularly in the aerospace industry. This application is due to a significant weight savings of aircraft with no loss of properties. The importance of these materials are derived from their high strength, stiffness and damping together with low specific weight. Low temperature mechanical properties of carbon fiber reinforced aluminum have to be assessed, because of these composite materials are subjected to low temperature in service [1]. The purpose of the static tensile tests wasto know the low temperature effects on the tensile strength, young modulus of three types of carbon fiber reinforced aluminum matrix (CFRA) in longitudinal and transverse directions. The current study presents experimental data of low temperature tensile properties at room (RT), zero $^{0}$C, -15 $^{0}$C and -30 $^{0}$C.

## Literature review

Kim et.al. [2] tested UD (unidirectional) glass-epoxy composite at low temperature and they found that increasing of modulus and tensile strength at cryogenic temperature. The same findings were found by Gong et.al.[3].Mohamed and Abdolhossein [1] tested unidirectional (UD) glass fiber-reinforced epoxy laminates in longitudinal and transverse directions at (RT), -20$^{0}$C and -60 $^{0}$C.They concluded that the strength and stiffness increase significantly as temperature decreases. The mean value of tensile strength increases from 700.11MPa at RT to 784.98 MPa at -60 $^{0}$C. While the stiffness rises from 23.05 GPa at RT to 28.65 GPa at -60 $^{0}$C. Gong et.al.[3] tested unidirectional glass-epoxy composite at low temperature and they observed a significant increase in tensile and modulus compared to RT results. Walsh et. al. [4] reported that both transverse tensile strength and stiffness increased as the temperature decrease based on RT using glass-epoxy composites. Mohamed [5] examined tensile, compressive and in-plane shear properties of UD glass fiber reinforced polymer composite under low temperatures. It was concluded that the tensile strength increased about 12% as the temperature reduced to -60$^{0}$C in longitudinal direction. Panchakshari H.V., et.al.[6] focused on the effect of deep cryogenic treatment on the microstructure, mechanical and fracture properties of Al6061/$Al_2O_3$ metal matrix composites (MMCs) at -196 $^{0}$C for different time duration. The modification of microstructure of MMCs due to cryogenic treatment shows significant improvement in mechanical properties of the MMCs. Kirz [7] investigated the static properties in tension of quasi-isotropic graphite fiber laminates from RT to -196 $^{0}$C. Wilson [8] tested different types of $CFRP_s$ in longitudinal and transverse directions from RT to -260 $^{0}$C. It was observed that both stiffness and tensile strength increase at -260 $^{0}$C decreased compared to RT. Dutta[9] tested unidirectional laminates of glass fiber-polyester and .It was found that modulus and ultimate stress increase when temperature decreases.

## Composite Materials

The imported composite material laminates used in this study is carbon fiber reinforced aluminum alloy. Woven carbon fibers (3K) and unidirectional carbon fibers (UD) have been used in this work in three different orientations (0°/90° for woven carbon fiber and /0°/,/90°/ for uni direction carbon fiber)

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as a reinforcement material, while (3003) Aluminum alloy has been employed as the matrix material. Figure (1) shows these types of carbon fibers. Manufacturing of this composite materials are done by using high temperature and vacuum pressure. The details of manufacturing process can be found in reference [10]. The fiber volume fraction of composites was constant and equal to 60%. Three types of laminated composite materials were used. Table (1) bellow illustrates the locations and orientations of each sample laminates (4 layers of carbon fibers and 2 layers of aluminum).

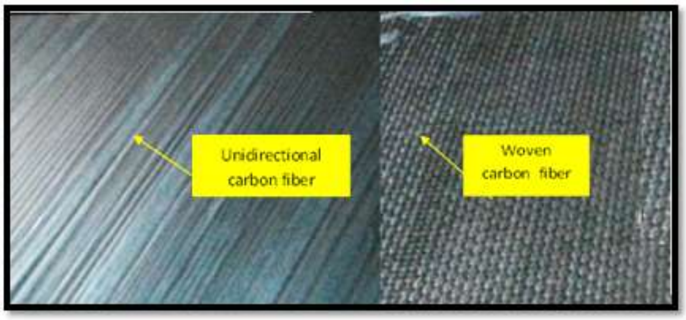


**Figure 1. (3K) woven carbon fiber and (UD) carbon fiber**

**Test equipments**

The tensile tests were performed in a Testometric M500 test machine as shown in Figure (2). The maximum load capacity of the test machine is 25kN. An environment chamber was attached with the tensile test rigand sealed with an insulation material. The chamber has the ability to cool down its temperature to -30 $^0$C.

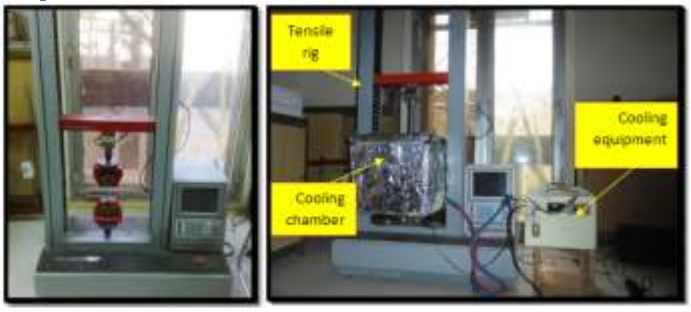


**Figure 2. Cooling chamber attached with tensile test.**

**Cooling chamber**

During the test, a pressurizing device was used to control the cooling time from room temperature (RT) to required temperature.Its consist from two boxes. The first box is cooling room and the second box contains the cooling equipments. Cooling chamber parts is: compressor, double evaporator, heat exchanger pipes (condenser), fan, thermostat and Freon type R134a was used as cooling gas. The cooling rate is 2 $^0$C /min. The temperature inside cooling room was calibrated by thermocouple. Delay time about 15min. was used to homogenize temperature through all thickness of specimen. Figure (3) shows grips of tensile machine inside cooling room.

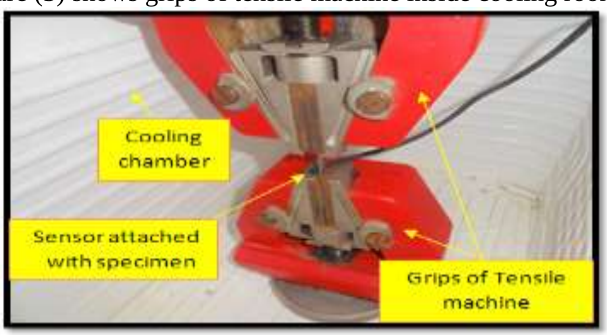


**Figure 3. Grips of tensile machine inside cooling room**

**Tensile Specimen**

The specimens for tensile testes were cut from standard sheet (400*500*0.85 mm) by CNC machine in both longitudinal and transverse directions according to standard test method for tensile properties of fiber reinforced metal matrix composites ASTM D3552 [11]. The strain rate was 0.0015 $s^{-1}$ for all tensile tests. Figure (4) (a) shows three samples sheets, (b) shows the geometry of the composite tensile specimens in both directions.

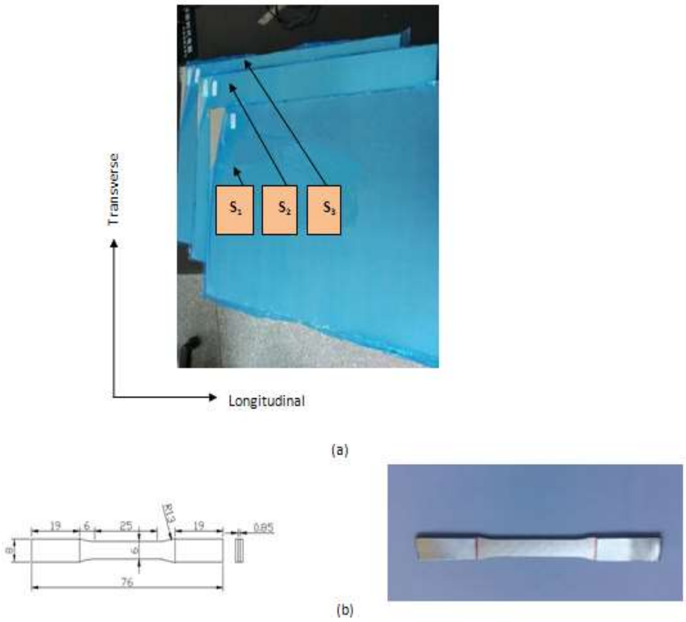


**Figure 4. (a) Three samples composite sheets, (b) Tensile test specimen of composite material in both directions (all dimension in mm)**

**Results and Discussions**

**Tensile test results**

Figure (5) (a), (b), and (c) shows the typical stress-strain diagrams of the three types $S_1$, $S_2$, and $S_3$ Aluminum-carbon fiber composites in transverse and longitudinal directions at RT (room temperature),zero $^0$C, -15 $^0$C and -30 $^0$C. Table (2) illustrates the values of tensile strength for three composites material that mentioned above.

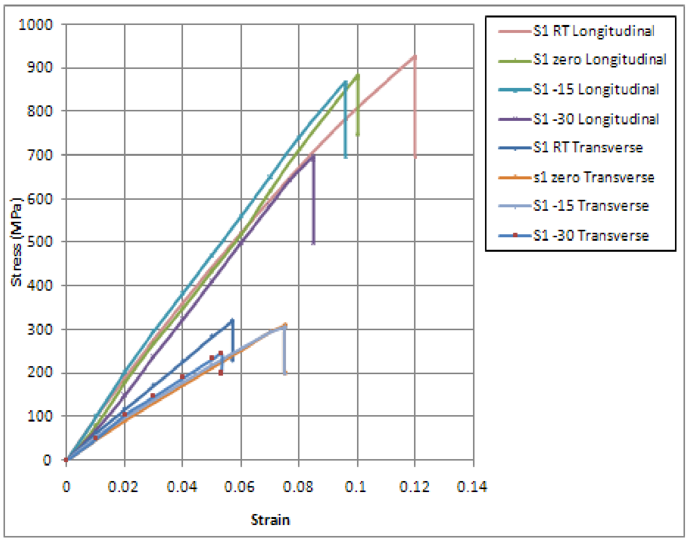


**Figure 5-a. Stress-strain relation for sample $S_1$at RT, zero $^0$C, -15 $^0$C and -30 for both directions.**

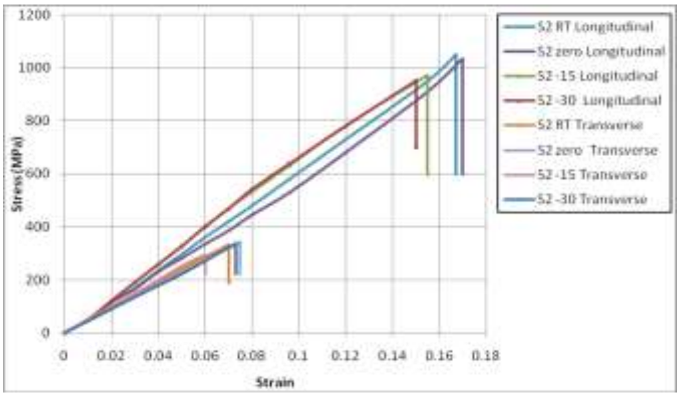


**Figure 5-b. Stress-strain relation for sample $S_2$ at RT, zero $^0$C, -15 $^0$C and -30 for both directions.**

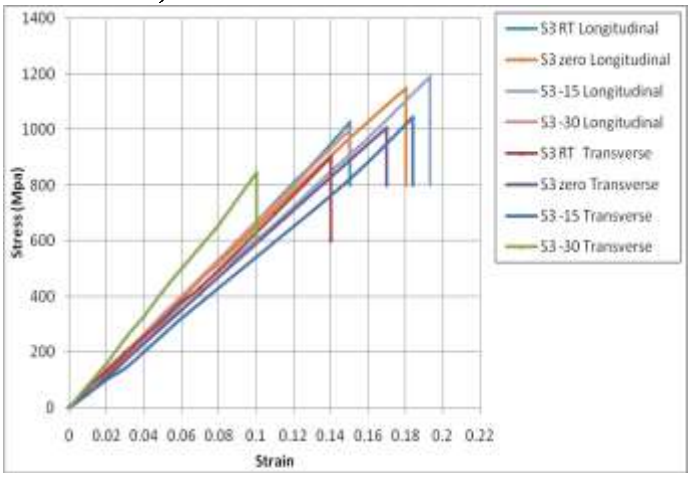


**Figure 5-c. Stress-strain relation for sample $S_3$ at RT, zero $^0$C, -15 $^0$C and -30 for both directions.**

**Sample ($S_1$)**

This sample exhibits approximately linear elastic characteristic, till break. The ultimate tensile stress is higher in longitudinal direction compared with the value in transverse direction. The maximum value of strain to failure in transverse direction does not reach 0.08 while in longitudinal direction the strain to failure is about 0.12. The ultimate stress decrease significantly as the temperature decreases. The average value of three readings reduces from 321 MPa to 242 MPa in transverse direction and from 924MPa to 698MPa in longitudinal direction at RT and -30 $^0$C respectively.Majerski et.al. [12] tested carbon fiber/epoxy laminates at room temperature (RT) and low temperatures. They reported that the tensile strength decreased about 7% at 223k compared to RT and about 8% at 153k .The present work observed a 24.5% decrease in longitudinal and transverse tensile strength at -30$^0$C compared to (RT).This finding is well agreed with reference [13].The reduction in ultimate stress may be caused by several factors such as a brittle matrix or an increase in residual stress in the composite material. At low temperatures the size of the carbon fibers increases in the radial direction and reduction in the size at longitudinal direction. But the aluminum –matrix expands in all directions [14-16].

**Sample ($S_2$)**

Figure (4-b) shows stress-strain curves for samples $S_2$. It can be observed that also linear elastic behavior for all specimens tested at various temperatures. The maximum value of strain exceed 0.15 in the case of longitudinaldirection, while in transverse direction, the values of strains are between 0.06 to 0.075.The maximum variation between tensile strength and temperatures for sample $S_2$ can be observed in figure (6).The tensile strength of sample ($S_2$) increased at 0 $^0$C and then decreased at -15 $^0$C and again increased at -30 $^0$C in transverse direction. This result confirmed with Reed and Golda [17] they concluded that an increase in tensile strength of a unidirection carbon fiber/epoxy laminate at low temperatures. The amount of percentage increase in tensile strength at -30 $^0$C as compared to room temperature (RT) is 1.68% in transverse direction test. Tensile strength in longitudinal direction is higher as compared to transverse direction. The same trends explained previously at sample ($S_1$) in longitudinal direction tensile test are observed again at sample ($S_2$) in the same direction, that the ultimate tensile strength decrease as the temperature decreased. The reduction in strength at -30 $^0$C is 10% based on tensile strength at RT.

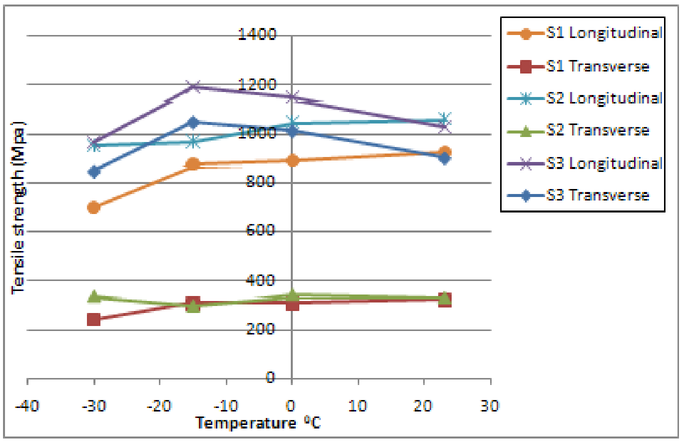


**Figure 6. The relationship between temperatures and tensile strength**

**Sample ($S_3$)**

The average values of tensile strength for sample ($S_3$) show a little change in longitudinal and transverse directions. From table (1), it can be observed that regardless of the orientation of carbon fibers for sample ($S_3$), the same type of four carbon fibers layers contribute to these little changes in the tensile strength in both directions. Figure (4-c) illustrates the strains, till specimen break for sample ($S_3$) which does not exceed 0.2in both directions. The ultimate tensile strength for ($S_3$) increased at zero $^0$C, -15 $^0$C and then decreased at -30 $^0$C in longitudinal and transverse directions. Kim et.al. [13] found that the strength of non-cycled specimens decreased about 9% more at -150 $^0$C than at RTfor graphite/epoxy composite. The current work exhibits a 6% reduction in tensile strength for both longitudinal and transverse directions at -30 $^0$C compared to RT.

The composite exhibits a linear elastic behavior till failure and the slope of this curve increases as the temperature decreases in both directions. This finding is in good agreement with reference [1].

Table (3) indicates that the stiffness increases due to decreasing the temperature for the three samples in both directions. The maximum increase is observed at -30 $^0$C for the three samples in both directions as illustrated in table (3) based on (RT).

The increase in tensile modulus of Al- carbon fiber composite coming from the residual thermal stresses generated in the composite which are subjected to low temperature (less than zero $^0$C). The stresses generated are a result of a different in the coefficient of thermal expansions between the carbon fiber and aluminum [5]. While Takeda et.al.[18] concluded that thermal stresses have no important effect on stiffness and Poisson ratio of woven glass/epoxy laminates.

**Table 1. Three types of carbon fiber-aluminum matrix composite material**

| Sample Ref. | Configuration | $V_f$ % | Number of reinforcement layer | Orientation of reinforcement |
|---|---|---|---|---|
| $S_1$ | [Al/3K/UD/3K/UD/Al] | 60 | 4 | 0°/90°- 0°- 0°/90°- 90° |
| $S_2$ | [Al/3K/UD/UD/3K/Al] | 60 | 4 | 0°/90°- 0°- 90°- 0°/90° |
| $S_3$ | [Al/UD/UD/UD/UD/Al] | 60 | 4 | 0°- 90°- 0°- 90° |

**Table 2. Values of tensile strength in longitudinal and transverse directions**

| Transverse Direction | | | | Longitudinal Direction | | | |
|---|---|---|---|---|---|---|---|
| Tensile strength (MPa) for $S_1$ | | | | | | | |
| RT | Zero $^0$C | -15 $^0$C | -30 $^0$C | RT | Zero $^0$C | -15 $^0$C | -30 $^0$C |
| 381 | 318 | 308 | 210 | 900 | 844 | 840 | 640 |
| 300 | 304 | 310 | 275 | 930 | 852 | 870 | 687 |
| 282 | 309 | 303 | 240 | 942 | 974 | 915 | 767 |
| Average of readings | | | | | | | |
| 321 | 310.33 | 307 | 242 | 924 | 890 | 875 | 698 |
| Tensile strength (MPa) for $S_2$ | | | | | | | |
| RT | Zero $^0$C | -15 $^0$C | -30 $^0$C | RT | Zero $^0$C | -15 $^0$C | -30 $^0$C |
| 309 | 377 | 300 | 344 | 986 | 1022 | 922 | 905 |
| 361 | 322 | 290 | 334 | 1025 | 1081 | 970 | 960 |
| 326 | 333 | 296 | 335 | 1160 | 1032 | 1012 | 988 |
| Average of readings | | | | | | | |
| 332 | 344 | 295.33 | 337.6 | 1057 | 1045 | 968 | 951 |
| Tensile strength (MPa) for $S_3$ | | | | | | | |
| RT | Zero $^0$C | -15 $^0$C | -30 $^0$C | RT | Zero $^0$C | -15 $^0$C | -30 $^0$C |
| 900 | 962 | 1057 | 848 | 989 | 1100 | 1200 | 960 |
| 905 | 1061 | 1044 | 830 | 1100 | 1085 | 1120 | 944 |
| 895 | 1003 | 1031 | 860 | 989 | 1262 | 1250 | 988 |
| Average of readings | | | | | | | |
| 900 | 1008.67 | 1044 | 846 | 1026 | 1149 | 1190 | 964 |

**Table 3. Values of tensile modulus of three composite materials in longitudinal and transverse directions**

| **Transversedirection** | | | **Longitudinal direction** | | | **Increasing in -30 $^0$C based on RT (%).** | |
|---|---|---|---|---|---|---|---|
| **Tensile Modulus (GPa) for $S_1$** | | | | | | | |
| Zero $^0$C | -15 $^0$C | -30$^0$C | Zero $^0$C | -15 $^0$C | -30 $^0$C | transverse | Longitudinal |
| 13.4 | 13.6 | 14.3 | 14.92 | 15.7 | 16.8 | 10 | 15.5 |
| Tensile Modulus (GPa) for $S_2$ | | | | | | | |
| 14.32 | 14.5 | 15.4 | 19.3 | 19.7 | 20.5 | 10 | 7.8 |
| Tensile Modulus (GPa) for $S_3$ | | | | | | | |
| 16.6 | 16.9 | 17.8 | 17.5 | 18 | 18.7 | 11.25 | 10 |

**Conclusions**

In this work the temperature dependences of the static tensile properties in longitudinal and transverse directions for three samples of different orientation of Al carbon fiber laminates was studied at RT, zero $^0$C, -15 $^0$C and -30$^0$C.

1-It was found that the tensile strength of sample $S_1$ reduced as temperature reduced and the reduction was compared to RT for both directions.

2-It was observed that tensile strength of $S_2$ was not effected by low temperature in transverse direction while it reduced by about 10% at -30$^0$C compared to RT in longitudinal direction.

3-For sample $S_3$, also a reduction in tensile strength was found in both directions at -30$^0$C compared to RT. This reduction was about 6% in both directions. But the value of tensile strength atzero $^0$C and -15 $^0$C was increased by about 12% and 16% compared to RT respectively.

4-The tensile modulus for the three samples was increased as the temperature decrease. This increase was 10% for both sample $S_1$ and $S_2$ while it was 11.25% for sample $S_3$ in transverse direction. But in longitudinaldirection the increase was 15.5% for $S_1$, 7.8% for $S_2$ and 10% for $S_3$.

5-For both tensile and modulus properties, the average values were observed higher in longitudinal direction compared to transversedirection.

**References**

[1] Mohamed A.T., Abdolhossein F., "Progressive Failure Analysis of Glass/Epoxy Composites at Low Temperatures", Material science, Advanced topics, (2013).

[2] Myung-Gon Kim, Sang-Guk Kang, Chun-Gon Kim, Cheol-Won Kong, "Tensile Response of Graphite/Epoxy Composites at Low Temperatures", Composite Structures 79, pp. 84–89, (2007).

[3] Gong,M., Wang X.F., Zhao, J.H. "Experimental Study on Mechanical Behavior of Laminates at Low Temperatures", Gryogenics, 47, p.p. 1-7, (2007).

[4] Walsh, R.P. Golskey J.D. , Reed R.P " Low Temperature Properties of a Unidirectionally Reinforced Epoxy Fiber Glass Composite, Cryogenics, 35, pp. 723-725, (1995).

[5] Mohammed A.T. "Tensile Compressive and Shear Properties of Unidirectional Glass/Epoxy Composites Subjected to Mechanical Loading and Low Temperature Services" , Indian Journal of Engineering and materials sciences, vol. 20, pp. 299-309, (2013).

[6] Panchakshari H.V, Girish D.P,M Krishn," Effect of Deep Cryogenic Treatmenton Microstructure, Mechanical and Fracture Properties of Aluminium-$AL_2O_3$ Metal Matrix Composites", International Journal of Soft Computing and Engineering (IJSCE), ISSN: 2231-2307, Volume-1, Issue-6, January (2012).

[7] Kirz R. "Influence of Ply Cracks on Fracture Strength of Graphite/Epoxy Laminates at 76k", Effect of Defects in Composite Materials, ASTM, STP, 65, (1983).

[8] Wilson J. Fulmer research Ltd DP, R1176/D9, (1990).

[9] Dutta P.K. "Low-Temperature Compressive Strength of Glass-Fiber-Reinforced Polymer Composites", Journal of Offshore Mechanics and Arctic Engineering, 116, pp. 167–172, (1994).

[10] DongGuanXieChuang Composite Material Co., Ltd., ShiMi an Vi ll age, WangDong Management District, WangNiuDun Town, DongGuan, GuangDong, China.

[11] Standard Test Method for Tensile Properties of Fiber Reinforced Metal Matrix Composites, ASTM D 3552 – 96 (2002).

[12] Majerski Krzysztof, Barbara Surowska, JarosławBieniaś," Tensile Properties of Carbon Fiber/Epoxy Laminatesat Lowand Room Temperatures", Composites Theory and Practice, pp.182-185, (2012).

[13] Myung-Gon Kim, Sang-Guk Kang, Chun-Gon Kim, Cheol-Won Kong, "Tensile Response of Graphite/Epoxy Composites at Low Temperatures", Composite Structures 79, pp. 84–89, (2007).

[14] Timmerman J.F. ,et al, "Matrix and Fiber Influences on The Cryogenic Microcracking of Carbon Fiber/Epoxy Composites", Composites part A, pp. 323-329, (2002).

[15] Yuanxin Zhou, Wang Yang, Yuanmin Xia, P.K. Mallick, "An experimental Study on The Tensile Behavior of a Unidirectional Carbon Fiber Reinforced Aluminum Composite at Different Strain Rates", Materials Science and Engineering A362, pp. 112–117, (2003).

[16] SuendraKumarr M. , Sharma N. , Ray B.C., "Mechanical Behavior of Glass/Epoxy Composites at Liquid Nitrogen Temperature", Journal of Reinforced Plastics and Composites, 27 (9), pp. 937-944, (2008).

[17] Reed R.P., Golda M., "Cryogenic Properties of Unidirection Composites", Cryogenics, 34 (11), pp. 909-928, (1994).

[18] Takeda T., Shindo Y., Narita F." Three-Dimensional Thermoelastic Analysis of Cracked Plain Weave Glass/Epoxy Composites at Cryogenic Temperatures", Compos. Sci. Technol., 64,pp. 2353–2362, (2004).