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AN EXPERIMENTAL STUDY ON TENSILE MODULUS AND STRENGTH OF METAL MATRIX COMPOSITE MATERIAL AT ROOM AND LOW TEMPERATURES

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ABSTRACT:
Tensile modulus and strength of 60% constant volume fraction of carbon fiber reinforced aluminum matrix composite materials have been investigated under room temperature (RT), zero °C, -15 °C and -30 °C using Testometric M500 tensile testing machine equipped with an environmental chamber. Three samples of different laminate arrangement and orientation were employed, namely $S_1$and S_2, which included both woven and unidirectional fibers, and S_3, which contained only unidirectional fibers. The results showed that the tensile modulus was slightly increased with decreasing temperatures. The tensile strength showed a slight decrease for samples S_1 and S_2 with decreasing temperature, but for sample S_3, the tensile strength increased as the temperature decreased from (RT) to -15 °C and then decreased at -30 °C. The S_3 laminate orientation with only unidirectional carbon fibers possessed the highest tensile modulus and strength.

Keywords: Composites, Carbon fibers, Aluminum matrix, Tensile modulus and strength, Low temperatures.

دراسة عملية لمعامل المرونة ومقاومة الشد لمادة متراكبة في درجة حرارة الغرفة ودرجات الحرارة الواطئة.

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الخلاصة:
تم دراسة معامل المرونة ومقاومة الشد لمادة متراكبة لها كسر حجمي مقداره (60%) اساسها الالمنيوم ومقواه بألياف الكاربون تحت ظروف اختبار بدرجات حرارية مختلفة: درجة حرارة الغرفة، 0، −15، −30 درجة سليزية بأستخدام جهاز اختبار الشد Testometric M500 وذلك بربط غرفة تبريد على الجهاز المذكور. تم استخدام ثلاث نماذج اختبار S_1, S_2, and S_3 باختلاف نوعية واتجاهات مادة التقوية. تتكون مادة التقوية للمتراكبتين S_1, S_2 من الياف الكاربون المنسوجة والياف الكاربون احادية الاتجاه ، اما المتراكبة S_3 فتتكون من الياف الكاربون احادية الاتجاه فقط. اوضحت النتائج بان معامل المرونة يزداد قليلا بانخفاض درجة الحرارة. بينما بينت نتائج مقاومة الشد انخفاض في النماذج S_1, S_2 بانخفاض درجة الحرارة، ولكن للنموذج S_3 تزداد مقاومة الشد بانخفاض درجة الحرارة من درجة حرارة الغرفة الى − 15 درجة سليزية وبعدها تنخفض عند − 30 درجة سليزية. كما يمتلك النموذج S_3 الذي يحتوي فقط على ألياف كاربون أحادية الأتجاه أعلى معامل مرونة ومقاومة شد.

الكلمات المفتاحية : الياف الكاربون، ارضية من الالمنيوم، مقاومة الشد ومعامل المرونة، درجات الحرارة الواطئة.

INTRODUCTION

Carbon fiber reinforced aluminum matrix composites have high specific strength, high specific stiffness, high thermal conductivity and low coefficient of thermal expansion (CTE). Aluminum-carbon fiber composites have attractive properties for a variety of automotive and aerospace applications [**Zhang Yun-he,2006- Daoud A,2005 - Lee Woei-shyan,2000**].

There is a great deal of research work on the tensile strength of carbon fiber reinforced aluminum at room temperature [**E. Hajjari,2010- Ahmed A,2011- Sheng-Han LI,2004- Yuanxin Zhou,2010- Yuanxin Zhou,2003**], but information on behavior of these metal matrix composites at low temperatures are rather scarce. [**Panchakshari H.V,2012**] 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 $^{\circ}$C for different time duration. The modification of microstructure of MMCs due to cryogenic treatment shows significant improvement in mechanical properties of the MMCs. [**Myung-Gon Kim,2007**] studied the tensile properties of a T700/epoxy composite material at room temperature (RT), -50 $^{\circ}$C, -100 $^{\circ}$C and -150 $^{\circ}$C. They concluded that tensile modulus tends to increase as temperature decreases. The amount of percentage increase of tensile modulus was found to be about 16% more at -150 $^{\circ}$C than at (RT). The reason of this increase was attributed to the brittleness of the fibers at low temperatures. [**Majerski,2012**] tested carbon fiber reinforced polymer (CFRP) to examine the tensile properties at temperatures (153, 223, and 295 ^{0}K). They found that the tensile modulus increases as the temperature decreases, but the increase in the range of 153 and 223 ^{0}K was smaller than that in the range of 223 to 295 ^{0}K which amount to 9%. The explanation of this increase may be due to a sharp increase in fiber brittleness at these low temperatures [**Myung-Gon Kim,2007**]. [**Myung-Gon Kim,2007**] found that the strength of non-cycled specimens decreased about 9% more at -150 $^{\circ}$C than RT for graphite/epoxy composite. [**Majerski,2012**] observed that the tensile strength is decreased about 7% at 223K compared to (RT) and about 8% at 153K for carbon fiber/epoxy laminates. On the other hand, [**Reed and Golda,1994**] reported an increase in tensile strength of a unidirectional carbon/epoxy laminate at low temperatures. The reduction in tensile strength may be caused by several factors such as a brittle matrix or an increase in residual stress in the composite material [**Majerski,2012**]. Other researchers explained the reasons of reduction in tensile strength due to increase in the size of fibers in the radial direction and shortening in the direction of the longitudinal axis, while matrix expands in all directions [**Majerski,2012- Timmerman J.F,2002- Suendra Kumarr M.,2008**].

This study aims at evaluate the tensile properties of carbon fiber multilayer configurations with aluminum composites laminates at low and room temperatures.

EXPERIMENTAL PROCEDURE:

Composite Materials:

The composite material laminates used in this study are carbon fiber reinforced aluminum alloy. Composite Materials have been fabricated in china. The basic structural components were: woven carbon fiber (3K) and unidirectional carbon fiber (UD) in three different fiber orientations (0°/90° for woven carbon fiber and /0°/, /90°/ for unidirectional) as a reinforcement and aluminum (3003) alloy as matrix. Fig. (1) shows these types of carbon fibers. Table (1) illustrates the locations and orientations of each sample laminates (4 layers of carbon fibers and 2 layers of aluminum). The production of these composite materials is carried out by using high temperature and vacuum pressure in Vacuum Bag Oven process. Composite laminates were laid down from the prepreg carbon fiber and aluminum foil and cured in a hot press inside the oven. Heating up to 190 $^{\circ}$C with a heating rate of 3 $^{\circ}$C/min. Vacuum pressure was 30 bar. After an applied holding time of 60 minutes, the pressure was released and the composite was allowed to cool to room temperature.

Test Specimens:

The specimens for tensile testes were cut from standard sheet (400*500*0.85 mm^3) by a CNC milling machine according to the standard test method for tensile properties of fiber reinforced metal matrix composites ASTM D3552[**ASTM,2002**]. Tensile test specimens were cut from transverse direction. The strain rate for all tensile tests was 0.0015 s^{-1}. Fig. (2) shows the shape and dimensions of the tensile test specimen.

Tensile Test Rig:

The tensile tests were performed in a Testometric M500 test machine as shown in Fig. (3-a). The maximum load capacity of the test machine is 25kN. An environment chamber was attached to the tensile test rig and sealed with an insulation material as in Fig. (3-b). The chamber has the ability to cool down its temperature to -30 ^oC.

Cooling Chamber:

During the test, a pressurizing device was used to control the cooling time from room temperature (RT) to required temperature. It consists of two boxes. The first box is cooling room and the second box contains the cooling equipment. The cooling chamber parts are: compressor, double evaporator, heat exchanger pipes (condenser), fan, thermostat and refrigerant feron type. The cooling rate was 2 $^{\circ}C$ /min. The temperature inside the cooling room was calibrated by thermocouple. A delay time of about 15minutes was used to homogenize temperature through the whole thickness of the specimen. Fig. (4) shows the grips of the tensile machine inside the cooling room.

RESULTS AND DISCUSSION:

The results of tensile modulus and strength in the (y) direction see figure (1), for the three types of composite materials mentioned in Table (1) and for four different temperatures, are presented in Table (2).

The tensile modulus and strength are shown as a function of temperature in Fig. (5) and (6) respectively. The results are based on the arithmetic average of three testing specimens.

Tensile Modulus:

Tensile modulus was determined by taking a slope of stress-strain curves of tensile test. The results show that as the temperature decreases, the tensile modulus slightly increases. The maximum increase occurred at -30 $^{\circ}C$ compared to the room temperature (RT) values for all orientations studied. The S_3 laminates arrangement and orientation, where all the four carbon fiber reinforcing laminates were of the unidirectional type, possessed the highest tensile modulus. Table (3) summarizes the amount of the percentage increase with decreasing temperature.

Tensile Strength:

Referring to table (2) and figure (6), it is noted that the tensile strength decreased as compared to (RT) for samples (S_1) and the significant decrease occurs only at -30 $^{\circ}C$. For samples (S_2), the tensile strength did not significantly change with temperature except at -15 $^{\circ}C$ where the lowest value was recorded. The tensile strength for sample S_3 increased with decreasing temperature except at -30 $^{\circ}C$ where the tensile strength was the lowest. Here again the S_3 laminate orientation with only unidirectional carbon fibers possessed the highest tensile strength which was between (2.8- 3.5) times the tensile strength of the S_1 orientation. This is attributed to the reason that, unidirectional carbon fibers are proportional manner (parallel) to the axis of tensile force. In the case of samples S_1, S_2 misalignment axis with respect to the tensile load axis will be occur due to different in fibers type and orientation causing the earlier failure in these composite samples.

CONCLUSIONS:

In this investigation, the tensile modulus and strength of carbon fiber-aluminum matrix composite materials of three types with constant volume fraction were studied at RT, zero $^{\circ}$C, -15 $^{\circ}$C and -30 $^{\circ}$C. The conclusions of this study are:

1- It was found that the tensile modulus of the considered laminates slightly increase with decreasing temperature. The maximum increase was observed at -30 $^{\circ}$C for all the types of sample orientations.
2- Tensile strength tends to decrease as temperature decreases down to -30 $^{\circ}$C for sample S_1 and S_2, where the reinforcement included laminates of woven carbon fibers, while it increases for sample S_3, where the reinforcement contained laminates of only unidirectional carbon fibers, from (RT) to -15 $^{\circ}$C and then decreases at -30 $^{\circ}$C.
3- The S_3 laminate orientation with only unidirectional carbon fibers possesses the highest tensile strength .

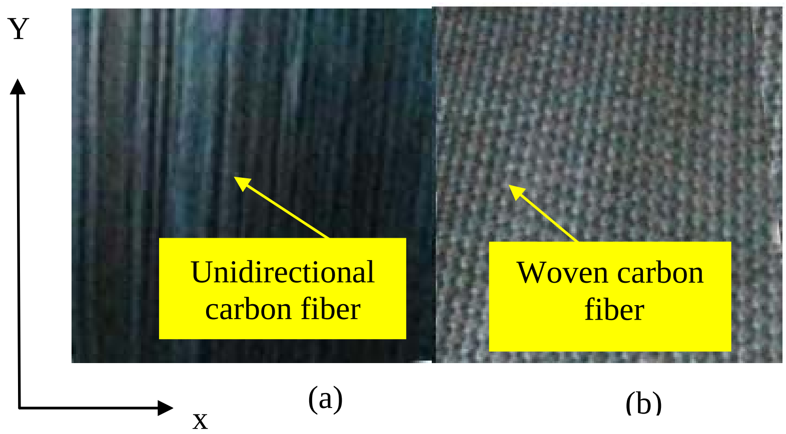
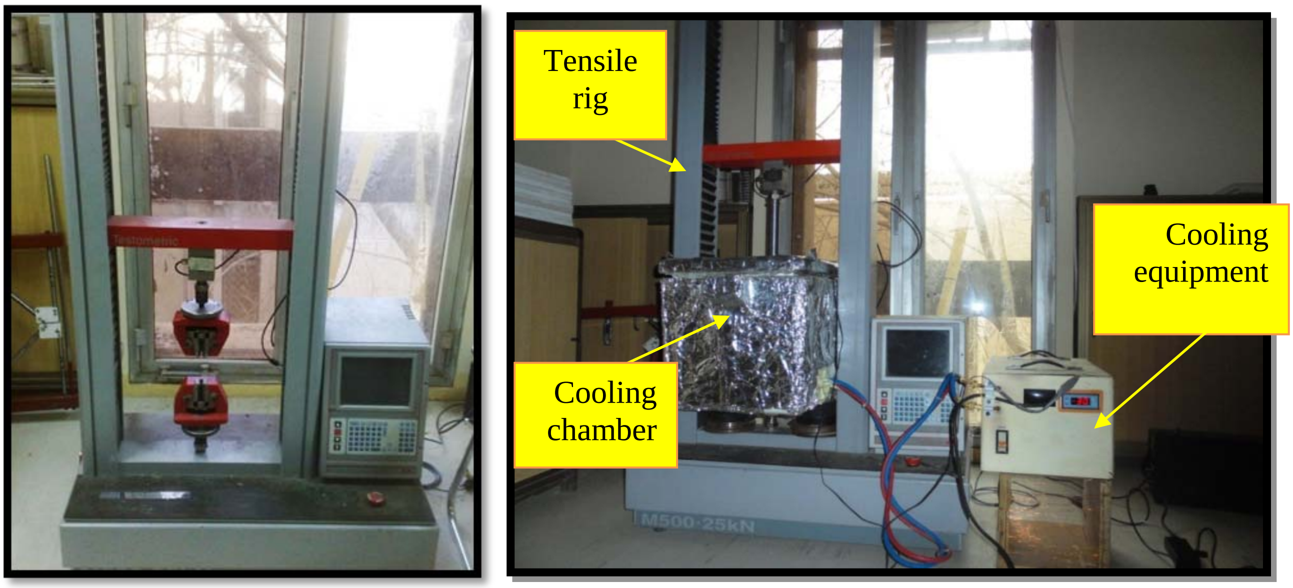


Figure (1) (a) Woven carbon fiber and (b) Uinidirection carbon fiber.

Figure (2): Tensile specimen of composite material according to ASTM D3552 (all dimensions in mm).



(a) **(b)**

Figure (3): (a) tensile test machine, (b) Cooling chamber attached to the tensile test rig.

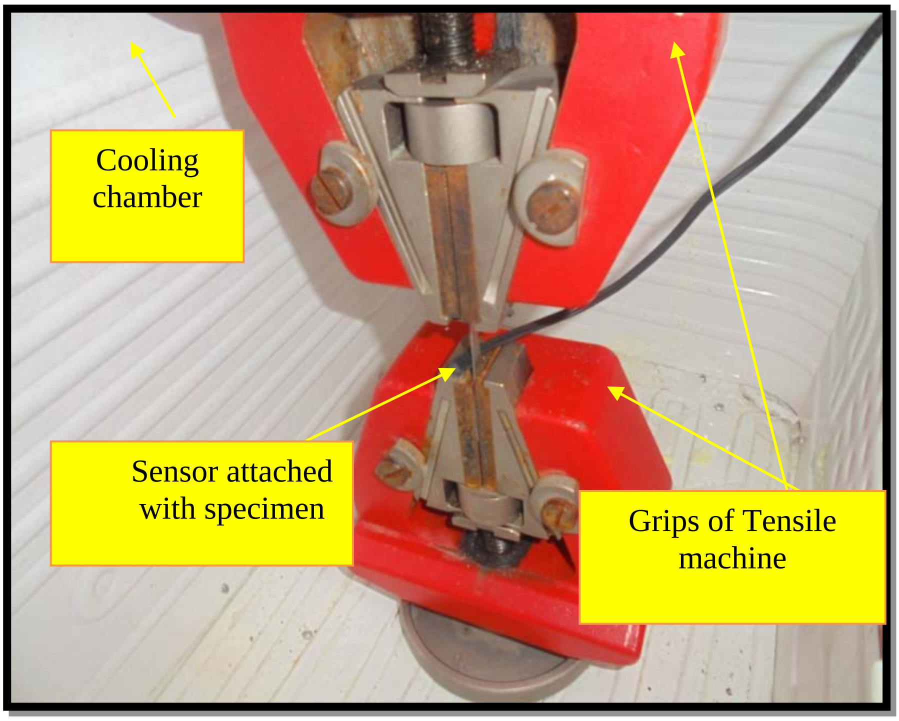


Figure (4): Grips of the tensile machine inside the cooling room.

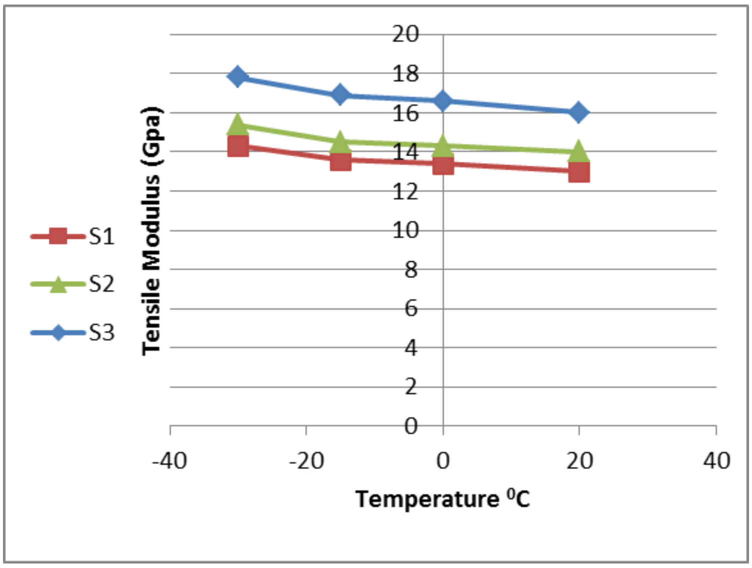


Figure (5): Tensile modulus as a function of temperature for three different orientations of composite materials.

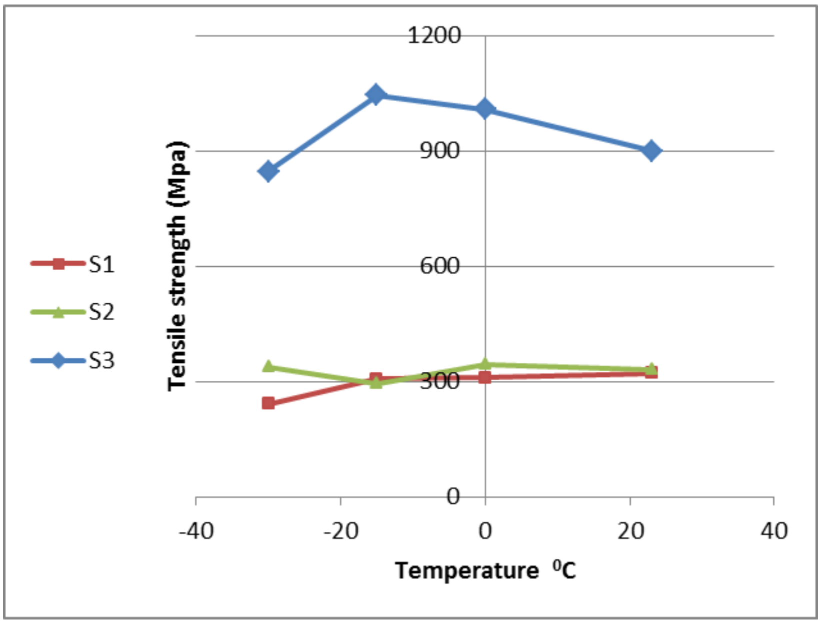


Figure (6): Tensile strength against temperature for three different orientations of composite materials.

Table (1): The three samples composite sheets with different laminate orientations.

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°- 0°
S_2	**[Al/3K/UD/UD/3K/Al]**	**60**	**4**	0°/90°- 0°- 0°- 0°/90°
S_3	**[Al/UD/UD/UD/UD/Al]**	**60**	**4**	90°- 0°- 0°- 90°

Table (2): Tensile modulus and strength of three composite materials at different temperatures: (a) RT, (b) zero °C, (c) -15 °C, (d) -30 °C.

(a)

Samples at room temperature (RT)					
S_1		S_2		S_3	
Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa
13 12.5 13.5	381 300 282	14 14.5 13.5	309 361 326	16 16.5 15.5	900 905 895
Average of readings					
13	321	14	332	16	900

(b)

Samples at zero temperature					
S_1		S_2		S_3	
Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa
12.9 13.5 13.8	318 304 309	14.15 14.21 14.6	377 322 333	16.4 16.6 16.8	962 1061 1003
Average of readings					
13.4	310.33	14.32	344	16.6	1008.67

(c)

Samples at -15 ^{0}C					
S_1		S_2		S_3	
Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa
13.2 13.5 14.1	308 310 303	14.3 14.5 14.7	300 290 296	16.6 16.9 17.2	1057 1044 1031
Average of readings					
13.6	307	14.5	295.33	16.9	1044

(d)

Samples at -30 ^{0}C					
S_1		S_2		S_3	
Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa	Tensile modulus GPa	Tensile strength MPa
13.8 14.2 14.9	210 275 240	15.1 15.6 15.7	344 334 335	17.6 17.8 18	848 830 860
Average of readings					
14.3	241.67	15.4	337.67	17.8	846

Table (3): The percentage increase in tensile modulus for the three samples.

Sample	**Temperature ($^\circ$C)**	**Tensile modulus (GPa)**	**Increase in tensile modulus (%)**
S1	RT	13	----
	0	13.4	3
	-15	13.6	4.6
	-30	14.3	10
S2	RT	14	---
	0	14.32	2.2
	`-15	14.5	3.57
	-30	15.4	10
S3	RT	16	----
	0	16.6	3.75
	-15	16.9	5.62
	-30	17.8	11.25

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