Eng. & Tech. Journal, Vol.30, No.11, 2012

The Influence of the Temperature on the Ultimate Tensile Strength of the Composite Materials at Constant Fiber Volume Fraction

Dr. Hussain J. Al-alkawi
Electromechanical Engineering Department, University of Technology/Baghdad
Email:uot_magaz@yahoo.com
Dr. Dhafir S. Al-Fattal
Machines & Equipment Engineering Department, University of Technology/Baghdad
Abdul-Jabar H. Ali
Engineering Collage, University of Baghdad/ Baghdad

Received on: 18 /10/2011 & Accepted on: 5/4/2012

Abstract

The aim of this work is to study the influence of the temperature on the ultimate tensile strength (UTS) of composite material which is manufactured from polyester and E-glass (woven roving, chopped strand mat) as a laminate with a constant fiber volume fraction (VF) of 33%. The results showed a little effect of temperature on tensile strength in the range of room temperature (RT) to 50 ^{o}C for laminates reinforced with E-glass (woven roving) [0/90, ±45,0/90], $[0/90]_3$, and [0/90, CSM, 0/90], but for laminates reinforced with E-glass chopped strand mat (CSM), as $[CSM]_3$ and [CSM, 0/90, CSM], a continuous reduction in strength was observed with increasing temperature from (RT) to 60 ^{o}C. The highest percentage reduction in strength was 23% at 60^{o}C as compared with (RT) for $[CSM]_3$ laminate.

Keywords: composite material, tensile strength, temperature.

تأثيردرجة الحرارة على مقاومة الشد للمواد المتراكبة بثبوت الكسر الحجمي للألياف

الخلاصة

بهدف هذا البحث الى دراسة تأثير درجات الحراره على مقاومةالشد للمواد المتراكبه المصنعه من البولستر والالياف الزجاجيه وبنسبه حجميه ثابتة للألياف الزجاجية مقدارها 33%. أظهرت نتائج البحث ان المواد المصنعه من [0/90, ±45, 0/90], [0/90, CSM, 0/90], [0/90]3 تتأثر قليلا بدرجات الحراره ما في مدى (درجة حرارة الغرفة و 50 درجه مئويه) في حين ان المواد المصنعه من [CSM, 0/90, CSM], [CSM]3 تظهر انخفاض مستمر في اجهاد الشد الاقصى مع زيادة درجة الحراره من درجه حرارة الغرفة الى 60 درجه مئويه وان اعلى نسبة انخفاض لمقاومة الشد كان مقدارها 23% وذلك عند 60 درجه مئويه مقارنة بمقاومة الشد عند درجه حرارة الغرفة وللماده المصنعه من [CSM]3 .

https://doi.org/10.30684/etj.30.11.8
2412-0758/University of Technology-Iraq, Baghdad, Iraq

INTRODUCTION

A composite material has been defined as: “A substance consisting of two or more materials, insoluble in each another, which are combined to form a useful engineering material having a certain properties not possessed by the constituents” [1]. These materials are discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement material; whereas the continuous phase is usually softer and is termed the matrix. The matrix holds the reinforcements in an orderly pattern [2]. This work focuses on fiber-reinforced composites composed of fibers embedded in a matrix; the fibers are long, continuous in one or multiple directions. Such materials offer advantages over conventional isotropic structural materials such as steel, aluminum and other types of metals. These advantages include high strength, good fatigue strength, light weight and corrosion resistance.

In addition, by changing the arrangement of the fibers, the properties of the material can be tailored to meet the requirements of a specific design [3]. The design of a structural component using composites involves both material and structural design. Unlike conventional materials, the properties of the composite material can be designed simultaneously with the structural aspects. Composite properties (e.g., stiffness, thermal expansion, etc.) can be varied continuously overa broad range of values, under the control of the designer [4]

William Walker Van Arsdell [5]: investigated the particle size effect on the monotonic tension, high temperature isothermal fatigue (IF) and thermo mechanical fatigue (TMF) behavior of a 2024 aluminum alloy with 0%, 10%, and 30% volume of 2µm and 30µm silicon carbide particles S_i C. The results showed that the alloy reinforced with 2µm particles had superior mechanical properties than reinforced with 30µm particles. Fatigue lives obtained for reinforced with 2µm were greater than those observed for reinforced with 30µm particles.

Mei Li [6]: identified resins that have a good temperature and moisture resistance while the resins included Ortho and ISO polyesters, vinyl ester and an epoxy, which is appropriate for wind turbine blades in terms of low cost and low viscosity for easy processing by resin transfer molding (RTM). The test included three conditions: room temperature dry, 50 ^{o}C dry and 50 ^{o}C in distilled water. Results showed that epoxy SC–14 and Ortho – polyester are the most sensitive to moisture and temperature.ISO–polyester has superior environmental resistance. However, both polyesters are relatively brittle, with low inter-laminar fracture toughness, compared with vinyl ester and epoxy.

P.M.H. Wong, et al [7]: This paper presents the results of experimental and numerical studies to determine the compression strength of short glass reinforced plastic (GRP) C-shaped channels at different elevated temperatures. Several possible compressive testing methods were explored to obtain the compression strength of the material. Eventually a pair of grooved steel end plates was used to restrain the test specimen under compression.

Kevin Jackson Smith, [8]: presented the results of experimental investigation into the behavior of a pultruded E – glass / polyester fiber reinforced polymer (FRP) composite under sustained loads at elevated temperature in the range of those that might be seen in service. This investigation involved compression creep tests of material coupons performed at a constant stress level of 33% of ultimate strength and three temperatures level, 23.3 ^{o}C, 37.7 ^{o}C and 54.4 ^{o}C.

Mohammad A. Hassan,[9]: investigated the compressive properties and crushing response of circular and square fiber glass reinforced plastic tubes subjected to impact testing at different temperatures. The results showed that the mechanical properties (tensile, compressive and shear) of the composite material used in this study decrease as temperature increases.

EXPERIMENTAL WORK

Materials:

There are numerous numbers of combinations of fibers and matrix to choose from in manufacturing composite materials. The design requirements of the engineered part as well as the availability of the materials usually determine which material is most appropriate. In this work, E-Glass fiber is used; it was obtained in the form of discontinuous and continuous woven strand mats. It was not possible to measure the glass fiber properties experimentally, hence reasonable values were chosen from the literature. Table (2-1) shows the composition of glass fibers and Table (2-2) shows some of the reported properties of E-glass fibers. Polyester (TOPAZ-1110 TP) unsaturated resin with1.5 % hardener was used for the matrix. The reported properties of polyester found in the literature seem to vary according to their manufacturing source. A brief summary of some of the reported properties is given in Table (2-2).

SPECIMEN PREPARATION:

(hand lay-up)

The choice of a manufacturing process depends on the type of matrix and fibers. Hand lay-up is the simplest and oldest open molding method of the composite fabrication processes, Laminate panels were prepared according to ASTM D5687 [10], and the following stages of preparation were used:

1. The mould, which was made of a thermal glass plate 60*80cm^2, was cleaned and treated with a release wax in order to prevent the finished product from sticking to the frame. The liquid resin was mixed with 1.5% hardener and applied over the wax.
2. The first layer of reinforcing material (45×75cm^2 woven roving mats) was laid over the resin while it was still wet, it was embedded into the resin and completely wetted with a stiff brush.
3. Any air bubbles trapped under the reinforcement were removed by working them out to the edge using special rollers.

4. The application of additional layers (3 layers) of fibers and resin was repeated to produce the final laminate $[CSM]_3$, $[0/90]_3$, [0/90, ±45, 0/90], [CSM, 0/90, CSM] and [0/90, CSM, 0/90] with a constant volume fraction of about 33%.
5. A heavy weight was applied on the cover of the mould giving a pressure of 4135 N/m^2 to prevent buckling during curing.
6. The laminate was left in the mould to cure for 24 hours at room temperature.
7. The laminate was trimmed to remove excess resin.
8. The product laminate was left 3 hours in oven at 60^oC in order to be sure that the curing process was achieved.
9. The part was ready to be cut into specimens; it was left 3 weeks before testing was carried out.

10-The laminates were cut out of 70×40 cm^2 panels and followed by polishing the cut edges in two stages in order to remove flaws and to obtain smooth and crack-free surfaces. Silicon carbide paper of grade 400 and 800 was used for this purpose.

THE TENSILE TEST SPECIMENS

Matrix: In order to find the mechanical properties of the matrix, tensile specimens were prepared according to ASTM D 638-97 [11]. Figure 2-1 shows the dimensions and geometry of tensile specimen for the matrix. A mixture of polyester and hardener was prepared and cast in mould as shown in Figure 2-2. After curing at room temperature for 24 hours, the specimen was peeled out from the mould.

COMPOSITE MATERIAL

Tests specimens were designed according to ASTM D3039 standards [12, 13]. The tensile test specimen configuration is shown in Figure (2-3).

Tensile Tests Procedure

The tensile tests were performed in a Tinius Olsen (H50KT) test machine at room, 40^oC, 50^oC and60^oC temperature. The maximum load capacity of the test machine is 5 ton. Figure (2-4) shows the specimen clamped securely in the fixture before applying the load with the furnace mounted in place. A constant gross head speed of 1 mm/min was used during the test until specimen failed [13].

The test results show different fracture modes which have taken place such as brittle fracture of the matrix and gradual breaking of the fibers depending on the type of the layers used in laminates. Figure (2-5) shows some examples of tensile test specimen before and after test.

TEMPERATURE CONTROL CIRCUIT

The circuit shown in figure (2-6) represents the operation of the temperature control board. The temperature control circuit is used to control the temperature inside the furnace by its thermostat, which switches off the electrical power when the temperature reaches the required temperature and switches it on when the temperature drops below the required temperature. The temperature inside the furnace is calibrated by using a digital thermometer with a thermocouple. The results are accurate within ± 0.2^{o}C and the heating rate is 1^{0}C/min.

EXPERIMENTAL RESULTS AND DISCUSSION

Table 3-1 shows the experimental tensile strength of the matrix at (RT) while table 3-2 shows the results of the fiber strengthened composite material at (RT) at the same volume fraction of fiber with different laminates (3 layers of different fiber orientation). It can be observed that regardless of the orientation of the fibers, the addition of the fibers contributes to strengthening of the composite. However, the $[0/90]_3$ and [0/90, CSM, 0/90] orientations yield the highest strengthening in the range of 7.32 to 7.64 times the strength of the original matrix. Strengthening of the other three fiber orientations, $[CSM]_{3,}$ [0/90, ±45, 0/90] and [CSM, 0/90, CSM], is only in the range of 4.04 to 4.64 times the strength of the original matrix.

Table 3-3, 3-4 and 3-5 show the tensile strength at temperatures of 40, 50 and 60^{o}C respectively. The same trends explained previously at room temperature are observed again at higher temperatures with the two orientations $[0/90]_3$ and[0/90, CSM, 0/90] stand for their high strength. Figures 3-1 to 3-5 show the effect of temperature on the ultimate tensile strength for all the fiber orientations studied. For the laminates $[CSM]_3$ and [CSM, 0/90, CSM] there is a continuous reduction in the tensile strength with increasing temperature. The amount of percentage reduction in strength at 60^{o}C as compared to room temperature strength is 23.6% and 8.7% for laminates $[CSM]_3$ and [CSM, 0/90, CSM] respectively. On the other hand, the three laminates [0/90, ±45, 0/90], $[0/90]_3$, [0/90. CSM, 0/90] show on average little change of tensile strength with temperature up to 50 ^{o}C. Nevertheless, the amount of percentage reduction in strength at 60 ^{o}C as compared to room temperature strength is 13.8%, 10.97% and 7.13% for the [0/90, ±45, 0/90], $[0/90]_3$ and [0/90, CSM, 0/90] respectively. Then;

1-It can be observed that the theoretical best fit linear relation between ultimate tensile strength and temperatures in the range (RT-60 ^{o}C) can be used for $[CSM]_3$, [CSM, 0/90, CSM] and $[0/90]_3$ laminates because the coefficient of correlation is 0.96, 0.846 and 0.89 respectively

2- But for [0/90, CSM, 0/90] and [0/90, ±45, 0/90] laminates the linear relation is invalid because the coefficient of correlation is 0.524 and 0.445 respectively.

3- Then it can be observed that the ultimate tensile strength of these laminates was decreases with the increasing temperature as a polynomial question of third order can fit the experimental data to include the temperature effect as a function of the temperature (T):

$$\sigma_{ult} = D_o + D_1T + D_2T^2 + D_3T^3 \quad \text{……..(3-1)}$$

Where σ_{ult} is the ultimate tensile strength (MPa), T is the temperature in ^{o}C and the coefficient D with subscripts 0, 1, 2 and 3 represent material constant which can be obtained from experiments as shown in table (3-6)

4-The best laminates in this study that have the combined properties of high strength and resistance to softening with increasing temperature is [0/90, CSM, 0/90] and $[0/90]_3$.

CONCLUSIONS

The following conditions may be drawn from the present work:

1- At a constant fiber volume fraction of 33% the tensile strength for $[0/90]_3$ and [0/90, CSM, 0/90] laminates are higher than that for $[CSM]_3$,[0/90, ±45, 0/90] and [CSM, 0/90, CSM] laminates.

2- For laminates [0/90, ±45, 0/90], $[0/90]_3$, and [0/90, CSM, 0/90]:

a- A little effect of temperature in range (room temperature to 50 ^{o}C) on tensile strength is observed.

b- Reduction in strength at 60^{o}C for [0/90, ±45, 0/90] laminate, $[0/90]_3$ laminate and for [0/90, CSM, 0/90] laminate is 13.79%, 10.97% and 7.13% respectively as compared to RT strength.

3- For laminates $[CSM]_3$ and [CSM, 0/90, CSM] , the results shows reduction in strength with increasing temperature from RT to 60 ^{o}C of about 23.6% for $[CSM]_3$ laminate and 8.7% for [CSM, 0/90, CSM] laminate.

4- The highest percentage reduction in strength was 23% at 60 ^{o}C as compared to RT ^{o}C for $[CSM]_3$ laminate.

5- It can be observed that the ultimate tensile strength of laminates used was decreases with the increasing temperature as a polynomial question of third order can fit the experimental data to include the temperature effect as a function of the temperature.

REFERENCES

[1]. Vinson, J. R. and Sierakowski, R.L. “The Behavior of Structures Composed of Composite Materials” Second Edition. Kluwer Academic Publisher, 2002.

[2]. P.K.Mallick “Fiber Reinforced materials, Manufacturing, and Design, 3rd Ed.” By Taylor and Francis Group, 2007.

[3]. Kullör L.P. and Springer, G.S. “Mechanics of Composite Structures” Cambridge University Press–Stanford, 2003.

[4]. Barbero, E. J. “Introduction to Composite Materials Design”, Materials Science & Engineering Series, 1st edition, Taylor & Francis, Inc, 1998.

[5] William Walker Van Arsdell, “The Effect of Particle Size on The Thermo-Mechanical Fatigue of Metal Matrix Composite’s, A report of material engineering – mechanical behavior, College of engineering, University of Illinois at Urbana-Champaign, Report No.163. August 1993.

[6] Mei Li “Temperature and moisture effects of composite material for wind Turbine blades” MSc. thesis, Montana State University – Bozeman 2000. [7]P.M.H. Wong, J.M. Davies, Y.C. Wang “An experimental and numerical study of the behavior of glass fibre reinforced plastics (GRP) short columns at elevated temperatures” Composite Structures 63 (2004) 33–43

[8] Kevin Jackson Smith “Compression creep of a pultruded E – glass / Polyester composite at elevated temperature” MSc thesis, The Academic Faculty, Georgia Institute of Technology, August 2005.

[9] Mohammad A. Hassan “Buckling Deformation of Composite Material under Impact Axial Loading at Elevated Temperatures” PhD thesis, Electromechanical Engineering Department /University of Technology, 2009

[10]. ASM Handbook, “Space Simulation; Aerospace and Aircraft; Composite Materials”, Vol. 15, 2000. ***http://mihd.net/yn9up8***

[11] .ASTM D638 Standard test method for tensile properties of plastics, Annual Book of ASTM standards American society for testing and material. Philadelphia, pp. 46-54. 1997.

[12] ASTM D3039. 1995. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. Annual Book of ASTM Standards, American society for Testing and Materials, Philadelphia. 14(2): 99-109.

[13] Hodgkinson.J.M “Mechanical testing of advanced fiber composites” Wood publishing limited, Cambridge England, 2006.

Table (2-1) Composition of glass fibers: [10]

Material	**Silicon dioxide**	**Aluminum Oxide**	**Boric Oxide**	**Sodium Oxide and potassium Oxide**	**Magnesium Oxide**	**Titanium dioxide**	**Iron Oxide**	**Iron**	**Calcium Oxide**
E-glass (range %)	52 to 56	12 to 16	5 to 10	0 to 2	0 to 5	Up to 1.5	0 to 0.8	0 to 1	16 to 25

Table (2-2) Mechanical properties of fibre glass and polyester (Resin)[10]

Material	Density g/cm3	Modulus of elastic (GPa)	Tensile Strength (MPa)	Poisson’s ratio
E-glass	2.54	72.4	3450	0.22
polyester	1.1-1.4	2.1-3.4	34.5-103	0.37-0.4

Table (3-1) Tensile test for matrix (polyester) at (RT) 30 ^{o}C

No.	Matrix , Resin	specimens			Ultimate tensile stress (UTS), MPa			Average UTS MPa
1	Polyester, TOPAZ 1110	1	2	3	33.38	31.75	32.59	32.567

Table (3-2) Tensile test for composite material at room temperature (RT)

No.	laminate description	specimens			UTS , (MPa)			Average UTS MPa
1	$[CSM]_3$	4	5	6	142	142.5	147.5	144
2	[0/90,±45,0/90]	7	8	9	155	121	119	132
3	[CSM,0/90,CSM]	10	11	12	155	123.3	173.5	151
4	$[0/90]_3$	13	14	15	256.7	240	250	249
5	[0/90,CSM,0/90]	16	17	18	221	249.5	245	239

Table (3-3) Tensile test for composite material at 40 °C

No.	laminate description	specimens			UTS , (MPa)			Average UTS MPa
1	$[CSM]_3$	19	20	21	134.7	130.5	128	131
2	[0/90,±45,0/90]	22	23	24	125.3	139.4	130	132
3	[CSM,0/90,CSM]	25	26	27	138.8	148.1	147	145
4	$[0/90]_3$	28	29	30	243.8	240.3	241.5	242
5	[0/90,CSM,0/90]	31	32	33	248	244.8	245.5	246

Table (3-4)Tensile test for composite material at 50 °C

No.	laminate description	specimens			UTS , (MPa)			Average UTS MPa
1	$[CSM]_3$	34	35	36	117.2	112	115	115
2	[0/90,±45,0/90]	37	38	39	138.4	132.2	136	136
3	[CSM,0/90,CSM]	40	41	42	127.2	144.6	136.1	136
4	$[0/90]_3$	43	44	45	243.1	234.6	237.9	239
5	[0/90,CSM,0/90]	46	47	48	229.8	247	238.2	239

Table (3-5) Tensile test for composite material at 60 °C

No.	laminate description	specimens			UTS , (MPa)			Average UTS MPa
1	$[CSM]_3$	49	50	51	110.9	109.2	110.1	110
2	[0/90,±45,0/90]	52	53	54	113.5	113.3	113.8	114
3	[CSM,0/90,CSM]	55	56	57	126	148.5	138	138
4	$[0/90]_3$	58	59	60	223.5	219.4	222	222
5	[0/90,CSM,0/90]	61	62	63	216.8	225.5	222.3	222

Table (3-6) polynomial coefficient D, constant material for laminates used

No.	laminate description	D_o	D_1	D_2	D_3	Percentage of accuracy Range %
1	$[CSM]_3$	10.6	11.8	-0.321	2.5×10^3	100%-95%
2	[0/90,±45,0/90]	455.5	-24.9	0.62	-5×10^3	100%-98%
3	[CSM,0/90,CSM]	8	11.5	-0.295	2.3×10^3	100%-98%
4	$[0/90]_3$	474	-16.2	0.38	-3×10^3	100%-99%
5	[0/90,CSM,0/90]	58	11.4	-0.215	1.16×10^3	100%-98%

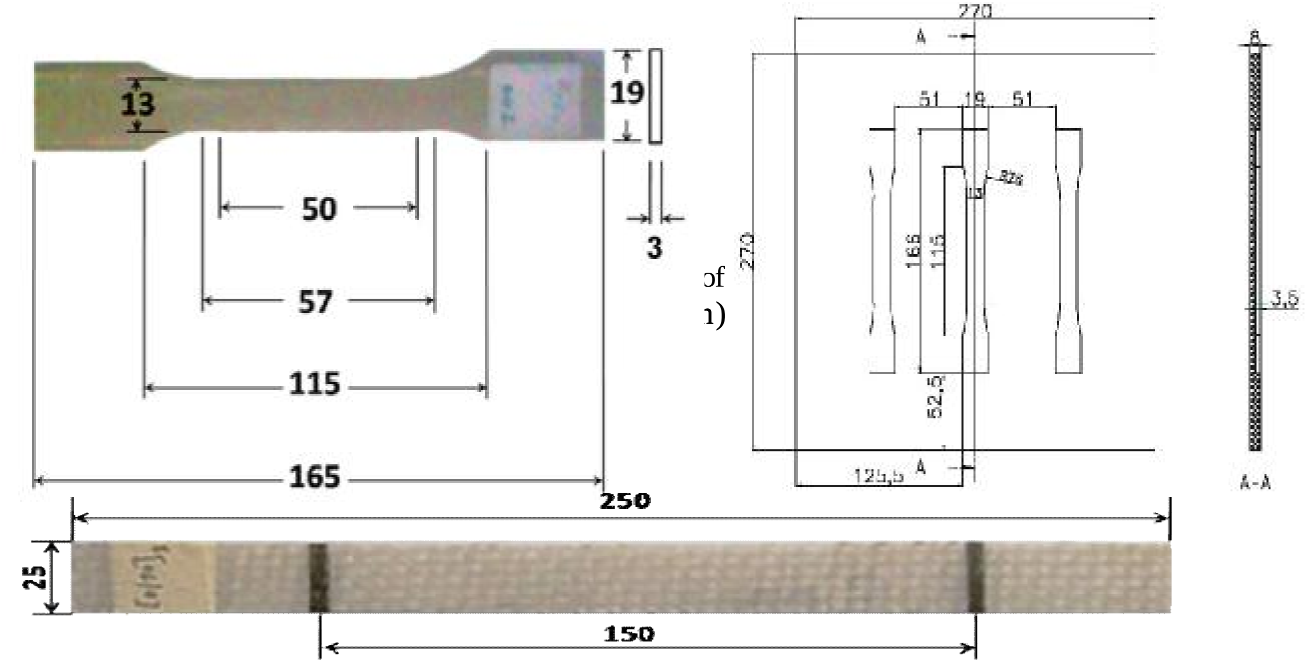
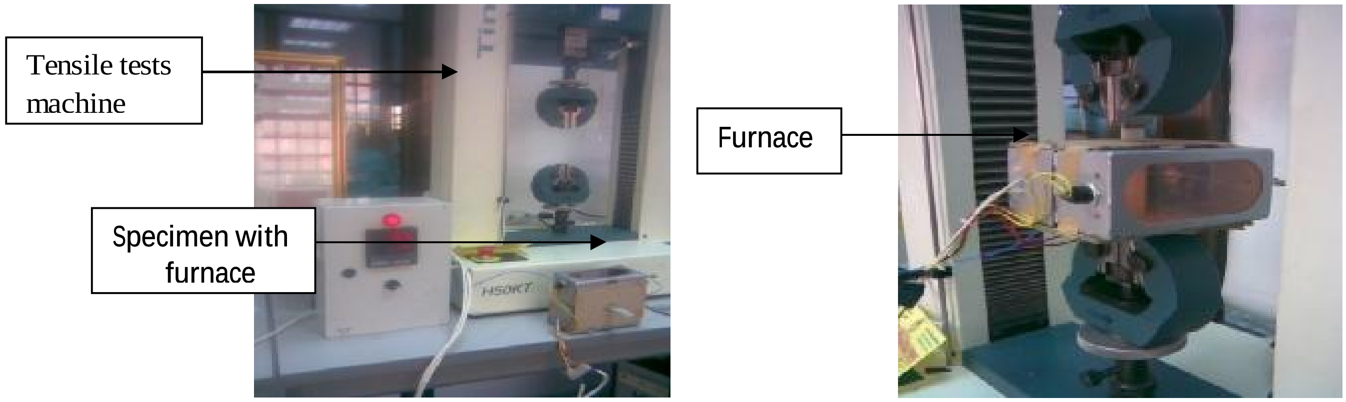


Figure (2-3) tensile test specimen dimensions



a-Specimen with the Furnace **b- Specimen Fixture with the Furnace**

Figure (2-4)

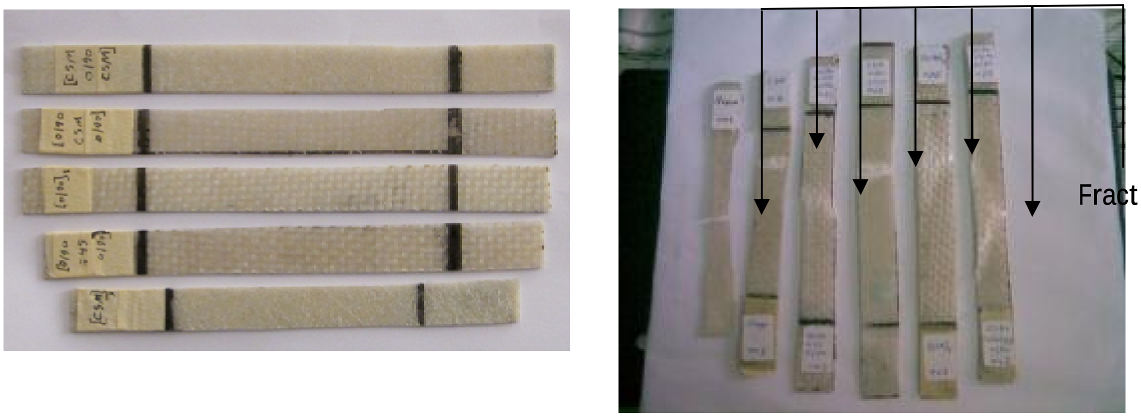


Figure (2-5) Examples of tensile specimens before and after failures

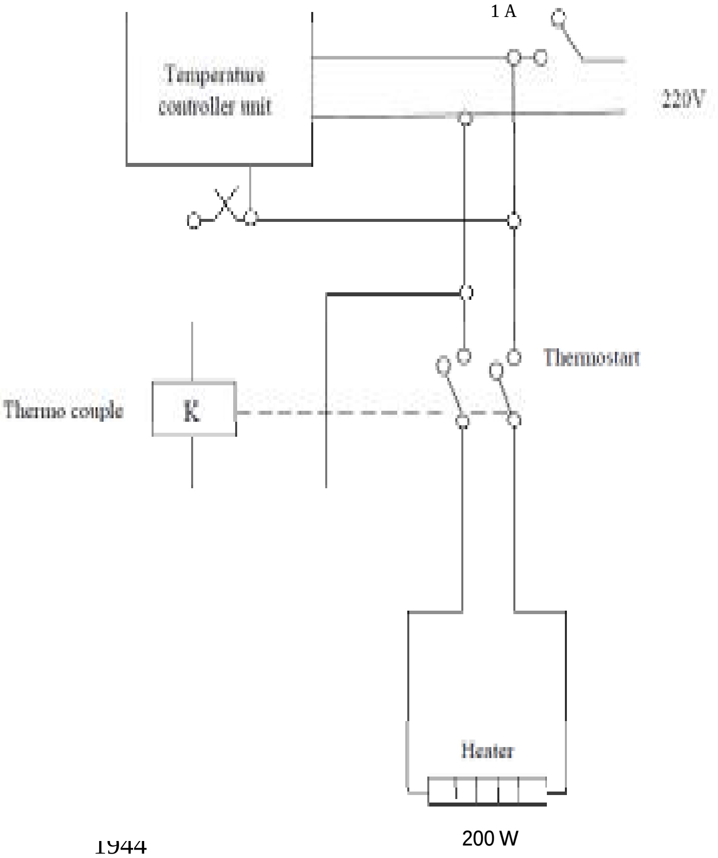


Figure (2-6) Diagram of the temperature control circuit

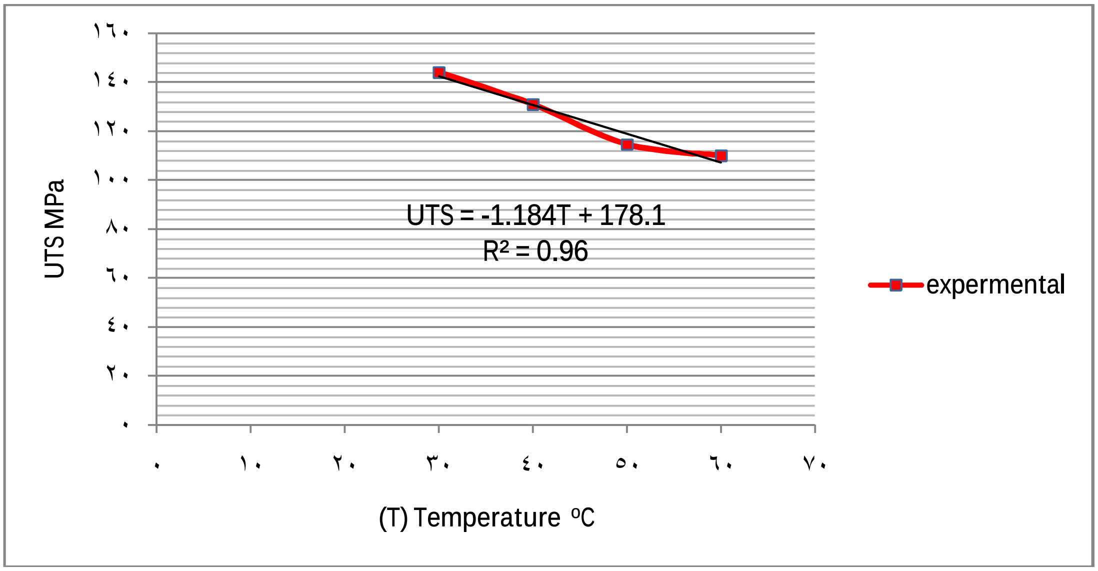


Figure (3-1) Variation of the average ultimate tensile strength for [CSM]$_3$ laminate with temperature rise

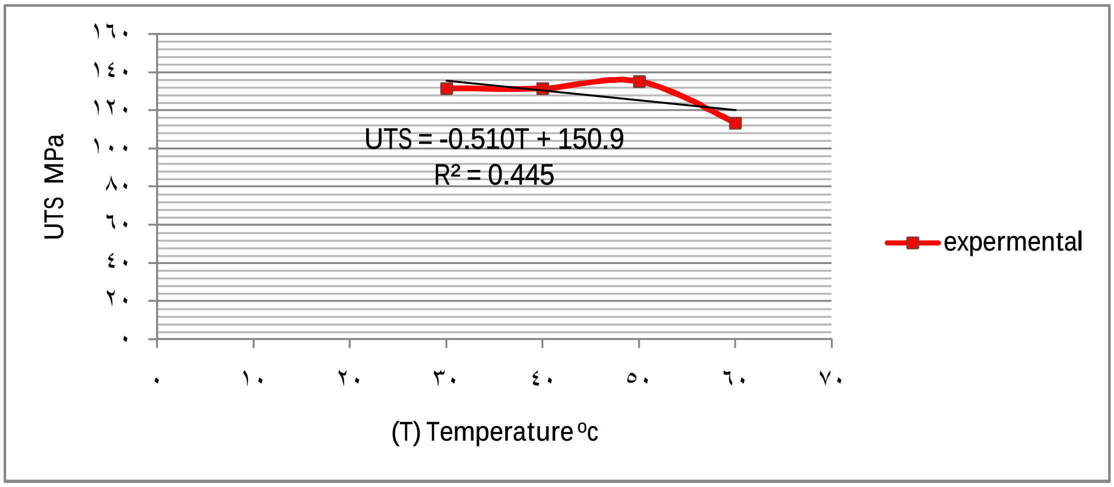


Figure (3-2) Variation of the average ultimate tensile strength for [090, ±45, 0/90] laminate with temperature rise

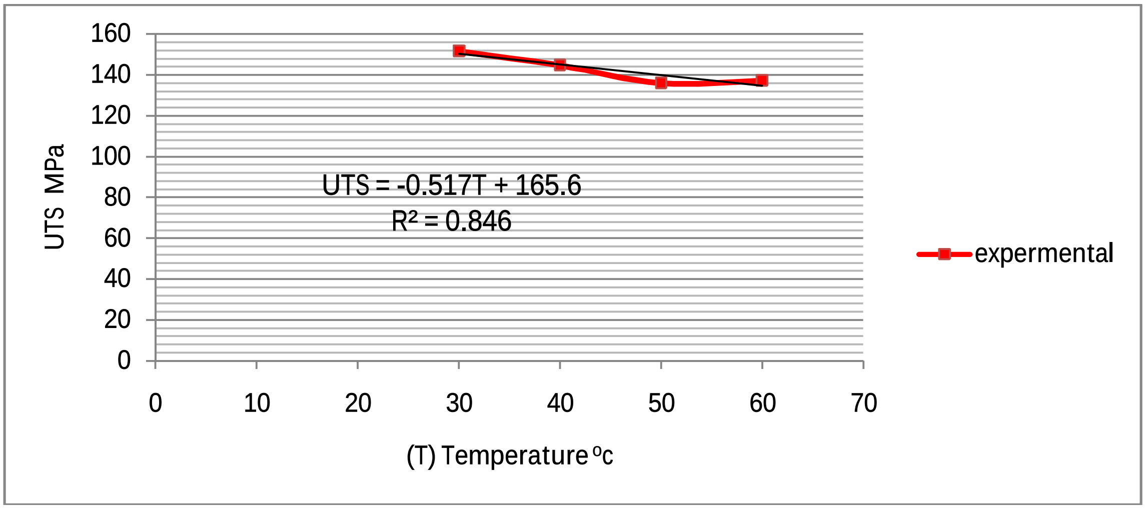


Figure (3-3) Variation of the average ultimate tensile strength for [CSM, 0/90, CSM] laminate with temperature rise

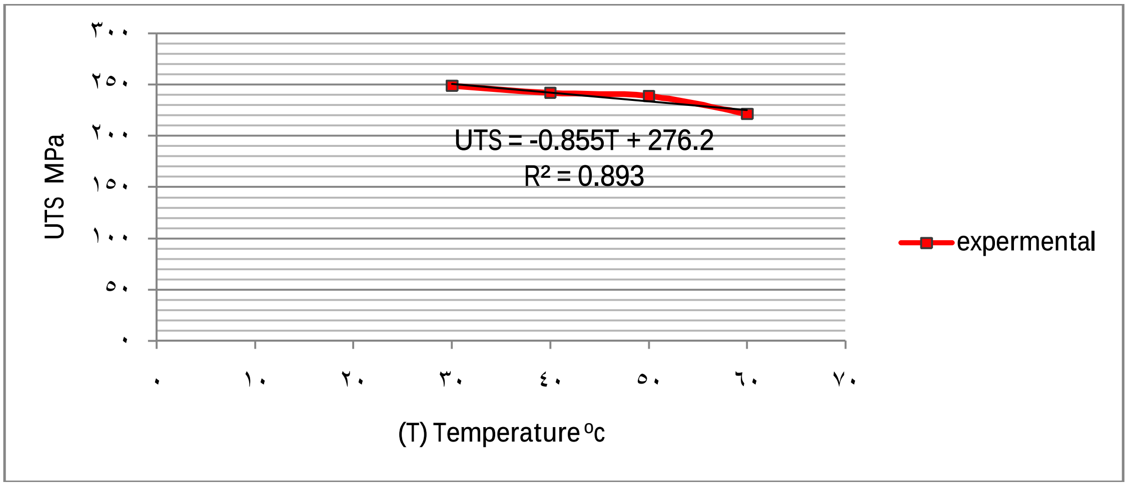


Figure (3-4) Variation of the average ultimate tensile strength for $[0/90]_3$ laminate with temperature rise

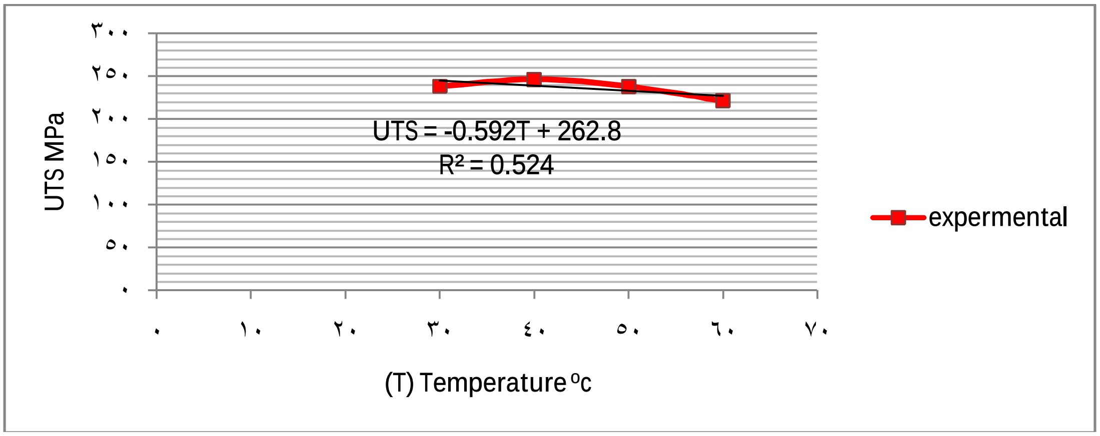


Figure (3-5) Variation of the average ultimate tensile stresses for [0/90, CSM, 0/90] laminate with temperature rise