Numerical and Experimental Investigation for Tensile Properties of Polyphenylene Sulfide Basis Composite Material

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ABSTRACT

This paper deals with experiments and numerical simulations of composite material with Polyphenylene sulfide matrix and carbon and glass fibres; the main goal is determine tensile properties of composite materials and compare with numerical simulations, to predict the properties and the study effect of fiber type, number of layers and fiber orientation on the properties. For this purpose tension test and their computational simulations by ANSYS were carried out. The results show that the tensile strength increases with the increase number of layers for both type of fibers, numerical simulation show good agreement with experimental results.

Key words: Polyphenylene sulfide, ANSYS, tensile properties, numerical simulation.

دراسة عملية ونظرية لتحديد خواص الشد للمادة المركبة ذات الاساس من بولي فنيلين سلفايد

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جامعة بابل، كلية هندسة المواد*

الجامعة التكنولوجية، قسم هندسة المواد**

العراق

الخلاصة

تم في هذا البحث دراسة خواص الشد للمادة المركبة المكونة من بوليمر بولي فنيلين سلفايد كمادة اساس مقواة بالياف من الكربون والزجاج، وقد تمت الدراسة عمليا وحسب المواصفات القياسية ونظريا بطريقة العناصر المحددة باستخدام برنامج (ANSYS) وقد تم دراسة عدد من المتغيرات وتأثيرها على خواص الشد مثل نوع الليف ، عدد الطبقات وتوجيه الالياف ، بينت النتائج العملية زيادة واضحة في خواص الشد مع زيادة عدد الطبقات ولكلا نوعي الالياف المستخدمة في البحث ، كما ان التحليل النظري بين توافق جيد مع النتائج العملية .

1-INTRODUCTION:

Traditional materials for aircraft construction include aluminum, steel and titanium. The primary benefits that composite components can offer are reduced weight and assembly simplification. In the past twenty years, the use of composite materials in the aircraft industry, among others, has grown immensely. Composite systems offer an advantage over traditional aircraft materials (metals) because they tend to exhibit higher strength/weight and stiffness/weight ratios than metals, thus making the aircraft lighter and improving performance.[1]

In the early 1970s, composite materials were introduced to airframe structures to increase the performance and life of the airframe. In 1977, the National Aeronautics and Space Administration (NASA) Advanced Composite Structures Program introduced the use of composites in primary structures in commercial aircraft, i.e., the Boeing 737 horizontal stabilizer. In 1994, the Advanced General Aviation Transport Experiments consortium, led by NASA and supported by the Federal Aviation Administration (FAA), industry, and academia, revitalized composite material product development in general aviation by developing cost-effective composite airframe structures. Modern improved composite materials and matured processes have encouraged commercial aircraft companies to increase the use of composites in primary and secondary structures. Driven by the demand for fuel-efficient, light-weight, and high-stiffness structures that have fatigue durability and corrosion resistance, the Boeing 787 Dreamliner is designed with more than 50 percent composite structure, marking a striking milestone in composite usage in commercial aviation. Meanwhile, the Airbus A350 commercial airplane is being designed with a similar percentage of composite materials in its structure. Figure (1) shows the use of composites in several commercial aircraft applications. [2, 3]

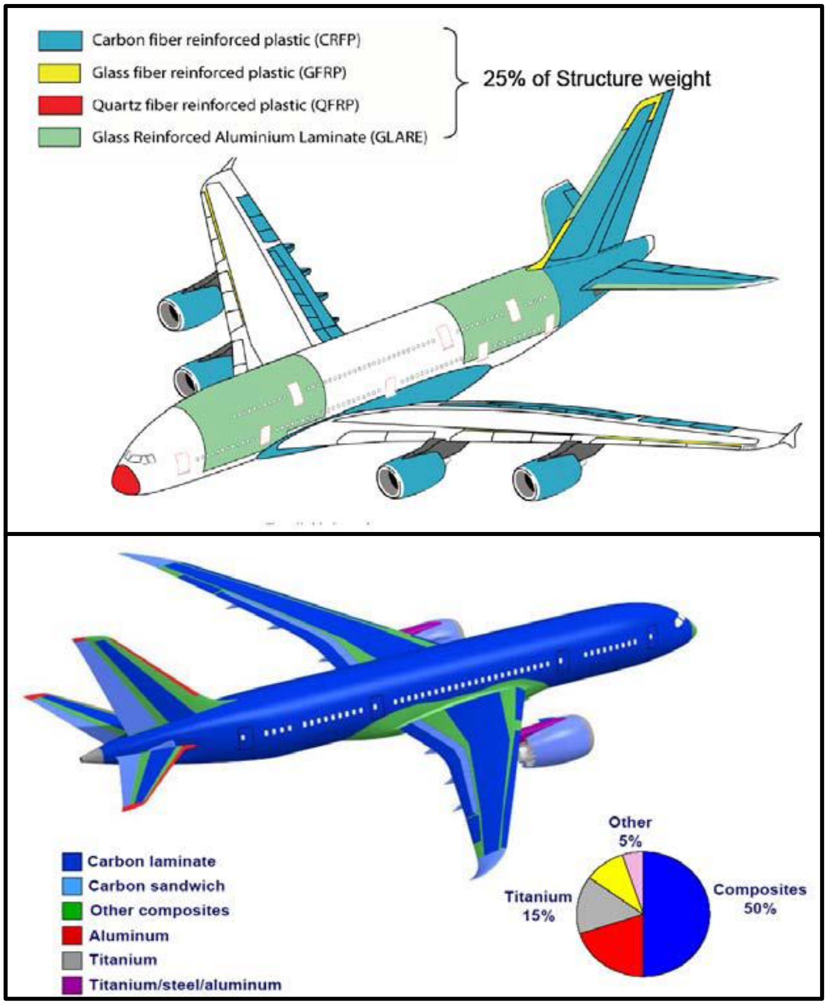


Figure (1) Composite Materials Applications in Commercial Aircraft [4]

Thermoplastic composite materials have shown great promise as materials for current and future aircraft components. It is likely that thermoplastic composite components will enter airframe service in the near future in the form of replacement components which were previously manufactured from metals or thermosetting composites such as graphite/epoxy. Thermoplastic resins offer a number of advantages over conventional thermosetting resins such as epoxies. Thermoplastics exhibit chemical and impact resistance and may be used over a wide range of temperatures. They have a very low level of moisture uptake which means their mechanical properties are less degraded under hot/wet conditions. [5]

A wide range of thermoplastics are available and in common use today. In the area of high performance thermoplastics, polyetheretherketone (PEEK) and Polyphenylene sulfide (PPS) are probably the most widely reported thermoplastic resins. [6]

Composite structures can be analyzed by using analytical and numerical methods. Generally, when a composite structure is modeled, some assumptions and simplifications have to be made. [7, 8] Rapid developments in computer hardware make the finite element method of complex determination responses increasingly applicable. The FEM is used worldwide to simulate the composite materials processes and has become a reliable numerical simulation technology. There are many FEM packages such as (MSC/NASTRAN, SUPERFORGE, ABAQUS, ALGOR, DIEKA, and ANSYS). [9, 10 and 11]

This paper presents the outcomes of the tensile properties investigation of an experimental and numerical composite material basis of PPS reinforced with carbon and glass fibers.

2- MATERIALS AND EXPERIMENTAL:

This section presents information pertaining to the properties of the Polyphenylene Sulfide (PPS) / reinforced fiber composite under study and its constituent materials.

2-1-The Matrix:

Polyphenylene sulfide (PPS) is a crystalline, wholly aromatic polymer that contains sulfide (–S–) linkages. The characteristics of the polymers depend on the molecular weight of the polymers. Three types of grades are available—neat resin, glass filled and glass/mineral filled. All PPS resins are characterized by outstanding chemical resistance and high-temperature stability, although they differ somewhat with respect to mechanical properties and processability. PPS resin manufacturing processes are broadly divided into partial cross-linking (branched or standard) and linear processes. Branched PPS (a polymer molecule has side chains branching out from its backbone) was introduced commercially in the 1970s, and the resulting resin is dark in color, hard and brittle. Process refinements in the 1980s led to a linear polymer. Linear PPS polymer (a molecule essentially consists of a long backbone) is said to offer significant cost and performance benefits over branched PPS, and to overcome the weak points of branched PPS. [12]

PPS material offer the broadest resistance to chemicals of any advanced engineering plastic. They have no known solvents below 392°F (200°C) and offer inertness to steam, strong bases, fuels and acids. A very low coefficient of linear thermal expansion, make these PPS products ideally suited for precise tolerance machined components. In addition. [12]

The type of PPS was used in this study has the properties shown in the table (1) and supplied as virgin sheet with dimensions (3×500×620)mm by Guangzhou Ideal Technology Co.,Ltd/China.[13]

Table (1) mechanical and physical properties of PPS. [13]

Property	Unite	Value
Tensile Strength	MPa	80
Tensile Modulus of Elasticity	GPa	3.7
Elongation	%	15
Poisson Ratio	/	0.35
Flexural Strength	MPa	140
Shear Strength	MPa	61
Shear Modulus	GPa	1.24
Melting Point	°C	293
Processes Tempe.	°C	330-360
Continuous Service Tempe. in Air	°C	220
Density	g/cm^3	1.3

2-2 The Fibers:

The main purpose of using the fibers in composite is to carry the load applied to composite while the matrix hold and protect the fibers thus distributing the load between them .The type of fibers used in the work is (E-glass) fiber and carbon fiber (type 300 C/60) are supplied by Sika Ypi Co., Ltd / Turkey. [14]

The general properties of the above fibers are shown in the table (2).

Table (2) Properties of Fibers Used in this Study. [14]

Fiber Type	Fiber Direction	Density (g/cm^3)	Tensile Strength (GPa)	Modulus of Elasticity (GPa)	Shear Modulus (GPa)	Elongation (%)	Poisson Ratio /
E-glass	(0°/90°) woven	2.6	2.5	74	33	3.5	0.25
Carbon	0° woven	1.75	3.2	230	50	1.3	0.3

The materials used in the work shown in the figure (2, a, b, c).

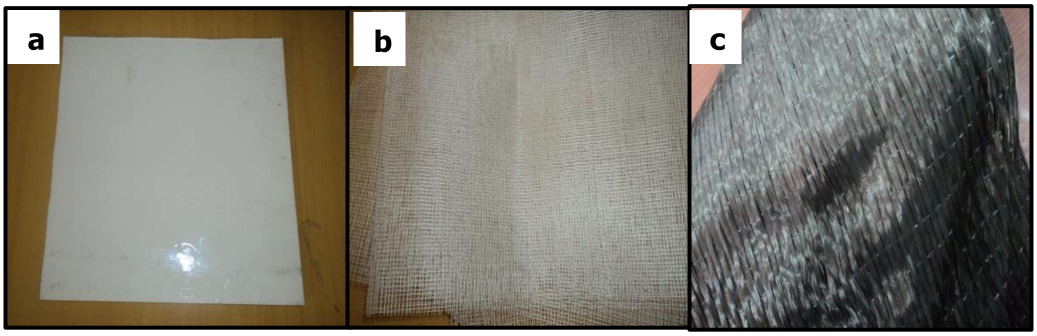


Figure (2) materials used in the work, a: PPS sheet, b: fiber glass, c: carbon fiber.

2-3-Product of Composite Sheet:

The production of composite sheet including the following steps:

Sheet preparing dies:

Carbon steel die was made by using milling machine and grinded to the gives final product composite sheet dimensions are (4×250×250) mm which it cut later to suitable shape of specimens. The die shows in the Figure (3).

Figure (3) Sheet preparing die

Production of the Composite Sheet:

The film stacking method was used to prepare the composite sheet. It consists of the following steps:

1-Preparation the die by covering it by aluminum foil to prevent adhesion with it faces then coat the aluminum foil by thermal grease (Lithium Grease) to prevent adhesion between polymer sheet and aluminum foil.

2-The fibers were arranged in the suitable angle and number of layers. PPS sheet with thickness of (3) mm was put under the fibers. Also another sheet of PPS with same thickness was put above the fibers and then the upper portion of die (punch) was fixed on the base portions (die) and then these parts were fixed by using bolts during the heating process.

3-Put the closed die in the thermal hydraulic pressing type (XLB-plate vulcanizer) shown in the figure (4) .Temperature on heating plates was adjusted to (300)ºC. This temperature degree is above the PPS melting point. The closed die remained under contact pressure until the temperature reach to (300) ºC and at this point apply the pressure for (30) min and it value equals 1.7 MPa (250psi). The die was cooled with water jet (5 L/min) at temperature (25) ºC and during cooling processes the pressure is maintained to avoid distortion of composite sheet, where cooling system was made from low carbon steel in dimensions of (300×300×20) mm, the inside grooves were made by the milling machine to allow water to flow for cooling , the die was opened and then the composite sheet was removed.

The procedure of this process was repeated to make a number of the composite sheets of different types 1, 2, 3 and 4 layers of glass fiber and carbon fiber with sequence of carbon layers is [0°, 0°/90°, 0°/90°/0°and 0°/45°/-45°/90°]. Different values of volume fraction are used are (6-32 %).

Figure (4) Thermal hydraulic pressing

2-4-Tensile Test

This test is performed according to (ASTM D3039) at room temperature with (1-50KN) applied range of loading and a range of speed (0.1-50 mm/min) with a graph plotter device by universal testing machine (Bongshin model WDW-SE).[15]

Figure (4) shows standard specimen for tensile test respectively.

Figure (4): Experimental tensile Specimen, (ASTM D3039).

The tensile load was applied to the sample by moving the lower grip was held downward with a speed of (2mm/min), while the upper grip still stationary until failure occurs. When the load is applied on the sample, the plotter will plot the relation between the stress and strain on a graph paper continuously according to the scale that is chosen by the operator of this machine. The applying of load will continue on the sample until failure occurs.

3-MODELING OF TENSILE TEST MODEL:

A 3D Finite Element model was created to simulate fracture test in ANSYS 13. Solving a numerical simulation was conducted based on laboratory conditions used in a practical test for the tensile test where we were taking into consideration the shape and geometry of the sample process and the boundary conditions. In this section, we will concentrate on two main aspects of this procedure.

Modeling the specimen, and calculating the stresses to failure. Conducted simulations using ANSYS structural (12.1) as the following:

3-1-Preprocessor steps:

1-Create the 3D model with dimensions same as the dimensions of experimental test samples (ASTM D3039).

2-The model is composed from polymer (PPS) used as matrix materials and carbon glass fibers that used as stiffeners and modeling as orthotropic materials with different fiber volume fraction (6-32%).

3-The element (SHELL181) may be used for layered applications for modeling laminated composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first order shear deformation theory (usually referred to as Mindlin-Reissner shell theory). [16]

4- The mesh of the model is (SHELL181) element that has 8-nodes and each node has (6 d.o.f) with element size of default size and using the free meshing type to mesh all the model as shown in Fig.(5).

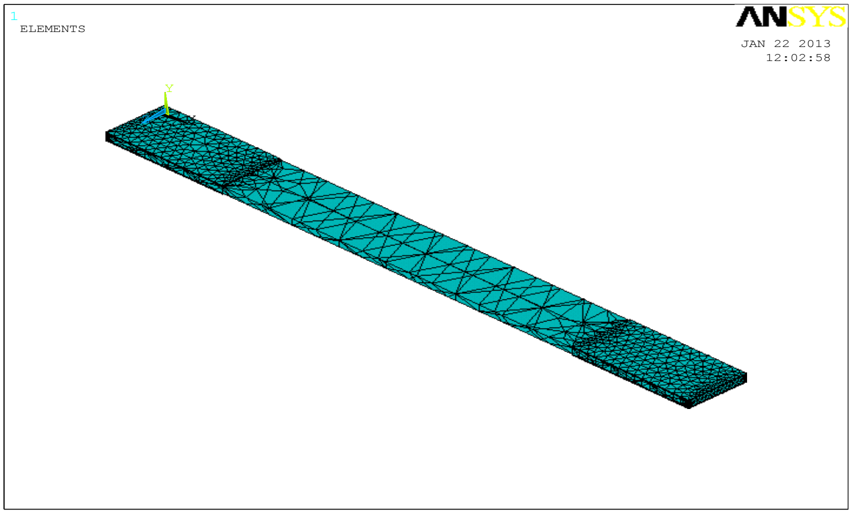


Figure (5) Finite element model of tensile test sample.

3-2-Material Properties:

The mechanical properties (Young's modulus, Shear modulus and Poisson's ratio) of the composite system used in this study are determined theoretically by using laminated theory of composite material. Table (3) contains elastic constant of the composites materials of this work.

Table (3) mechanical properties used in numerical simulation.

Material type	E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	v_{12}	v_{13}	v_{23}	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)
0°G	9.3	3.44	3.44	0.342	0.342	0.125	1.34	1. 34	1. 5
0°/90°G	10.9	10.9	3.21	0.334	0.098	0.098	1.47	1.46	1.46
0°/90°/0°G	17.15	3.01	3.01	0.326	0.326	0.057	1.62	1.62	1.42
0°/45°/-45°/90°G	18.88	18.88	2.84	0.318	0.05	0.05	1.806	1.35	1.35
0°C	17.27	3.5	3.5	0.347	0.347	0.07	1.318	1.318	1.64
0°/90°C	18.9	18.9	3.31	0.344	0.06	0.06	1.406	1.59	1.59
0°/90°/0°C	33.1	3.14	3.14	0.341	0.341	0.04	1.507	1.507	1.51
0°/45°/-45°/90°C	26.66	26.66	2.99	0.338	0.04	0.04	1.624	1.44	1.44

***G is meaning glass.**

****C is meaning carbon.**

3-3- Solution Processor:

1- To define the load on model (tensile load) apply the load as distributed load on nodes at one end of the model the same as the load values in experimental test and fixed the model at the other end .

2- Solving of model analysis used to finish the solution process.

These steps are repeated for each model of tensile loading with difference number of layers.

4-RESULTS AND DISCUSSION:

The experimental results and finite element (ANSYS) results for the composite plate that subjected to tensile test to study the effect of fiber orientation and number of layers on the mechanical properties of composite plate with volume fraction (V_f =6-32%).The modeling for the experimental samples by finite element (ANSYS) was compare the experimental results with finite element results. The tensile test gives a clear idea about the tensile strength of the composite. Figure (6, 7) shows the stress-strain curves for glass reinforced composite materials and carbon fiber reinforced composite materials respectively.

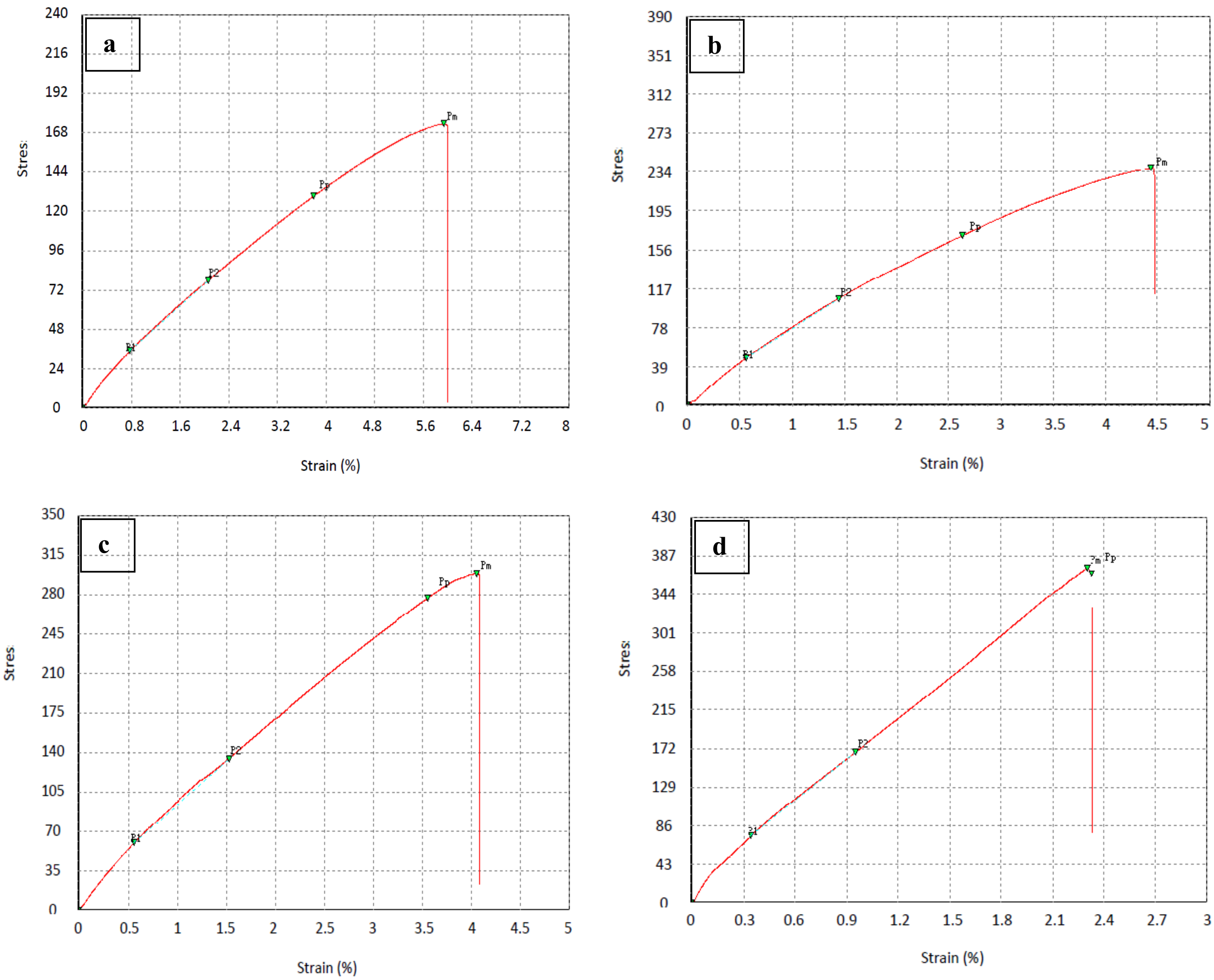


Figure (7). Stress-strain curves for glass reinforced composite: a) 1 layer, b) 2 layers, c) 3 layers, d) 4 layers.

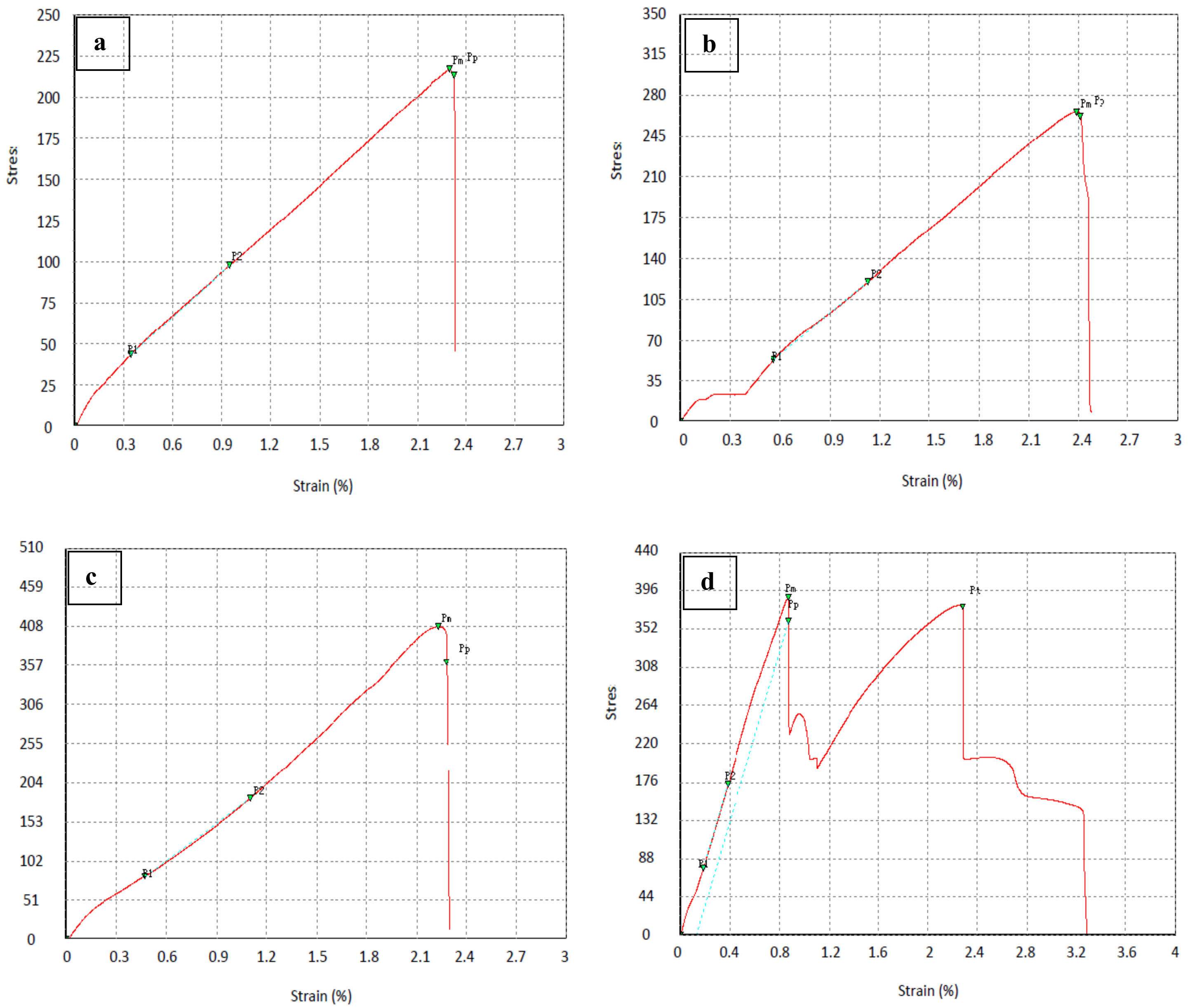


Figure (7). Stress-strain curves for carbon reinforced composite: a) 1 layer (0°), b) 2 layers (0°/90°), c) 3 layers (0°/90°/0°), d) 4 layers (0°/45°/-45°/90°).

From this figures its noted that the tensile strength is increased from (173.6MPa) at one layer of glass fiber to reach (363.52MPa) at four layers of glass fiber with percentage increase of (109%), while the tensile strength is increased from (213.76MPa) at one layer of carbon fiber to reach (394.24MPa) at four layers of carbon with percentage increase of (84%). The increase in tensile strength occurs because the increase in number of layers meaning increasing in volume fraction of fibers will make the crack initiation and crack propagation need more energy to create the crack and propagate to end with failure and it makes the composite need more forces to failure and that means increasing in strength for composite materials.

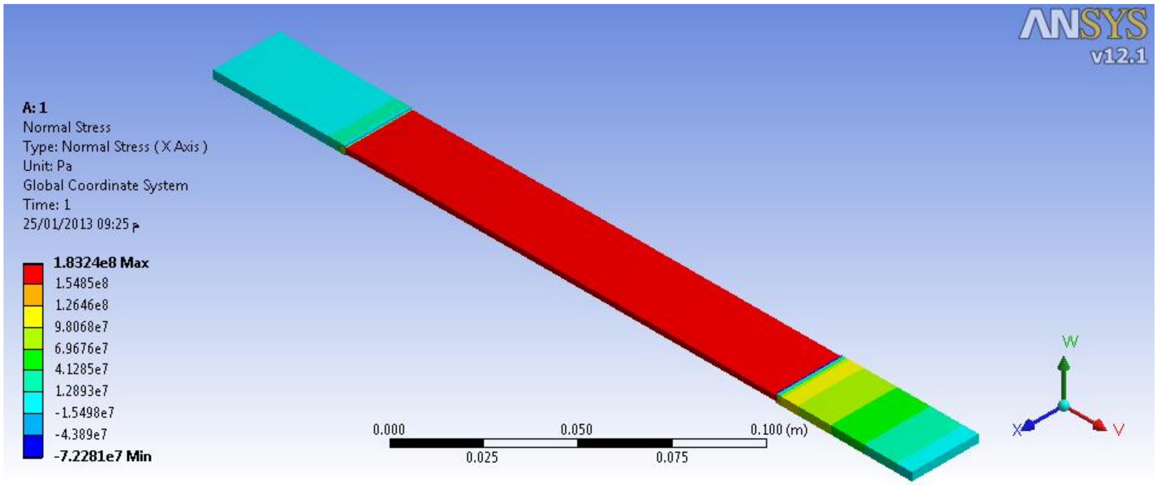
Table (4) show the modulus of elasticity for composite materials under study and taken from the experimental tensile test in different directions and depending on fiber orientation.

Table (4). The modulus of elasticity for composite materials under study.

Material type	E_1 **(GPa)**	E_2 **(GPa)**	E_3 **(GPa)**
1G	6.44	6.44	3.44
2G	8.2	8.2	3.21
3G	10.73	10.73	3.01
4G	13.2	13.2	2.84
0°C	13.82	4.82	4.82
0°/90°C	16.77	16.77	3.31
0°/90°/0°C	26.27	12.09	3.14
0°/45°/-45°/90°C	25.4	25.4	3

Note the table above find a clear increase in the modulus of elasticity of composite materials with increasing the number of layers and thereby increase the volume fraction of the fiber and it was due to the fiber, which owns a high modulus of elasticity compared with matrix, It can also note that the modulus of elasticity of the carbon fiber reinforced composite material greater than the modulus of elasticity of composite materials reinforced with glass fiber and it was due to the carbon fiber has a modulus of elasticity greater than glass fibers, this is in line with the findings of the other researchers. [17, 18]

The following figures show results that obtained from numerical simulations by ANSYS program were taking into consideration laboratory conditions in the simulation process and depending on the theoretical properties of composite materials.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W
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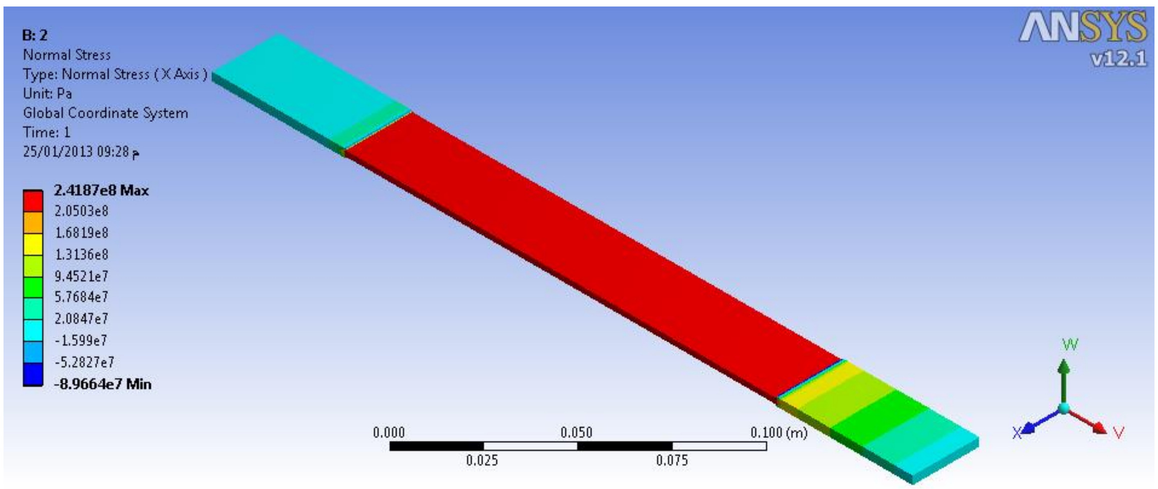
V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W
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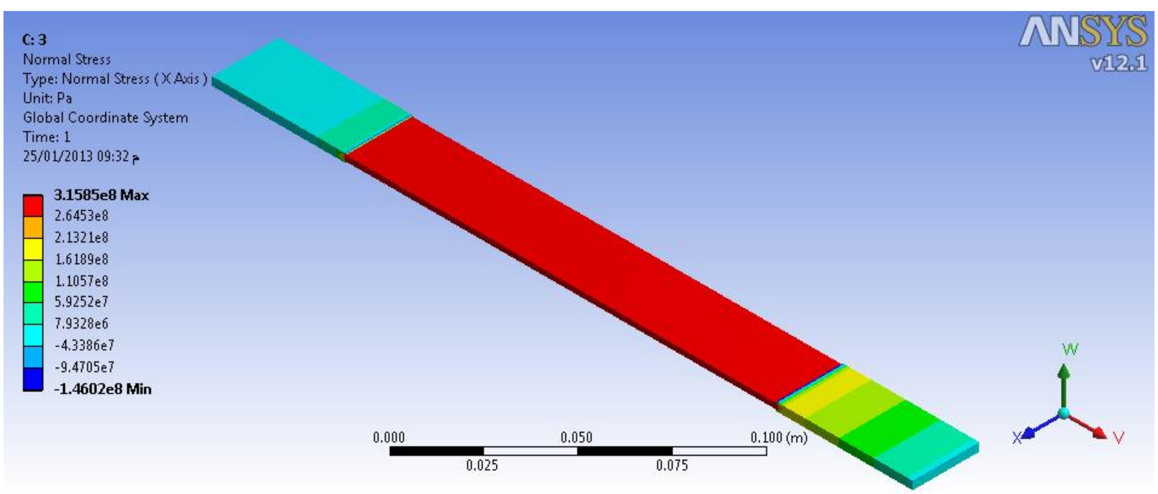
V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X
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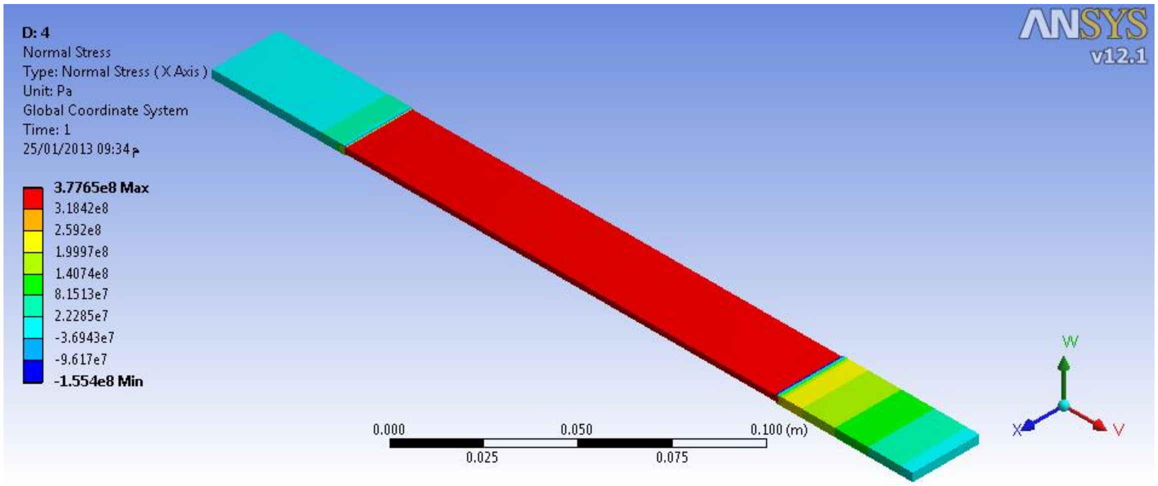
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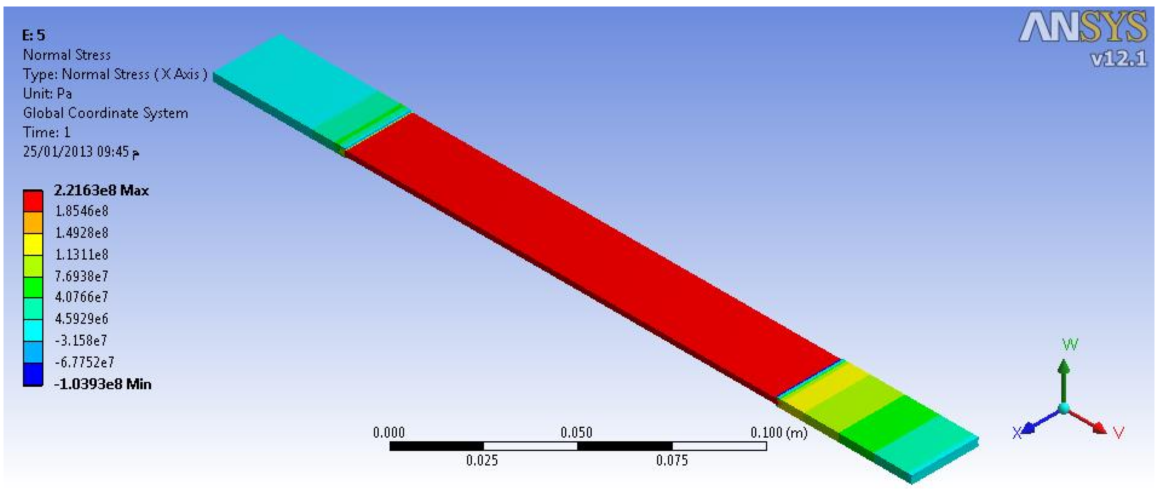
W
X
V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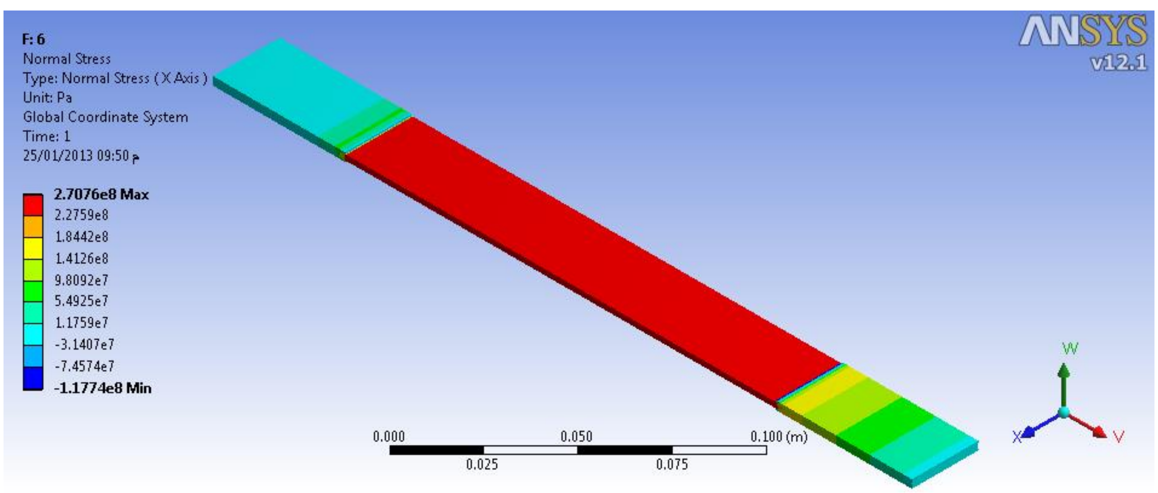
W
X
V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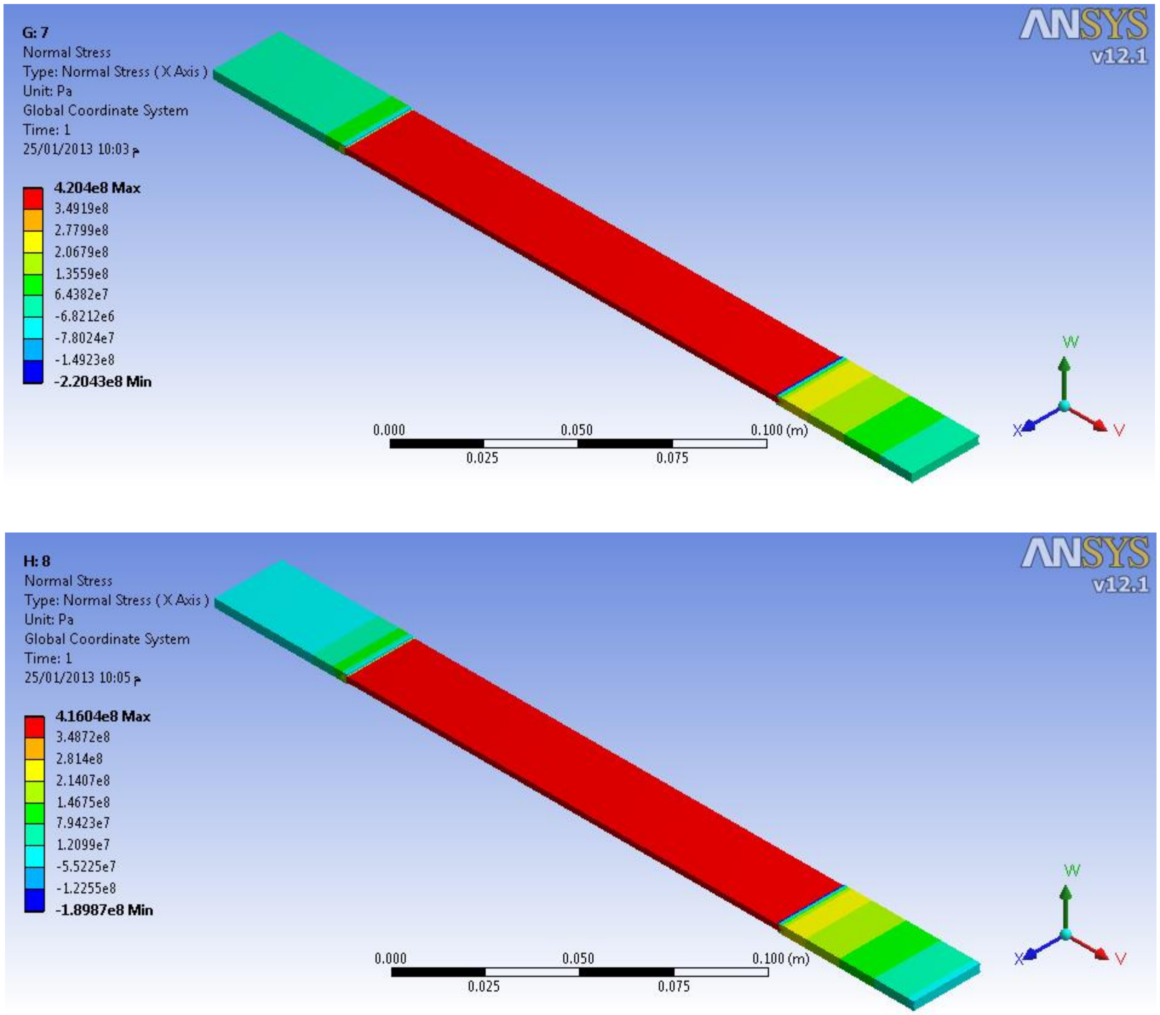
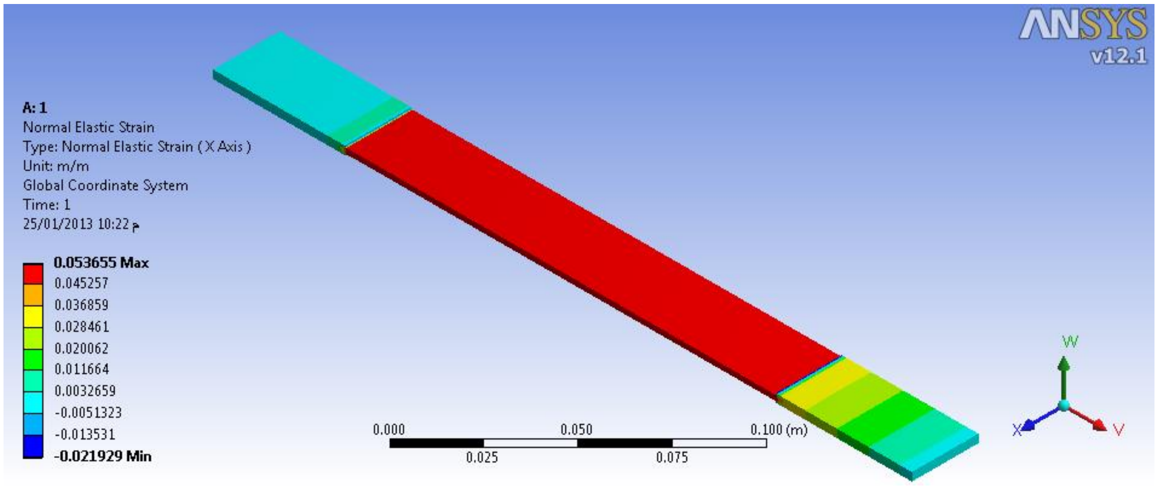


Figure (8). Finite element normal stress for glass and carbon reinforced composite: A) glass 1 layer, B) glass 2 layers, C) glass 3 layers, D) glass 4 layers E) carbon 1 layer (0°), F) carbon 2 layers (0°/90°), G) carbon 3 layers (0°/90°/0°), H) carbon 4 layers (0°/45°/-45°/90°).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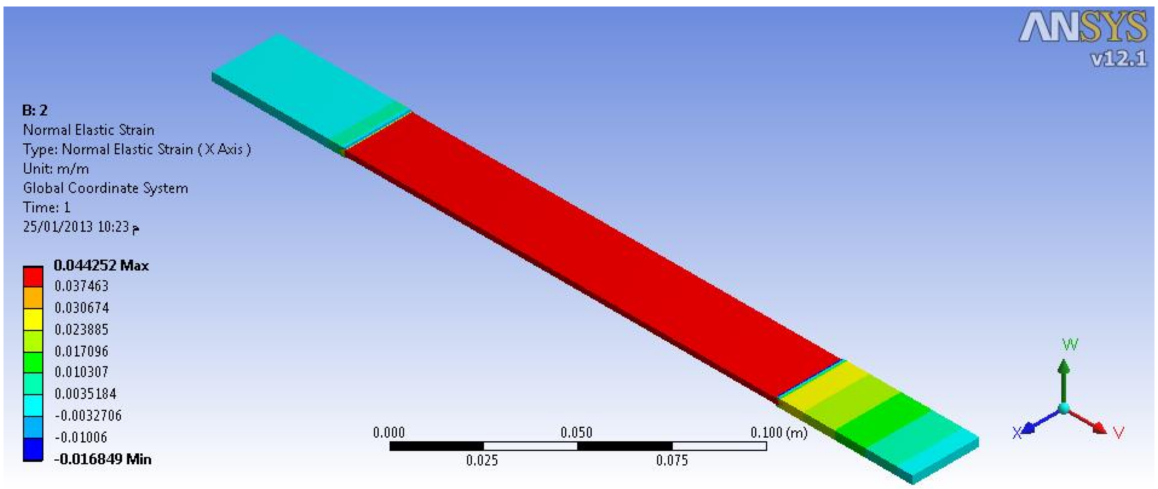
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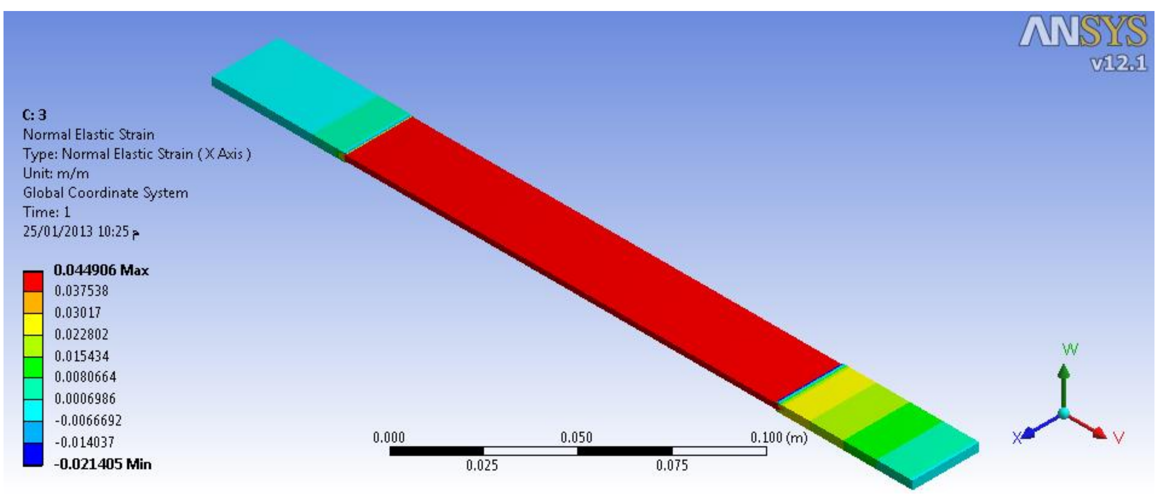
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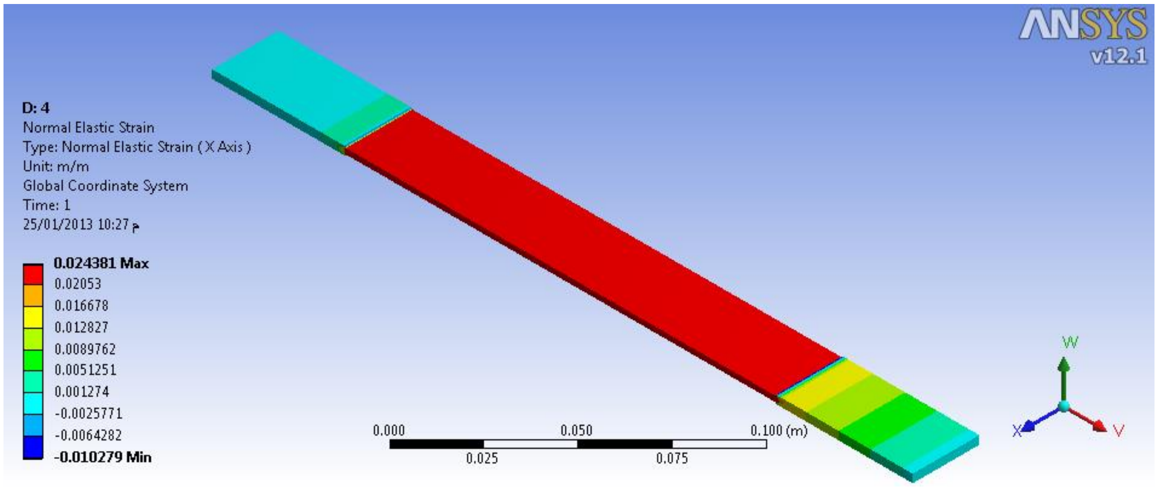
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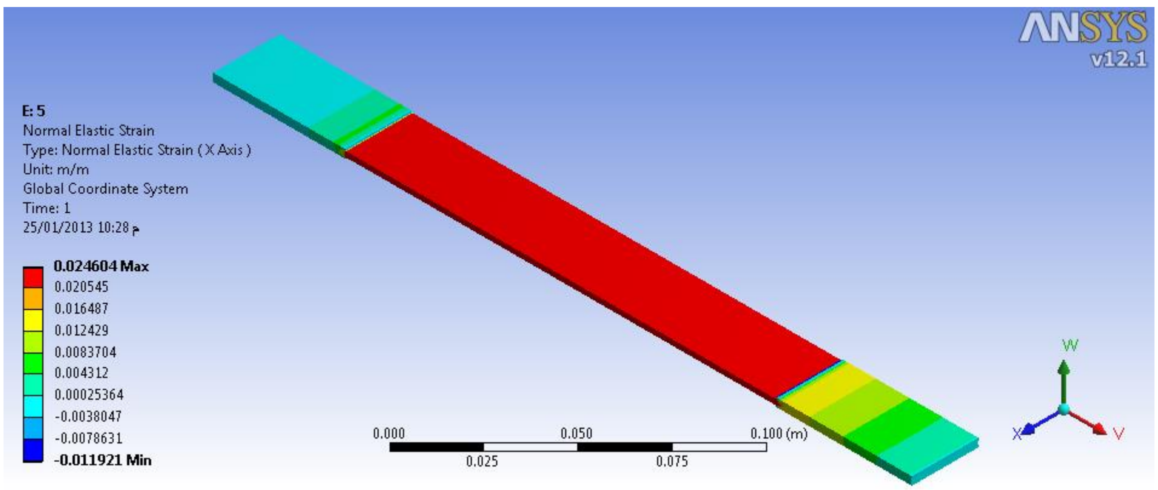
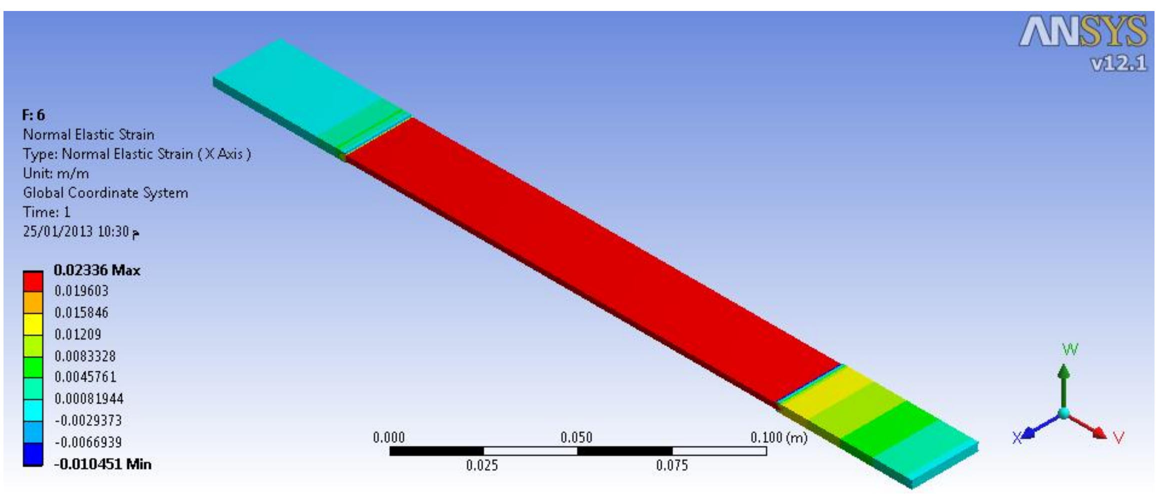
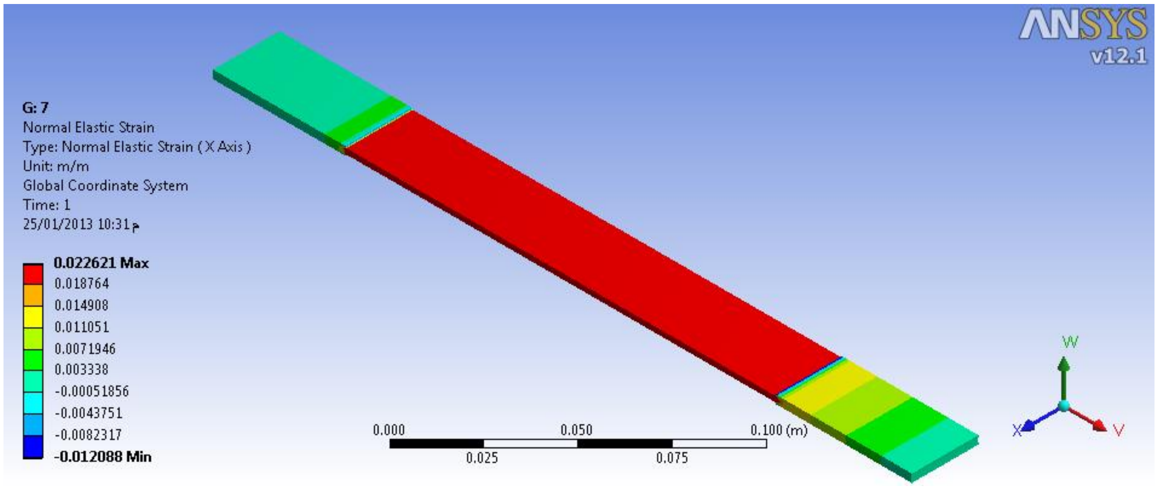
0.025
0.075


ANSYS
v12.1
E: 5
Normal Elastic Strain
Type: Normal Elastic Strain (X Axis)
Unit: m/m
Global Coordinate System
Time: 1
25/01/2013 10:28 م
0.024604 Max
0.020545
0.016487
0.012429
0.0083704
0.004312
0.00025364
-0.0038047
-0.0078631
-0.011921 Min
0.000
0.050
0.100 (m)
0.025
0.075


ANSYS
v12.1
F: 6
Normal Elastic Strain
Type: Normal Elastic Strain (X Axis)
Unit: m/m
Global Coordinate System
Time: 1
25/01/2013 10:30 م
0.02336 Max
0.019603
0.015846
0.01209
0.0083328
0.0045761
0.00081944
-0.0029373
-0.0066939
-0.010451 Min
0.000
0.050
0.100 (m)
0.025
0.075



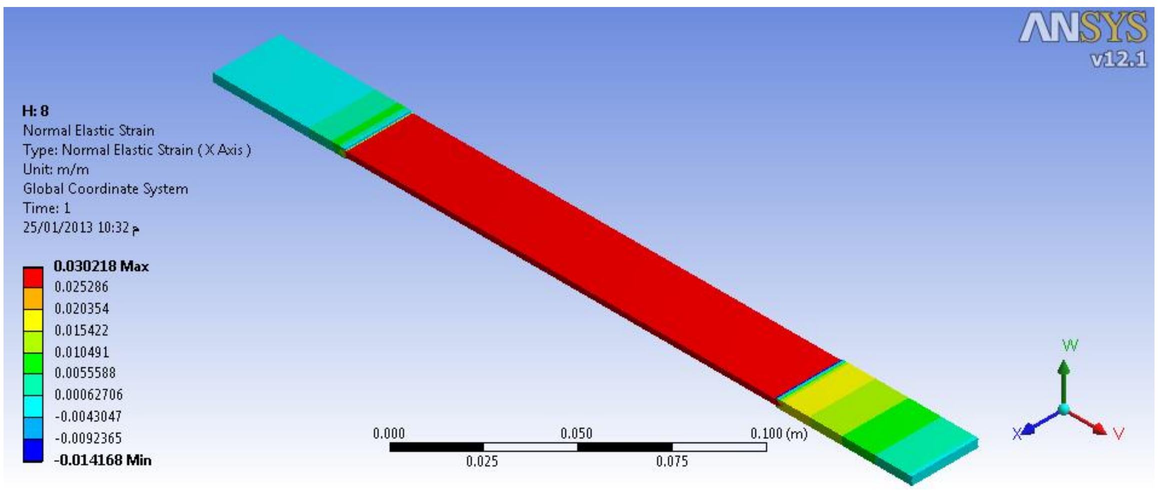


Figure (9). Finite element normal strain for glass and carbon reinforced composite: A) glass 1 layer, B) glass 2 layers, C) glass 3 layers, D) glass 4 layers E) carbon 1 layer (0°), F) carbon 2 layers (0°/90°), G) carbon 3 layers (0°/90°/0°), H) carbon 4 layers (0°/45°/-45°/90°).

In the above figures, note increase tensile strength with increasing the number of layers of composite material, and volume fraction this is due to the increase of modulus of elasticity that leads to impede the progress of the failure through the composite material and thus to decrease the strain to failure of the composite material and this corresponds with the findings of the other researchers. [19, 20 and 21]

If we want to compare the results of the theoretical and experimental results, we find that there is a good agreement and that also it is found that there is no more (12.31%) error in estimation of tensile strength and tensile strain as shown in the table (5). This discrepancy in estimated magnitudes of tensile properties attributed to true loading condition and method of composite fabrication, experimental tensile test.

Table (5), theoretical and experimental tensile properties and their comparison.

Material type	Tensile strength (MPa)		Percentage error	Tensile strain (%)		Percentage error
	experi	ANSYS		experi	ANSYS	
1G	173.6	183.24	5.55	6.02	5.36	12.31
2G	237.2	241.87	1.96	4.49	4.42	1.58
3G	306.68	315.85	2.99	4.12	4.49	8.9
4G	363.52	377.65	3.88	2.31	2.43	5.2
0°C	213.76	221.63	3.68	2.33	2.46	5.57
0°/90°C	268.8	270.76	0.5	2.48	2.33	6.43
0°/90°/0°C	409.2	420.4	2.73	2.34	2.26	3.53
0°/45°/-45°/90°C	394.24	416.04	5.53	3.29	3.02	8.94

CONCLUSIONS:

The experimental investigations have shown that, as number of layers and the fiber volume fraction increases, the tensile strength will also increase but it is significantly dependent on the fiber orientation for carbon fiber. The tensile properties of laminates with three layers of carbon fiber is superior as compared to one layers of carbon fiber specimen composite materials, and for four layers of glass fiber is superior as compared to one layer and also the matrix material (Polyphenylene sulfide) features high flexibility and the ability to demonstrate high resilience and therefore high strain, this behaviour is true for all volumes fraction of fibre, number of layers and orientations. It is reasonable to assume that the main tensile behaviour mechanisms are delamination and deformation including tear deformations because of fiber breakage.

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