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Study of Fatigue Behavior of Composite Materials with the Basis of Polyphenylene Sulfide (PPS) Reinforced with Glass Fiber and Carbon

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ABSTRACT

In present paper the fatigue failure behavior studies of composite materials with the basis of Polyphenylene sulfide (PPS) reinforced with glass fiber and carbon .Different composite materials are prepared by using the laminated technique, layers stacking process uses to manufacture of the composite plate. The pressure and temperature in the stacking process are (300°C, 1.7 MPa (250psi) and for (30 min). The results show that the fatigue strength increases with the addition of layers of material carbon fiber.

Keywords: *Polyphenylene sulfide (PPS), composite materials, fatigue.*

1. INTRODUCTION

Over the past 25 years, the use of advanced composite materials in aircraft primary structures has increased significantly. In 1994, with the Advanced General Aviation Transport Experiments program, the National Aeronautics and Space Administration and the Federal Aviation Administration revitalized the use of composites in general and commercial aviation. Driven by the demand for fuel-efficient, light-weight, and high stiffness structures that have fatigue durability and corrosion resistance, modern large commercial aircraft are designed with more than 50 percent composite materials. Although there are key differences between metal and composite damage mechanics and durability concerns, the certification philosophy for composites must meet the same structural integrity, safety, and durability requirements as that of metals. Despite the many advantages, composite structural certification becomes challenging due to the lack of experience in large-scale structures, complex interactive failure mechanisms, sensitivity to temperature and moisture, and scatter in the data, especially in fatigue. [1, 2]

The overall objective of this research was to provide guidance into structural substantiation of composite airframe structures under repeated loads through an efficient approach that weighs both the economic aspects of certification and the timeframe required for testing, while ensuring safety. The research methodology reported here consisted of combining existing certification approaches used by various aircraft manufacturers with protocols for applying these methodologies. This will permit extension of the methodologies to new material systems and construction techniques.

2. BACKGROUND

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. [3]

In present paper the fatigue failure behavior studies of composite materials with the basis of Polyphenylene sulfide (PPS) reinforced with glass fiber and carbon and which prepared by using the laminated technique.

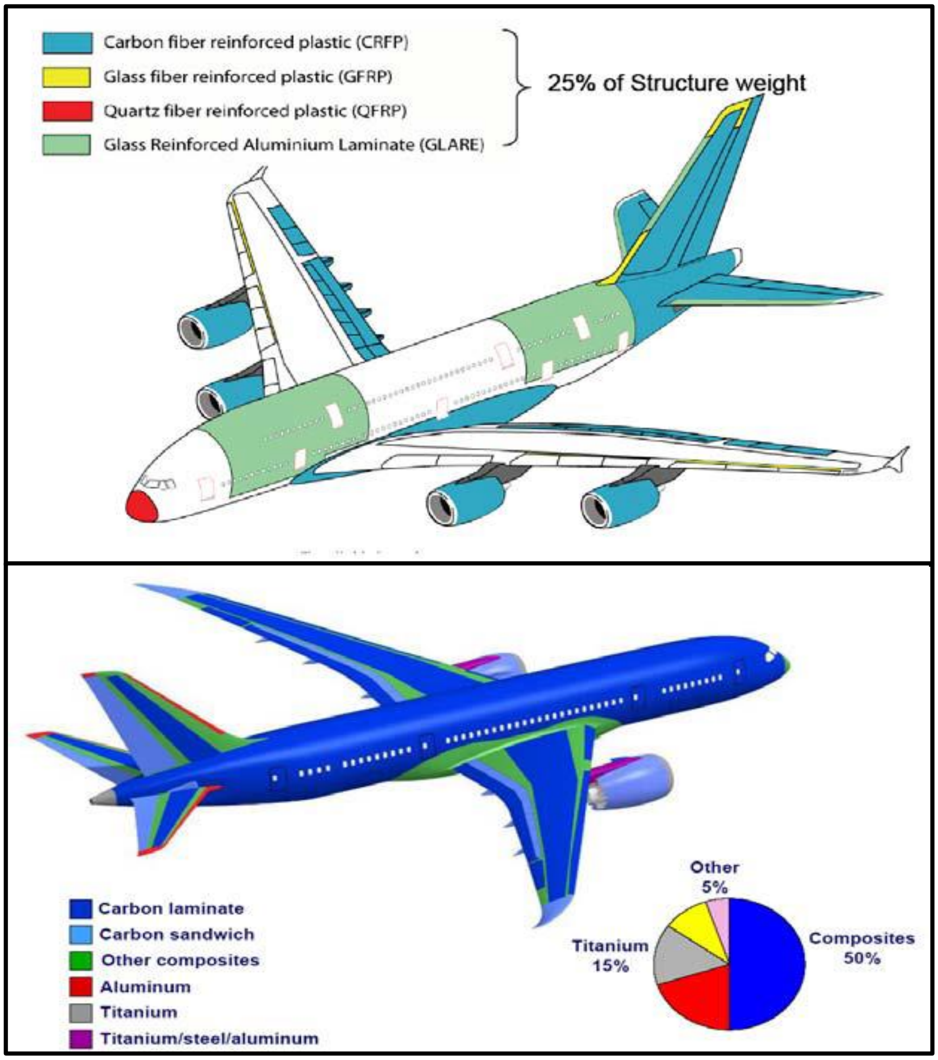

Figure (1) Composite Materials Applications in Commercial Aircraft [3]

3. 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.

3.1 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. [4]

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. [4]

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.[5]

3.2 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. [6]

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

Table (1) mechanical and physical properties of PPS. [5]

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

Table (2) Properties of Fibers Used in this Study. [6]

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).

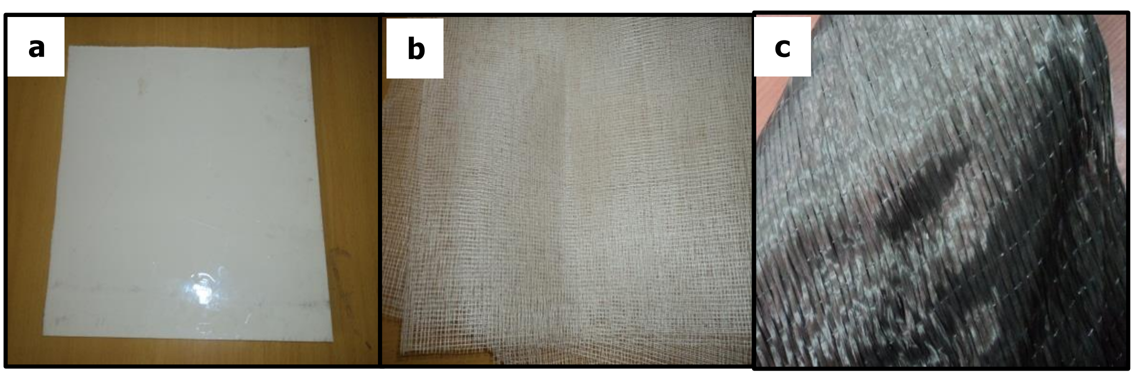

Figure (2) materials used in the work, a: PPS sheet, b: fiber glass, c: carbon fiber

3.3 Product of Composite Sheet

The production of composite sheet including the following steps:

3.3.1 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

3.3.2 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)^{o}C. This temperature degree is above the PPS melting point. The closed die remained under contact pressure until the temperature reach to (300) ^{o}C 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) ^{o}C 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

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3.4 Testing

The following tests were performed:-

3.4.1 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).[7]

Figure (5 a and b) shows standard specimen for tensile test and the machine it used in the test respectively.

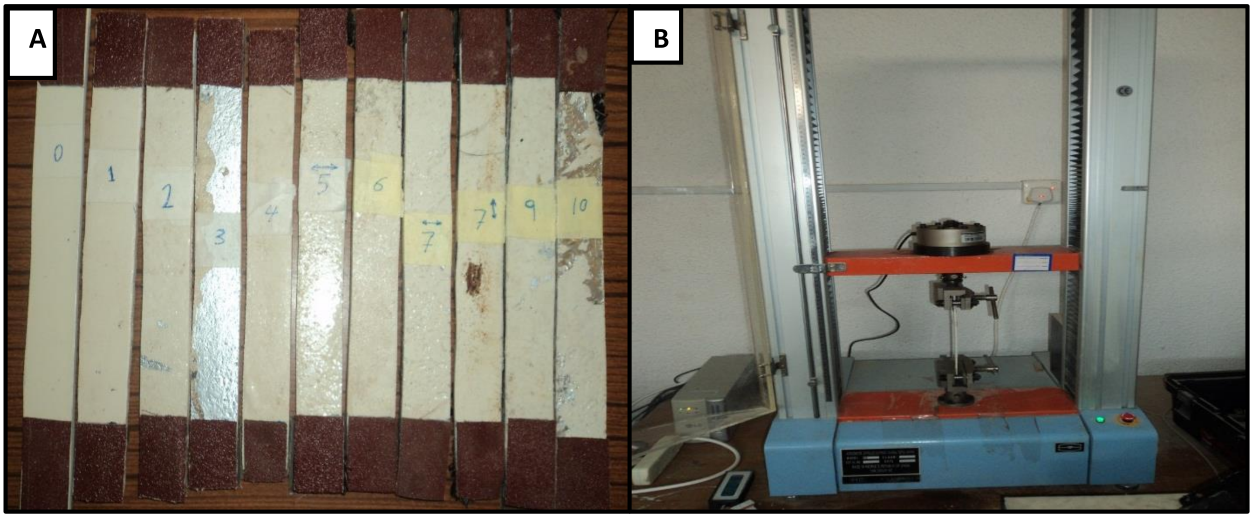

Figure (5): (a) Experimental tensile Specimen, (ASTM D3039), (b) Tensile testing machine

3.4.2 Fatigue Test

The Fatigue testing used was by an alternating-bending fatigue testing machine with the specification of (fatigue testing machine HSM20, 1400 rpm ,spanning voltage 230 V, frequency 20Hz,Normal power 0.4 Kw), and performed at room temperature and a stress ratio of R= - 1 (tension– compression). Figure (6 a, b and c) shows a standard specimen for fatigue test according to the machine's manual , machine test and the fixation of specimen on fatigue machine respectively.

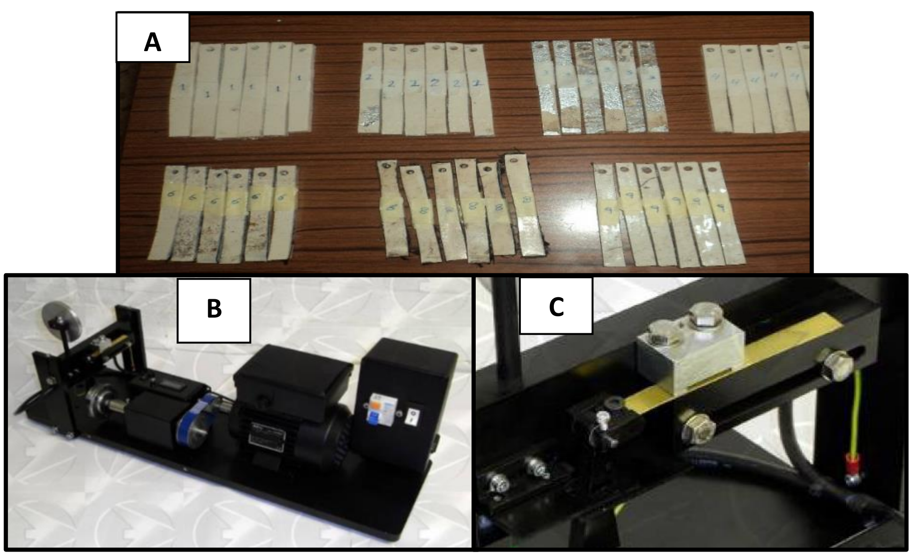

Figure (6): (a) Experimental fatigue specimen, (b) fatigue testing machine and (c) Fixation of specimen

The elementary bending stress can be estimated using the following: [8]

$$\sigma = \frac{M.y}{I} = \frac{6p.l}{b.t^2} \qquad (1)$$

Then

$$\delta = \frac{pl^3}{3EI} = \frac{4pl^3}{Ebt^2} \qquad (2)$$

Hence

$$l^2 = \frac{1.5Et\delta}{\sigma} \qquad (3)$$

Where:

M: moment of inertia (N.mm).

Y : position of neutral axis (mm).
I : moment of inertia (mm^4).
P : applied load (N).
l :length of the specimen (mm).
b : width of the specimen (mm).
t : thickness of the specimen (mm).
δ : free end deflection (mm) .
E : modulus of elasticity (N/mm^2)

4. RESULTS AND DISCUSSION

The tensile test was conducted for composite materials used in this study for the purpose of determine the modulus of elasticity to these materials, which enters in the calculation of fatigue stresses and table (3) show the modulus of elasticity of composite materials manufacturer.

Table (3). Modulus of elasticity for composite materials used in the study

Material type	E_1 (GPa)	E_2 (GPa)	E_3 (GPa)
1 layer glass	6.44	6.44	3.44
2 layers glass	8.2	8.2	3.21
3 layers glass	10.73	10.73	3.01
4 layers glass	13.2	13.2	2.84
0°carbon	13.82	4.82	4.82
0°/90° carbon	16.77	16.77	3.31
0°/90°/0° carbon	26.27	12.09	3.14
0°/45°/-45°/90° carbon	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. [9, 10] by observing the figures (7 and 8), which shows the relationship between stress and number of cycles until failure for glass and carbon reinforced respectively for composite materials prepared from different layers of fiber glass and carbon individually and angles strengthen it different note that the fatigue strength increases with the addition of layers of material carbon fiber and this is due to resistance and high strength of this fiber also manufacture different layers of different fiber orientations for composite materials enhances the fatigue strength is very large, this corresponds with the findings of the other researchers. [11, 12 and 13]

5. CONCLUSIONS

The experimental investigations have shown that, as number of layers and the fiber volume fraction increases, the fatigue strength will also increase but it is not significantly dependent on the fiber orientation. The fatigue strength of laminates with four layers of carbon and glass fiber is superior as compared to one layer of both fiber specimen composite materials, and also the matrix material (Polyphenylene sulfide) features high flexibility and the ability to resist the bending stress due to fatigue test procedure, this behaviour is true for all volumes fraction of both type of fibre, number of layers and orientations.

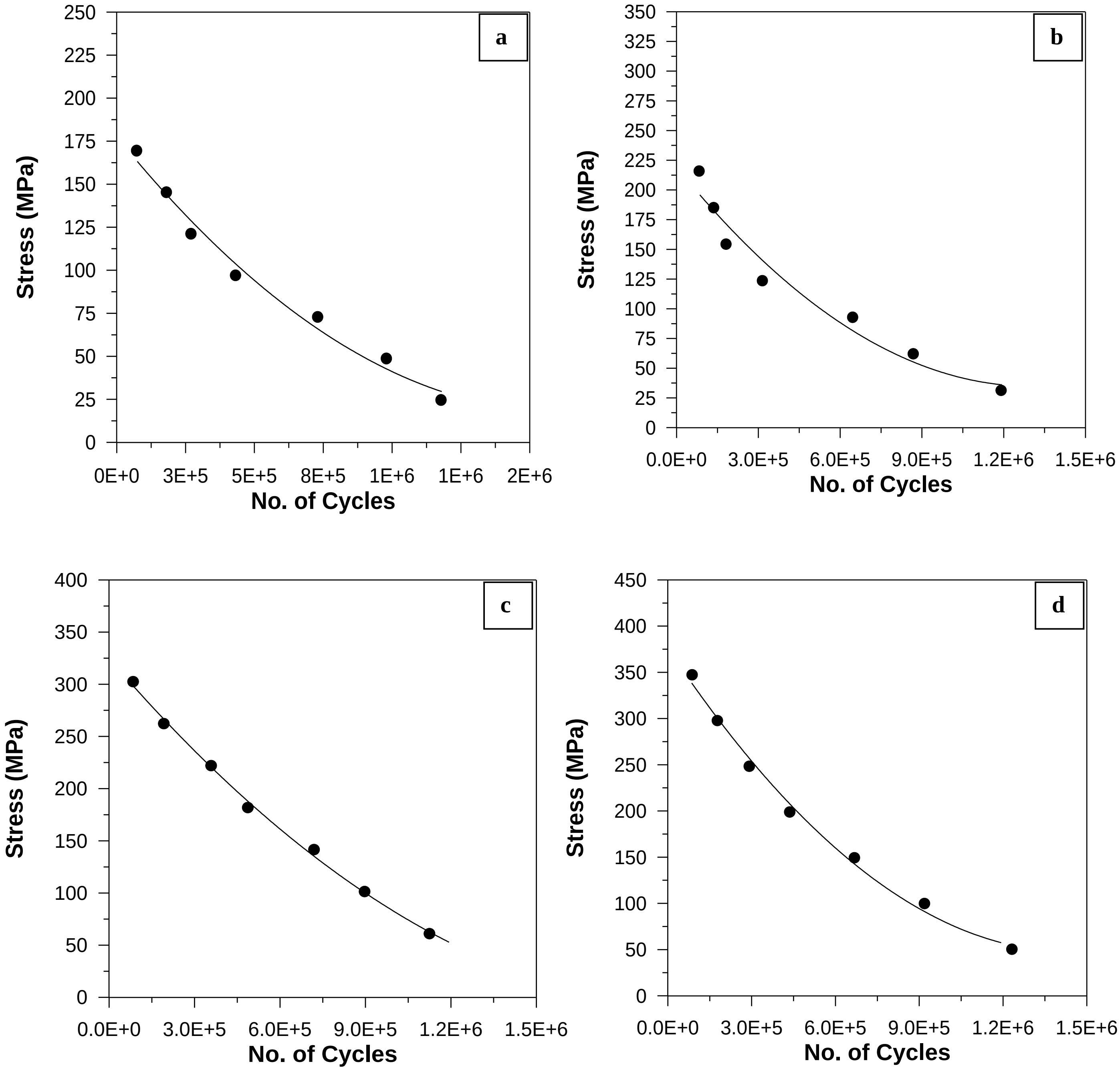

Figure (7). The relation between stress and No. of cycle to failure for glass reinforced composite: a) 1 layer, b) 2 layers, c) 3 layers, d) 4 layers.

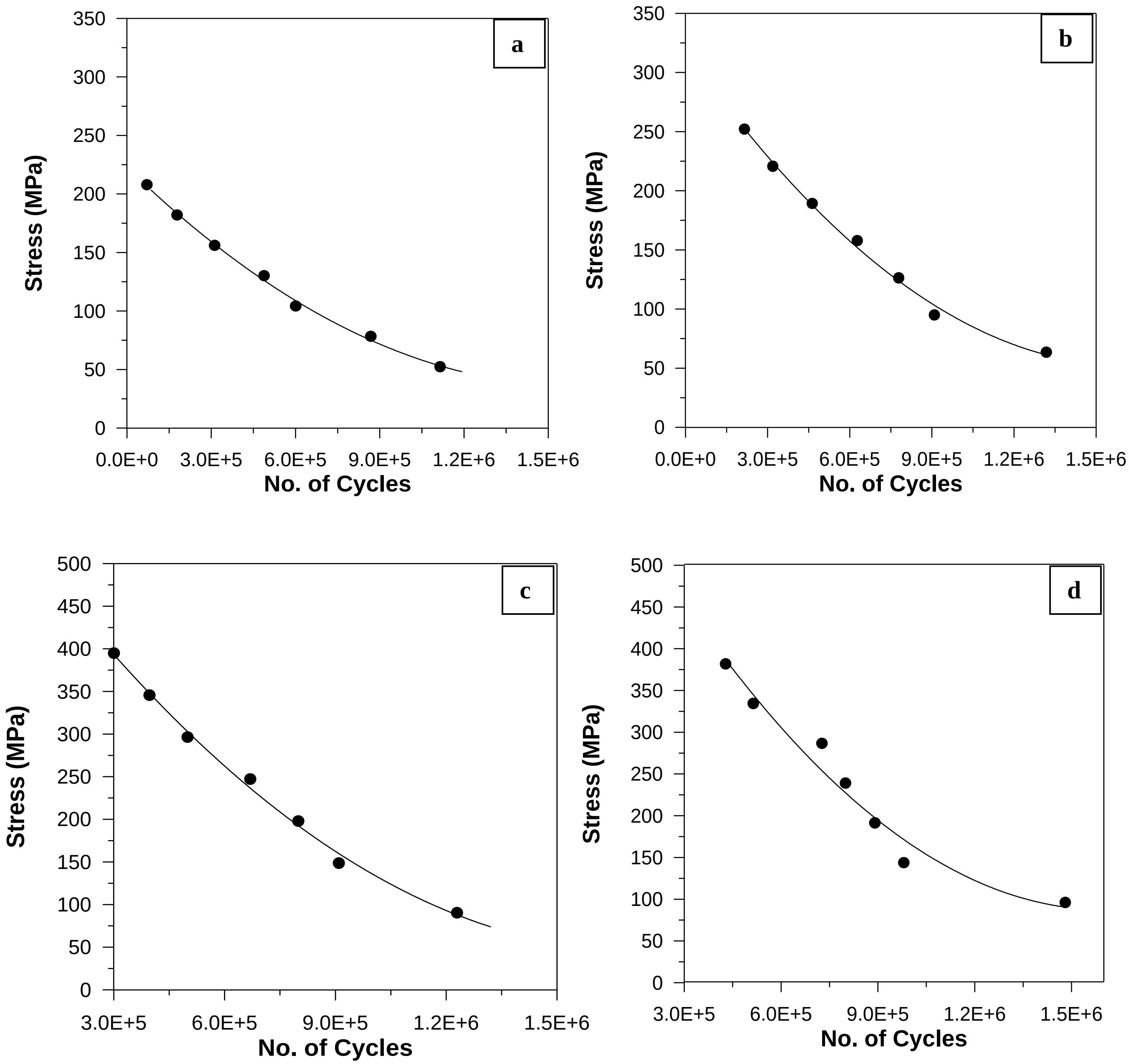

Figure (8). The relation between stress and No. of cycle to failure for carbon reinforced composite: a) 1 layer (0°), b) 2 layers (0°/90°), c) 3 layers (0°/90°/0°), d) 4 layers (0°/45°/-45°/90°)

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