Evaluation of Composite Material used in the Wings of Typical Airplane based on Stress Analysis

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Abstract—This research has focused on the evaluation of raw materials that used in the wings of modern airplane. These materials either would be fiberglass, carbon-fiber or aramid based composites like Kevlar. These common materials have been selected and evaluated depending on experimental data obtained from mechanical tests. These tests include: hardness, tensile strength and bending stress. The results show increasing in the hardness value of graphite-epoxy by 9% comparing with that of fiberglass and by 18% comparing with that of Kevlar-epoxy. The results also show an increasing in the maximum tensile strength of graphite-epoxy by 2.9 times to that of fiberglass and by 5.5 times to that of Kevlar-epoxy. Furthermore, the results of bending stress test show increasing of the maximum strength of Kevlar-epoxy by 30% comparing to that of glass fiber and by 75% comparing to that of graphite-epoxy.

Index Terms—Composite Materials; Fiberglass; Graphite; Kevlar; Airplane

I. INTRODUCTION

Airplanes industry has witnessed great developments to endure huge loads, reduce the costs and increase the security factors by the orientation towards novel and multifunctional materials which are the composites. These materials satisfy many advantages by replacing the metals by equivalent composite components. The composite materials used in aircraft industry are generally reinforced fibers or particles embedded in a resin matrix [1]. Generally, the modern airplanes with composite parts are about 20-50% lighter than their conventional versions [2]-[5].

Composites can be very strong and stiff, yet very light in weight, so ratios of strength-to-weight and stiffness-to-weight are several times greater than steel or aluminum. The advantages of composites could be noticed by their [3]-[11]:

- High specific strength and stiffness; as well as long fatigue life
- High creep resistance
- Better wear resistance
- Improved corrosion resistance
- Low density, thermal conductivity and thermal expansion

The composites also have some inherent weaknesses like: laminated structure with weak interfaces and poor resistance to tensile loads, as well as, consequent degradation of high temperature performance [6]-[12]. However, properties of many important composites are anisotropic; where many of the polymer-based composites are subject to attack by chemicals or solvents, just as they are susceptible to attack [11]. Composite materials are generally expensive manufacturing, as well as the methods for shaping composite materials are often slow and costly.

The use of composites in the airplane industry has increased dramatically since the 1970s [10]. Traditional materials for aircraft construction include aluminum, steel and titanium have replaced by a bunch of composites like fiberglass. The performance advantages associated with reducing the weight of aircraft structural elements has been the major impetus for military aviation composites development. In airplane manufacturing, most types of composites are those reinforced with fiberglass, carbon fiber and aramid fiber like Kevlar [8]-[13]. Various components of airplane are fabricated by composites, e.g. rudder, spoilers, airbrakes, elevators, LG doors, engine cowlings, keel beam, rear bulkhead, wing ribs, main wings, turbine engine fan blades, propellers, interior components, as shown in Fig. 1.

Fig. 1. Common composites used in modern airplanes [13]

Wings or (airfoils) are the parts of airplanes which provide lift and support the entire weight of the aircraft and its contents while in flight, it is consisting from several parts like flaps and ailerons, as shown in Fig. 2 [14]. Flaps are the movable sections of an airplane's wings closest to the fuselage; they are moved in the same direction (down) and enable the airplane to fly more slowly. Ailerons are the outward movable sections of an airplane’s wings which move in opposite directions (one up, one down).
Wings were manufactured from Aluminum alloys for civil applications or from Titanium alloys for military applications. Recently, composites are the most substructure materials used in the airplane wing, including the skin, controlling surfaces, and the body core [15], [16].

Fiberglass is often used for wing tips. There are E-glass which is made from borosilicate glass, and S-glass that has a higher strength than E-glass. Kevlar is DuPont name for aramid fibers. Aramid fibers are light weight, strong, and tough. Two types of Aramid fiber are used in the aviation industry. Kevlar 49 has a high stiffness and Kevlar 29 has a low stiffness. Kevlar is often used for body-wing connecting applications. It has a natural yellow color and is available as dry fabric material. Carbon and graphite fibers are based on graphene (hexagonal) layer networks present in carbon. Carbon fibers are very stiff and strong 3 to 10 times than glass fibers. Carbon fiber is used for primary wing structure [17]–[19].

Stresses on the wings of the aircraft are tension, compression, shear, bending, and torsion. These stresses are absorbed by each component of the wing structure and transmitted to the fuselage structure. These stresses are known as loads, and the study of loads is called a stress analysis [20], [21]. Stresses should be analyzed and considered when the wing of aircraft is designed.

II. EXPERIMENTAL WORK

The present study sets focus on the evaluation of composite materials used in wings of typical airplane. The work includes experimental tests on three common composite materials: fiberglass, graphite-epoxy and an aramid-epoxy (Kevlar). The mechanical properties of these materials including hardness, tensile and bending were obtained. Specimens were formed according to ASTM standards. The obtained results were compared with each other and with reasonable references in order to get the evaluation.

In the beginning, a plastic mold has been used to form the specimens. Where, it has wrapped with a thin aluminum foil and lubricated to prevent adhesion and save the shape. The hardener (Metaphenylene Diamic) was added to the epoxy resin by the ratio of (3:1). This makes the volumetric shrinkage less than 2% and increases the mechanical properties [22]. The mixing of epoxy and hardener is poured for 6 hours. Meanwhile, the reinforced layer has inserted with continuous pressing using a suitable brush to extract bubbles from the mold. The next layers have made similarly, and the same procedure was repeated for all composite materials used. After the samples have completely solidified, they were released and modified with cutting and sharpening to satisfy the desired composite materials, as shown in Fig. 3.

In the present study, the composite materials that used in the analysis were (see Fig. 4):

A. Graphite-Epoxy

The first reinforced material used was the graphite-epoxy, where the graphite sheets are submerged into the resin in crossed directions. The total area of the mat used for specimens was about 20 x 40 cm².

B. Kevlar-Epoxy

The second reinforced material was Kevlar-epoxy fibers. Kevlar is the trademark for an aramid synthetic fiber. The type of Kevlar used was Kevlar-49.

C. Glass Fiber

The third reinforced material was glass wool fibers, which is the most common composite. It has good stiffness and reduces creep, particularly at higher temperatures. Glass fibers strings have a general diameter of 10 to 15 microns.
results show that the hardness of graphite-epoxy is the best comparing to others, where it was higher by 9% comparing to that of fiberglass and by 18% comparing to that of Kevlar, as shown in Table I.

III. MEASUREMENTS

Several tests have been occurred, in the Testing Lab of Department of Engineering Materials, to find the mechanical properties of the composites which are:

A. Hardness Test

Hardness is the resistance of the material to plastic deformation caused by indentation. Principle of any hardness test is forcing an indenter into the sample surface followed by measuring dimensions of the indentation (depth). Shore hardness method, using the device type (D) was used in this measurement, as shown in Fig. 5. Generally, polymers have low hardness value but reinforcing by fibers increases its hardness due to distribution of load on the fibers which reduces the rate of penetration of the material surface of the material. The

| Material          | 1st sample | 2nd sample | 3rd sample | Average Hardness value |
|-------------------|------------|------------|------------|------------------------|
| Graphite-epoxy    | 98.5       | 96.3       | 80.6       | 91.8                   |
| Kevlar-epoxy      | 77.8       | 75.6       | 81.0       | 78.1                   |
| Glass fiber       | 77.7       | 88.0       | 88.8       | 84.8                   |

B. Tensile Stress Test

This test was done under the ASTM standard D638 Type I with the dimensions shown in Fig. 6 where the thickness was 4 mm. Three specimens are formed for each composite (Fig. 7) using a lathe machine which is available in the lab. The tensile limit has been recorded using (TiniusOlsen-H100 U) machine with speed of (5 mm/min), as shown in Fig. 8. The results of testing are shown in Table II, where the tensile strength of graphite-epoxy was higher by 2.9 times to that of fiberglass and by 5.5 times to that of Kevlar-epoxy.
C. Bending Stress Test

This test was done under the ASTM standard D790 with the dimensions shown in Fig. 9 with a thickness of 4 mm. Three specimens were formed for all composites, as shown in Fig.10, and tested by (Instron cold bend) machine, as shown in Fig. 11. The results of testing are shown in Table III, where bending limit of Kevlar-epoxy was higher by 30% comparing to that of glass fiber and by 75% comparing to that of graphite-epoxy.

| Material          | 1<sup>st</sup> sample load (KN) | 2<sup>nd</sup> sample load (KN) | 3<sup>rd</sup> sample load (KN) | Average value of bending strength (MN/mm<sup>2</sup>) |
|-------------------|---------------------------------|---------------------------------|---------------------------------|-----------------------------------------------|
| Graphite-epoxy    | 0.7                             | 1                               | 0.9                             | 1800                                           |
| Kevlar-epoxy      | 1.6                             | 1.6                             | 1.5                             | 3200                                           |
| Glass fiber       | 1.2                             | 1.3                             | 1.2                             | 2500                                           |

IV. CONCLUSION

It is obviously noticed, from the obtained results, that the behavior of the composite materials was differed from test to another based on the applied load, thus the purpose of using. According to the stress analysis, the following advises could be concluded when the composite materials are used in the wings:

1. The using of graphite-epoxy is preferable in the outer shell of the wing due to its high hardness.
2. The using of the graphite-epoxy is preferable in the parts of the wing exposed to high tension because of its highest tensile strength. Glass fiber could be used in the parts of the wing exposed to less tension due to its reliable strength, as well as the advantage of its low cost comparing to the graphite-epoxy.
3. The using of the Kevlar-epoxy is preferable in the parts of the wing exposed to high bending stress because of its highest bending strength. However, this material can be used as supporting beams along the wing.
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