Effects of Fiber Orientations on Mechanical Properties of a Carbon Fiber Reinforced Composite Material used in Aircraft Applications

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Abstract

The aim of this research is to investigate how fiber orientations in composite materials used in aircraft applications increase mechanical properties. Consideration was given to two different fiber-to-matrix ratios in order to improve the mechanical properties. The materials used for fabrication are graphite powder (2.12 g/cm3), carbon fiber Sikawrap-301 C, E-glass fiber EWR450, and aluminum alloy sheet 2024–T3. In this study, carbon fiber, glass fiber, and glass carbon fiber specimens are created by hand lay-up for testing. The fiber orientation and fiber-to-matrix ratio were used to create these specimens. On universal testing machines (UTMs), tensile and flexural tests were performed on the sample. Tensile testing is done at three different angles on a sample: 0°, 45°, and 90°. The results of tensile tests first show that the strength of the double layer of carbon fiber-reinforced polymer CFRP reduces with increasing fiber orientation. Second, the highest stress a material can resist for the three samples made up of a single layer is 45°. For flexural tests, a three-point bend at 45 degrees demonstrates excellent strength for carbon fiber compared with glass carbon fiber and glass fiber. The results show that fiber orientation improves the composites' mechanical properties and increases adhesion. Carbon fiber-reinforced aluminum laminates are lighter than aircraft wing alloy 2024-T3.

Keywords: Composites; Carbon Fiber; Epoxy; Fiber Orientations.

تأثيرات اتجاهات الألياف على الخواص الميكانيكية للمواد المركبة المقواة بألياف الكربون لتطبيقات الطائرات

خضر نجم عبد، سعد ذياب فارس، ايمان محمد نعمة

الخلاصة:

الهدف من هذا البحث هو معرفة كيف تحسن اتجاهات الألياف في المواد المركبة المستخدمة في تطبيقات الطائرات من الخواص الميكانيكية. تم النظر في نسبتين مختلفتين من الألياف إلى المصفوفة من أجل تحسين الخواص الميكانيكية. المواد المستخدمة في التصنيع هي مسحوق الجرافيت (٢,١٢ جم \ سم ٣) وألياف الكربون Sikawrap-301 C والألياف الزجاجية EWR450 وصفائح سبائك الألومنيوم ٢٠٢٤-T3. في هذه الدراسة ، يتم إنشاء عينات من ألياف الكربون والألياف الزجاجية وألياف الكربون الزجاجية عن طريق وضع اليد للاختبار. تم استخدام اتجاه الألياف ونسبة الألياف إلى المصفوفة لإنشاء هذه العينات. على آلات الاختبار العامة (UTMs) ، تم إجراء اختبارات الشد والانثناء على العينة. يتم إجراء اختبار الشد في ثلاث زوايا مختلفة على عينة: ٠ درجة و ٤٥ درجة و ٩٠ درجة. تظهر نتائج اختبارات الشد أولاً أن قوة الطبقة المزدوجة من البوليمر المقوى بألياف الكربون CFRP تقل مع زيادة اتجاه الألياف. ثانيًا ، أعلى ضغط يمكن أن تقاومه المادة للعينات الثلاث المكونة من طبقة واحدة هو ٤٥ درجة. بالنسبة لاختبارات الانحناء ، يوضح الانحناء من ثلاث نقاط عند ٤٥ درجة قوة ممتازة لألياف الكربون مقارنة بألياف الكربون الزجاجية والألياف الزجاجية. أظهرت النتائج أن توجيه الألياف يحسن الخواص الميكانيكية للمركبات ويزيد من الالتصاق. تعتبر صفائح الألمنيوم المقواة بألياف الكربون أخف من سبائك ٢٠٢٤-T3 لأجنحة الطائرات.

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1. Introduction

Commercial and military aircraft, in specific, use composite materials for control surfaces, wings, aero engines, and other purposes. Lightweight, high-tensile-strength, corrosion-resistant carbon fiber reinforced polymer composites are in high demand. Depletion of fossil fuels worries the auto industry; thus, it produces composite parts to reduce vehicle weight and boost fuel economy. Automakers employ more carbon fiber epoxy resin composites [1]. Paiva et al. [2] investigated flexural and interlaminar shear on four aeronautical CFRC types. The compression test distinguishes between three non-conditioned and three conditioned CFRC families. Hand lay-up in an autoclave was used to make the composites, which included epoxy prepregs (F155 and F584) and carbon fiber fabric reinforcements (PW-"Plain Weave" and 8HS-"Eight Harness Satin"). The laminates were cut into ASTM D790 flexural, ASTM D2344 interlaminar shear, and ASTM D3410 compressive test specimens after molding. The mechanical properties of F584-epoxy matrix laminates outperform those of F155-epoxy laminates. The investigation of shear-and flexural-tested samples using SEM and stereoscopy revealed typical fractured surfaces. Hygrothermal conditioning lowered compressive strength by 8-20% depending on the laminate type. Vehicle weight reduction has been a significant focus in order to improve fuel efficiency in automobiles and airplanes. A 6-8 percent reduction in vehicle weight represents a 10% improvement in fuel efficiency and a 10% reduction in vehicle emissions. In 2008, the transportation sector responsible for 70% of total fuel use in the United States. Energy consumption is proportional to vehicle weight. Many automobile industries were looking for new technology and strategies to improve vehicle performance while lowering fuel consumption. However, fuel usage is directly related to vehicle weight [3]. By reducing vehicle weight, it has also become a key component in improving vehicle efficiency. Some metal components of vehicles in the airplane or car fields would be replaced by reinforced composite materials of the same tensile strength to drop weight and enhance efficiency by 10%. These efforts were made in response to the mid-depletion of fossil fuels [4]. One of the practical ways of reducing vehicle weight is the use of carbon fiber reinforced material. Since excellent mechanical and thermal properties have led to the use of CF polymer composites in the automobile and aerospace fields, the mechanical properties of these reinforced composite materials have been enhanced depending on the application. Because their mechanical properties have gotten better, research in these fields has become more important [5]. Advanced structural fibers were employed for advanced fiber reinforced composites. Because of its advantages, such as high strength, stiffness, heat resistance, and low weight, CF has emerged as an important advanced composite fiber. A composite is a structural material that consists of two or more materials that bind together to form a third material. The reinforcing material was in the form of fiber [6]. The matrix material is available in solid and liquid forms. Fiber reinforced composites are made up of high strength and high modulus fibers that are bound by a matrix with different boundaries. Normally, the fiber behaves as the load-carrying medium while the matrix acts as the fiber's surrounding substance, known as the load-transfer medium between them. Fiber functions as reinforcement to the matrix in these compositions and certain other ingredients were also introduced to enhance the binding characteristics of the fiber reinforced composite material, forming a third material with desired features. Coupling agents, coatings, and fillers were among them. The concept of the matrix, the concept of being in nature, was not created by humans [7,8.9]. Wood was one of the examples taken into consideration. In this case, lignin serves as a matrix that is reinforced with cellulosic fiber. Several hundred years ago, people built their homes using combined husks or straw mixed with clay, which is an example of a composite. Rahmani et al. [10] evaluated the effects of various laminates, resin types, and fiber orientations on the mechanical properties of laminated composites. The hand lay-up method was used to create composites for the sample preparation, with a fiber-to-resin ratio of 40:60. (w: w). Angles of 0°, 35°, 45°, and 90° were chosen to examine the impact of fiber orientation. The results indicate that the number of laminates followed by the fiber orientations had the greatest influence on the mechanical qualities in terms of tensile, flexural, and impact strengths. The composites created with EM500 epoxy resin demonstrated the highest mechanical performance when compared to other examined composites at a similar fiber orientation. The differences weren't really significant, though. According to the findings, five-ply composites generally had slightly better mechanical properties than three-ply composites. Ahmed et al. [11] performed an experimental investigation on how to reduce weight and improve the mechanical properties of aircraft wings by employing hybrid materials known as fiber-metallic films (FMLs). In this investigation, seven layers of aluminum alloy 2024-T3 reinforced by carbon and glass fibers were bonded utilizing a graphite and polyester blend as adhesive.

The goal of this study is to determine the effect of fiber orientation and loading axis on the composite material performance used in an aircraft application. Carbon fiber, glass fiber, and glass carbon fiber specimens are created by hand lay-up for testing. The fiber orientation and fiber-to-matrix ratio were used to create these specimens. Tensile testing is done at three different angles on a sample: 0°, 45°, and 90°.

2. The Objectives of the Study

Following a comprehensive review of literature, the following goals for the current work have been established:

- The primary goal is to create an advanced composite material with high tensile and flexural strength. These goals drew attention to the importance of selecting the fiber and matrix in such a way that it has strong temperature resistance as well as water resistance when exposed to the environment.

- Natural fiber and thermoplastic polymer research are limited due to their hygroscopic nature, and it is expensive.
- Until date, much research has been conducted on carbon fiber by mixing it with a polymer matrix to increase mechanical properties. The orientation of the fiber has an effect on the mechanical properties, according to the literature review.
- The mechanical parameters of the composite were compared to determine which orientation provides the highest strength. A carbon fiber reinforced polymer composite was created through experimentation.

3. Practical side

The use of thermoset polymers as a matrix has grown due to their mechanical and thermal-mechanical properties, as well as their ease of fabrication via hand lay-up. The hand lay-up technique is used in this study to create a project composite. The materials used for fabrication are graphite powder (2.12 g/cm3), carbon fiber Sikawrap-301 C, E-glass fiber EWR450, and aluminum alloy sheet 2024–T3. In this study, carbon fiber, glass fiber, and glass carbon fiber specimens are created by hand lay-up for testing. The fiber orientation and fiber-to-matrix ratio were used to create these specimens. The orientation of the E-glass fiber EWR450 woven roving is 45 degrees and unidirectional (0 degrees) for carbon fiber Sikawrap-301 C to give the same stress in all directions. A wooden mold was first created, and then the classical process that can easily make composites that require time for sample preparation and finishing based on the needs was used. The specimens, which are carbon fiber, glass fiber, and glass carbon fiber, were created using fiber orientation and fiber-to-matrix ratio. The UTM was subjected to two different tests: a tensile test and a flexural test, and the mechanical characteristics of both were demonstrated by this test. Figure (1) displays samples after casting and prior to cutting, a. containing epoxy and carbon fiber, and b. containing epoxy, carbon fiber, and fiber glass.

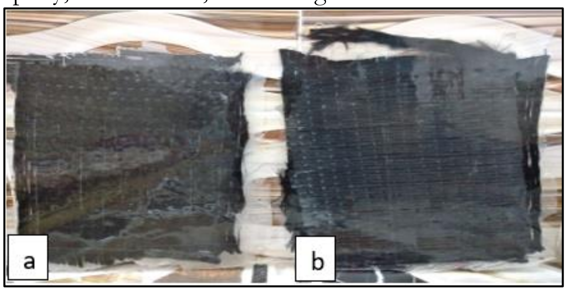

Figure (1): After casting and before cutting samples

Figures 2, 3 & 4 illustrate the sample's tensile test, the Bending testing of the sample, and the fracture of a class fiber sample after a tensile test.

Figure (2): The tensile test of the sample.

Figure (3): Bending testing of the sample

Figure (4): shows the fracture of a class fiber sample after a tensile test

4. Results and discussions:

The material tensile and flexural tests of the composite were evaluated on the UTM machine, which also provided the stress-strain graph and the load-displacement graph. The resulting graph also yielded values for strength, young's modulus, peak load, break load, and elongation. The mechanical properties of the fiber were found to vary depending on its orientation and fiber content. Fiber orientation gives macroscopic stiffness and strength, which are essential for improving the mechanical properties of a material. In addition, fiber-reinforced composites get chemical characteristics from their polymer matrixes and fiber reinforcements.

Tensile test results of a single layer of carbon fiber-reinforced polymer (CFRP) composite and a double layer of CFRP were compared using fiber orientation. A tension load was applied to the specimen in this case to determine the resistance of the breaking material. The tensile result demonstrates that as the fiber orientation increased, the strength of the double layer of CFRP composites decreased because the loading orientation remained constant while the fiber orientation changed. Tensile testing results also show that the orientation of the 0° double-layer of CFRP was desired due to the composite's high tensile strength and young modulus.

In tensile and flexural tests on a single layer, the effect of fiber orientation and loading axis is significant for all samples, as demonstrated in the figures below: Figure (5) illustrates tensile testing done at three different angles on a carbon fiber sample: 0°, 45°, and 90°. T1 is the highest stress that a material can withstand at 45 degrees, as opposed to 0 degrees, which represents stress T2, and 90 degrees, which represents stress T3.

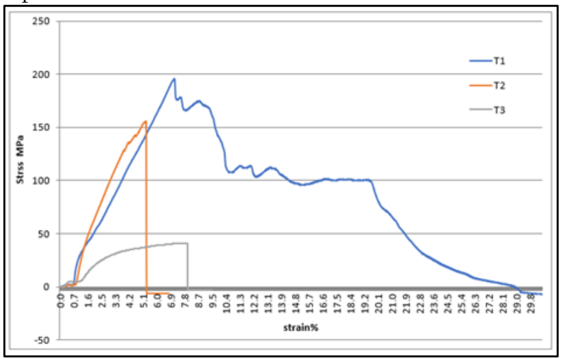

Figure (5): tensile testing on a carbon fiber sample at three angles: 0°, 45°, and 90° angles.

Figure (6) presents the tensile testing on carbon fiber and glass fiber samples shows 0°, 45°, and 90° angles. The greatest stress that the material can withstand at angle 45° is represented by stress ft1, as opposed to angles 0° and 90°, which represent stress ft2 and stress ft3, respectively.

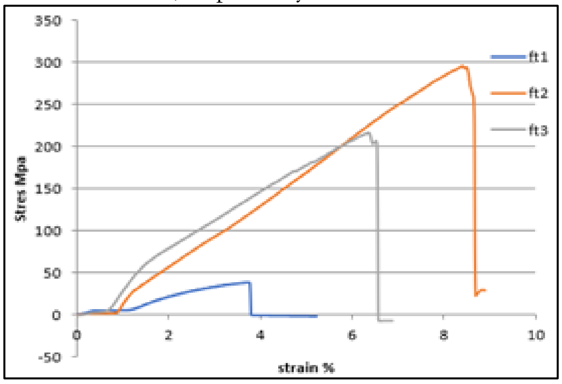

Figure (6): Tensile testing on carbon fiber and glass fiber samples shows 0°, 45°, and 90° angles.

During tensile testing, a glass fiber sample was held at three different angles: 0, 45 and 90 degrees. The largest stress that the material can withstand at angle 45° symbolizes stress gft1, as compared to angle 0°, stress gft2, and 90° stress gft3. (as shown in Fig. 7)

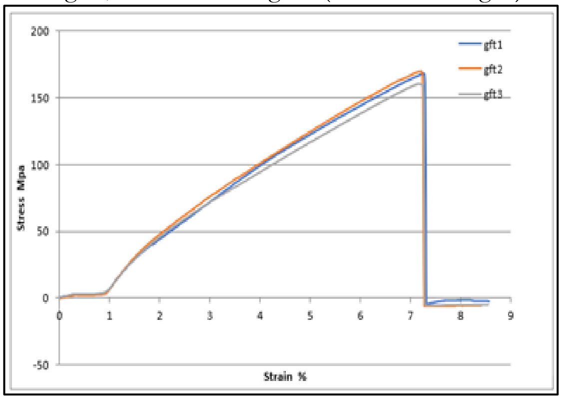

Figure (7): During tensile testing, a glass fiber sample was held at three different angles: 0°, 45°, and 90° angles.

Figure (8) depicts flexural tests on carbon fiber, glass carbon fiber, and glass fiber samples. The flexural test is done according to the standard ASTM D790 at room temperature. Stress b1 is the highest stress that carbon fiber can withstand, followed by stress b2 for glass carbon fiber and stress b3 for glass fiber. The results show that the fiber orientation at 45° degrees has good strength when compared to other composite orientations. The study's flexural testing indicates that the orientation of the 45°double layer of carbon fiber was favored over the single layer due to the composites' high flexural strength and Young's modulus.

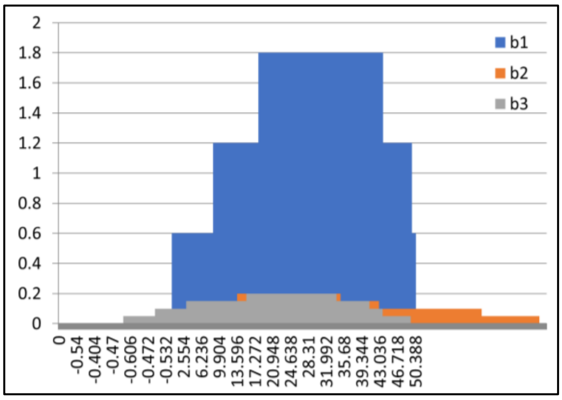

Figure (8): flexural tests on carbon fiber, glass carbon fiber, and glass fiber

In figure (9) the compression test shows that the carbon fiber, which has a stress rating of 1, can handle the most stress. This is in contrast to the glass carbon fiber, which has a stress rating of 2, and the glass fiber, which has a stress rating of 3. Figure (10) depicts the life count for CAGRALLs under the fluctuating stresses that cause failure. A range of strains (R = -1) were used in this investigation. At reversed stress (100 MPa), the number of cycles until failure was approximately 4 x 10^4. The number of life cycles for CAGRALLs was estimated to be 1 x 10^4 at a reversed stress of 200 MPa. These results give a good agreement with the research using Epoxy–Novolac [14]

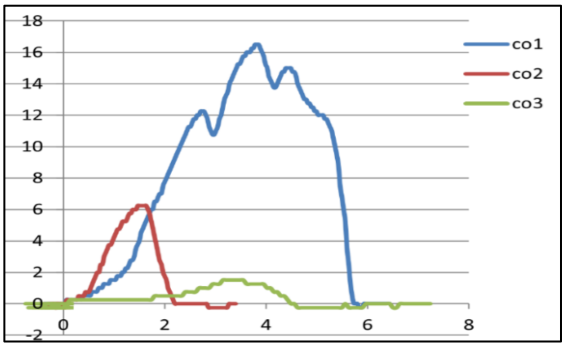

Figure (9): The compression test

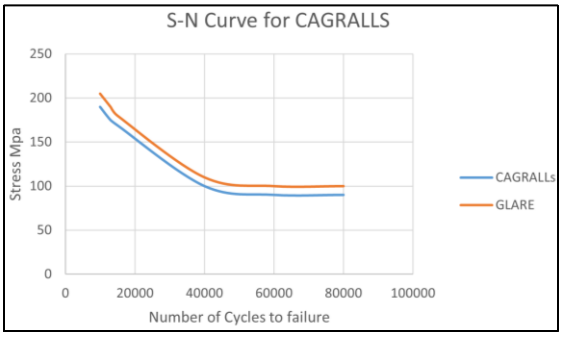

Figure (10): S-N curve for CAGRALLs

5. Conclusion

The comparison of the tensile test between the single layer of carbon fiber reinforced polymer (CFRP) composite and the double layer of CFRP was done based on the orientation of the fiber. The tensile result demonstrates that as the fiber orientation increased, the strength of the double layer of CFRP composites decreased. Tensile testing of the results revealed that the orientation of the 0° double-layer carbon fiber was preferred due to the composite's high tensile strength and young modulus. The highest stress a material can resist for the three samples made up of a single layer is 45°. The tensile test shows the strength of the composites was going to decrease as the orientation of the fiber increased because the loading orientation remained the same but the fiber orientation was going to change. In the case of flexural tests, the results show that the fiber orientation at 45° has good strength when compared to other composite orientations. According to the results of the flexural testing, the orientation of the 45° of carbon fiber was preferred because of the good flexural strength and Young's modulus of the composites. The influence of the orientation of the fiber and the loading axis plays an important role in the tensile and flexural tests. The use of thermoset polymers as a matrix increased because of their mechanical and thermomechanical properties and the ease of making the composites through hand lay-up.

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