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RESEARCH ARTICLE

Mechanical properties of an aluminium-carbon fiber composite for aircraft wing spar applications

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Abstract

Objective: The aim of this article is to solve the problem of wing spar flexibility of an aluminium drone aircraft. A 200 × 30 [mm × mm] aluminium sample weighing 32 g was collected corresponding to a density of 0.53 g/cm3, a bending load of 0.77 [kN] and a deflection of 45.54 mm. The goal is to increase flexion resistance and lightness. **Methods:** The following procedure was used to prepare the composite: a mold made up of two glass plates 250 mm long and 50 mm wide, gel-coated to prevent sticking. The mold was placed in a bag using vacuum bag technology by means of a refrigerator compressor. The bag was then heated at 80 °C for seven hours to prepare composites of acceptable quality and viscosity avoiding air bubbles and ensuring desired thickness. The first sample was prepared by inserting aluminium powder between four layers of glass fiber. In the second sample, the inserted layer was replaced by date pit powder. The third sample was prepared by placing four layers of glass fiber and two layers of carbon fiber in the lower layer and the upper layer. It was observed that aluminium powder inclusion resulted in better mechanical properties in comparison to date pit powder. **Findings:** However, the mechanical characteristics of the third sample were much better than those of the other samples. Based on these observations, the first and third samples were mixed to make the fourth sample in which four layers of glass fiber between each layer were used, placing the aluminium powder plus two layers of carbon fiber in the lower and upper layers with the aim of achieving the desired mechanical properties. The latter sample exhibited high strength and better curvature, high rigidity and corrosion resistance with the possibility of creating structures that are more integrated. These properties make the aluminium powder –carbon fiber based composite suitable for a drone aircraft wing spar. The obtained composite material prepared from glass fiber, aluminium powder, carbon fiber composed of four layers of glass fiber and aluminium powder between each layer and carbon fiber in the bottom layer and top layer exhibited has high strength, better bending, high stiffness and corrosion resistance with the possibility of creating more integrated structures. The prepared sample may outstand aluminium -based aircraft wing spar.

Keywords: Wing spar; bending; composite materials; aluminiumcarbon fiber

1 Introduction

Due to globalization and military needs, the aircraft industry has become very crucial and useful in all fields and aspects of modern life. Increasing demand for novel models of planes including pilotless planes has led research to the development of new materials. Since the 1960's, composite materials, owing to outstanding properties, have been introduced successfully in aviation and space technology [1,2]. Today, composite materials are mainly used for industrial purposes for diverse reasons [3]. These include an excellent mass/rigidity/resistance ratio in comparison with metallic materials, a design of appropriate materials in solicitation axes in order to make additional weight gains [4] and increased fatigue resistance in comparison with metallic materials [5]. A composite material consists of a matrix and a fibre reinforcement [6]. Matrices can be divided into four categories according to industrial need: thermosetting matrices, thermoplastic matrices, thermostable matrices, metal and ceramic matrices [7]. Knowledge of the mechanical properties and structure of a composite makes it possible to understand, even predict its behaviour in service. The understanding of the mechanical characteristics of a composite material and its structures open doors for the comprehension and prediction of its behaviour in service.

To characterize composite behaviour under specified conditions, a number of tests were carried out in this work, including: Static tests (Traction, compression and bending) [8,9]; Dynamic tests [10] (Impact, resilience, fatigue) [11,12] ; Shearing; Torsion-tube test ; Hardness test; Mechanical tests on the fibre-matrix interface [13,14]. Parts may be subjected to different mechanical stresses during their service whose harmful effects may be deepened by weather and aggressive environment. Their behaviour depends highly on microstructural parameters. Due to their heterogeneous nature, damage behaviour of composites can be very complex [15]. Usually, damage occurs through the combination of three modes: fibre rupture, fibre-matrix interface debonding [16] and matrix cracking [17].

Composite structures are becoming increasingly popular. The technology offers high precision, good surface quality and the possibility of making cells with very complicated shapes [18]. But mold preparation and high manufacturing costs are a limiting factor. However, costs are eventually offset by the life cycle and cost savings [18].

In fact, aerospace engineers have successfully reduced components weight using carbon fibre compared to ordinary materials such as metals. However, several types of composite materials are usually used since no single part can exhibit all of the required characteristics for the construction of an aircraft entire structure.

In this work, we were interested in reinforcing an aircraft wing spar using aluminium and carbon fibre to reduce bending. The aim of this research was to analyse the mechanical behaviour of composites using the laminated plates method to address composite bending problems.

2 Materials and methods

The following procedure was used to prepare composites by adding aluminium powder, date pit powder and selecting specimen sizes for the flexural tests.

2.1 Materials

2.1.1 Carbon Fibre

High resistance (HR) standard satin weave fibres were used because they are well adapted to the moulding of complex forms [19]. The face of the fibre consists of warp or filing floats produced in the repeat of the weave. The number of warp and weft yarns for this type of fibre that pass over each other before interlacing is higher. Each satin fabric is characterized by a number, usually 4, indicating that the warp threads pass over 4 weft threads (Figure 1). The result is a fabric with one side that contains more warp yarns and another side more weft yarns. The mechanical properties are summarized in Table 1.

Fig 1. Carbon Fiber (HR)

Table 1. Mechanical characteristics of carbon fibres (HR)

Young's Modulus	Break strength	Density	Specific Modulus	Specific stress
E [GPa]	σ_u [MPa]	ρ [kg/m^3]	E/ρ [MN m/Kg]	σ_u/ρ [kN m/kg]
220	3500	1750	120	1890

2.1.2 Glass fibre

Taffeta glass fibres (R) with the properties mentioned in Table 2 were used in this work[20].

Table 2. Mechanical characteristics of glass fibres (HR)

Density	Young's Modulus	Break strength	Elongation at break
ρ [kg/m^3]	E_f [GPa]	σ_{fu} [MPa]	ε_{fu} [%]
2550	86	4400	5.2

They are known for their corrosion resistance, high mechanical resistance, chemical attack resistance, good insulating properties, cold and heat resistance, easy colouring and shaping.

2.1.3 Aluminium powder

Aluminium powder (series 1000) was tested owing to malleability, ductility qualities as well as excellent corrosion resistance and great longevity. Aluminium is also nonmagnetic and does not spark[21,22].

2.1.4 Date pit powder

Date pit powder was employed (Figure 4) for void filling and surface viscosity increase[23,24].

2.1.5 Epoxy resin + Hardener

Taking into account the good mechanical characteristics, excellent chemical resistance, good behaviour at high temperature, and excellent adherence to metallic materials (Figure 5) exhibited by epoxy resins (EP), we tested a resin with the following properties: (Table 3)

Table 3. Mechanical properties of the epoxy resin used

Density ρ (kg/m^3)	Modulus of elasticity in traction (GPa)	Tensile stress at break (Mpa)	Flexural strength at break (MPa)	Shear Strength (MPa)	Deflection Temperature Under Load (1.8MPa)°C
1100 to 1500	3 to 5	60 to 80	100 to 150	30 to50	290

2.1.6 Mould release agent

We used a mould release agent by a nearby boat repair company.(TR) (Figure 6)

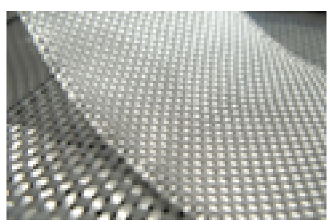

Fig 2. Glass Fiber (R)

Fig 3. Aluminium Powder

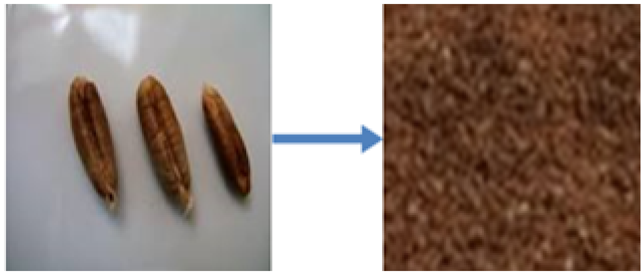

Fig 4. Date pit powder

Fig 5. Epoxy resin + Hardener

Fig 6. Mould release agent

2.2 Methods

2.2.1 Steps for the preparation of composites

The mould was prepared by first using two 250 x 50 (mm x mm) glass plates (Figure 7), coated with a release agent to prevent sticking (Figure 8) and then inserting the prepared composite in between (Figure 9). The mold was placed in a bag using vacuum bag technology by means of a refrigerator compressor(Figure 10). After vacuuming, the assembly was heated for seven hours at 80 °C using the experimental setup shown in (Figure 11).

Fig 7. mold of two glass plates size 250 x 50

2.2.2 Suggestions for choosing the layers of composite materials

The four samples prepared are depicted in (Figure 12). Aluminum powder was placed between the four layers of glass fiber. In the second sample, aluminium powder was replaced by date pit powder. In the third sample, we put four layers of glass fiber and two layers of carbon fiber

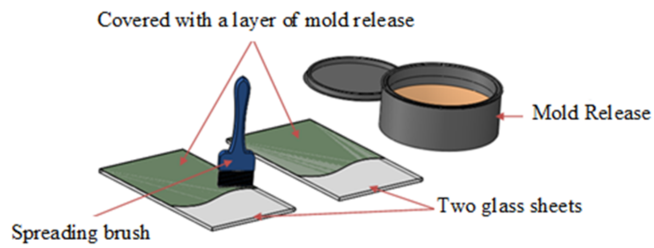

Fig 8. release agent to prevent sticking

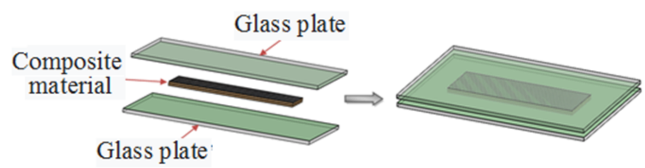

Fig 9. Place the composite material plate between the two glass plates

Fig 10. Install the whole in a special bag easy to clos to make a vacuum

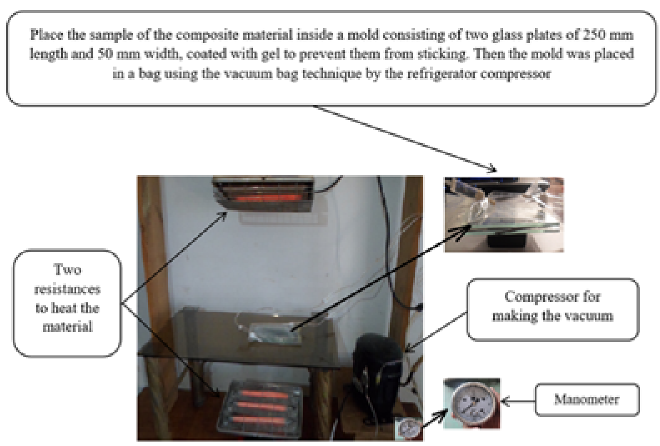

Fig 11. Experimental set up of a two-resistor furnace to heat the material and a vacuum compressor.

in the lower layer and the top layer and in the fourth sample, we placed four layers of glass fiber between each layer, placing the aluminium powder plus two layers of carbon fiber in the bottom layer and the top layer.

3 Results

After the preparation of composite materials, the parameters to be assessed were viscosity of the surface quality of composite material, aesthetic quality, absence of air bubbles, uniform thickness, good joining, and easy machining (Figure 13).

Three-point bending tests were performed on the prepared specimens according to NFT57-104 and105 standard procedures[25] as depicted in (Figure 14). (L=200 mm , b=30 mm , h=2mm)

The maximum flexural stress and the load at the fracture point (NR) were measured using a multipurpose INSTRON machine (Figures 15 and 16).

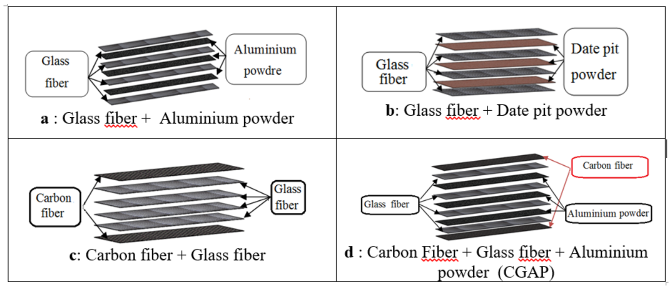

Fig 12. Preparation of the four composites using carbon fiber and glass fiber

Fig 13. Quality of the prepared materials

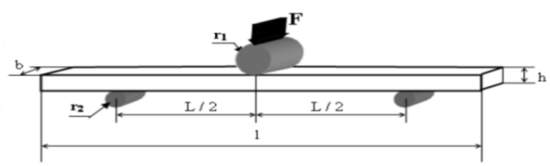

Fig 14. Bending test specimen dimensions

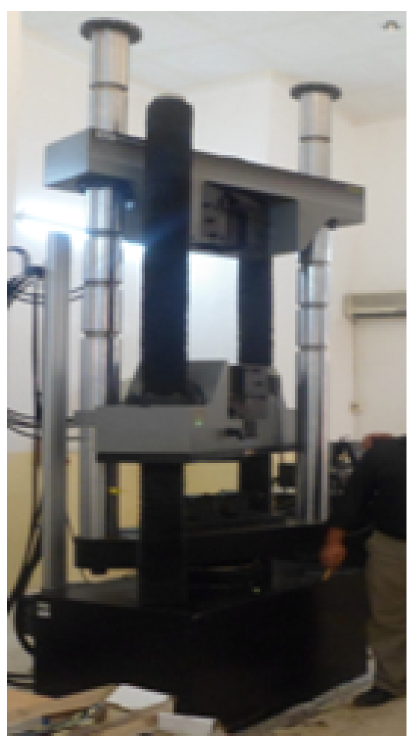

Fig 15. Instron machine used

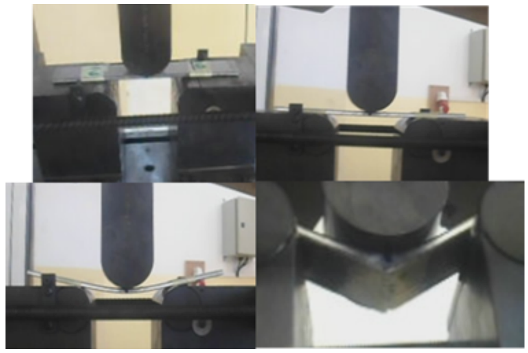

Fig 16. Flexure tests on prepared specimens

3.1 The results for the bending test of each specimen

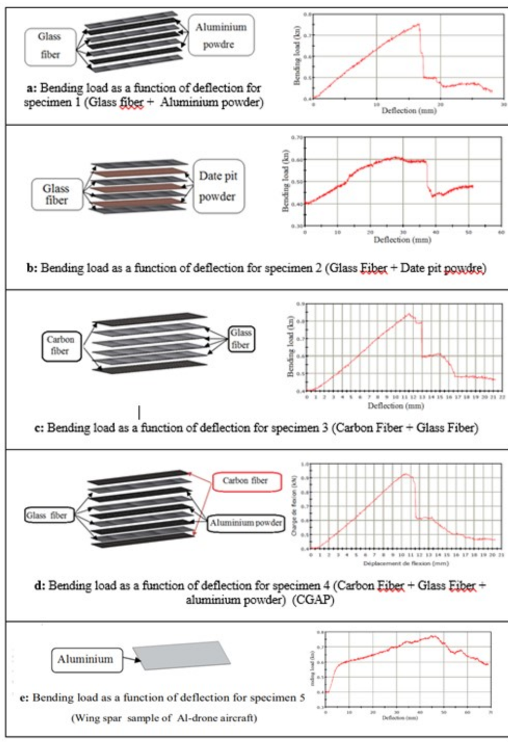

Fig 17. Flexural load as a function of deflection for the specimens prepared in comparison to analuminium wing spar sample taken as a control

3.2 Global flexure tests results

For the sake of comparison, (Figure 18) regroups all the graphical results.

For the lightest specimen (18 g), it was observed that when a force of 0 to 0.3 kN was applied, almost no deflection occurred, but as soon as the force was further increased by 0.1 kN, a 5 mm deflection was observed. Maximum bending of this specimen was 0.75 kN corresponding to 17.34 mm deflection (Figure 17a).

For Specimen 2 (20g), a deflection of 12 mm was noted for a 0.1 kN load . The maximum bending load of this specimen was 0.61 kN for a deflection at break of 27.49 mm (Figure 17b).

While for specimen 3 (19g), no deflection was observed for an applied force up to 0.4kN but when the force was further increased by 0.1 kN , a 3mm increase in deflection was observed. Maximum bending load and deflection corresponded to 0.84 kN and 13 mm, respectively (Figure 17c).

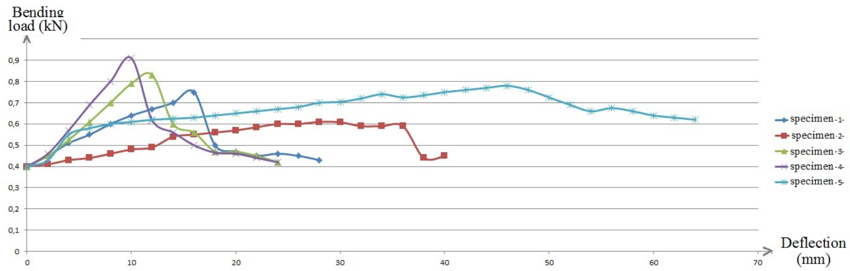

Fig 18. Global flexure tests results

As for Specimen 4 (21g) exhibited also a 2 mm deflection for a load increase of 0.1 kN and for a maximum bending load of 0.93 kN, the deflection at break was 11.55 mm (Figure 17d).

finally specimen 5 (Figure 17e) which we took from the wing spar of the aircraft, its weight is 32 g the maximum bending load of 0.77 KN, the deflection at break was 45.54mm

Table 4. Flexure tests results for the specimens prepared in comparison to control specimen (5)

	Weight (g)	Flexural stress (MPa)	Bending load (kN)	Percent bending (%)	Deflection (mm)
Specimen -1-	18	953.17	0.75	0.60	17.34
Specimen -2-	20	1578.72	0.61	0.67	27.49
Specimen -3-	19	1541.48	0.84	0.37	13
Specimen -4-	21	1696.97	0.93	0.33	11.55
Specimen -5-(control)	32	3444	0.77	0.83	45.54

3.3 Comparison of Results

The following table classifies samples according to weight, bending load, deflection.

Table 5. Classification of specimens with respect to: weight, flexural load and deflection

Classification	Weight	Bending load	Deflection
1	Specimen 1 18g	Specimen 4 0.93KN	Specimen 4 11.55mm
2	Specimen 3 19g	Specimen 3 0.84KN	Specimen 3 13.00mm
3	Specimen 2 20g	Specimen 5 0.77KN	Specimen 1 17.34mm
4	Specimen 4 21g	Specimen 1 0.75KN	Specimen2 27.49mm
5	Specimen 5 32g	Specimen 2 0.61KN	Specimen 5 45.54mm

The first sample is lighter than the second sample (18 g and 20 g, respectively). The first sample bending load is 22.9 % larger while its deflection is smaller by ca. 10 mm, pleading for the use of aluminium powder instead of date pit powder. But the mechanical properties of the third sample are much more acceptable than those of the first and second sample, because it is characterized by a bending load of 0.84 kN and a deflection of 13 mm. For this reason, we made a mixture between the third sample and the first sample to build the fourth sample to improve its mechanical properties. From the above comparison, we can say that the best test specimen is the fourth CGAP specimen (Figure 12d) because its mechanical properties are better than the other test specimens and it is better than the fifth specimen (aluminium) used for aircraft wing spar, so that the fourth CGAP sample has a high strength and a better load of bending (0.93 kN), deflection (11.55 mm) and an acceptable weight of 21 g, compared to the aluminium material used (the fifth sample), which had a weight of 32 g and a load of bending of 0.77 kN and a deflection of 45.54 mm.

Therefore, the prepared material may prove more interesting than aluminum-based one for wing spar applications.

4 Conclusion

This work studied the mechanical properties of four different composites for their suitability for drone aircraft wing spar applications. The first and second samples were prepared by introducing aluminum powder, then date kernel powder between four layers of glass fibers. By comparison, we found that the first sample was better than the second. Therefore, we concluded that using aluminium powder was better than date powder. While the third sample was prepared with four layers of glass fiber and two layers of carbon fiber, its mechanical properties were significantly better than those of the other samples. Based on these observations, the first and third samples were mixed to make the fourth sample, where four layers of glass fibers were used between each layer and we applied aluminium powder plus two layers of carbon fiber This sample has shown high strength With a bending load of 0.93 kN, better deflection (11.55 mm), an acceptable weight of 21 g with good corrosion resistance, compared to the materials used for for drone aircraft wing spar with a weight of 32 g and a bending load of 0.77 kN and a deflection of 45,54 mm

The obtained composite material CGAP (Carbon Fiber + Glass Fiber + aluminium powder) has high strength, better bending, high stiffness and corrosion resistance with the possibility of creating more integrated structures.

The CGAP composite material was used to manufacture a wing spar for a drone aircraft with a wing loading of 36.9 kg/m^2 It was afterwards subjected to bending loads. The results were satisfactory and applied to the construction of an aircraft wing.

The prepared sample can outperform an aluminum-based drone wing spar. The high initial manufacturing cost may be offset by longer service life.

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