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Molding preparation and tensile properties test of carbon fiber reinforced aluminum laminates

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ABSTRACT

Due to their excellent mechanical properties, Carbon fiber reinforced aluminum laminates (CARALL) are widely used in aerospace, transportation, military and navigation fields. In this study, a method of preparing CARALL by molding process was introduced. We used this method to obtain two kinds of CARALL, Al-CFRP-Al laminated plate and CFRP-Al-CFRP laminated plate. Then we tested their tensile properties. The experimental results indicated that the tensile properties of Al-CFRP-Al laminates were 865.1 MPa, while the tensile properties of CFRP-Al-CFRP laminates were 718.2 MPa. In comparison to pure aluminum alloy, the tensile strength of both laminates had been significantly improved. By observing the microstructure of the fiber layer of the laminated plate, it was found that the carbon fiber is a brittle material, and its fiber bundle can effectively enhance the material properties during the tensile process. Finally, the tensile failure behavior of the prepared CARALL was analyzed by finite element simulation, which further confirmed that the use of carbon fiber composite can effectively enhance the tensile properties of aluminum alloy. Through this study, the tensile properties of aluminum alloy were successfully enhanced by CFRP, which provided a method for the study of aluminum alloy performance enhancement.

Keywords: FMLs (Fiber metal laminates); CARALL (Carbon Reinforced Aluminum Laminates); Molding preparation, tensile test; finite element simulation.

1. INTRODUCTION

With the rapid development of the aerospace and automotive industries, in order to meet the lightweight of structural parts and maintain excellent mechanics. Fiber metal laminates (FMLs) are formed by stacking metal and composite materials in a thin layer, heating and pressurizing the equipment, and finally curing to form FMLs [1]. Figure 1 shows the model diagram of FMLS. The laminated plate obtained in this way combines the advantages of composite materials and metal materials, and has many advantages such as high fatigue resistance, impact resistance, specific strength, light weight, and strong designability. Carbon fiber reinforced polymer (CFRP) has gradually replaced many traditional materials and enhanced the mechanical properties of materials by adding CFRP due to its excellent properties of light weight and high strength. These characteristics make the applicability of CFRP improved [2]. Carbon fiber reinforced aluminum laminate (CARALL) is considered to be the third generation FMLS [3]. Due to the large elastic modulus of carbon fiber, the crack growth rate of CARALL is low. So that its fatigue resistance is excellent, with excellent specific strength, specific modulus and impact resistance [4, 5]. The excellent comprehensive performance of CARALL makes it have broad application prospects in the fields of aviation, transportation, military and navigation [6]. However, due to the large difference in physical properties (thermal expansion coefficient, elastic-plastic) between the two parts of the laminated plate after CARALL forming, it is easy to produce interface delamination and fracture under the combined working environment of thermal and mechanical [7, 8]. One of the basic methods of tensile evaluation of mechanical properties of composite materials [9]. Our experiment aims to test the tensile strength of the prepared samples by tensile test. Compared with the aluminum alloy plate, determine whether it can enhance the material properties.

Progressive damage analysis method is considered to be an effective method to analyze the damage of composite materials by many scholars [10]. Hashin failure criterion is a widely used failure criterion because of

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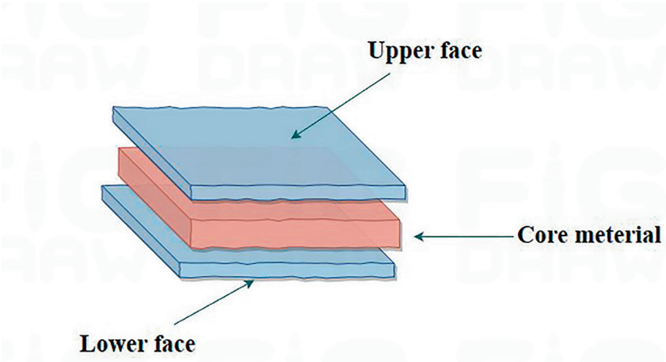

Figure 1: The schematic diagram of fiber metal laminates (FLMs).

its simplicity and understandability. It has been integrated into Abaqus finite element analysis software [11, 12]. The 2D Hashin failure criterion is used as the damage criterion. Considering the linear stiffness degradation after composite failure, considering the four failure modes of fiber tensile and compression failure, matrix tensile and compression failure, the composite material is modeled by continuous shell element SC8R. The calculation results are in good agreement with the experimental results [13, 14].

In this study, carbon fiber reinforced polymer was laminated with aluminum alloy 6061 (AA6061) by molding technology to obtain two materials of Al-CFRP-Al and CRFP-Al-CRFP. Then the corresponding tensile experiments were carried out. Compared with the tensile strength of AA6061, the strength of laminates was both higher than that of AA6061, but the strength of the two laminates were also different. Then we observed the microscopic changes after tensile deformation by electron microscopy and analyzed its enhancement mechanism. Finally, the experiment was verified by finite element simulation to ensure the accuracy of the experiment. We found that the CARALL prepared by molding can effectively strengthen the tensile properties of aluminum alloy. In this way, an idea of strengthening the mechanical properties of metals by molding CARALL was provided. It is believed that through continuous exploration and research, CARALL application scenarios will be more extensive.

2. MATERIALS AND METHODS

2.1. Raw materials

CARALL is made of T700 carbon fiber reinforced polymer and aluminum alloy 6061. The thickness of carbon fiber reinforced polymer is 0.125mm. The thickness of AA6061 plate is 0.5mm. Carbon fiber reinforced polymer is provided by Hansort Advanced Materials Co., Ltd. The chemical constituents of AA6061 are shown in Table 1.

2.2. Preparation of CARALL

We first carry out some phase treatment on the surface of aluminum alloy. We first perform some treatments on the surface of the aluminum alloy. Including mechanical grinding and acid-base corrosion treatment. The process flow is shown in the Figure 2. The composition and process parameters of acid-base cleaning solution are shown in Table 2. The purpose of this step is to increase the roughness of the aluminum alloy surface to increase the interlayer bonding properties of the laminates [15].

The carbon fiber reinforced polymer and the treated aluminum alloy plate were laid according to Al-CFRP-Al and CFRP-Al-CFRP, respectively. The carbon fiber reinforced polymer is fully symmetrically ply with 0°, 90°, 0°, 90°... This layering method effectively eliminates the residual stress after the laminated plate is formed, prevents the laminated plate from warping after cooling to room temperature, and ensures the flatness of the laminated plate.

The preparation of laminated plates adopts the molding process. Figure 3 shows the variation of pressure and temperature with time during molding process. The laminated material was vacuumized at room temperature, and then pressurized to more than 0.7 MPa. After holding at 125° ± 5°C for 90–120 minutes, the part with a thickness of 2mm was obtained. According to ASTM D3039 standard [16], the two kinds of laminates were cut into 250mm × 10mm × 2mm test samples, as shown in Figure 4. Figure 5 shows the CARALL fabricated by the above process.

Table 1: Chemical composition of aluminum alloy 6061.

ELEMENT	MASS FRACTION (%)
Si	0.60
Fe	0.70
Cu	0.15
Mn	0.15
Mg	1.20
Ti	0.15
Zn	0.25
Cr	0.20

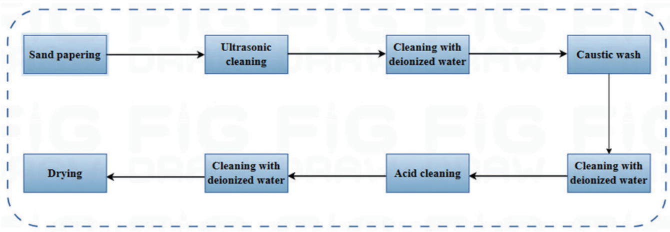

Figure 2: Aluminum alloy surface treatment flow chart.

Table 2: Composition and process parameters of acid-base washing solution.

REAGENT NAME	CONCENTRATION	TEMPERATURE	HANDLING TIME	CONCENTRATION
NaOH	100g/L	40–50°C	3–5min	Aladdin
HNO3	100g/L	25°C	2–4min	Aladdin
Deionized water	NONE	25°C	1–3min	Self preparation

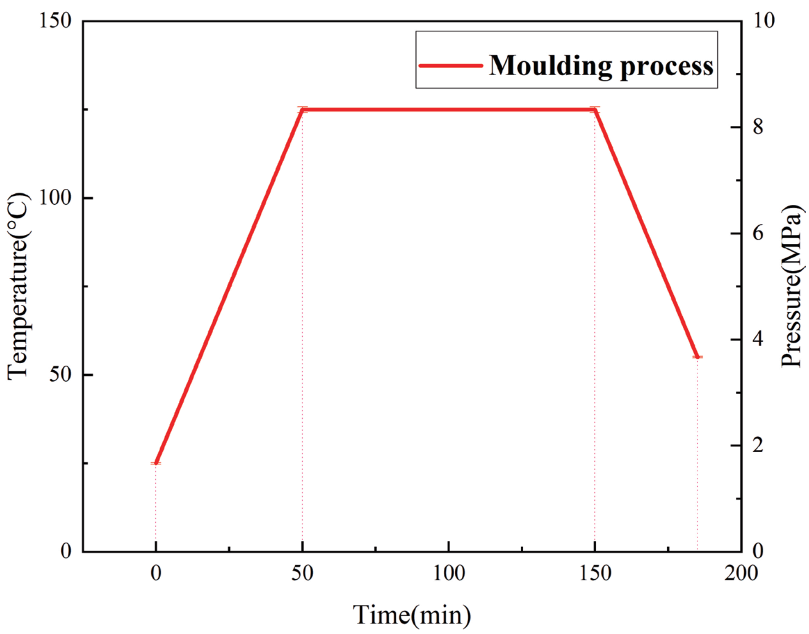

Figure 3: Molding process parameter diagram.

Figure 4: CARALL sample size chart.

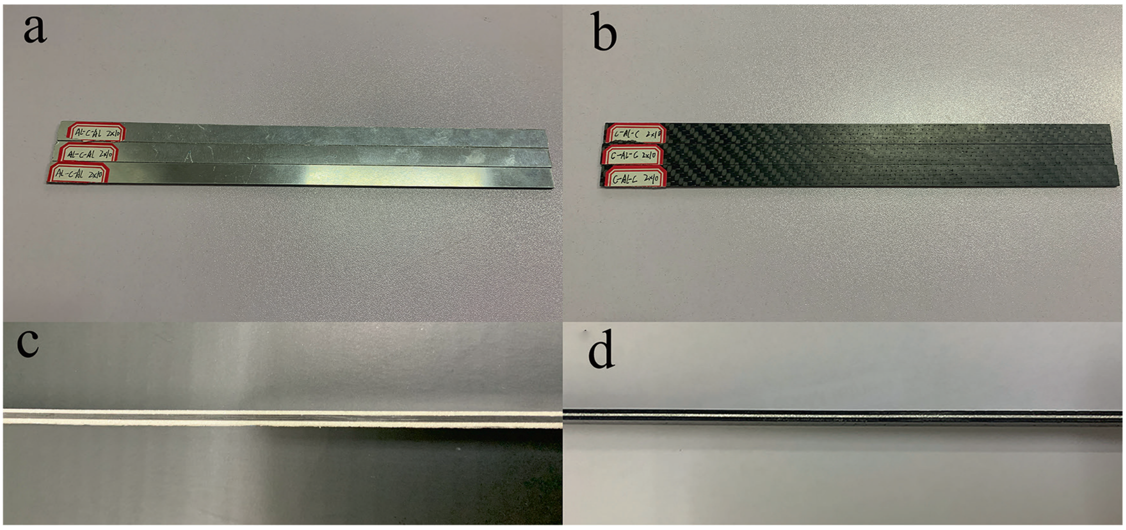

Figure 5: Laminated plate prepared by molding process: (a) Al-CFRP-Al laminated plate after cutting; (b) CFRP-Al-CFRP laminated plate after cutting; (c) Cross-section of Al-CFRP-Al laminated plate; (d) Cross-section of CFRP-Al-CFRP laminated plate.

Figure 6: MTS tensile test machine.

2.3. Tensile test

The test sample was subjected to uniaxial tensile test with MTS tensile test machine, as shown in Figure 6. The loading rate is 1mm/min. The tensile strength of the specimen is calculated according to Equation (1), where F is the ultimate load of the specimen and S_0 is the initial cross-sectional area of the specimen.

$$\sigma = \frac{F}{S_0} \tag{1}$$

3. RESULTS AND DISCUSSION

3.1. Results of tensile test

Figure 7 shows the state of the two laminates after tensile fracture. It can be seen that the aluminum alloys had undergone plastic deformation during the stretching process, and it broke after exceeding the elongation limit. On the contrary, the carbon fiber layer had no obvious deformation during the stretching process. Carbon fibers were brittle fracture due to their material properties.

We plotted the load-displacement curves of two laminates based on the tensile test data, as shown in Figure 8. The tensile test results show that the maximum load of Al-CFRP-Al laminate is 17.302 kN, and the maximum load of B is 14.364 kN. Through calculation, the ultimate tensile strength of Al-CFRP-Al laminate is 865.1 MPa, and the ultimate tensile strength of CFRP-Al-CFRP laminate is 718.2 MPa. Figure 9 shows the tensile strength comparison between the two laminates and AA6061. It can be seen from the figure that the prepared CARALL significantly improved the tensile strength of AA6061.

3.2. Microstructure of CFRP

In order to more carefully see the morphology of the laminates after stretching, we used a scanning electron microscope to photograph the microstructure of the fiber layer at the fracture of the two laminates. Figure 10

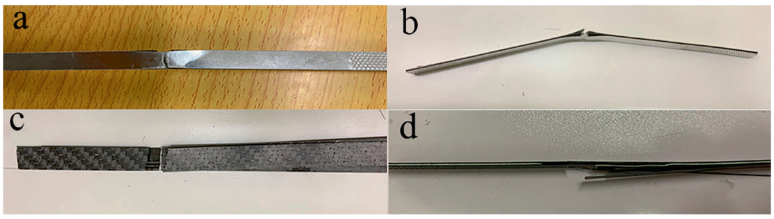

Figure 7: CARALL after tensile fracture: (a) (b) Al-CFRP-Al laminate; (c) (d) CFRP-Al-CFRP laminate.

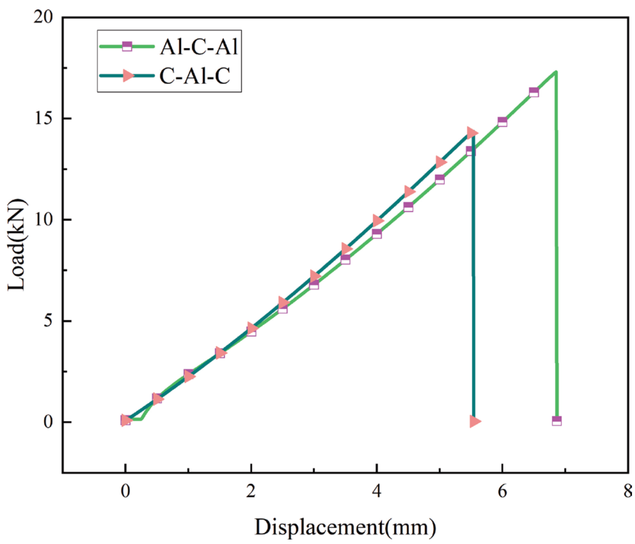

Figure 8: Tensile test load-displacement curve.

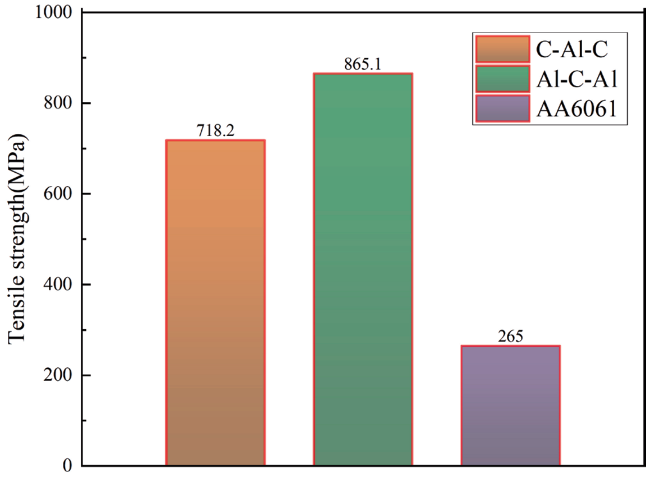

Figure 9: Comparison of tensile strength.

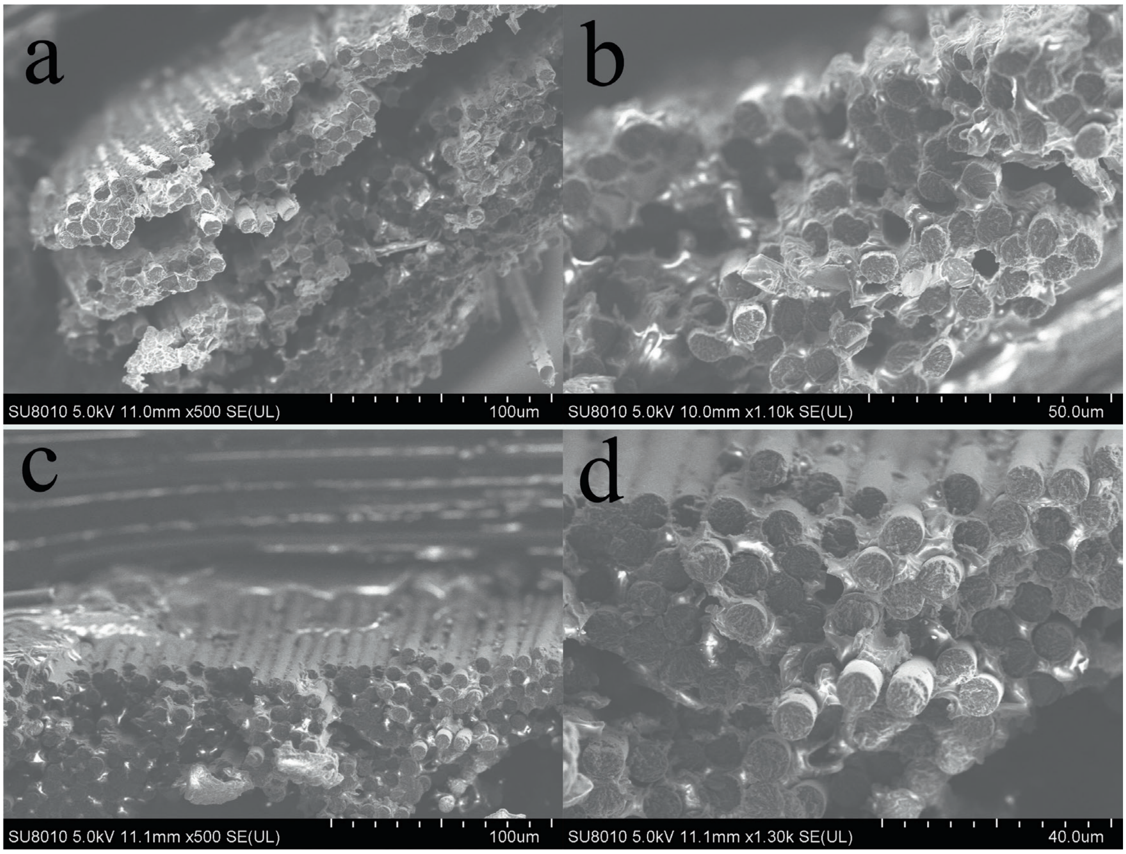

Figure 10: SEM photos of CARALL fracture fiber layer: (a) Al-CFRP-Al laminate magnified 500 times; (b) Al-CFRP-Al laminate magnified 1100 times; (c) CFRP-Al-CFRP laminate magnified 500 times; (d) CFRP-Al-CFRP laminate magnified 1300 times.

shows a SEM photo taken, where (a) (b) belongs to Al-CFRP-Al laminates, (c) (d) belongs to CFRP-Al-CFRP laminates. It can be seen from the diagram that the microstructure of the two laminates is similar after tensile fracture. During the tensile process, a large area of fiber bundles in the 0° direction were broken, and some fiber bundles were pulled out, which was the direct cause of CARALL failure. Due to the adhesion agent, there is no obvious dislocation and deformation of the fiber bundle during the stretching process.

3.3. Finite element simulation analysis

In order to verify the validity of the experiment and analyze the failure mode of CARALL, we used the finite element simulation software Abaqus to simulate the tensile experiment. The model diagram is shown in Figure 11. Because the failure modes are basically the same, we simulated the a-laminated plate with better performance. Firstly, according to the parameters of carbon fiber composites in Table 3, we established a geometric model. We assigned these material properties to the model and set the kinetic display analysis step. Thus, the load application state in the whole tensile test process was simulated.

It is found that the model generally breaks when the load reaches about 17kN, which is very close to the tensile test results. Figure 12 is the failure cloud diagram of finite element simulation. The failure cloud diagram results are also consistent with the experimental results. The aluminum alloy plate of CARALL shrinks and deforms under load, and finally breaks. On the contrary, the carbon fiber layer fails due to brittle fracture in an instant. The damage area of the carbon fiber layer is much larger than that of the aluminum alloy layer, which indicates that the carbon fiber layer plays a major role in the tensile process. The Abaqus model used the 2D Hashin criterion as the carbon fiber failure criterion, and there was no obvious mesh distortion at the fiber tensile fracture, which was consistent with the experimental fracture morphology and close to the actual results.

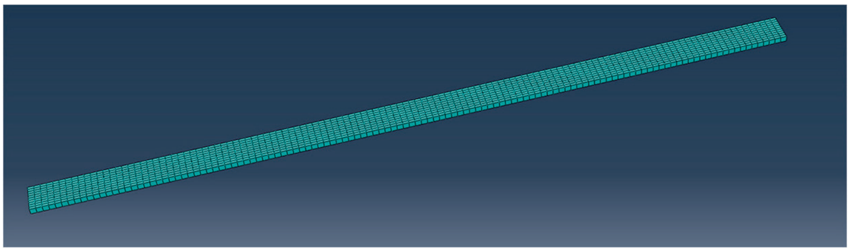

Figure 11: Geometric model of CARALLL specimen.

Table 3: Material parameters of carbon fiber composite.

PARAMETER TYPE	MATERIAL PARAMETER
Elastic modulus	E1 = 120000 MPa, E2 = E3 = 7800 MPa
Poisson ratio	v12 = v13 = v23 = 0.3v
Shear modulus	G12 = G23 = 4000 MPa, G23 = 3600 MPa
Density	ρ = 2000 kg/m^3
Ultimate strength	XT = 2250 MPa, XC =1520 MPa, YT = ZT = 50 MPa YC = ZC = 150 MPa, S12 = S13 = 93 MPa, S23 = 50 MPa
Fracture energy	$G_{11}^{T} = G_{11}^{c} = 40$ kJ/m^2, $G_{22}^{T} = 0.25$ kJ/m^2, $G_{22}^{c} = 0.75$ kJ/m^2

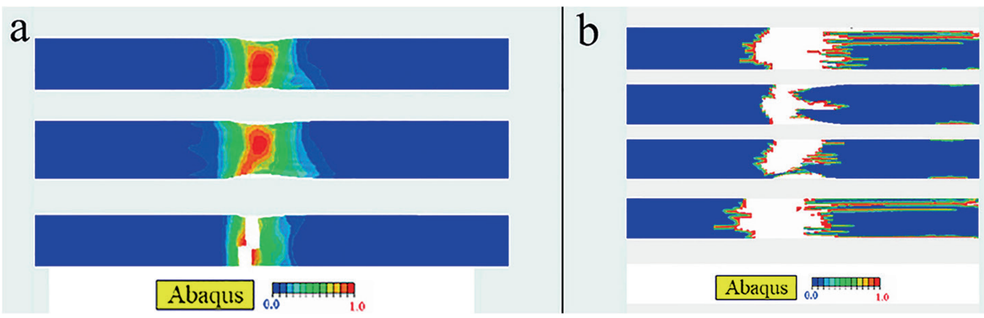

Figure 12: Finite element simulation failure cloud diagram: (a) failure cloud diagram of aluminum alloy plate; (b) Carbon fiber layer failure cloud diagram.

4. CONCLUSIONS

This study introduced the preparation and tensile test process of two kinds of CARALL. Then we observed the microstructure of the fracture position of the laminate with the help of scanning electron microscope. The rationality of the experimental data was verified by finite element simulation. And its failure behavior was further analyzed.

In general, the two kinds of CARALL prepared by molding process have greatly enhanced the tensile properties of aluminum alloy. The results of tensile test of CARALL showed that, which the tensile strength of Al-CFRP-Al CARALL can reach 865.1 MPa, and the tensile strength of CFRP-Al-CFRP CARALL can reach 718.2 MPa. The tensile strength of Al-CFRP-Al CARALL is 326.4% higher than that of AA6061, and the tensile strength of CFRP-Al-CFRP CARALL is 271.0% higher than that of AA6061.

By observing the microstructure of the fiber layer on the fracture surface of the laminate, it was found that the fiber bundle fractured brittlely during the tensile process. Because the height of 0 ° fiber bundle was in the same direction, the tensile properties of the material were greatly enhanced.

Overall, the finite element simulation results were consistent with the experimental results. The Abaqus model used the 2D Hashin criterion as the carbon fiber failure criterion, and there was no obvious mesh distortion at the fiber tensile fracture, which was consistent with the experimental fracture morphology and close to the actual results. By analyzing the failure cloud diagram, it was further confirmed that carbon fiber could effectively enhance the tensile properties of aluminum alloy.

Through this study, we have clarified that the use of carbon fiber composite materials to prepare laminates has a good reinforcing effect on the metal matrix in terms of tensile properties. This method can effectively achieve the material requirements of light weight and high strength. This study only introduces the preparation of CARALL by molding process to enhance the tensile properties of aluminum alloy. Through the idea of this research, we can also use this method to enhance the mechanical properties of materials such as titanium alloys to meet various application scenarios. It is believed that through the continuous innovation and research of researchers, CARALL will have better performance in the fields of aerospace, ship and automobile manufacturing.

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