Effect of anodic oxidation of 2024-T3 aluminum alloy on interface properties of metal fiber laminates

Zhiqiang Zhou [1], Changjiang Qian [2], Zonghao Hu [1], Feiyuan Yang [3], Meiduo Lou [4], Guangan Xie [2]

[1] Shenyang Aircraft Design Institute, Shenyang 110000, China
[2] College of Aerospace Engineering, Shenyang Aerospace University, Shenyang 110136, China
[3] Shenyang Tancho Industrial Co. LTD, Shenyang, 110041, China
[5] School of Electric Power, Shenyang Institute of Engineering, Shenyang 110136, China

Abstract: Interlaminar fracture failure is the main factor restricting the development and application of fiber metal laminates. In this paper, the interlayer bonding properties of 2024-T3 aluminum alloy plates with different surface treatments were compared and studied through lap-shear experiments. Compared with the aluminum plate treated with acid and alkali corrosion, the interlaminar shear strength of the aluminum plate after sulfuric acid anodization increased by 34.3%. After different surface treatments, experimental stress-strain curves of 2024-T3 aluminum alloys reveal the enhancement mechanism and changing trend of interlaminar shear strength.

Keywords: Metal fiber laminate; Surface treatment; Aluminum anodizing; lap-shear experiment.

1. Introduction

Metal fiber laminate is a new type of composite material formed by alternately bonding metal plates and fiber materials. Composite materials have the advantages of strong corrosion resistance, high specific strength, high specific modulus, light weight, non-magnetic, and good designability compared with traditional steel [1]. Although the many advantages of metal fiber laminate composites will make the design of auxiliary equipment in aerospace and other fields more abundant and diverse, but the unique directionality and layering of composite materials will also make their structural characteristics different from traditional metal structures [2]. Metal fiber laminates have a completely different damage form from general isotropic metal materials due to the high anisotropy of each ply, the bonding method between component materials, and the bonding method between plies and plies. Damage can occur within a ply or between two plies called intra-laminar and inter-laminar. Interlaminar damage generally refers to delamination damage. The bonding performance between the layers of composite laminates is not enhanced so delamination damage can occur under lower loads, and the stiffness, strength and stability of the structure will be reduced. Delamination damage is one of the most easily accumulated damage forms in composite materials, and severe delamination damage can directly lead to the overall failure of the structure. Therefore, the study of delamination damage is one of the most popular topics in composite damage mechanics. The occurrence and expansion of delamination mean the degradation of the interlayer performance of adjacent materials and the interlayer delamination significantly reduces the structural integrity, which will lead to a significant reduction in the structural strength and stiffness of the composite laminates, which seriously restricts the application in spacecraft structure. There are many reasons for the delamination failure of metal fiber laminates, including delamination caused by defects in the manufacturing process, cracks in the matrix during impact, etc. [3]. Mohammad Ahsin Muflikun investigated the stress-strain failure mode behavior, and mechanical properties of carbon fiber reinforced plastic-steel cold commercial (CFRP-SPCC) hybrid thin laminates through axial tensile and bending tests. The tensile test results show that premature failure of CFRP laminates can be delayed by up to 58.5% by adding SPCC to hybrid laminates[4]. Miguel Angel Caminello conducted tensile and three-point bending tests to study the different behavior of composites in tension and compression to evaluate their effect on failure modes and to determine the strength of different CFRP laminates and mechanical responses of stiffness[5]. Pagano and Piper combined the interlaminar stress analysis and experiment to propose the maximum tensile interlaminar normal stress criterion for resin matrix composites [6,7]. Dong Lei studied the effect of anodizing on the bonding properties of 6061 aluminum alloy and peeked through lap shear experiments [8]. V. FioreF. Di Franco studied the effect of anodizing surface treatment on the mechanical strength of 5083 aluminum alloy on fiber reinforced composite bonded joints[9]. In this paper, the surface of 2024-T3 aluminum alloy was corroded with sodium hydroxide solution and hydrochloric acid solution for 2 minutes, respectively, and anodized in the sulfuric acid solution for 15 minutes. The maximum interlaminar shear strength of the acid-base corrosion aluminum plate is 5.86MPa, and the maximum interlaminar shear strength of the hydrochloric acid anodized aluminum plate is 7.87MPa, which is 34.3% higher than that of the acid-base corrosion specimen.

2. Materials and Experimental Procedures

2.1 Materials

In this experiment, the main materials are aluminum alloy plate, glass fiber and epoxy resin. The metal material is 2024-T3 magnesium-aluminium alloy, and the fiber layer is the EW100 glass fiber woven material which is 0.11 mm thick, produced by Shanghai Yaohong Glass Fiber Co. Ltd. China. The matrix material is epoxy resin produced by Ciba Geigy in Australia, and the curing agent is Jeffamine D230 produced by Huntsman in the United States.

2.2 Material Pretreatment and Forming

First, put the 120*25mm 2024-T3 aluminum alloy sheet into acetone for ultrasonic degreasing for 2 minutes, then rinse with deionized water and dry it for later use. Take a part of the aluminum sheets and put them into the 5wt% NaOH solution for corrosion for 2 minutes, rinse them with deionized water after taking them out, dry them and put them in the 11 wt% HCL solution and rinse them with deionized water after taking them out and wipe them dry. Take the remaining aluminum sheets as the cathode and the graphite plate as the anode, put them into a 180g/L H2SO4 solution and connect to the DC power supply, and the power parameters are adjusted to 15V and 2A/dm2. Take them out after 20 minutes of power on and rinse them with deionized water and wipe them dry. During the anodization process, the circulating flow rate of the oxidation bath directly affects the temperature uniformity in the bath. Whether the anodized thick film on all aluminum workpieces in the whole anodization bath is uniform depends to a large extent on the inside of the bath. temperature is uniform[10]. Usually, the bath temperature is controlled within ±2°C for ordinary anodizing requirements; and the bath temperature is controlled within ±1°C for hard anodizing requirements.

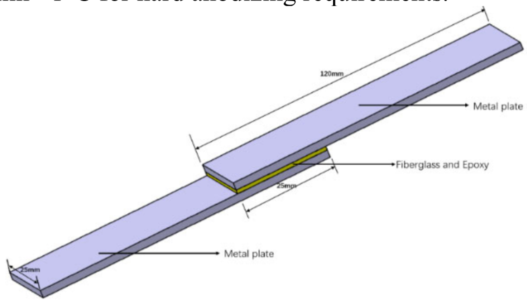


Figure 1 Schematic diagram of bonding

Then, cutting the glass fiber in 25*25mm as the bonding intermediate layer,and mixing the epoxy resin and D230 curing agent in a ratio of 3.3/1. Stiring that evenly and vacuuming to remove air bubbles as the adhesive. According to ASTM D5868-01, the surface-treated aluminum alloy sheets are bonded with epoxy resin according to the bonding area of 25*25mm, and the bonding area of the two aluminum alloy sheets is sandwiched with a layer of glass fiber to simulate the interlayer of the metal fiber laminate. After applying adhesive, fix it with dovetail clips and put it in an oven at 120°C for 2 hours to cure. The sample after bonding is shown in Figure 1.

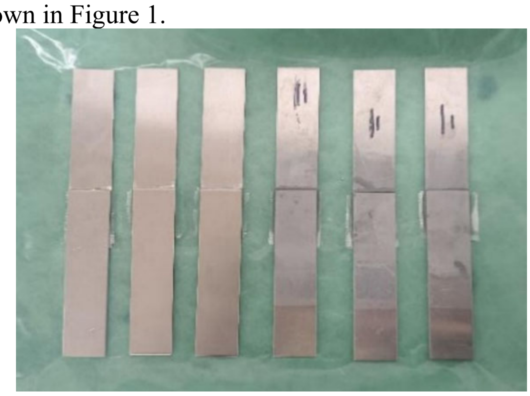


Figure 2 Samples after bonding

2.3 Experiment and performance test

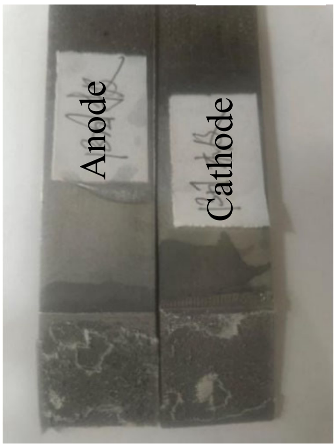
According to ASTM D5868-01, the lap-shear experiment can measure the maximum interlaminar shear strength of the laminate. The samples shown in Figure 2. Each surface treatment sample was tested at a tensile speed of 2 mm/min. The lap-shear experiment is shown in Figure 3. The lap-shear experiment is repeated at least three times, and the maximum tensile stress obtained in the test divided by the bonding area is the maximum interlaminar shear strength of the sample.

Figure 3 The lap-shear expriment

3. Results and Discussion

The cross-section of the sample after stretching is shown in Figure 4. Figure a is the acid-base corrosion sample, and Figure b is the anodized sample. It can be seen from the figure that the cross-section of the acid-base treated sample fails with the degumming of glass fiber and aluminum plate. The main failure mode of the anodized samples is tearing the glass fiber in the middle layer. The maximum interlaminar shear strength of the acid-base corrosion sample measured in the experiment is 5.86MPa, while the maximum interlaminar shear strength of the sulfuric acid anodized sample is 7.87MPa. The maximum shear strength of the anodized sample increased by 34.3% compared with the acid-base corrosion sample, and the stress-strain curve of the lap-shear experiment is shown in Figure 5.

It can be concluded that the interlayer mechanical properties of the 2024-T3 aluminum alloy after sulfuric acid anodizing treatment are significantly improved compared with that of acid-base corrosion, according to the experimental data, because sulfuric acid anodizing can generate a diameter of about 12 nm and a pore wall thickness of 12 nm on the surface of the aluminum alloy. The 0.8nm/V dense oxide film layer has a smaller and denser pore size than the oxide film produced by the acid-base etching process, and it combines firmly with the metal matrix and provides more adhesion area for the adhesive. Therefore, the experiment can withstand more tremendous interlaminar shear stress.



a. Acid-base corrosion

b. Anodizing

Figure 4 Section of the specimen after stretching

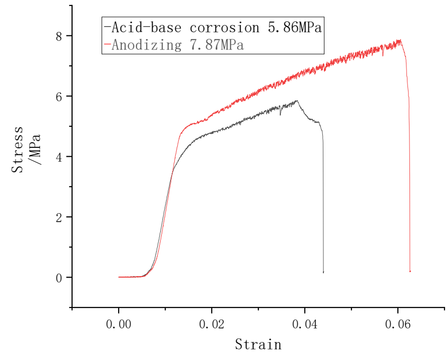


Figure 5 Stress-strain curve of lap-shear experiment

4. Conclusion

The bonding fracture mode can be divided into cohesive failure inside the adhesive layer and interface failure between the adhesive layer and the adherend. Competition relationship. When the cohesive strength is higher than the interface strength, interfacial failure occurs; when the cohesive strength is lower than the interface strength, cohesive failure occurs[11]. The fracture force for cohesive failure is usually higher than for interfacial failure. Therefore, the surface treatment state is essential to obtain a good bonding effect.

This paper mainly studies the effect of 2024-T3 aluminum alloy on the interlaminar mechanical properties of metal fiber laminates after acid-base corrosion and sulfuric acid anodization. Dense, the interlaminar mechanical properties of the metal fiber laminates are greatly improved. The maximum interlaminar shear strength of this group of samples reaches 7.87MPa, which is 34.3% higher than that of the acid-base corrosion samples. Compared with the traditional acid-base corrosion pretreatment method, sulfuric acid anodizing can significantly improve the common delamination phenomenon of metal fiber laminates. To sum up, the anodizing treatment of the inner side of the metal layer of the metal fiber laminate can significantly improve the interlaminar mechanical properties of the laminate, and the anodizing treatment can also be used for the anti-corrosion process on the outside of the metal layer. The overall mechanical properties and reliability of the parts are helpful.

Acknowledgments

This work was financially supported by the Key Research and Development program of the Ministry of Science and Technology of China (2017YFB1104001), Aeronautical Science Foundation of China (2020Z055054002)

References

1. Xiao-yan Huang, Liu Yuan, Liu Bo. Application of composite materials on ships [J]. Jiangsu Ships, 2008(02):13-17. (in Chinese)

2. WU Kai. Structural Analysis and Optimal Design of Composite Laminates [D]. Dalian University of Technology, 2019. (in Chinese)
3. ZHANG Xia. Research on fatigue delamination expansion of composite laminates with fastening [D]. Nanjing University of Aeronautics and Astronautics, 2019. (in Chinese)
4. Muhammad Akhsin Muflikhun,Ryo Higuchi, Tomohiro Yokozeki,Takahira Aoki. The evaluation of failure mode behavior of CFRP/Adhesive/SPCC hybrid thin laminates under axial and flexural loading for structural applications[J]. Composites Part B, 2020,185(C).
5. Miguel Angel Caminero, Gloria Patricia RodrAguez, Jesus Miguel ChacAn, Irene GarcAaaMoreno. Tensile and flexural damage response of symmetric angleaply carbon fiberareinforced epoxy laminates: Nonalinear response and effects of thickness and plyastacking sequence[J]. Polymer Composites, 2019,40(9).
6. Pagano N.J, Pipes R. B. The Influence of stacking sequence on laminate strength [J]. Journalof composite materials, 1971, 5:50-57.
7. Pagano N.J, Pipes R. B. Some Observations on the Interlaminar Strength of CompositeLaminates [J].International journal of mechanical Sciences, 1973, 15(8):679-686.
8. Lei Dong. Effect of anodizing surface morphology on the adhesion performance of 6061 aluminum alloy [J]. International Journal of Adhesion and Adhesives, Volume 113, 2022.
9. V. Fiore. Effects of anodizing surface treatment on the mechanical strength of aluminum alloy 5083 to fibre reinforced composites adhesive joints [J]. International Journal of Adhesion and Adhesives,Volume 108, 2021,
10. Yun-fang Huang. Aluminum anodic oxidation thick film process and control of main influencing factors[J]. Guangzhou Chemical Industry, 2021, 49(12):154-156.
11. Ying-dong Li. Effect of Anodizing Treatment on Bonding Properties of 5754 Aluminum Alloy Sheet[J]. Processing Technology of Light Alloy, 2021,49(08):39-43.