MECHANICAL BEHAVIOR OF THE INTERFACE IN THE INDUSTRIAL JOINING OF CFRP – METAL HYBRID STRUCTURES

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ABSTRACT

Adhesive-based joining methods are widely used for metal-composite hybrid structures in the defense and aerospace sectors to meet the demands for lightweight and high strength. This study investigated the bonding of AA7075-T6 alloy aluminum plate to carbon fiber-reinforced epoxy matrix composite (CFRP) plates using adhesive film, and the effects of different surface preparation processes on the interfacial bond strength. Various mechanical and chemical surface preparation processes, such as glass-sand blasting, anodizing, and cross-marking, were applied to the surfaces of the aluminum plates. The CFRP plates were prepared to dimensions in accordance with the ASTM D1002 standard and then bonded to the aluminum plates with an epoxy-based adhesive film. Shear tests were applied to the prepared samples. Precision cutting was then performed for metallographic examination, and the samples were embedded in Bakelite. Optical microscope analyses were performed. The results showed that glass-sand blasting and anodizing provided significantly higher shear strength at the AA7075-T6/CFRP joint interface compared to other surface preparation methods. However, a significant decrease in bond strength was observed on cross-ribbed surfaces. The study demonstrates that AA7075-T6 alloy can be used effectively in high-performance hybrid bonds with CFRP structures with appropriate surface preparation methods.

Keywords: CFRP, AA7075-T6 , Adhesive, Surface Treatments, Shear Strength

1. INTRODUCTION

The use of lightweight materials with high specific strength has been increasing since the 1940s to increase energy efficiency and maximize performance in the aerospace, defense, and automotive industries. Advances in composite material technology, particularly in recent years, have expanded the use of polymer matrix composites (CFRP) in structural elements. However, in industrial applications, it is not always possible for a single material group to meet all design requirements such as ductility, toughness and impact resistance. Therefore, the design of "hybrid structures", which combine the ductility and toughness of metals with the lightweight and high strength properties of composites, plays a critical role in engineering [1-3].

The biggest challenge in the production of hybrid structures is the reliable joining of these materials (metal-composite), which have completely different physical and chemical properties. Conventional mechanical joining methods (riveting, bolting) cause stress concentrations, fiber ruptures, and increased weight in composite structures, while welding methods have limited applicability due to material incompatibilities [4-7]. Adhesive bonding, in this context, stands out as a strong alternative to mechanical joining because it allows materials with different properties to be joined, provides uniform stress distribution, increases corrosion resistance, and provides lightweight construction. [8-12].

The mechanical behavior and durability of adhesive joints depend largely on the interface properties between the surfaces joined by the adhesive. Failure mechanisms that can occur at the interface can occur as adhesive, cohesive, or mixed failure. The joint areas are subjected to various types of stresses, such as tension, compression, shear, separation, and peeling. Figure 1 illustrates the different types of loads that can occur on the adhesive joints. These joints can support each of the specified loads individually or can withstand the combined application of multiple loads [13, 14]. Especially in the joining of aerospace-grade aluminum alloys such as AA7075-T6 with CFRP, the structure of the natural oxide layer on the aluminum surface and surface roughness are factors that directly affect bond strength. Studies in the literature on the problems encountered in determining the mechanical properties of adhesives and ensuring reproducibility emphasize the critical importance of surface preparation processes [15]. Various mechanical and chemical treatments such as sandblasting, acid etching, and anodizing are applied to increase the surface energy and ensure mechanical locking [16].



Figure 1. Different types of loads in the area of the adhesively bonded sections [10]

Öztürk [17], in their study on AA7075-T6 aluminum alloys, investigated the effects of surface roughness and surface free energy on bond strength and reported that hybrid etching methods increased strength. Similarly, Çakır and Kınay [18] investigated the effects of surface treatment and overlap length on mechanical properties in joining aluminum and glass fiber composites. However, comparative studies on the effects of different surface treatments (especially combinations of anodizing and sandblasting) on interfacial shear strength in AA7075-T6 and CFRP hybrid structures, particularly in industrial applications, using "film adhesives" to stabilize adhesive thickness, are rarely found in literature.

This study addresses the bonding of AA7075-T6 aluminum alloy, widely used in the aerospace and defense industries, with Carbon Fiber Reinforced Polymer (CFRP) composite plates using an epoxy-based structural film adhesive. Three different surface treatments were applied to the aluminum surfaces: mechanical abrasion (cross-hatchting/Al-Cross), silica sand blasting (Al-Sandb), and glass sand blasting followed by anodizing (Al-Coating). Lap-shear tests were applied to the produced hybrid samples in accordance with ASTM D1002, and the mechanical behavior of the interface was investigated.

2. MATERIAL AND METHOD

2.1. Materials

In this research, hybrid structures formed by the joining of aluminum alloy (AA7075-T6) and CFRP materials via a Solvay MTA 240 epoxy-matrix adhesive were analyzed.

2.1.1. Aluminum plate (AA7075-T6)

This study aimed to improve the bonding performance of 7075 aluminum alloy, a frequently used material in the aerospace industry. Three different surface configurations were tested on aluminum specimens measuring 100x25x3 mm to optimize bond strength with the CFRP structure. Three specimens were used for each process type.

2.1.2. Pre-preg carbon fabric

The fabric plies were oriented in a balanced, symmetrical pattern. A total of 10 fabric layers were used to create a 2.7 mm thick sheet. The layer orientations were laid at 0°/45°/90°/-45°/0°/0°/-45°/90°/45°/0°. During the laydown, a vacuum was applied every other layer and held under vacuum for 5 minutes. Twill weaving was preferred because the composite provides equal strength in all directions.

2.1.3. Adhesive film

Epoxy-based Solvay MTA 240 Adhesive Film (MTA240/PK13-313g/m²) was used to bond the metal and composite. This adhesive was selected because it is suitable for use on both metal and composite surfaces and its pre-impregnated film structure ensures that the adhesive amount can be applied equally to all specimens during bonding.

2.2. Bonding Operation

Surface preparation is the most critical element in bonding processes, followed by curing procedures. This study aimed to create a bond between epoxy resin-based carbon fiber-reinforced composite panels and metal materials using an adhesive film containing an epoxy resin matrix. To achieve this goal, various pretreatments were applied to metal surfaces, and the effects of these treatments on bonding performance were investigated. The bonded areas of the composite panels were subjected to a surface abrasion treatment, measuring 12.5x25 mm and then all specimens were cleaned with alcohol. The areas outside the bonding area were covered with high-temperature-resistant masking tape. After the cleaning process was completed, the specimens were then bonded using the adhesive film. Figure 2 shows the bonded plates.



Figure 2. Joined composite-metal plates

2.3. Shear Test

The universal testing machine Instron 8503 (500 kN) was used in the tests. The tensile speed was 1.3 mm/min, as specified in the ASTM D1002 standard. The highest results for aluminum specimens after the shear test were observed in samples treated with glass sandblasting and anodizing (Al-Coating), while the lowest strength values were recorded for the specimens featuring cross-hatching patterns (Al-Cross). The resulting interfaces after the lap-shear tests are displayed in Figures 3a and 3b**.**

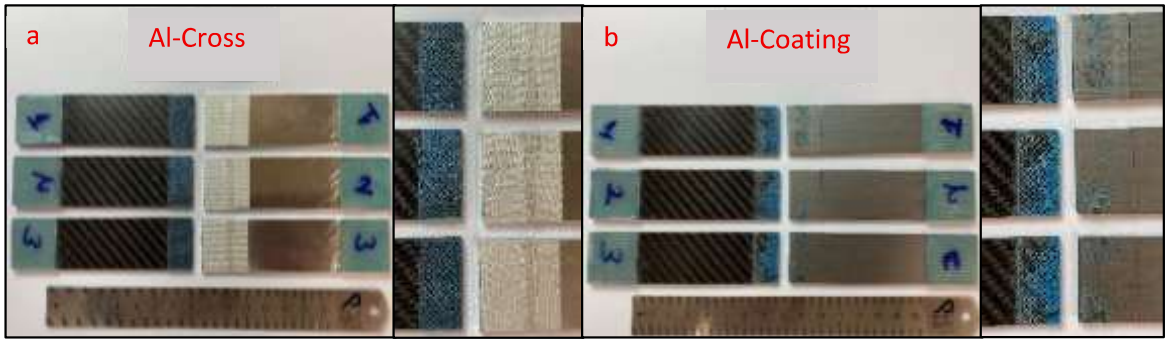


Figure 3. Visual representation of the AA7075-CFRP specimen following the shear test **a)** Al-Cross **b)** Al-Coating

2.4. Characterization

For metallographic examinations, the specimens were embedded in bakelite and subsequently subjected to grinding and polishing procedures. On the prepared specimens, investigations of the interfacial bond formed between the composite and the metal after the shear test were conducted. For these investigations, the 10x15 mm bakelite-mounted specimens were examined using an inverted optical microscope.

3. EXPERIMENTAL RESULTS

Inverted microscope images illustrating the interfacial bond between the residual adhesive and the metallic surface, following the lap-shear test of the Aluminum/CFRP specimens, are presented in Figures 4a, 4b, and 4c. In these images, the regions colored black represent the CFRP, the white regions correspond to the aluminum, and the intermediate, relatively gray regions belong to the adhesive.

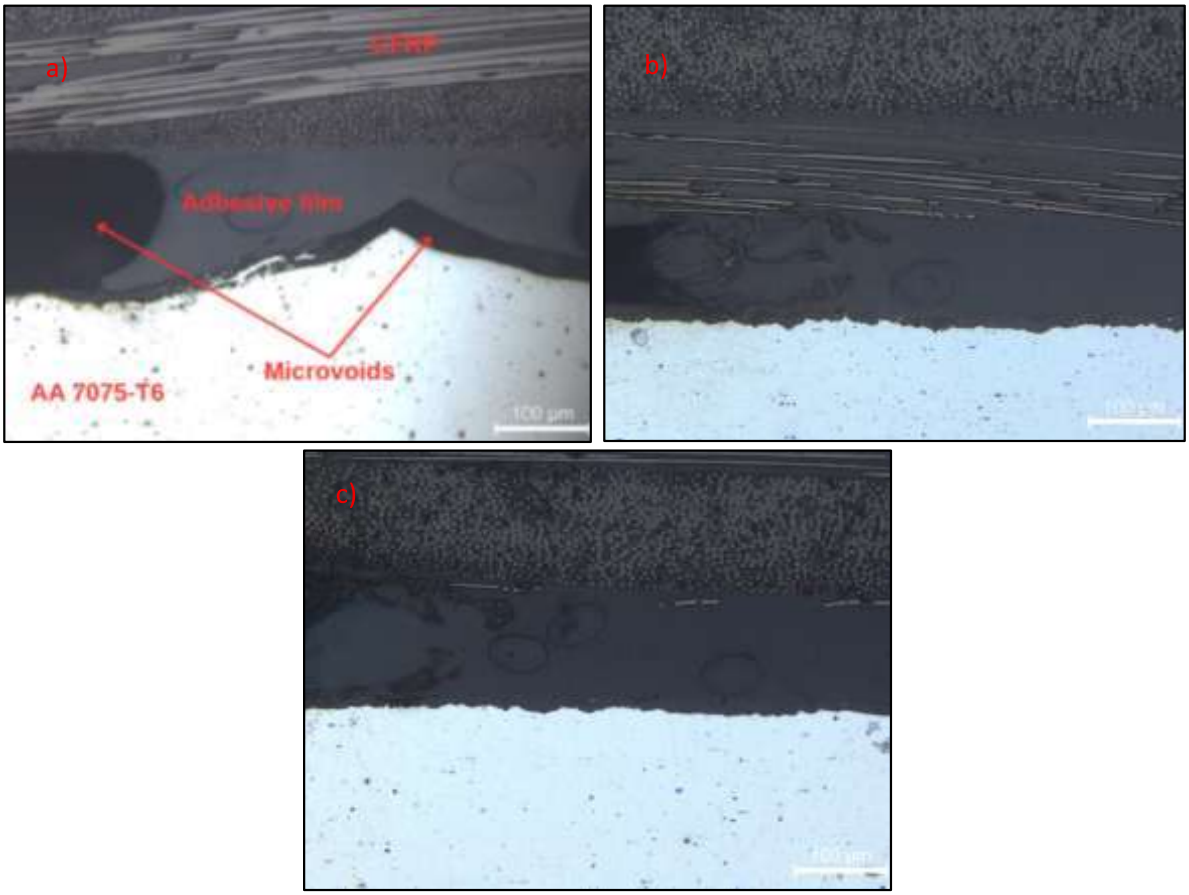


Figure 4. a) Cross-hatching patterns (Al-Cross) **b)** Sandblasting with silica sand (Al-Sandb) **c)** glass-blasting combined with anodization (Al-Coating)

In the AA 7075 specimen where cross-hatching patterns were created, regions featuring deep indentations and protrusions, burrs, and notches (or cracks) are observed on the metallic material, resulting from the material removal process during the formation of these patterns. Especially, this morphology suggests that the deformed adhesive film lacked sufficient thickness, and consequently enough volume, to effectively fill the deep recesses located particularly at the peak regions of these marks. This condition resulted in excessive micro-voids and adhesion deficiencies. Furthermore, it was observed that the adhesive was completely absent in some regions, while residual adhesive was only located within the recessed areas, accompanied by voids (Figure 4a). The very low level of adhesive presence at the end sections of the resulting traces is clearly reflected in the shear test results given in Figure 5. The cross-geometric roughness can cause stress concentrations, making it difficult for the adhesive to fully wettability or mechanically lock onto the surface.

The Al-Sandb sample exhibited a much rougher surface than the other samples. High surface roughness accompanies plastic deformation of the matrix, resulting in greater fracture energy consumption. Several areas of voids are observed between the samples and the adhesive (Figure 4b).

In this study, the adhesion strengths, the interfacial bonds between the materials, and the effects of mechanical and chemical abrasion surface treatments on the adhesion strength of the specimens were investigated. The lap-shear test graph for the specimens is provided in Figure 5. As observed, the highest strength value among the specimens was recorded for the Al-Coating specimen, which underwent glass-blasting combined with anodization, at 15.77 MPa,

while the lowest strength value of 7.30 MPa was found in the Al-Cross specimen featuring cross-hatching patterns.

In the sample, which called Al-Coating, the surface roughness profile was observed to be more stable and contain fewer pits than the Al-Sandb sample. The depth of the roughened area was observed to be greater compared to the other samples. It was also observed that the adhesive thickness and density were more dense between the two materials (Figure 4c). This indicates that the interfacial bond between the samples will be strong. It is believed that increasing the surface roughness and creating traces in different directions will be beneficial in future studies.

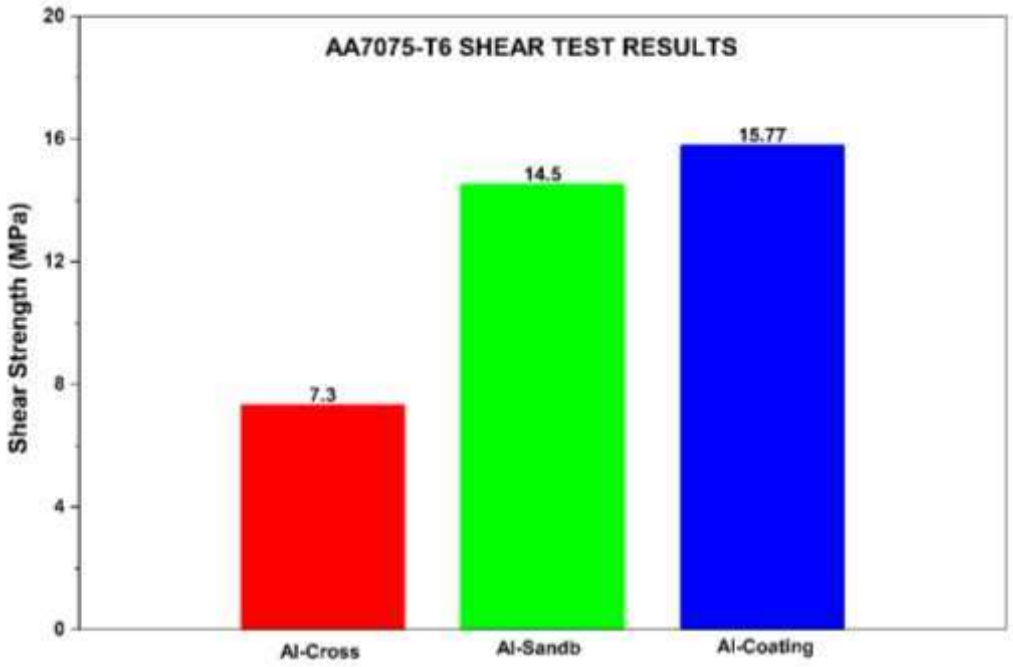


Figure 5. Effect of metal surface treatments on joint shear strength

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