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ANALYSIS AND IMPROVEMENT OF THE STRUCTURAL REPAIR PROCESS IN COMPOSITE PANELS

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Abstract. *Repairs to the 7075-T6 aluminum alloy composite structure of the aircraft flap trailling edge undergoing detachments at airlines around the world. Some particular factors of this structure intensify the probability of a detachment in the region - a high temperature of operation of the component, low quality repairs caused by human factors and the application of an inefficient surface preparation method. The purpose of this study is to list which method of surface preparation is the most suitable for repairs to the component, in order to increase the durability of repairs in the region. Tensile tests were carried out, standardized by the ASTM D 1002 standard, with the aim of comparing the maximum rupture force and the type of proof failure treated using Alodine 1200 and Boegel compounds, with or without the application of a bonding primer. After these tests, the final conclusion is the effectiveness of the treatment using the Boegel compound without applying the bonding primer. This method has greater efficiency among those tested and greater dimensions of adhesion related to cohesive type fractures.*

Keywords: *composites, adhesive, adhesion, SLJ, surface treatment.*

1. INTRODUCTION

The adhesion properties between the layers of composite materials directly depend on the surface preparation conditions. Bearing in mind that variations occur during the production process, mainly due to human factors, it is widely beneficial to analyze and classify how different manufacturing methods interfere with the mechanical properties of these materials.

High temperature is an important aspect to be taken into consideration when it comes to the adhesion strength of a collage, as we often encounter parts of the aircraft that have a high service temperature, for example, the engine exhaust outlet .

The cost of an AOG for an airline will depend on its type of operation, which can be expensive. For example, a company that had an aircraft prevented from flying due to a mechanical problem during the period of one day, had an estimated loss of approximately US 221,020.00 with a stop of this aircraft, Ghelli (2017). That said, it is of utmost importance the continuous process of improvement in repairs regarding composite materials in aircraft, since a poor repair can be the reason for an unscheduled stoppage of an airplane, thus causing damage to millionaires like those already above.

A Brazilian Airline had, from June 2018 to November 2020, a total of 10 AOG incidents, confirmed by its maintenance, caused by the detachment of flap trailling edge wedge sandwich panels, which caused an average of two days of stoppage for each aircraft.

The objective of this study was to verify which method of surface preparation will lead to a longer repair time for flap trailling edge wedge, in order to increase the durability of repairs in the region. Comparing specimens treated with Alodine 1200 and Boegel compounds, with or without the application of a bonding primer.

Therefore, they were evaluated as metal-metal of aluminum alloy 7075-T6, which is a type of material widely used in commercial aviation. The manufacture of the specimens follows the ASTM D 1002 standard, which regulates the apparent shear strength test of metal specimens bonded with a tension load label.

2. Theoretical foundation

The integrity of a structure can be determined by joint strength, surface preparation has a great importance in the adhesion strength of a component, Correia *et al.* (2018). The purpose of applying a surface treatment is to provide the best possible glue condition for the surfaces to be joined.

According to the studies of Azar (1982) and Niu (2006), the properties of resistance to shear forces in sandwich panels decreases as the thickness of the panel decreases, which causes detachment preferably in areas where there is less

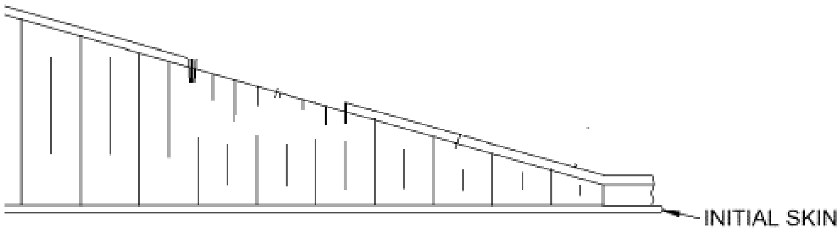

Figure 1. Structure of Flap Trailling Edge Wedge

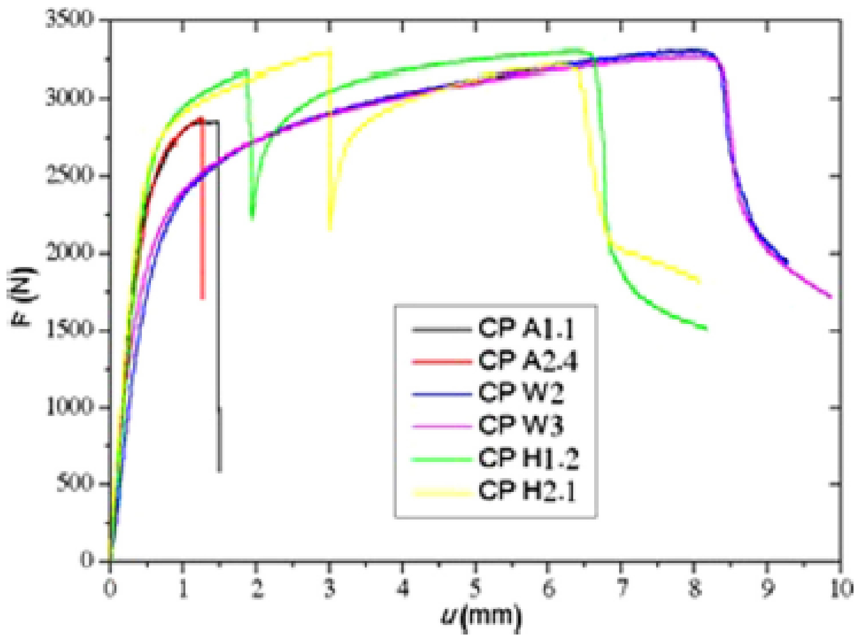

Figure 2. Force x Displacement Chart Font: Costa *et al.* (2015)

thickness. In the case of the aircraft flap, this point is on the trailing edge.

Another aspect that can interfere with the adhesive strength of sandwich panels is the presence of water, which causes a degradation of the adhesive according to Whitehead *et al.* (2000) and can also generate corrosion within the structure, Quartiermeister *et al.* (2017).

In addition, exposure to high temperatures can cause the adhesive to reach its glass transition temperature, Fogaça (2015), which is characterized as the temperature at which an amorphous polymer becomes hard and brittle (glassy state) and above of which the same polymer is soft ("rubbery" state), Reis *et al.* (2012). In experimental terms, it is the heating temperature of the material from which it becomes a viscous liquid and flows. For this reason, it is essential to know the glass transition temperature when you want to select an amorphous polymer for a given application, Mittal (1977),Anes *et al.* (2016).

The most relevant factor in the life of a repair in the Flap Trailling Edge Wedge, Figure 1, it is the operating temperature, as it is in the way of the outlet of the nozzle flow motor. Since the component in question cannot change this operating temperature, it is largely beneficial to evaluate how the method of surface preparation used during the execution of the repair interferes with the adhesion strength of the structure. In addition to preventing water from entering the Flap Trailling Edge Wedge.

In the study by the authors use the ASTM D 1002 standard to compare the mechanical properties of welded, glued and hybridized joints (welded and glued), Costa *et al.* (2015). The author in question used steel specimens manufactured in accordance with the ASTM D 1002 standard with the Syntho-Subsea LV Epoxy adhesive. Where through the tensile test performed it was possible to reach curves, as shown in Figure 2, which relate Force and deformation for each of the cases, being (W) for welded joints, (A) for glued and (H) for the hybrids.

The conclusion is that hybrid joints have better shear strength characteristics when compared to the other two types. Although the joining of the plates in a hybrid joint of this type undergoes thermal effects that can weaken the adhesion force of the adhesive. In addition, the author cites the fact that the thickness of the adhesive is very important for the joint to have greater resistance to efforts.

3. Methodology

An aluminum alloy 7075-T6 of the type BARE with a thickness of 1.6.mm was used. To prepare the surface of the aluminum plate, five methods were used. In the first method, the bonding process was carried out between two 7075 aluminum alloy sheets that did not undergo any type of surface preparation for bonding, only abrasion of an aluminum oxide sandpaper with 120 granulation. The second method consisted of a surface preparation with the compound Alodine 1200. The third method of surface preparation used the material BOEGEL (AC130), which is a type of complex inorganic polymer in the sol-gel family of chemical compounds. In the fourth and fifth preparation methods, it was used together with the compounds Boegel and Alodine 1200, a bonding primer BMS10-79 TYPE III, which is the identification primer indicated by the manufacturer for applications in conjunction with the compound Alodine.

To cure the adhesive, a machine approved for aeronautical use, of the Hot-Bond type, from serial number 13861452 was used to control the cure temperature of the adhesive.

The adhesive film used was that of Part Number BMS5-101 Type II which is described in SRM as suitable for the situation, where the curing temperature is 250ºC.

Due to limitations in the amount of adhesive film and aluminum foil raw material, only three samples were manufactured with each bonding process. Therefore, in order to ascertain the integrity of the plate and the adhesive film, a non-destructive ultrasound pulse echo test was performed. For the non-destructive ultrasound test, an electronic ultrasound equipment of Part Number USMGO from the manufacturer GE was used. Two transducers from the manufacturer Aerofab were also used, operating at a frequency of 1MHz to 50MHz, in addition to a reference standard that simulates the situation of two glued plates.

For the shear test of glued joints, a traction machine belonging to the Federal University of Minas Gerais model AG-IS from the manufacturer Shimadzu with a 100 KN load cell was used.

At the end of the bonding process, 3 specimens were manufactured for each type of surface preparation, the specimens were shown in Table 1.

Table 1. Proof bodies

Specimen number	Types of surface preparation
CP1, CP2, CP3	Without Treatment
CP4, CP5, CP6	Alodine 1200 Treatment
CP7, CP8, CP9	Alodine 1200 + Bonding Primer Treatment
CP10, CP11, CP12	Boegel treatment
CP13, CP14, CP15	Boegel + Bonding Primer Treatment

The standard for mechanical testing used was ASTM D 1002, which consists of a standard test method for resistance to apparent shear of adhesive from metal joints through tensile load.

For the test in question, the recommendation in the standard was followed. The samples were positioned in the claws of the machine so that 25 mm of the sample are in contact with the grips of the test equipment. Always ensuring that the long axis of the sample matches the uniaxial tension applied by the machine. A load was applied at a speed of 1.3 mm/s, continuing the load until failure. Test records are in Figure 3.

4. Results and discussions

In view of the importance of using the appropriate surface preparation method in the durability of a bonded repair, tests were then carried out to compare these methods.

The Force x Displacement curves for the shear stress of all surface preparation condition are shown in Figure 4. From the analysis of the curves of Figure 4 corresponding to the specimens 1, 2 and 3 that had their surface prepared only by sanding it, it is possible to notice that these samples obtained an average value for the force maximum burst value of 4077.92 N.

When we analyze the curves of Figure 4, corresponding to specimens 4, 5 and 6, that had their surface preparade with Boegel, it is possible to notice that the average for the maximum breaking force was 3065.63 N. For the analysis of the image curves 4, which correspond to the specimens 7, 8 and 9, that had their surface preparade with Boegel, it is possible to notice that the average of the maximum breaking force of the joint was 1656.46 N.

When we analyzed the average breaking force for bodies 10, 11 and 12 in Figure 4 that had a surface preparation of the type Boegel + Primer, it is possible to see that it was 2508.54 N. Finally, when we do the analysis for joints prepared

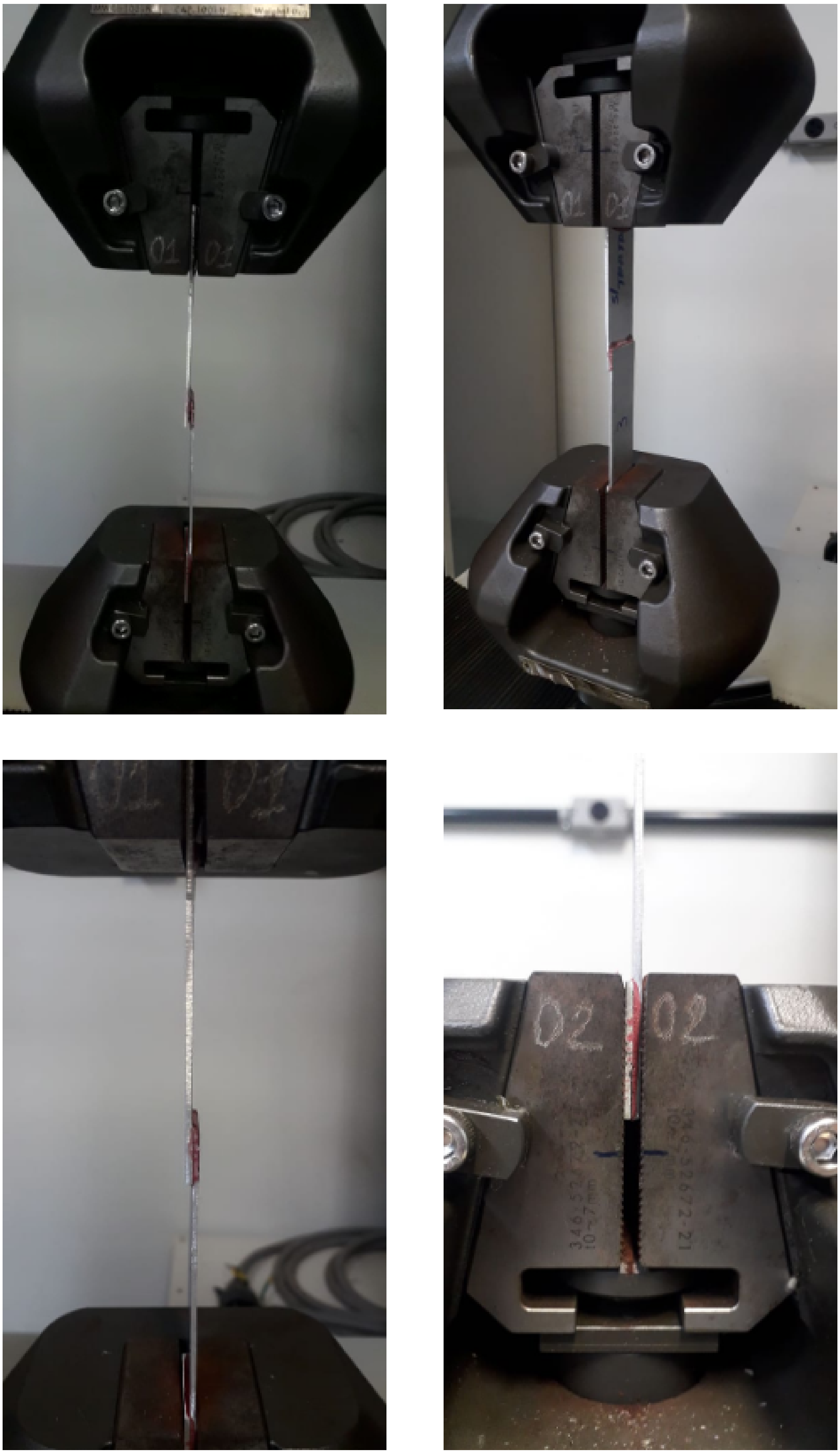

Figure 3. Mechanical test

with Alodine + Primer, which correspond to bodies 13, 14 and 15 arranged in Figure 4, we observed that the mean joint breaking force was 2257.50 N .

When we analyze Figure 4 and Table 3, it is possible to observe the projection of the curves, the mean breaking force

Table 2. Proof bodies

Type of surface preparation	Maximum Breaking Force (N)	Standard Deviation (N)
No Treatment	4077.92	1461.13
Alodine 1200 treatment	1656.46	417.65
Alodine 1200 Treatment + Bonding Primer	2257.50	191.81
Boegel treatment	3065.63	170.93
Boegel Treatment + Bonding Primer	2508.54	596.58

and the standard deviation for each of the surface preparation methods.

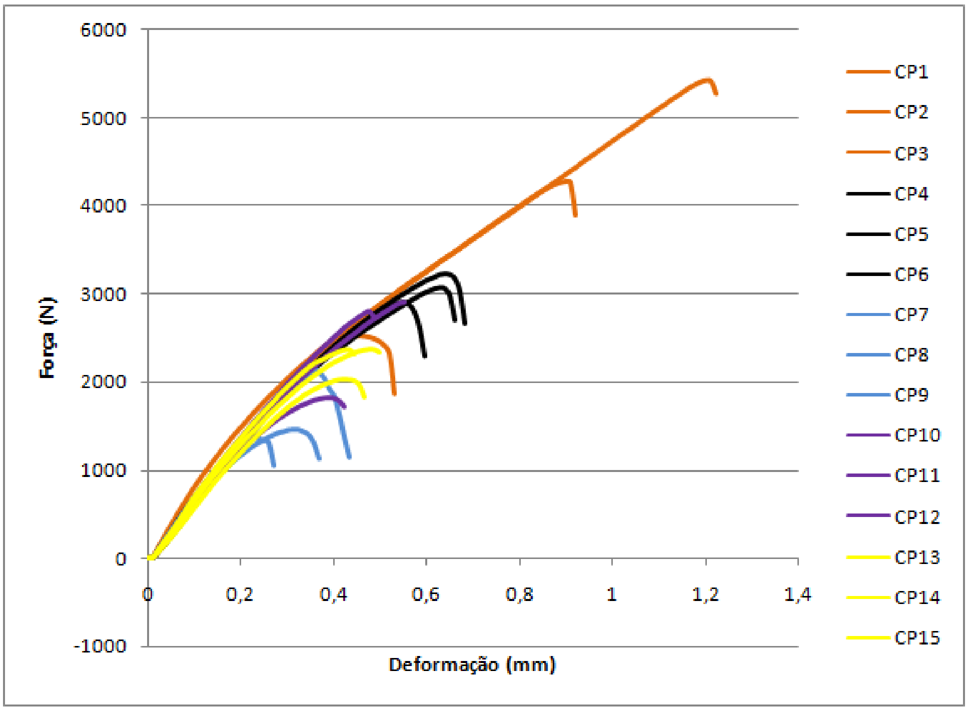

Figure 4. Force X Displacement Chart - General

It is possible to perceive that the specimens without treatment obtained the highest maximum breaking force among the tested methods despite having presented the highest standard deviation. Therefore, despite a great breaking force, this method has not presented results that can be taken into account, requiring a greater number of tests with this type of treatment to reach concrete conclusions.

The specimens treated with Alodine and Alodine + Bonding Primer, on the other hand, had the lowest maximum breaking strength, but had the lowest standard deviation values when compared to samples without treatment.

On the other hand, the bodies prepared with Boegel and Boegel + Primer obtained maximum intermediate breaking strength when compared to specimens without treatment and treated with Alodine, in addition to presenting lower values, among the five methods of surface preparation, for the standard deviation.

From the tests, it was also possible to compare the type of fracture that each of the specimens suffered.

First, the fractures that occurred in the untreated specimens respectively for samples 1, 2 and 3. Specimen 1 suffered an adhesive-cohesive failure, as did sample 2, however when comparing the two samples, it is possible to notice that specimen 2 obtained greater percentage of adhesive failure than sample 1. Test specimen 3 obtained a cohesive failure.

From the analysis of the fractures in the specimens treated with Boegel, corresponding to samples 4,5 and 6, it is possible to observe that all samples prepared with Boegel's surface treatment suffered cohesive failure.

When we analyze the fractures that occurred in the specimens prepared with alodine, corresponding to samples 7,8 and 9, it is possible to see that the specimens 7 and 9 that had their surface preparation with Alodine suffered an adhesive-cohesive failure with each type of failure. Sample 8, on the other hand, suffered an adhesive failure.

For specimens treated with Boegel + Primer, the types of fractures corresponding to bodies 10, 11 and 12 respectively, it is possible conclude that these samples suffered adhesive-cohesive failure.

Finally, the fractures corresponding to the samples prepared with Alodine + Primer corresponding to specimens 13,14 and 15. When analyzing these samples it is possible realize that all specimens prepared with Alodine + Primer obtained the adhesive-cohesive failure. However, it is worth noting that sample 13 had an almost 100% adhesive fracture.

Therefore, in order to facilitate visualization of the results, type of fracture for the five types of treatments were compiled in table 3.

Table 3. Fracture Type

Number of specimens	**Fracture Type**
CP1	Cohesive-adhesive
CP2	Cohesive-adhesive
CP3	Cohesive
CP4	Cohesive
CP5	Cohesive
CP6	Cohesive
CP7	Cohesive-adhesive
CP8	Adhesive
CP9	Cohesive-adhesive
CP10	Cohesive-adhesive
CP11	Cohesive-adhesive
CP12	Cohesive-adhesive
CP13	Cohesive-adhesive
CP14	Cohesive-adhesive
CP15	Cohesive-adhesive

5. Conclusions

Increasing the durability of bonded structural repairs of the metal-to-metal type is one of the greatest challenges of the aviation industry today, as repairs with low resistance can cause exorbitant losses for aircraft operators. Bearing in mind that variations occur during repairs, mainly due to human factors, it becomes increasingly important to verify the effectiveness of the types of surface preparation in adhering to a repair of this type.

After the conclusion of the tests, it was possible to notice that the method of surface preparation called "Without treatment" obtained a higher average for maximum breaking force. However, with the highest standard deviation among the tested arrangements, this fact may be related mainly with respect to the variation in the process that the technician who performed the gluing can introduce, considering that the figure of the professional gluer is scarce in the job market. Therefore, this method has not presented results that can be taken into account, requiring a greater number of trials with this type of treatment to reach concrete conclusions.

In addition, it is possible to observe that among the bodies treated with the Alodine compound, those that had applied the bonding primer obtained better results for maximum breaking strength and standard deviation. This fact did not occur for the bodies treated with Boegel, as it was found that among these specimens, those that did not apply the bonding primer obtained greater maximum breaking strength and less standard deviation.

Therefore, it is worth noting that, for samples prepared with Boegel, the use of the bonding primer probably reduced the surface roughness, and consequently the mechanical anchoring of the adhesive on the substrate. This is similar to what occurred when preparing the surface using both the Boegel and Alodine compounds, since samples submitted to these treatments, with or without primer, obtained lower breaking forces when compared to the specimens that suffered only previous abrasion.

The results presented can also be explained by the type of failure that each of the specimens suffered. It is possible to notice that the samples that offered higher values of maximum breaking force, presented cohesive failure. Intermediate values of maximum breaking force are related to cohesive-adhesive failure. On the other hand, lower values of maximum strength are indicated in samples that showed adhesive failure. Therefore, it is important to note that the specimens treated with Boegel obtained a good relationship between maximum breaking strength and reliability, due to the fact that all samples of this type result in cohesive type failure.

Therefore, it is concluded that the most effective method of surface preparation, among those tested, was the Boegel treatment without the primer. Because it showed a better relationship between resistance and homogeneity in its result, therefore what would lead to greater durability and reliability of the structural repair. While treatment with Alodine produced the least adhesion forces, even producing adhesive fractures.

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