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Surface Treatments Effect on Carbon Fiber Composite-Different Alloy Couples Adhesion Performance

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Abstract

Carbon fiber reinforced composites have a wide range of uses, especially in aviation and aerospace, marine and automotive. The adhesion properties of these high-tech materials with other materials are critical. Adhesive selection, surface treatment type and surface preparation procedures control adhesion performance. In this study, the effect of surface treatments that increase adhesion strength in carbon fiber composite (CFRP) structures was investigated. In order to improve the adhesion properties of carbon fiber composite materials with different metals, mechanical and physical surface treatment techniques have been used. 7075 aluminum alloy (Al) and 304 stainless steel alloy (SS) were subjected to sandblasting and plasma activation processes after surface cleaning in experimental studies. After surface activation processes, the surface wetting angle was measured and adhesion tests were carried out. In experimental results, it has been observed that plasma and sandblasting processes increase adhesion strength by 30-50%.

Key words: Carbon fiber composite, Adhesion, Surface Treatment, Plasma

1. Introduction

The necessity in automotive and aerospace industries to increase fuel efficiency is achievable by weight reduction. With the proper design, engineering polymers can offer greater properties than metals. Reinforced polymers are a type of composite material where the limitations of the polymer such as fatigue sensitivity, low strength and stiffness can be overcome by reinforcing it with fibers. Composite materials are formed by combining two or more materials in order to achieve properties that cannot be obtained using the original materials alone. These materials can be selected to achieve unique combinations of stiffness, strength, weight, temperature resistance, corrosion resistance, hardness conductivity, etc. [1]. Although there are many types of composite materials, the following features can be distinguished within all of them: Reinforcement agent: a phase of discrete nature where its orientation is crucial to defining the mechanical properties of the material. Matrix: a continuous component which is responsible for the physical and chemical properties of the composite. It transmits load to the reinforcement agent. It also protects it and gives cohesion to the material. Adhesive bonding has been extensively used alongside mechanical fastening in the aerospace, marine and automotive industry, but not on its own in primary structures. The qualification of the adhesive bonding process (in terms of durability and bond strength) is still a concern that must be investigated and solved before the aerospace authorities can allow the implementation of adhesive bonding in primary structures [2]. Effective structural adhesive bonding relies on the creation of surfaces which are easily wetted by the adhesive and provide an appropriate topography and chemistry that promotes and maximises adhesion. These can be achieved through different surface pre-treatments prior to bonding the substrates.

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There are several parameters which need to be considered for the assembly of components by adhesive bonding to ensure the reliability and the durability of the joint. Among these parameters, it will be necessary to select the most appropriate surface pre-treatment and adhesive, considering also the joint design. The performance of the joint will also be influenced by the chemical and physical properties of the substrate material. For any adhesive to be successful during the bonding process, it has to wet the surface of the substrate. The capability of an adhesive to wet a solid surface can be quantified by the surface free energy of the substrate material. This concept will be discussed further in this study. There are five main mechanisms for the adhesion between an adhesive and an adherent: mechanical interlocking, diffusion, electrostatic attraction, adsorption and chemisorption chemical bonding, and molecular forces and dipole interactions. These mechanisms can happen either alone or in combination to produce the adhesive bond. Among the parameters under consideration, surface pre-treatment is the key factor to achieve strong and durable joints [3].

1.1.Surface pre-treatments

Surface pre-treatments activate the surface of the adherents and this can lead to higher bond strengths. Through surface pre-treatments, surface free energy, surface roughness, and the chemical composition of the surfaces can be modified. Surface pre-treatments also prevent or remove contamination from the adherents. Surface pre-treatments can be classified into five categories: cleaning, mechanical, chemical, energetic and use of priming or coupling agents. Selection of the most appropriate surface pre-treatment should be based on considerations such as cost, production, performance, compatibility, durability and EHS aspects. Current surface pre-treatments in the aerospace industry involve solvent cleaning, mechanical roughening, and peel ply removal (in the case of composites), either separately or in combination [4-6]. Mechanical roughening techniques use abrasion to increase the roughness of the surfaces and remove contaminants from them. Mechanical roughening includes manual abrasion and grit blasting. Manual abrasion is carried out using abrasive papers through rotary pads, followed by the cleaning of the composite structures using vacuum cleaning followed with a solvent wipe and then allowed to dry. Grit blasting is another form of mechanical abrasion, where a stream of abrasive material is expelled against a surface using compressed air to roughen the surface and remove contaminants. The other category of surface pre-treatments involves methods such as plasma, flame, laser, etc. These physical pre-treatments cause a change in the surface chemistry of the adherents, brought about by the interaction of highly energetic species with the adherent surface. These energetic processes have the advantages of not requiring contact with the surface and by being dry. Plasma is an excited gas containing molecules, free radicals, electrons, and ions. It is also called the fourth state of matter [7]. The four common states or phases of matter.

If the contact angle formed by a liquid when placed in contact with a solid surface is higher than 90°, the surfaces are called hydrophobic, and they present a low surface free energy. These surfaces will be characterised by poor wetting and therefore poor adhesiveness (Figure 1a). If the contact angle is below 90° the surfaces are hydrophilic. They possess higher surface energy, providing better wetting and therefore better adhesiveness [8] (Figure 1b). Figure 1c shows the ideal situation where the adhesive completely wets the surface (spreading).

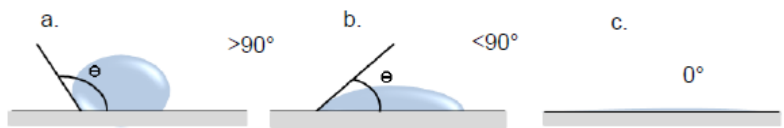


Figure 1. a. hydrophobic surface, b. hydrophilic surface, c. adhesive completely wets the surface.

In low pressure plasma technology, the plasma is generated using a high frequency generator. This technology is highly controllable in terms of gas/plasma composition, power, duration of the treatment, etc. When the process is complete and the chamber is back to atmospheric pressure, the door can be opened and the samples removed from the chamber. Unlike low pressure plasma systems, atmospheric pressure plasmas (AP) can treat substrates in a continuous way at high speed, achieving processing cost savings [9]. AP has the potential to be automated with relatively low power consumption. In AP technology, the plasma is generated with a high tension generator. The gas used to generate the plasma can come from different sources. It is a less controllable system than low pressure plasma technology.

1.2.Adhesive selection

The selection of the most appropriate adhesive for a specific application is another important parameter to consider in the bonding process. This task can be challenging due to the very wide range of commercial products available. However, the choice can be simplified by considering simple rules such as knowing which family of adhesives meet the requirements of the assembly. Figure 2 lists some of the parameters which need to be considered during the selection process of the most suitable adhesive.

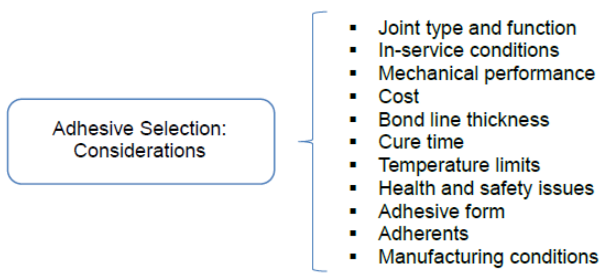


Figure 2. Adhesive selection: considerations

1.3.Joint design

As cited before, one of the advantages of adhesive bonding is the better distribution of the stresses through the joint. The loading modes experienced by adhesive joints can be compression, shear, peel, cleavage, and tension. Adhesive bonded joints can experience several of these loading modes at the same time. Single lap shear joints will be considered in this research as they are the simplest joint geometry where the shear stresses are achieved by traction on the two substrates, as shown in Figure 3. In this type of joint geometry, peel stresses will still appear.

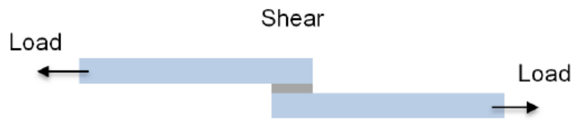


Figure 3. Single lap shear joint design.

2. Materials and Method

In this study, we examined the adhesion strength of CFRP/Stainless steel (SS) and CFRP/Aluminum(Al) 7075 couples. Different surface pre-treatments have been investigated in this experimental research. Different material couples were pre-treated by grit blasting and plasma treatment. Once the substrates had been pre-treated through the different methods (grit blasting and plasma), the adherents were ready to be bonded. From the different epoxy adhesives available on the market, Aradur 43-1/ Araldite 480 was selected. Before the adhesive application process, contact wetting angle was measured on the unprocessed surfaces. Then plasma treated samples were measured (Fig.4).

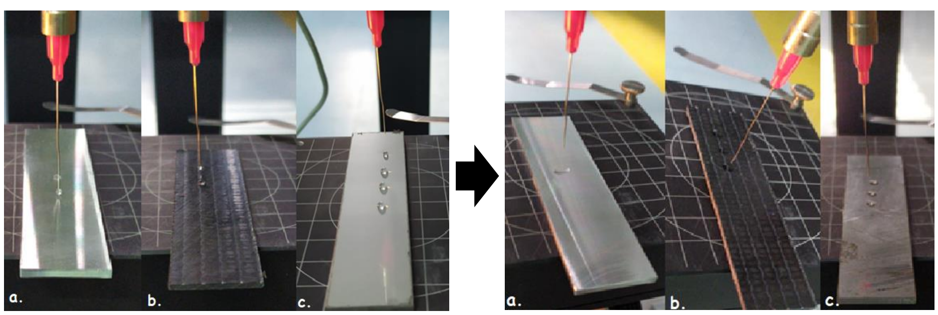


Figure 4. Contact Angle Measurements before and after plasma treatment a.Al, b. CFRP, c. SS

In order to achieve reproducible and high quality joints, the bonding process was aided using further assembly equipment. The dimensions of each plate were 25mm width and 100mm length Firstly, the correct position of the substrates will be guaranteed since the components will not be able to move. Secondly, a consistent overlap length of 12.5mm will be ensured for all the joints during the bonding process. Once the joint was assembled, the quality of the joints was assessed through testing. The test was based on BS ISO 4587 (Figure 5) [13]. The machine used to carry out the static test was a Zwick 50kN tensile machine. Tensile test was performed on samples kept under room conditions for 7 days after the adhesive curing process.

Figure 5. Specimens under tensile lap shear test.

3. Results and Discussions

Contact angles could be reduced from 90º,80º,105º respectively, to <10º,<10º and 20º after plasma treatment for Al, SS and composite. The wetting ability could be improved by surface plasma treatment. Tensile lap shear test results are given in Figure 6 and Figure 7. As a result of the CFRP-Al adhesion test, the plasma-pretreated value increases by 40% compared to the unprocessed value. At the same time, a 75% increase is observed compared to the value without grit blasting pre-treatment. Comparing the CFRP-SS adhesive process, the plasma pre-treated test was 60% higher than the test results unprocessed. Comparing the Al-SS tensile test results, the plasma pre-treatment increased by 20% and the grit blasting pre-treatment test increased by 35% compared to the unprocessed.

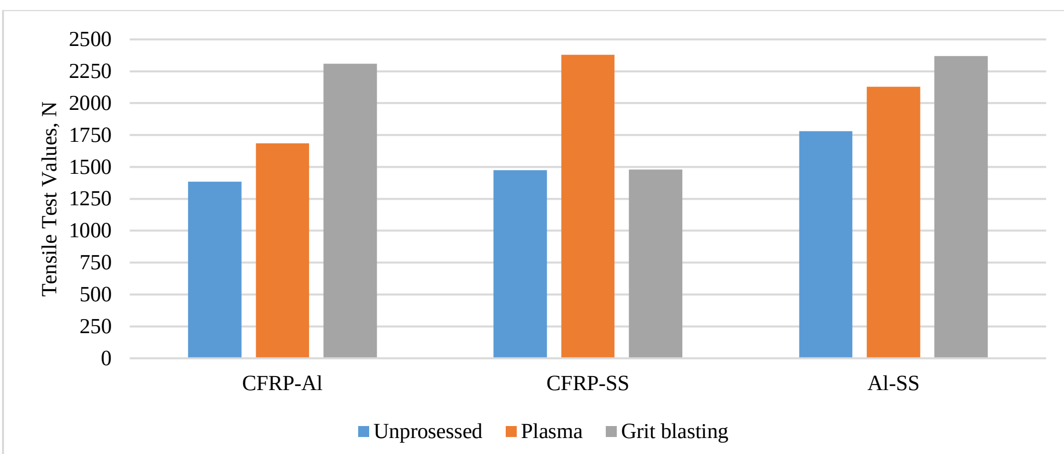


Figure 6. Results of Lap Shear Test

The plasma pre-treatment showed an increase of 70% compared to the unprocessed test. In the Al-Al adhesion test, the result of the plasma pre-treatment test increased by approximately 40% compared to the unprocessed test result, while the result of grit blasting pre-treatment increased by 80%. There was an approximately 20% increase in SS-SS test results after plasma treatment compared to the unprocessed test in Figure 7.

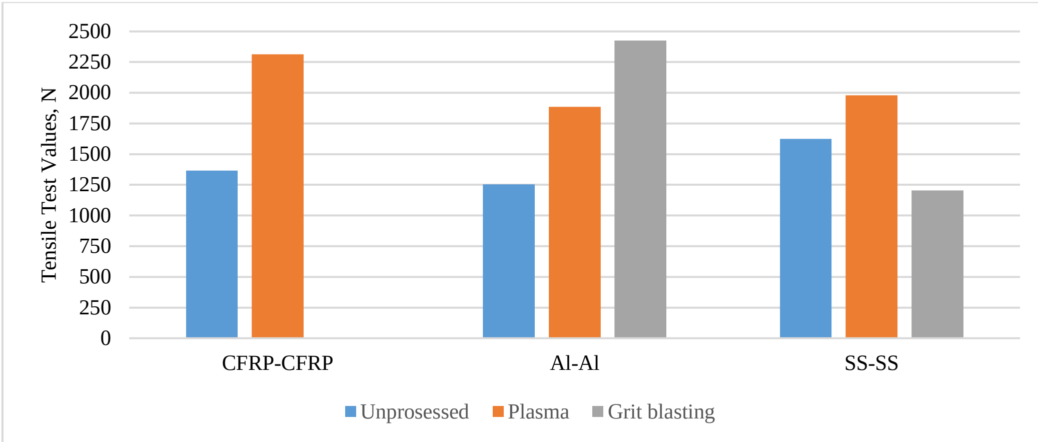
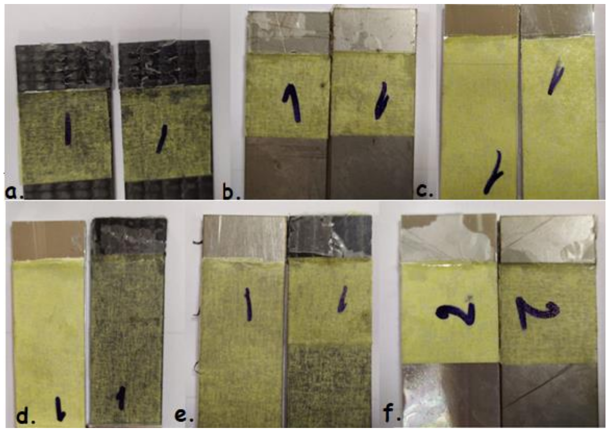


Figure 7. Result of Lap Shear Test

Cohesive and adhesive forces are related to mass (or macroscopic) properties and therefore the terms cannot be applied to discussion of atomic and molecular properties. When a liquid comes into contact with a surface, both adhesive and adhesive forces act on it. The term "cohesive forces" is a general term for the collective intermolecular forces responsible for the bulk property of liquids resistant to separation. Specifically, these attractive forces exist between molecules of the same substance. This force tends to aggregate the molecules of a liquid and bring them together into relatively large clusters due to the dislike of the molecules around them. Likewise, the term adhesive forces refers to attractive forces between different substances, such as mechanical forces (adhesion to each other) and electrostatic forces (attraction due to opposing charges). In the case of a liquid wetting agent, the adhesion causes the liquid to stick to the surface on which it rests. After the lap shear test, the samples are seen in the Figure 8.

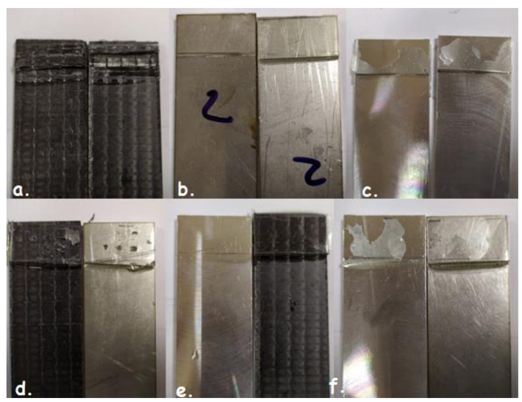
Conclusions

It has been observed that different surface activation processes can significantly control the surface adhesion properties. Adhesion properties between metal / metal or metal / composite structures have been determined. Besides the type of adhesive and the way of application, the importance of the front surface treatments comes out. The adhesion strength of the composites without any pre-treatment is increased by pre-treating the samples through grit blasting, and plasma treatment. As can be seen in the wetting angle measurement results, surface wetting ability could be increased significantly after plasma treatment. The contact angle decreased in the CFRP, Al and stainless steel material after plasma pre-treatment. In the experimental results, it has been observed that plasma and grit blasting processes increase the adhesion strength by 30-50%. Surface cleaning and activation processes before bonding play a critical role in the performance of mechanical strength in a multi-joint-bonded construction and help increase strength.



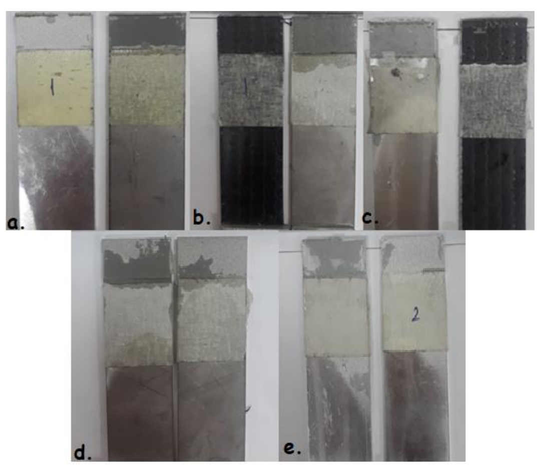
Unprocessed Test Samples

a. CFRP-CFRP, b. SS-SS, c. Al-Al, d. Al-CFRP, e. SS-CFRP f. Al-SS



Plasma Pre-Treatment Test Samples

a. CFRP-CFRP, b. SS-SS, c. Al-Al, d.CFRP-SS, e.Al-CFRP, f. Al-SS



Grit blasting test samples

a. Al-SS, b. CFRP-SS, c. Al-CFRP, d. SS-SS, e. Al-Al

Figure 8. Test sample view after lap shear test

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