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COMPARISON OF THE EFFECT OF NANOMODIFIED ADHESIVE FOR METALLIC AND HYBRID SINGLE-LAP JOINTS

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Abstract. *Bonded joints are attractive to structural applications due to its good cost-effect ratio and versatility. Since the joint is often considered the region of weakness, many different studies have been developed aiming to improve this aspect and the present work contributes with such purpose. This paper analyzed single lap joints in two different types of configurations: with metallic adherents and hybrid (i.e. composite with metal). Furthermore, this study also investigated the effect of the dispersion of carbon based nanostructures in structural adhesives used for the bonded joints. This study is associated to the growing demand for the use of structural adhesives in high performance composites, due to advantages evidenced in adhesives when compared to other methods of repair/fixing. The carbon based nanostructures, i.e. multi-walled carbon nanotubes (MWNT) and multilayered graphene (MLG) were dispersed in different concentrations in epoxy adhesives and those adhesives were tested in the two configurations of single-lap joints (SLJ) mentioned for samples of Aluminum and GFRP/Aluminum. All concentrations presented improvements in their mechanic properties, peel and shear tests were made. Finally, with the results obtained, it was possible to draw conclusions about the best mechanical performance and whether or not the joints showed improvements with the specific configurations. The addition of nanoparticles improved the hybrid joint resistance in 40%, though the joints with only aluminum as adherent still have higher resistance (30% more when compared to the nanomodified hybrid one).*

Keywords: *Adhesives, Composites, bonded joints, Graphene, CNT*

1. INTRODUCTION

The limitation in regard of shear strength of adhesives in bonded joints has been restricted the use of this type of joining in engineering applications, even though it has so much potential and a wide range of application. Some strategies are taken in account in order to have such limitations suppressed and increase the load capacity of bonded joints. Some examples are tests with combination of different kinds of adherents or even modification of the adhesive in such a way that they have their performance improved. Since adhesives are often associated with composite materials, the possibility of manipulation of such materials with recent technologies makes the improvement possible and some new features may take the main role: nano-reinforcement and multi-functionality.

According to Thostenson *et al.* (2005), nanostructures are so important because they have their dimensions between 1 nm and 100 nm, what represent a high contact surface area. Some of the most important carbon nanostructures, carbon nanotubes (CNTs) and graphene sheets (GN) are relatively recent discoveries and already have quite prominent applications. CNTs have been the center of many researches due to its dimensions and remarkable mechanical and electrical properties (Avila *et al*., 2014). Graphene sheets may be cheaper but has no less significance and also has incredible strength and considerable lightness other than having important properties such as considerable contact surface, good heat conduction and electricity, to name a few.

As for bonded joints, there are some key vantages and disadvantages of using composites to manipulate components' and structures' properties. Mazumdar (2002), Gay *et al*. (2003) and Kaw (2006) mention some advantages like good chemical's stability, good fatigue resistance, design flexibility and good dynamical properties. Disadvantages could be high humidity absorption, low thermal stability, often pricey and complicated to recycle or reuse.

The aeronautic industry could be chosen as a reference that uses a good amount of structural adhesives and composite materials. Famous airplanes like Boeing 787 have a great portion of its parts and material made of composites and that is illustrated in Fig. 1.

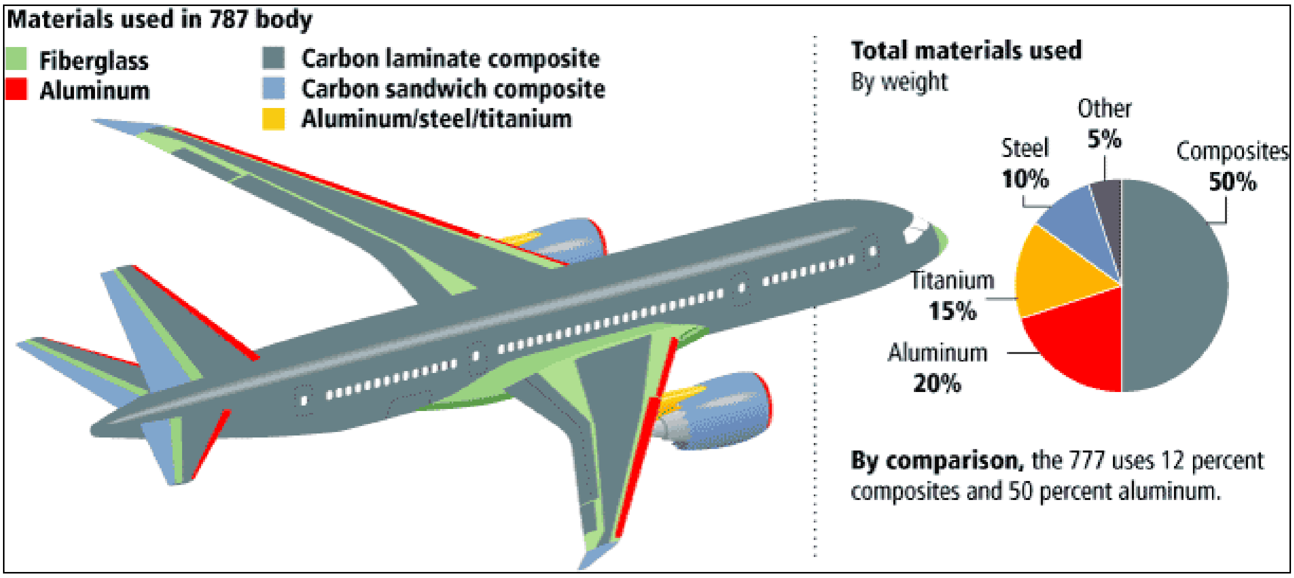


Figure 1. Composite materials in aviation (Modern Airlines, 2015)

1.1 Objective

The main objective of this work is to compare the dispersion of nanoparticles in two different types of SLJ: metallic joint (aluminum/aluminum) and hybrid joints based on Composite/Aluminum. The composite is a glass fiber reinforced plastic (GFRP). Moreover, it was studied the dispersion of the carbon-based nanostructures (Graphene and CNT) in the structural adhesive for the hybrid joint. The aim was to increase the load capacity of the joint, knowing the best combination of adherents and increasing the performance of the adhesive by the dispersion of hard points (nanostructures) in it.

2. SPECIMEN PREPARATION AND EXPERIMENTAL PROCEDURE

The experiment was conducted after the study of appropriate theory such as ASTM D1002-10 standard (2013), illustrated in Fig. 2, and similar cases, like the works of Oliva *et al*. (2015) and Cruz *et al*. (2013). The hybrid single lap joints were made of adherents of aluminum 2024-T3 with thickness of 3.18 mm and width of 25.4 mm and GFRP laminated with 12 layers and having the same dimensions of the sample of aluminum.

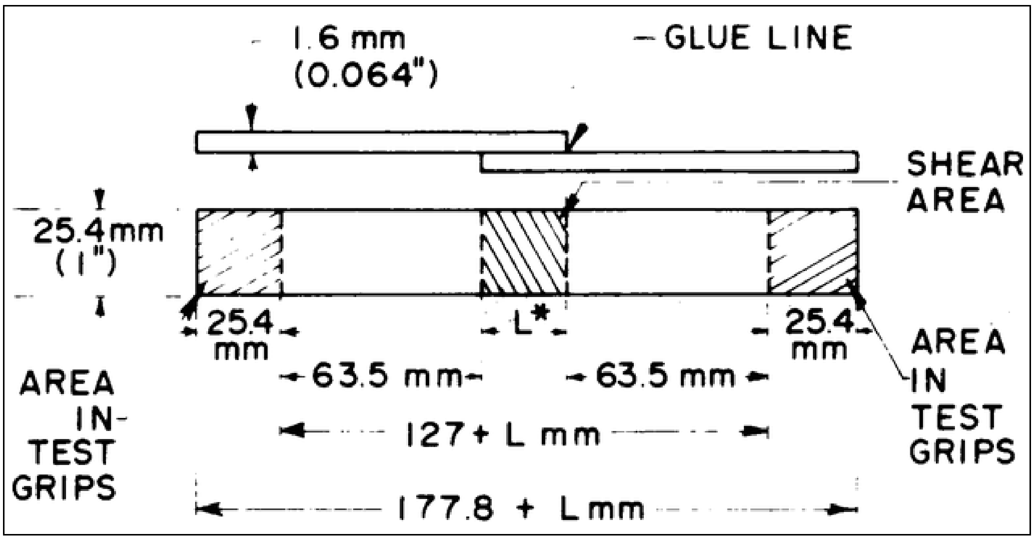


Figure 2. Single-lap joint dimensions (ASTM-1002, 2013).

For the L dimension, shown in Fig. 2, it was chosen the value of 25.4 mm. Hence, the total length of the samples was 114.3 mm.

The adhesive employed in this work is an epoxy system AR300 with hardener AH30-150 supplied by Barracuda Advanced Composites. The adhesive was nanomodified by graphene and Carbon Nanotubes (CNT) dispersion. The idea behind this analysis was to compare the results with some available data in literature. The work done by Oliva *et al.* (2015) reported an improvement into load capacity of at least 300% with the addition of 1.0 wt.% of graphene. However, in Oliva's case, the adherents were aluminum and all samples had 0.3 wt.% of CNT. In the present case, two groups of single lap joints were tested in order to complement the previous study mentioned.

Table 1 shows the groups considered for comparison. Also, there's a group with no nanoparticles in order to have a control of the improvement caused by them. In the table, H-blank, H-CNTG and CNTG refers to, respectively, hybrid joint with no nanoparticles in the adhesive, the hybrid joint with the same concentration of the sample with the best result from the work of Oliva *et al.* (2015) and metallic joint from the work of Oliva *et al.* (2015).

Table 1. Nanoparticle concentrations in specimens.

#Group	Nome	MLG [wt.%]*	MWNT [wt.%]*
1	H-blank	0.0	0.0
2	H-CNTG	1.0	0.3
3	CNTG	1.0	0.3

3. DATA ANALYSIS

In order to compare the performance of the different joints, tests to respect of its shear strength and deformation were necessary. Based on data/results obtained, it was possible to compare this work with the similar one mentioned, in respect to the adherent and then to say which was the best combination.

Figure 3 shows the results for the load-displacement data obtained for the Hybrid joint with no nanoparticles (Group 1), the nanomodified hybrid single-lap joint (Group 2) and the one of only aluminum with the same concentration of nanoparticles (Group 3).

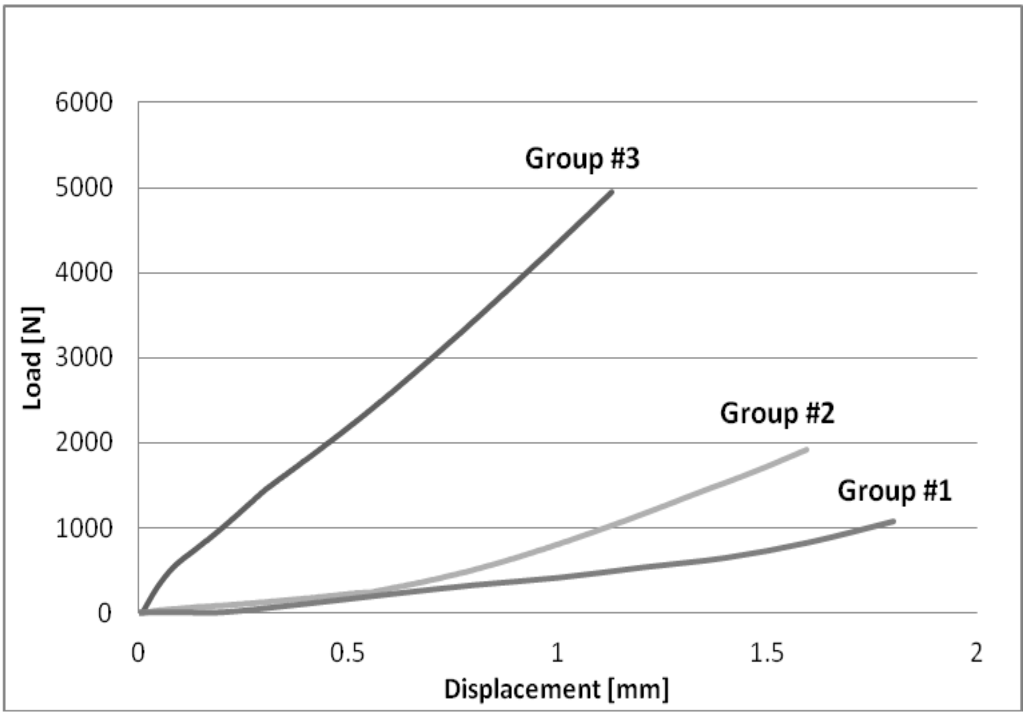


Figure 3. Load-Displacement curves

As it can be observed on Fig. 3, as expected the Aluminum/Aluminum SLJ has a much larger stiffness (higher slope). However, the addition of carbon based nanostructures seems to increase the overall SLJ stiffness by approximately 85% (see Tab. 2).

Table 2. Estimated Stiffness of the Single-lap Joints

Group #	Stiffness [N/mm]
1	553
2	1023
3	4197

According to the maximum mean stress of both types of samples, it is shown that the presence of nanoparticles in the structural adhesive has improved its failure load (see Fig. 4). Hence, the nanoparticles of graphene and CNT are beneficial to the adhesion process of the joint. However, when the concentration of nanoparticles is the one of Group 2 and it comes to the union of both adherents made of aluminum (i.e. Group 3), the resistance is still bigger than the one shown for the hybrid joint studied in this work, as it is reported in Oliva *et al.* (2015). Figure 4 illustrates the comparison of the three groups shown in Tab. 1.

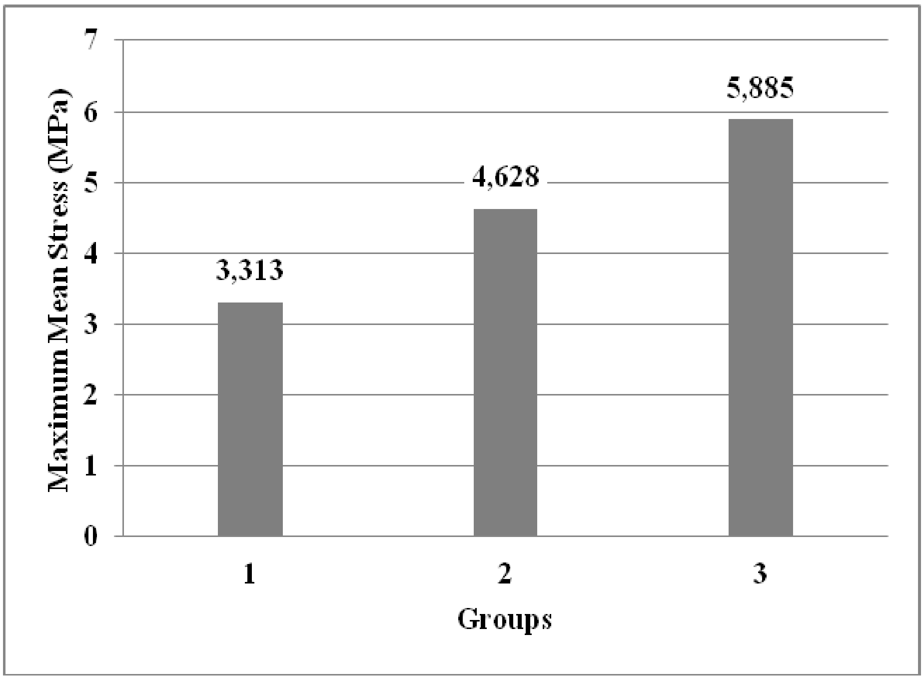
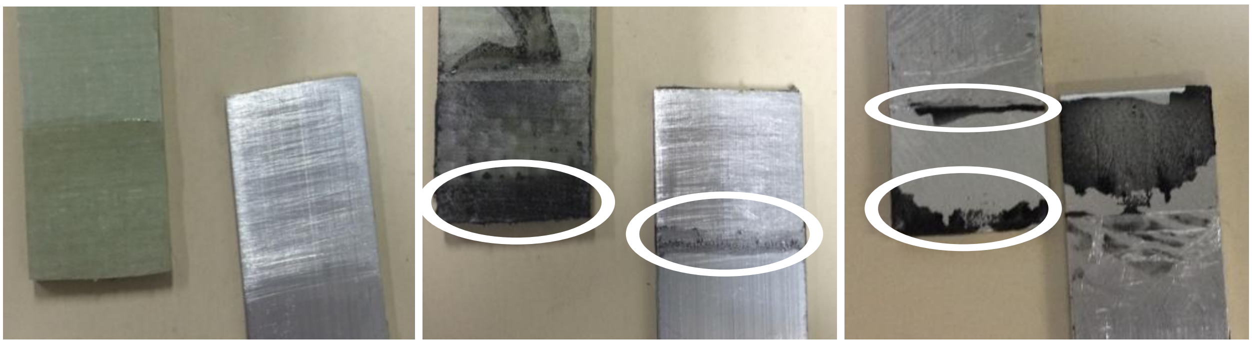


Figure 4. Mean Rupture Stress for all groups

According to Petrie (2007), there are different ways in which an adhesive joint may fail, but the two dominant ways are the ones called adhesive and cohesive failures. Adhesive failure is a failure of the interfacial bond between the adhesive and the adherent and tends to indicate the existence of a week adhesive to adherent interface. The cohesive failure happens when the fracture occurs in the adhesive so that an adhesive layer remains on both adherents. A flaw is hardly purely adhesive or cohesive; instead a mix of both types commonly occurs.

Failure modes for representative samples are shown in Fig. 5 for all three groups mentioned. As it can be noticed in Fig. 5, for the pure adhesive hybrid SLJ, the failure is adhesive dominated. On the other hand, groups 2 and 3 are adhesive/cohesive mix modes. The cohesive failure areas, however, are different. As it can be noticed by the white circles on Figs. 5B-C, the cohesive area for the metal/metal SLJ is larger. This can be the reason for such increase on load capacity, as the energy release rate can be bigger. For group 2, there is something around 20% cohesive failure and group 3 has something around 70% adhesive failure.



(A) (B) (C)

Figure 5. Failure modes for representative samples: (A) Group 1; (B) Group 2; (C) Group 3 (OLIVA *et al.*, 2015)

To be able to understand the failure mechanism an Atomic Force Microscopy (ATM) analysis was performed. As it can be seen in Fig. 6., the Graphene-CNT nanostructure created a rough surface. Although the adhesive surface seems to provide "an extra" grip, the adherent surfaces are different. Such divergence on surface preparation can be the reason for this dissimilar behavior.

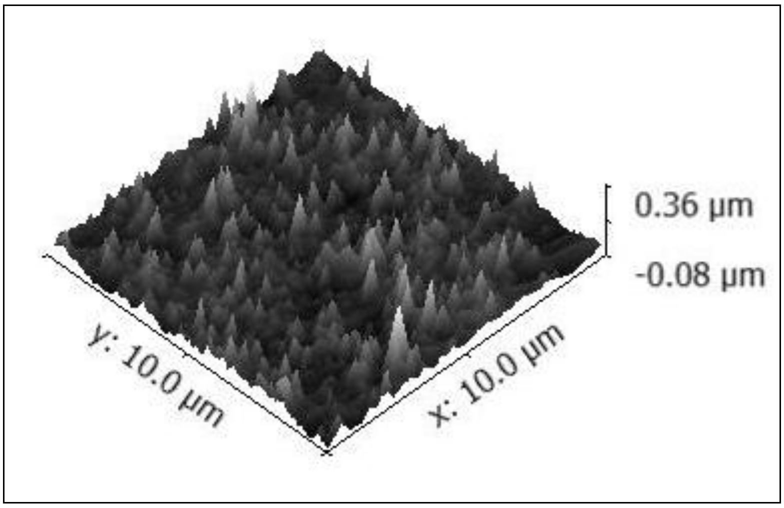


Figure 6. Atomic Force Microscopy (ATM) of the surface of the adhesive used in this study.

4. CONCLUSION

Different configurations of single lap joints where compared and the influence of nanoparticles in structural adhesives was taken in account. The comparison with a previous work provided important information in terms of the joints and factors that may affect its performance.

According to the data provided it was seen that the addition of the specific concentrations of nanoparticles experienced in this work improved the hybrid joint performance in around 40%. Also, comparing with a previous work that used the single-lap joint with the same material for both adherents and the same concentration of nanoparticles used here, it was concluded that their results were even better. In other words, for the joint with 1% of graphene in Oliva *et al.* (2015), when compared to the nanomodified hybrid one tested here, still holds an improvement of almost 30% of shear strength. Then, some different types of composites may be needed to be tested in order to figure if there's advantages in designing hybrid joints to replace the ones with the same adherents.

5. ACKNOWLEGMENTS

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