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Damage analysis of a GLARE laminate subjected to interlaminar shear

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Abstract

GLARE (Glass Laminate Aluminum Reinforced Epoxy) is a hybrid material composed of aluminum sheets alternated to fibre glass composite material and it is used for some applications in the aeronautical field. In the present work, the mechanical performance of a GLARE laminate is compared to that one of a GFRP (Glass Fibre Reinforced Polymer) laminate. In particular, the ILSS (Interlaminar Shear Strength) of both laminates were determined through a three-point bending test carried out on short beam specimens. From the experimental results, a slightly higher strength was found for the GFRP laminate, even if the difference was similar to the experimental scattering. Moreover, the analysis of the whole shear stress trend as a function of the loading nose displacement highlighted that the loading nose displacement at the first breakage of the GLARE was higher than that of the GFRP, as well as the residual strength (after the first breakage) of the former was higher than that of the latter. Therefore, the GFRP has a brittle behavior, while the GLARE has a higher toughness.

Keywords: GLARE; ILSS; Structural behaviour.

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1. Introduction

FMLs (Fibre Metal Laminates) are a kind of hybrid material consisting of metal sheets stacked together with fibre reinforced polymer layers. They are becoming more and more used in the aeronautical field, due to their peculiar mechanical characteristics. In fact, they combine the better properties of metals with that of composite materials, giving rise to a material characterized by not only low weight and high strength (Ortiz de Mendibil et al. (2016) and Tsartsaris et al. (2011)), but also impact and fatigue resistance, low environmental degradation and good fire resistance (Sinmazçelik et al. (2011) and Mamalis (2019)). Today, there are different types of FMLs, with different types of metal and composite material. In general, the metal sheets are made of aluminium, even if titanium or magnesium sheets are applied for specific employments, while the composite material layers are based on carbon, aramid or glass fibres, as stated by Bellini et al. (2019 a and b). As asserted by Xu et al. (2017), the carbon fibres are suitable to obtain hybrid laminates presenting higher strength, stiffness, fatigue resistance and energy absorption capacity than FMLs based on glass or aramid fibres. According to the research of Botelho et al. (2006), carbon-based FMLs are 10% tougher compared to glass-based ones.

Despite this, several aircraft parts, as wing leading edges and fuselage, are made of GLARE (Glass Laminate Aluminum Reinforced Epoxy), thanks to its good level of damage tolerance and impact and fatigue resistance, combined to the high weight-saving potential, as asserted by Huang et al. and Hu et al. There are several grades of GLARE, depending on the stacking sequence and fibre direction of the composite material layers between the aluminium sheets. At first glance, the mechanical characteristics of this kind of laminates seem to be largely controlled by the characteristics of the constituent materials; however, the ultimate properties rely not only on those ones of the starting materials, but also on the strength of the interface between the metal sheets and the composite layers, as stated by Abdullah et al. (2015). According to Liu et al (2016), in an FML there exists an intricate system of interfaces; in fact, there are the fibre-matrix interface in the composite material, the aluminium-composite matrix interface and the aluminium-fibre interface. Moreover, the scenario gets more complicated if an adhesive layer is introduced in the stacking sequence, between the aluminum sheets and the composite material. The shear load induced by torsion or bending causes the failure of the interface between the different layers of the hybrid laminate, as asserted by Wu et al. (2005). In fact, the most dangerous failure mechanism in an FML is the delamination, and the propagation of local delamination causes the failure of the whole structure during service, as described by Pahr et al. (2002) and Remmers and De Borst (2001). Therefore, determining the ILSS (Interlaminar Shear Strength) of a laminate is very important; in fact, several tests have been introduced and used to determine this mechanical property, as asserted by Schneider et al. (2001). For example, Hinz et al. carried out a double-notch shear test to calculate the ILSS of laminates, but in this test the buckling of the specimen can happen due to the compression load exerted on the ends of the specimen. A better method to determine the ILSS of a laminate is the three-point bending on a short beam, that has been adopted in several research works, like those of Park et al. (2010 a and b), Botelho et al. (2008) and Bellini et al. (2019 and 2020).

This work deals with the analysis of the ILSS of GLARE laminates, studying the behaviour of this material subjected to flexural load. The attention was focused both on the maximum shear strength and the shear-deformation response after the peak shear stress, that is reached at the end of the elastic loading phase. In fact, the residual shear strength is an important parameter to understand the safety level of a material. When subjected to in-plane shear or compression loading, a laminate tends to buckle, and this is a problem as the different layers get separated due to the decrease of interlaminar stiffness or the beginning of delamination. In fact, as this phenomenon happens there is a sudden decrement of the bending stiffness, since the separated layers cannot sustain the load. This decrement makes the deformation increase, leading to a delamination increment and so on, till the failure of the structure. In this work, the results determined for the GLARE panels were compared with those obtained from GFRP (Glass Fibre Reinforced Polymer) laminates. The stress-displacement curves of the two analysed types of specimens were compared and consequently the maximum load they resist, the shear stress to which they are subjected during the test and the type of behaviour with increasing applied deformation were compared.

2. Materials and methods

In the present work, the mechanical behaviour of hybrid GLARE laminates was analysed and compared with that of traditional GFRP laminates. In particular, the shear characteristics were analysed carrying out three-point bending test on short beam specimens, extracted from hybrid and traditional laminates. The GLARE laminates were made of three aluminium sheets with a thickness of 0.3 mm, alternated to composite material layers made of glass fibre. The bonding between the composite layers and the metal sheets was guaranteed by a film of AF 163 2K, a structural adhesive commonly used for aeronautical applications, as indicated by Sorrentino et al (2018).

As concerns the manufacturing process of the laminates, the standard prepreg vacuum bag procedure was adopted. First of all, three aluminium sheets, 12 glass fibre prepreg and four adhesive patches were cut in the right dimension for the stacking operation, as visible in Fig. 1. Then, the layers were piled according to the following sequence: a layer of adhesive was placed on a metal sheet, then six prepreg plies were stacked on the adhesive, with a cross ply stratification sequence. Another ply of adhesive was laid on the glass prepreg, followed by the second aluminium sheet, on which the second layer of composite material, constituted by six plies of prepreg, was piled together with the necessary adhesive plies. The stack was finished with the last aluminium sheet. After the completion of the stacking sequence, the laid laminate was covered with a breather cloth, necessary to collect the excess of resin, and the whole stack was sealed in a vacuum bag. The mould closed in the vacuum bag was connected to the vacuum pump and, after drawing the air present in the bag, the mould was put in the oven for the cure cycle.

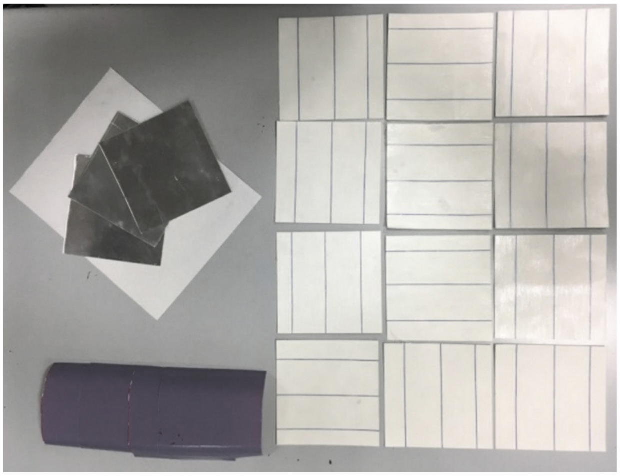

Fig. 1. Raw materials used to produce a GLARE laminate.

The temperature cycle adopted for the curing of the GLARE laminate was suitable for both the prepreg material and the adhesive. It consisted of a heating ramp, a dwell at constant temperature and a cooling ramp. At the end of the cool down, the obtained laminate was extracted from the bag and cut with a diamond disk saw, in order to obtain the specimens to be tested. The dimension of each specimen depended on the thickness of the laminate: since it was 5.5 mm, each specimen had a length of 33 mm and a width of 11 mm. As aforementioned, the material was tested according to the three-point bending test on a short beam, that is according to the ASTM D2344 standard. In particular, for this work a span length of 22 mm and a loading nose speed of 1 mm/min were adopted. A specimen subjected to the three-point bending load is reported in Fig. 2.

The same procedure was adopted for the GFRP laminates, whose ILSS behavior was compared with that one of the GLARE. In particular, 16 plies of glass fibre prepreg were cut and stacked on the mould surface, according to a cross ply sequence, then the laminate was cured as for the GLARE one. The obtained laminate had a thickness of 3.5 mm, so the specimen width was 9 mm and the specimen length 25 mm.

Fig. 2. Three-point bending test on a GLARE specimen.

3. Results and discussion

After carrying out tests on GLARE and GFRP specimens, the obtained results were analysed to determine which of the two materials was the more resistant concerning interlaminar shear stresses and which exhibited a better behaviour even after damage. Since the two different types of laminate had two different thicknesses, the adoption of a specific relation was needed to carry out a reasonable comparison. Therefore, the following formula was used to calculate the shear stress τ, normalizing the applied load P with the width b and the thickness h of the specimen:

$$\tau = \frac{3\,P}{4\,b\,h} \tag{1}$$

The eq. 1 is a relation commonly adopted in the literature and it is reported also in the ASTM D2344 standard. It must be remembered that four specimens were tested for each type of laminate, for a total of eight experimental runs. The results obtained from the experimental campaign are visible in Fig. 3. From these values it seems that the GFRP has a higher ILSS than the GLARE, that is the former get damaged for a higher level of shear stress; in fact, the average ILSS of the GLARE is 39.22 MPa, while that one of the GFRP is 44.83 MPa. However, if the CoV (Coefficient of Variation) is taken into account, the ILSS obtained for the two different materials can be considered almost comparable; in fact, the CoV of the GLARE is 2.69%, while that one of the GFRP was 14.92%. Therefore, the obtained statistical error can justify the gap of the ILSS between the two studied kinds of laminate.

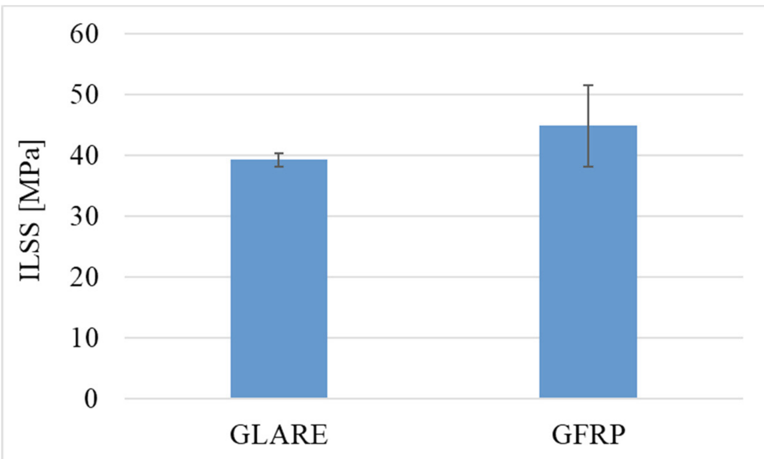

Fig. 3. ILSS obtained for GLARE and GFRP laminates.

For a more comprehensive comparison, the shear stress trends as a function of the load nose displacement were plotted and compared for both laminates. In Fig. 4 the curves representative of a GLARE specimen is plotted together with the curve of a GFRP specimen. By observing the stress-displacement curves of the two different kinds of specimens subjected to the same type of load, it can be seen that the maximum level of shear stress was quite similar for both the specimens, even if the GFRP one showed a slightly higher value. However, for a detailed analysis of the mechanical behavior of the specimens, the trends of the whole curves were investigated and they resulted to be quite different for the two samples. In particular, even if the maximum shear stress of the GLARE specimen was lower than that of the GFRP, the relevant displacement was higher, that is the GLARE failure deformation is higher than that of the GFRP. Moreover, the behaviour after the first shear stress peak was different; in fact, the GLARE specimen was able to sustain a quite elevated load after the first breakage, while the residual shear strength of the GFRP was lower. This graph demonstrates that the GLARE laminate is safer than the GFRP because its residual shear strength after the first breakage is higher.

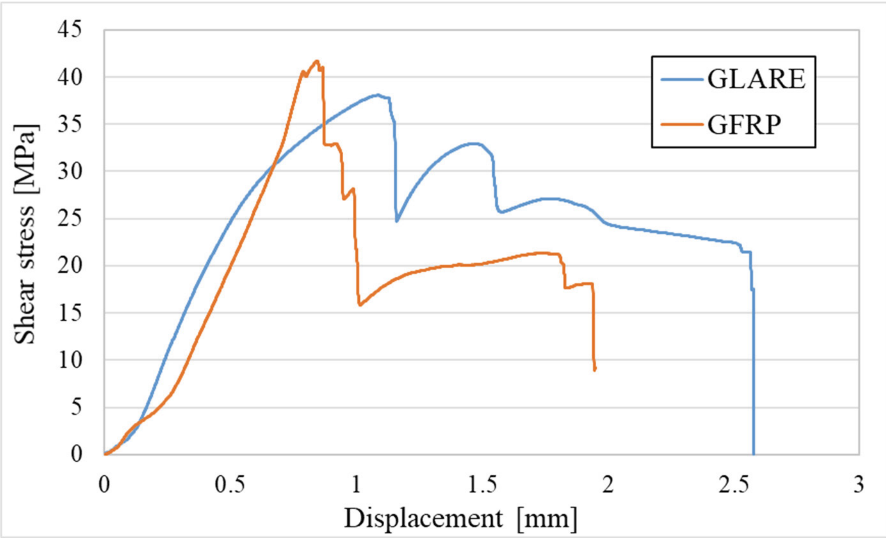

Fig. 4. Shear stress trend as a function of loading nose displacement.

4. Conclusion

GLARE (Glass Laminate Aluminum Reinforced Epoxy) laminates are more and more used for several applications in the aeronautical field since they present high structural characteristics. They are made of aluminum sheets alternated to glass fibre composite layers. The aim of this work was the analysis of the ILSS (Interlaminar Shear Strength) behaviour of this material and the comparison with a monolithic GFRP (Glass Fibre Reinforced Polymer) laminate, in order to delineate the advantages of the former respect to the latter.

The ILSS of both GLARE and GFRP samples were determined through the three-point bending test on a short beam. From the experimental tests resulted that the GFRP reached a maximum shear strength slightly higher than that of the GLARE, but the latter presented a higher deformation before the first breakage. Moreover, the analysis of the whole shear stress trend as a function of the loading nose displacement highlighted that the residual strength (after the first breakage) of the GLARE was higher than that of the GFRP. In view of the above, it can be concluded that, concerning the interlaminar shear performance, the GFRP has a brittle behavior, while the GLARE has a higher toughness, due to the presence of the aluminium sheets in the stacking sequence.

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