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LETTER

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Flexural strength of aluminium carbon/epoxy fibre metal laminates

Abstract

Fibre-metal laminate (FML) is a material constituted by composite laminae and metal sheets, whose mechanical properties can be tailored by varying the thickness and the number of layers. For this reason, in the present work different types of FML made of carbon-fibre–reinforced polymer and aluminium sheets were produced and tested; in particular, the influence of both the layer thickness and the layer adhesion was analysed through three-point bending tests. It was found that both the abovementioned factors influenced the flexural strength of FML; precisely, the presence of an adhesive layer between the composite plies and the metal sheet made the flexural strength decrease, while this mechanical parameter increased passing from two metal sheets to only one.

1 | INTRODUCTION

Nowadays, fibre-metal laminates (FMLs) are increasingly adopted for applications in several field, as aeronautics, automotive, and sport goods, since they present outstanding mechanical characteristics. FLMs are a kind of hybrid material consisting in metal sheets alternating to composite material laminates. The exceptional structural properties are due to the peculiarities of the materials the FMLs are made of; in fact, the FMLs constructed by aluminium and glass-fibre composite that are the most used one for aeronautical applications are less strong than those based on carbon-fibre reinforced polymer (CFRP)[1,2]: carbon fibre–reinforced aluminium laminates (CARALL) are about 10% stronger than glass fibre–reinforced aluminium laminates (GLARE) for tensile loads.[3] In general, carbon-based FMLs have superior characteristics, such as concerns energy-absorption capacity, yield strength, tensile modulus, and fatigue strength, in comparison with aramid or glass fibre–based FMLs.[4] FLMs present another exceptional peculiarity; mechanical properties can be easily tailored to specific requirements by changing the composite ply orientation, the thickness, and the number of layers[5]; moreover, is some cases, they can simplify the manufacturing process.[6]

Structural frames are subjected to bending loading that represents the most diffused and consequently most studied, failure mode. Hu et al[7] studied the flexural behaviour of FMLs based on carbon fibre–reinforced PMR polyimide and titanium, determining a good structural strength at both room and high temperature. The effect of the metal-layers position in the material stacking was analysed by Dhaliwal and Newaz[8] that produced and tested some CARALL specimens with carbon-fibre laminate as outside layers. They compared the flexural behaviour of those laminates with that of standard CARALL, presenting aluminium layers outside, and found a superior strength. The effect of the aluminium-layers strength and the fibres orientations on the in-plane bending behaviour of CARALLs was studied by Xu et al.[1] They found an increment of the bending strength as the quantity of the longitudinal fibres and the aluminium strength were increased. As concerns the progressive failure mechanism, at first the aluminium layers yield happened, coupled with a tension damage of both resin and fibre in the section bottom and compression damage of the resin in the section top; after, the delamination arose in the laminate mid-span, because of the unstable deformation.

The aim of the present work concerns the flexural behaviour study of CARALL specimens, analysing the influence of both layer thickness and the adhesion between CFRP layer and aluminium sheet.

2 | MATERIALS, METHODS, AND MAIN RESULTS

The full factorial plan of the experimental activity is composed of two levels for each of the examined factors that are the stacking sequence and the bonding method. As concerns the former element, two FMLs were considered: one consisting of an aluminium layer surrounded by two ones made of composite, the other formed by three layers of composite alternated with two aluminium sheets. With regard to the bonding technique, the interface between composite and metal was assured by an adhesive layer or by the resin contained in the composite material. The laminates were produced by vacuum bag process, so the raw materials were stacked on a plane mould as requested; then the stack was closed in the bag and cured in the autoclave. After curing, the specimens were cut from the laminates and tested.[9] The flexural strength was determined by three points bending test according to ASTM D790, as shown in Figure 1.

The flexural strength ranged between 562.75 and 641.86 MPa for the laminate with one aluminium sheet bonded with adhesive (type A), while it oscillated between 644.25 and 734.00 MPa for the same laminate without the adhesive (type B), in which the composite material bonding on aluminium sheet was assured by the sole prepreg resin. As concerns the CARALL with two metal layers, the flexural strength interval went from 468.88 to 553.30 MPa for the laminate with adhesive (type C) and from 498.38 to 641.38 MPa for that one without adhesive (type D). It is worth to note that the results found in this experimental campaign are in accordance with other works on this class of material.[7,10,11] For all the CARALL types, the coefficient of variation (CoV) was very low; in fact, it was equal to about 5.5% to 7.3%, and only for the FML with two metal sheets bonded with resin it reached 10%.

From the results in Figure 2, it can be noted that the highest strength belonged to the laminate with only an aluminium sheet bonded with only resin, while the lowest value to that one with two metal sheets joined with adhesive. Moreover, the data scattering is low, so the results are repeatable. Therefore, it can be concluded that the presence of adhesive was negative for the material strength, while the decrease of metal sheet numerousness was beneficial. The negative influence of the adhesive is apparently in contradiction with past literature,[12] but in the same paper, it is affirmed that the results depend on the specimen dimension, so a reliable comparison is difficult. The presence of adhesive lessens the overall fibre content, and so the material flexural strength is affected.

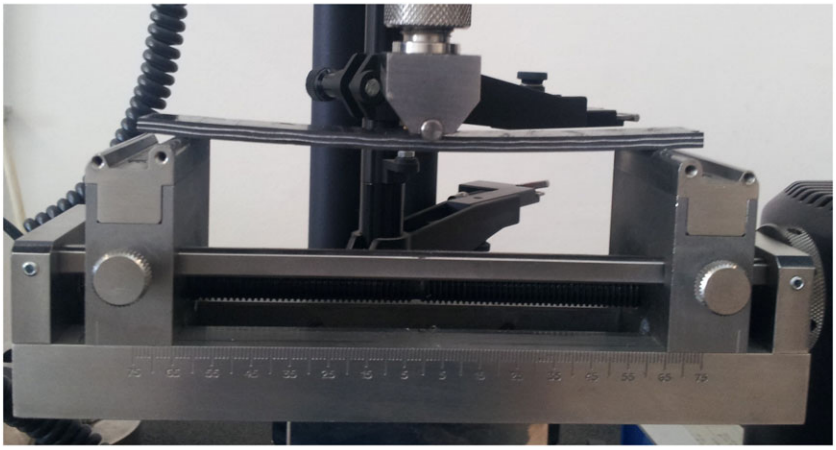

FIGURE 1 An example of the three-point bending test

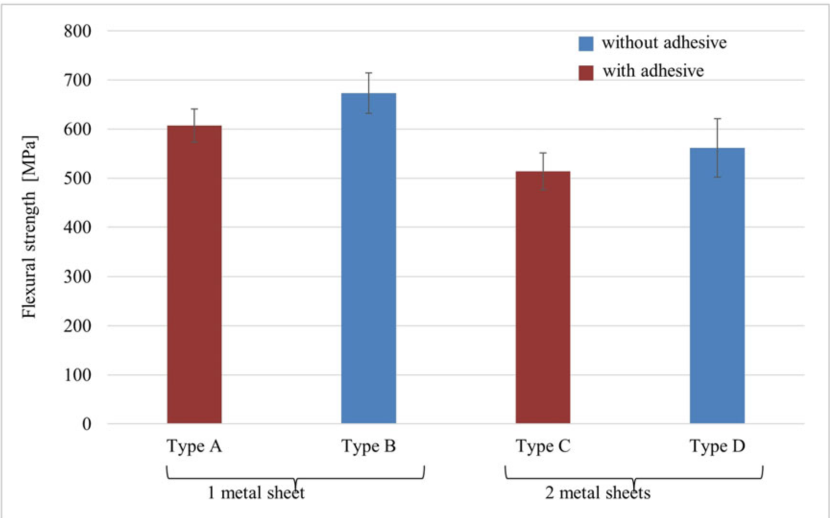

FIGURE 2 Comparison of flexural strength for the different type of carbon fibre–reinforced aluminium laminates (CARALL)

3 | FUTURE DEVELOPMENTS AND CHALLENGES

The application fields of the FML are destined to expand in the coming years, thanks to the remarkable structural properties and the low weight that are fundamental characteristics for the weight reduction in the transport industry with a view to reducing the fuel consumption and, consequently, the polluting emissions. Therefore, further investigations on the mechanical properties will be required in the future; several aspects can be investigated, from the static and dynamic characterization up to durability tests, intended both as a fatigue life and corrosion resistance. The deep understanding of FML properties will allow the accurate simulation and calculation of the material behaviour, necessary for designing and validating structures made of this material; in fact, FMLs are halfway between a material and a structure, so the material can be tailored for sustaining the loads a particular structure is subjected to. As concerns corrosion, CARALL is the most problematic one; in fact, galvanic corrosion is present as two conductive materials are connected by an electrolyte: both aluminium sheet and carbon fibres are conductive, so greater efforts will have to be spent to limit or eliminate this type of problem.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTION

The project was conceived by all the authors, C.B. and V.D.C. performed the experiments and wrote the paper, and F.I. and L.S. revised the manuscript.

Keywords

carbon/epoxy, fibre-metal laminate, strength

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