BEARING STRENGTH HIGH PERFORMANCE FIBRE METAL THIN-PLY LAMINATES

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1. Introduction

Conventional carbon fibre reinforced polymer (CFRP) laminates or structures do not exploit the full potential of the used carbon fibres. One approach to improve their performance is to reduce the layer thickness. The degree of freedom in design increases with decreasing layer thickness due to the larger number of used layers or more precise load-dependent design. As well, the failure behaviour is significantly dependent on the layer thickness. With decreasing layer thickness, the initiation of transverse microcracking shifts to higher strains and delaminations are suppressed. The failure mode changes from complex delamination dominated failure to a brittle failure mode, and tensile and compressive strength increases up to 42 % respectively 24 % [1]. With increasing strength, the requirements on the material increase in areas of load introduction and stress concentrations. Especially in areas of stress concentrations, adverse effects of the brittle failure behaviour can be observed. Studies demonstrate that in open hole tensile (OHT) tests the strength decreases with decreasing layer thickness [1, 2]. As pre-damages in the material are suppressed, stresses in areas of high concentration are not diverted or reduced by pre-damages, resulting in a high local stress concentration and results in premature failure. In the case of load introduction by bolts, although the bearing strength increases with decreasing layer thickness, the difference between un-notched and notched strength increases, so that the structure, material or number of bolts must be adapted to exploit the full potential of Thin-Ply laminates. This study investigates the influence of local stainless steel hybridisation of Thin- and Thick-Ply CFRP laminates on the open hole and bearing properties.

2. Materials and methods

The open hole tensile and bearing strength tests were performed according to ASTM D5766 and ASTM D5961, respectively, using a quasi-isotropic layup. Two layer thicknesses of CFRP unidirectional prepregs with the area weights of 40 g/m² and 160 g/m² were used. Stainless steel foil (1.4310) patches with the same thicknesses as the layers replaced locally 90° CFRP layers in

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areas with high-stress concentrations or load introduction. The local stainless steel volume content varies from 6.25 %, 12.5 % to 25.0 %. If the steel content is lower than 25.0 %, the outer 90° layers are replaced symmetrical to the mid-plane (see figure 1). A high-performance sol-gel surface pre-treatment process using 3M's AC-130-2 surface pre-treatment system, an aircraft certified water-based system, was applied to increase the adhesion between steel and matrix.

3. Results and Discussion

The OHT strength of the neat Thin-Ply samples recorded a 9 % lower strength than the Thick-Ply specimens. The results correspond to other studies in this field [1, 2]. With increasing steel content, the OHT strength increases. With a local steel content of 25.0 %, the strength rises by 64 % ,and even the specific strength rises by up to 36 %. The specific open hole tensile strength represents the ratio of the strength and the global density of the specimen, and the notch sensitivity decreases.

In contrast to the thin layer fibre metal laminates, the laminates with thicker layers show delaminations between the stainless steel and the CFRP layers. These delaminations are initiated at the transition zone between the steel foils and the 90° CFRP layers. Digital Image Correlation System images show stress concentrations in the transition zone even at low strains. Due to the low layer thickness, it is possible to arrange the steel patches in a stepwise pattern in the area of the transition zone (see figure 1), thus reducing possible stress concentrations, and due to the higher number of interfaces between the layers, the interlaminar stresses decreased with decreasing layer thickness. Both effects results in no delaminations.

Due to the hybridisation with stainless steel foils, significantly higher bearing strengths can be observed. In contrast to the neat Thin-Ply samples with a bearing strength of 979.6 MPa, the strength of the samples with stainless steel foil increases to 1165.4 MPa in the case of 6.25 % stainless steel, via 1239.5 MPa in the case of 12.5 %, to 1513.9 MPa if all 90° layers are replaced by steel patches. In addition to the increased bearing strength, failure behaviour has changed. In contrast to the brittle failure of the Thin-Ply specimens, pre-damage occurs with increasing steel content, but the pre-damages do not result in final failure. The outer steel layers support the laminate through their relatively high bending stiffness so that local buckling does not lead to final failure. The results of the bearing strength are shown in figure 2. The diagram presents the maximum bearing strength, the offset strength at 2 % elongation and the stress of the first failure. As written above, although the maximum strength increases with increased steel content, the first damage of all hybrid configurations occurs at the same stress level and the offset limit defined for the design of a structure does not change. For the industrial application, a hybridisation of more than 6.25 % of steel content does not provide further advantages. The only significant increase is in the safety factor for ultimate failure. It is noticeable that the thick fibre metal laminates show the highest stresses concerning the first failure or offset stress. They exhibit the best bearing performance, because of the high bending stiffness of the thicker stainless steel foil patches.

This study shows that the hybridisation of Thin-Ply CFRP laminates with stainless steel patches in areas of stress concentration and load introduction significantly increases open hole tensile and bearing strength. The previous limitation of the gap between unnotched strength and open hole or bearing strength can be reduced, allowing the potential of thin layers to be applied in structural light weight applications.

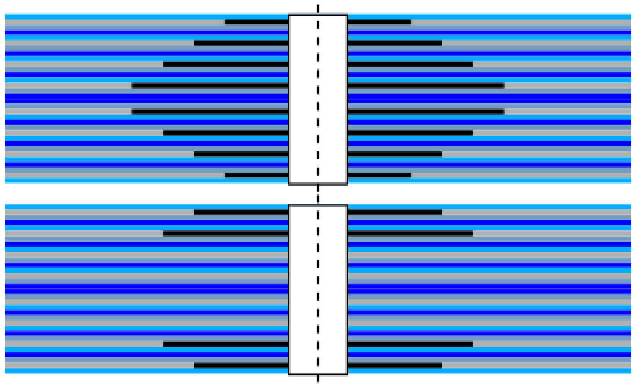

Fig. 1. Laminate layup for 25 % and 12.5 % stainless steel (black areas) content

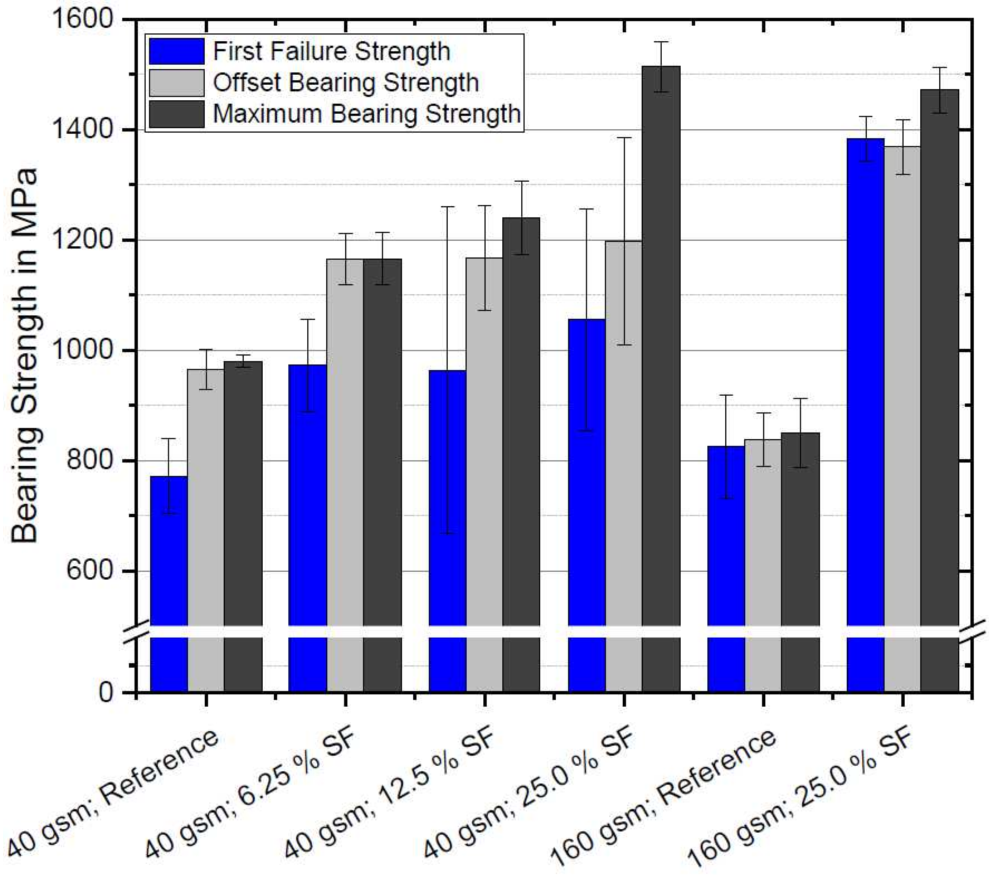

Fig. 2. First failure (blue), offset (grey) and maximum (black) bearing strength for neat and fibre metal laminates

4. References

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