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Interlaminar shear strength of fibre metal laminates after thermal cycles

Patryk Jakubczak*, Jaroslaw Bienias, Barbara Surowska

Department of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland

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ABSTRACT

Fibre Metal Laminates are characterized by low density, high static and fatigue strength, high impact resistance and good corrosion resistance. Currently some new solutions of FML which will contain carbon fibre reinforced polymer layers with aluminium (CARALL laminates) are tested.

The purpose of the study was to investigate the influence of the thermal cycles on interlaminar shear strength and microstructure of aluminium-carbon fibres laminates modified by additional glass interlayer.

Six different variants of laminates were tested. The 1500 thermal cycles were used. Before and after thermal cycles, the Interlaminar Shear Strength tests were conducted to compare the shear properties of CARALL and CARALL with thin glass interlayer. No delamination, cracks of matrix or fibres were observed after thermal cycles. The interlaminar shear tests have shown that the strength is not dependent on thermal cycles. However, some differences in microstructure of FML after ILSS were noted. Laminates without thermal cycles were damaged more often by delamination at the metal/composite interphases in the middle region of sample (directly under the stamp), whilst the laminates after thermal cycles were damaged also by delamination at the metal/composite interphases but the delamination mostly originated from the edges of the samples. National Science Centre, Poland UMO-2014/15/B/ST8/03447.

1. Introduction

Fibre Metal Laminates (FML) are relatively new hybrid materials based on metal and polymer/matrix composites. Actually only GLARE (GLass Aluminum REinforced) type of FML were used commercially in Airbus A380. FML materials have excellent mechanical, fatigue and corrosion resistance, which is crucial in aerospace constructions. Other well-known types of FML, such as ARALLs (Aramid Reinforced ALuminium Laminates) or CARALLs (Carbon Reinforced ALuminium Laminates), can provide mechanical, fatigue and impact resistance, yet certain other problems do occur. ARALLs are unprofitable and they have poor mechanical properties of fibre/matrix interface. Much more perspective are laminates with aluminium and carbon fibres. Apart from higher strength as compared to others FML, CARALLs also have the lowest density and the highest stiffness [1].

However, one of the problem in hybrid materials could be their long-time performance under thermal cycles. Aluminium, anodic layer, glass fibres and carbon fibres have differences up to 80% in the coefficient of thermal expansion (CTE) of the components [2]. The first aspect of the above is the fact that manufacturing process takes place in high temperature (curing), which can give initial internal stresses. Another point is that FML, used in aircraft fuselages, would be subject to cyclic temperature exposure ranging from −50 to +80 °C, a typical operation envelope. Then the thermal cycles may cause degradation of mechanical properties, because of degradation of interfaces in FML. In the case of CARALL, extra glass fibre layers are used to separate carbon and aluminium because of galvanic corrosion [3–6]. Glass fibres, often in opposite direction then carbon fibres, as well as aluminium layers are characterized by different thermal expansion coefficient, which can generate extra stresses inside the laminate at the layers interfaces during temperature changes [7–9]. A similar modification of surface treatment by e.g. sealing of anodic surface beforehand to improve corrosion resistance, can also decrease the adhesion at the metal-composite interface which can have a negative effect when extra thermal stresses occurs. All of the abovementioned factors are important in the case of fibre metal laminates, especially in term of metal-composite and composite-composite interface.

The thermal fatigue of different fibre metal laminates has been the subject of a number of scientific works till now. De Costa et al. [2] contemporary work deals with the effect of two thousand thermal cycles in two important properties of FML, tensile and ILSS. The authors concluded that the strength and elongation remained practically unchanged after thermal cycling, and the failure mode was the same for all samples. This was true in the case of tensile as well as ILSS.

* Corresponding author.
E-mail address: p.jakubczak@pollub.pl (P. Jakubczak).

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Table 1
Fibre Metal Laminates subjected to thermal fatigue and ILSS test.

S – FML after manufacturing T – FML after thermal fatigue		Metal surface protection	
		SAA + primer (**1._**)	SAA + sealing + primer (**2._**)
Interlayer glass protection	No glass interlayer (**_.1**)	S1.1 T1.1	S2.1 T2.1
	longitudinal UD thin glass layer (**_.2**)	S1.2 T1.2	S2.2 T2.2
	transverse UD thin glass layer (**_.3**)	S1.3 T1.3	S2.3 T2.3

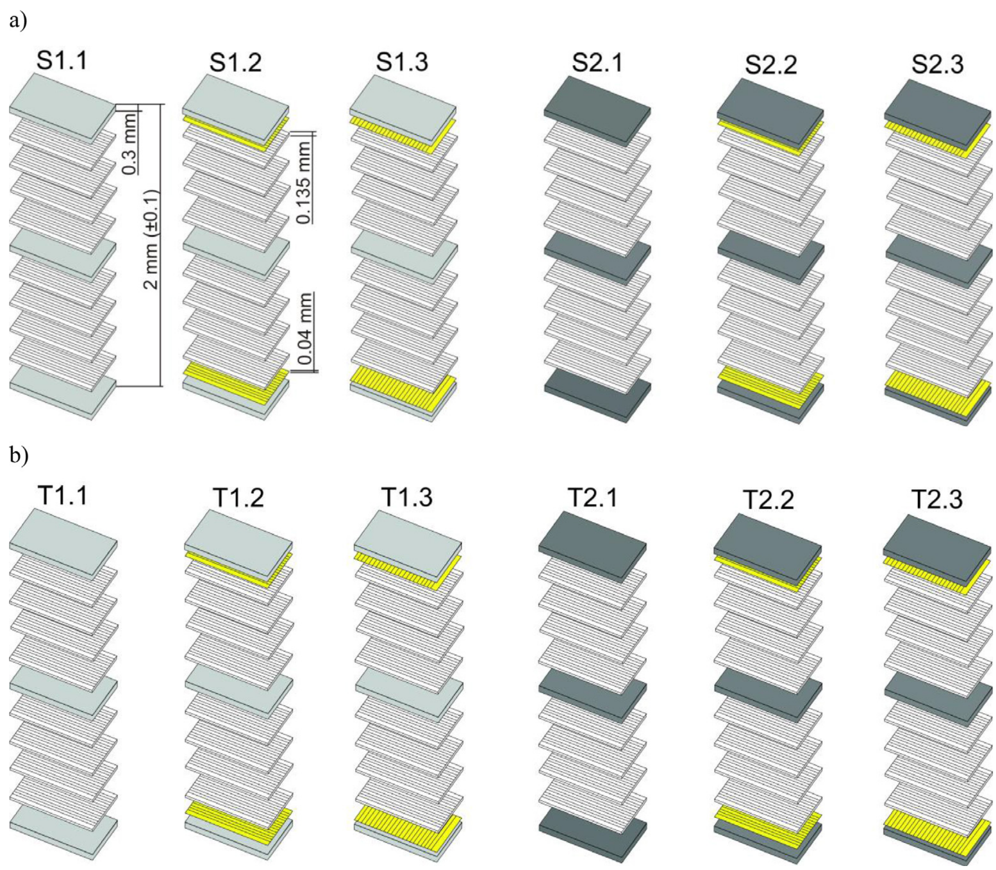

Fig. 1. Scheme of tested fibre metal laminates (a) samples without environmental exposition and (b) samples after thermal fatigue.

Hu et al. [10] tested titanium-carbon fibre laminates, among others, by thermal cycles (up to 1500 cycles) in the range from RT (room temperature) to 300 °C. After thermal cycles, the ILSS tests were used to check the influence of cyclic temperature changes. Authors concluded that the tested titanium–prepreg interface from the same cross-section reveals that the interphase is indeed continuous under 1000 cycles. When the number of cycles was 1500 delamination between the titanium and the carbon were observed. Difference in the coefficient of thermal expansion caused that prepreg layers tend to shrink more than the titanium layers every-time they cool down.

Park et al. [11] tested selected Glare types laminates by using 1500 thermal cycles (from + 25 to + 125 °C). The authors observed that there is 9–18% decrease in ILSS for Glare after 1500 cycles due to the large CTE difference between the constituent materials. However, the authors did not take into account differences of failure mechanisms and it is still not known what differences are in microstructure after mechanical tests of FML before and after thermal cycles.

The additional glass fibres in CARALL laminates can decrease mechanical properties even by 10% [12]. However, it can also improve corrosion resistance by separating carbon and aluminium (galvanic problem). The different surface treatment can influence the adhesion. Each of above factors can be important in terms of thermal problem because of different thermal expansion coefficient [7–9] of FML elements.

The works about thermal cycles of FML are scarce and present only basic types of FML, without detailed investigation of relations between thermal cycles – properties degradation – microstructure. Moreover, the possibilities of manufacturing of FML with different fibres are important in terms of thermal cycles resistance. Examples are laminates with carbon fibre core with extra interlayers of glass as a separation (because of galvanic corrosion) between aluminium and carbon. That is why the purpose of the study was to investigate the influence of thermal cycles in standard range for aircraft operation, on interlaminar shear strength and microstructure of aluminum-carbon fibres laminates and modified by application additional glass interlayer protection.