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Effect of prepreg gaps and overlaps on mechanical properties of fibre metal laminates

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A R T I C L E I N F O

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A B S T R A C T

During the automated manufacturing of fibre reinforced laminates, defects can be produced. Gaps and overlaps between adjacent prepreg layers can be produced in composites during the tape-layup process. However, the topic is not yet studied for hybrid materials, in which metal sheets and thin prepreg layers lead to different effects due to the defects than in full composites. Here, the effect of gaps and overlaps on the mechanical properties of the Fibre metal laminates (FML) is evaluated. Specimens are manufactured with a specified width of gaps/overlaps and the mechanical performance of the panels is evaluated by some selected mechanical tests. Gaps show to have a considerable effect on the mechanical performance of FML. Compression strength of samples with overlaps was rather increased. Discussions are presented on the influence on each mechanical property according to the severity of the defect (gaps/overlap) and the failure mode(s) under consideration.

1. Introduction

Fibre metal laminates (FML) are hybrid materials composed of metallic and (fibre/polymer) composite constituents. Besides their high values of strength/weight ratios, alternating metal and composite layers in FML result in high structural performances like fatigue life, residual strength and damage tolerance [1,2] which enhance safety and performance to the aircraft. Fuselage panels and leading edges of tail planes are among structural parts of aircraft in which FML have found applications. For aerospace, Glass Aluminium Reinforced Epoxy (GLARE) serves as the most common type of FML, consisting of aluminium sheets laminated with glass fibre epoxy prepreg layers (Fig. 1).

Research is being conducted in the Faculty of Aerospace Engineering at TU Delft, on the analysis and prediction of manufacturing processes of fuselage panels made of FML. The reader can be referred to published papers in this regard which are mostly about the curing-induced phenomena during manufacturing of FML [4–7].

Although, the range, understanding and applications of FML are further developed by researchers [8–10], the effects of manufacturing processes on the final product are not studied in detail yet. The project “Effects of Defects during automated manufacturing of GLARE” at TU Delft aims (í) to develop techniques to detect the possible defects and (ii) to evaluate the effects of the defects on the mechanical performance of panels made from GLARE. Studies on the detection and evaluation of the gaps/overlaps in GLARE are presented in another paper by the authors [11]. In this paper, after an introduction to the manufacturing process of GLARE, the effects of gaps and overlaps are evaluated on the mechanical properties. Gaps/overlaps may occur during the automated tape-layup process. Until now, production of small number of GLARE was done manually. However, the need for manufacturing large number of panels necessitates an automated procedure. The automated layup process which incorporates narrow tapes of prepreg to be put on the aluminium sheets, increases the possibility of gaps and overlaps.

It should be noted that the manufacturing defects considered in this paper are common with full composites within an automated layup process. Therefore, some research already done on full composites can be considered as references to study the similar phenomena occurring during the automated layup process for GLARE (see for example Refs. [12;13]). On the other hand, the detection and the effects of gaps and overlaps are different in case of GLARE. During the autoclave curing (under pressure), aluminium sheets make difference by flattening the prepreg layers and therefore increase or decrease the gap or overlap width and also may need different detection procedures and techniques. Furthermore, the glass/epoxy layers are fewer in number, consisting of thin prepregs between aluminium sheets which leads to more sever effect by the presence of a gap (missing fibres).

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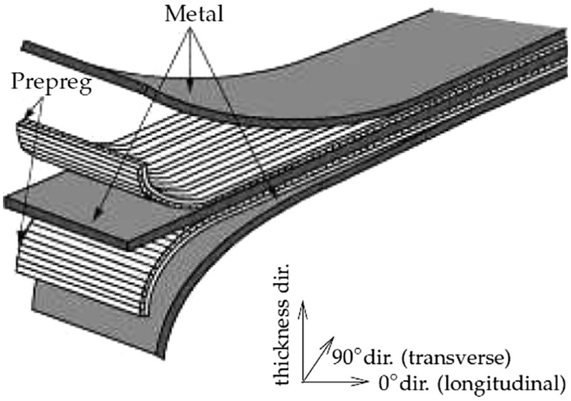

Fig. 1. Typical configuration of GLARE [3].

Table 1
Material properties for GLARE constituents.

S2-Glass/FM-94 prepreg [6]					
E_1 [GPa]	$E_2 = E_3$ [GPa]	$G_{12} = G_{13}$ [GPa]	$\nu_{12} = \nu_{13}$	α_1 [1/C]	α_2 [1/C]
52.0	7.4	3.0	0.33	4.1×10^{-6}	48.6×10^{-6}
Aluminium 2024-T3 [14]					
E [GPa]	G [GPa]	ν	α [1/C]		
72.4	27.6	0.33	22×10^{-6}		

Fig. 2. Layup process for panels made from GLARE. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

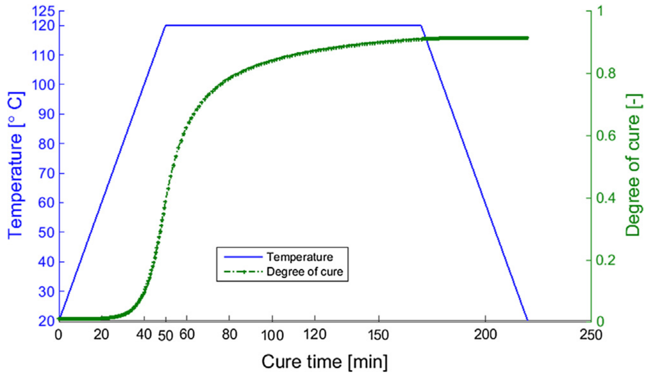

Fig. 3. Cure cycle of GLARE [15]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Material type and manufacturing of GLARE

The FML investigated here is GLARE which is composed of aluminium sheets (*2024-T3)* laminated with prepreg layers in between. The unidirectional (UD) prepreg layers have *S2-Glass* fibres *and FM-94* epoxy adhesive [14]. The elastic properties of the constituents are listed in Table 1. For the details of the calculations for the laminate response in elastic and viscoelastic (temperature-dependent) regions, the reader can refer to a previous paper [6].

2.1. General manufacturing procedure

Hand layup is used in the conventional manufacturing of GLARE. Sheets of aluminium and prepreg layers are cut to size and laminated according to the desired layup. In Fig. 2, the layup procedure is shown. Important to notice is that according to the standard layup of GLARE, fibre orientations of the prepreg layers are specified with respect to the rolling direction of the aluminium layers. In other words, the 0-degree fibre layers are along the rolling direction of aluminium and 90-degree fibre layers are put perpendicular to the rolling direction of aluminium. Accordingly, later in this paper, L and LT symbols refer to the directions along and perpendicular to the rolling direction.

The layup is done on a mould made from aluminium and after preparing a vacuum bag, the laminate is cured in an autoclave under pressure to cure the resin and to bond the layers. A standard cure cycle of GLARE is shown in Fig. 3 in which the temperature profile together with the degree of cure development is illustrated. The evolution of the degree of cure is already measured for the used FM-94 epoxy, as published in an earlier work by the authors [15]. The autoclave pressure is set at 6 bar.

Fuselage panels made from GLARE can be complex with features including thickness changes, splices, doublers and stringers (see Fig. 4). Splices are used to attach adjacent panels and make larger fuselage panels. Doublers are extra aluminium sheets that locally reinforce the panels which can be seen around the cut-outs. Reinforcements like stringers which are used to stiffen the panels against buckling (increase stability) and also large doublers may be bonded to the panel in a second autoclave cure cycle which is actually called a bonding cycle.

Up to now, the layup process is being carried out manually. This made possible the accurate placement of fibre layers between aluminium sheets and works for a small number of products. Manufacturing time can be decreased through automated layup processes, which becomes especially critical when a large number of panels is going to be produced. One example would be smaller airplanes like Airbus A320 which a larger number of aircraft is aimed for, compared to large aircrafts like Airbus A380. On the other hand, the automated manufacturing may cause defects like gaps and overlaps and there is more probability for them to occur.

2.2. Defect types-features during manufacturing

The defect type of gaps and overlaps is not new within the manufacturing of full composites. As an example, in 2011, Croft et Al. have investigated the effects from the existence of gaps, overlaps, half gap/overlap, and twisted tows during the automated fibre placement process of composites [12]. They have done measurements on the properties at the laminae and laminate levels, separately. As a result, the ultimate strength was decreased by 5% at the laminae level and by 13% at the laminate level. Another work was reported by Seon et Al. in 2013 [16] who studied the effect of porosity on the inter-laminar tensile fatigue response of carbon fibre epoxy laminates. Another rather elaborate study was carried out by Lan et Al. in 2015 and 2016 [13,17] to measure the effects from the embedded gaps/overlaps during the automated fibre placement process on some properties of the carbon-epoxy composite including tensile, inplane shear, and compression. C-scan and Scanning Electron Microscopy (SEM) were used to study the