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Impact behaviour of glass fibre-reinforced epoxy/aluminium fibre metal laminate manufactured by Vacuum Assisted Resin Transfer Moulding

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Fibre Metal Laminates have been manufactured by liquid moulding. Flow paths have been drilled to enable the impregnation through the aluminium sheets. The effect of these holes on the low velocity impact behaviour has been studied. Damage mechanisms, dissipated energy and peak force of drilled samples have been compared to those of reference samples without holes. Results show that the presence of the holes has no effect on the performance of the plate and that the internal damage is confined to the surrounding of the impact zone. When the holes are inside the impact contact zone cracks in aluminium sheets propagate through the holes, but their effect is mitigated by the fibre bridging mechanism. Holes located out of the impact contact zone have no effect in the damage mechanisms.

1. Introduction

Fibre Metal Laminates (FMLs), which are hybrid materials where thin metal sheets and fibre-reinforced composites are alternatively layered, are interesting for substituting monolithic metal sheets of the same areal density [1,2]. FMLs combine the superior fatigue and fracture characteristics of the composites with the ductility of the metals. Although the initial attention to FMLs was on the improvement of fatigue properties [1,2], numerous experiments have demonstrated that FMLs also show superior impact properties [3–5].

The most widely used and studied FMLs consist of alternating 2024-T3 aluminium and glass fibre-reinforced epoxy, manufactured by prepreg/autoclave technology. Thus, even if FMLs are promising lightweight materials for aeronautic applications, cost-effective out-of-autoclave processes should be developed in order to consider the feasibility of these materials for other transport sectors. One of such alternative could be the Liquid Composite Moulding technologies (LCM).

Vacuum Assisted Resin Transfer Moulding (VARTM) has been proved to be a successful technology to manufacture FMLs [6–13]. The proposed method consists on the alternative piling of aluminium sheets and dry glass fibre fabrics, and the posterior infusion of the resin into the reinforcement preform. In order to allow the resin flowing through the thickness, an arrangement of holes have to be drilled in the aluminium sheets. This technique is still at its earliest stage and needs more extensive research. Preliminary studies focused on processing viability [6–10] and fatigue behaviour [11–13] of these new FMLs, but there is a lack of knowledge about their impact behaviour, since in the published works addressing the impact behaviour of FML [3–5] the aluminium sheets were not drilled.

The damage behaviour of FMLs can be classified in terms of their failure type into two groups; “fibre dominated” and “metal dominated”. Glass fibre-reinforced epoxy/aluminium has “metal dominated” behaviour [3], so any modification on the aluminium sheets could alter the impact performance of the FMLs. The holes could act as stress concentrators, so their effect on impact behaviour should be understood in order to balance fast impregnation and mechanical performances.

The scope of the present work is to evaluate the effect of the holes on the impact behaviour of glass fibre-reinforced epoxy/aluminium FMLs produced by VARTM. The effect of the distance between the impact point and the hole is analysed, and additionally, the results are compared to reference specimens without holes.

2. Materials and experimental methods

2.1. Materials and FML manufacturing

The thermosetting system used in this study was an SR 8100 epoxy resin and SD 8820 hardener (supplied by SICOMIN Composites). The resin/hardener mix ratio was 100:31 parts by weight. In order to remove air bubbles created at the initial resin–hardener

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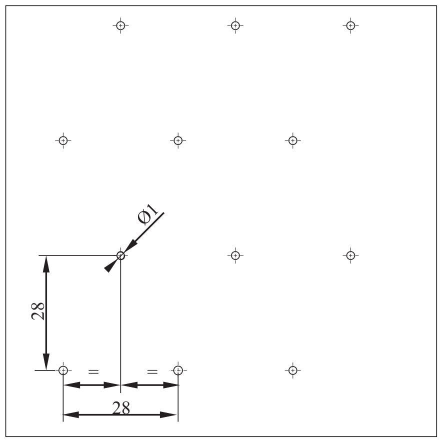

Fig. 1. Distribution of the holes that generate the flow paths.

mixing stage, the mixture was left for 10–15 min under vacuum in a degassing chamber. The reinforcement used was E-type glass fibre fabric with plain weave architecture and has an areal density of 290 g/m^2. The fibre volume fraction of the composite phase in the FML is approximately 48%.

The 2024-T3 aluminium alloy used in this research was a 0.41 mm thick sheet supplied by Alcoa. In order to improve the aluminium/epoxy interface, a Chromic Acid Anodizing (CAA) surface treatment was performed to the aluminium sheets [2], additionally a BR 127 corrosion inhibiting epoxy primer coating was applied.

Holes were drilled in the central zone of the aluminium sheets in order to produce flow paths through the metal layers. The holes were drilled following a pattern as shown in Fig. 1 with a 1 mm tool (Unimax Drill C-UMD 2100-100, Union Tools) mounted on a high precision micromilling machine (Kern Evo). Drilling conditions were set to spindle speed of 6400 rpm and feed rate 60 mm/min. High dimensional quality and low roughness are obtained with these drilling parameters. A transverse permeability through the metal of 1.89×10^{-11} m^2 was calculated based on the permeability model proposed by Roy et al. [14].

The VARTM set-up is shown in Fig. 2. Resin was introduced by the inlet pipe (1) and distributed by a flow media placed on top of the central zone of the plate (2). Then resin was forced to impregnate the preform (3) through the drilled aluminium sheets (4), generating a through-thickness flow. In the outer zones of the laminate there was no flow between fibre phases and the resin was forced to advance in the planar dimension, this constrain leaded to two parallel resin infusions. The pulling force was created by applying vacuum at the outlet pipes (5) situated at the end of the plate. Compaction was obtained with a vacuum bag (6) sealed with tapes (7).

FML plates were constructed with a 3/2 configuration and a thickness of 2.99 ± 0.08 mm. The total dimensions of the plates were 300×600 mm^2 and the size of the central zone, where the SCRIMP type infusion was given, was 300×300 mm^2. The Metal Volume Fraction (MVF) and the areal density of the resulting FMLs were 0.40 and 6.44 ± 0.98 kg/m^2, respectively. The rolling direction of the aluminium sheets coincided with the weft direction of the glass fibre fabric.

2.2. Impact characterisation

Circular impact specimens of 60 mm of diameter were cut by water-jet. Samples with holes were obtained from the central part of the plate and reference specimens without holes were cut from the outer zones. In order to study the effect of the position of the holes, FML specimens with different hole-locations were obtained. In Fig. 3 the distance between the impact contact zone and the nearest hole is represented, the distance in the different directions (aluminium lamination direction, perpendicular direction) and the radial distance (described in the parenthesis) is result of the samples cutting process, with a random distribution. Each point corresponds to a different FML sample.

Low velocity impact tests were carried out in a falling weight test equipment (Fractovis-Plus, Ceast). The impactor was equipped with a 20 kN load cell attached to the impactor which recorded the contact force history. The hemispherical head of the impactor had a diameter of 20 mm, multiple collisions were avoided by anti-rebound device. For impact energies ranging from 2 J to 50 J The impactor mass was kept constant and equal to 5.045 kg while the impact velocity was modified varying the drop height between the limits of 0.98 m/s and 4.43 m/s. In order to achieve higher dam-

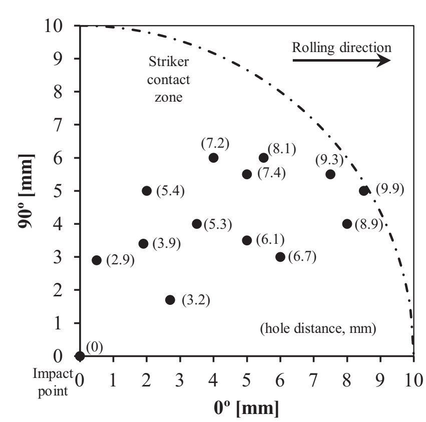

Fig. 3. Hole position in different FML samples.

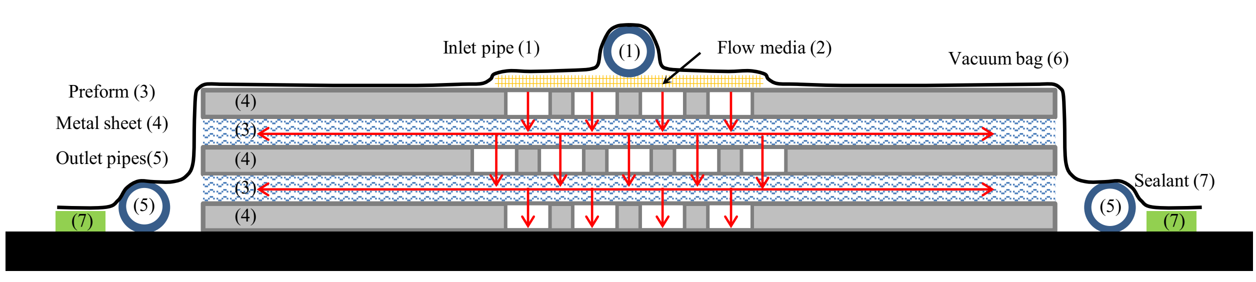

Fig. 2. VARTM process set-up schema.