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Interfacial fracture of the fibre-metal laminates based on fibre reinforced thermoplastics

M.R. Abdullah [a], Y. Prawoto [b,*], W.J. Cantwell [c,d]

[a] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor 81310, Malaysia
[b] Department of Physics Energy Engineering, Surya University, Jl. Boulevard Gading Serpong Blok O/1, Summarecon Serpong Tangerang 15810 Indonesia
[c] Department of Aerospace Engineering, Khalifa University of Science, Technology and Research (KUSTAR), PO Box 127788, Abu Dhabi, United Arab Emirates
[d] Department of Engineering, University of Liverpool, Liverpool L69 3BX, United Kingdom

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ABSTRACT

As the adhesion quality plays an important role in determining the mechanical performance and environmental stability of most types of fibre-metal laminates (FMLs), investigating the interfacial fracture properties becomes one of the key factors for the improvement. Adhesion of a self-reinforced polypropylene (SRPP) and glass fibre reinforced polypropylene (GFPP) based FML is evaluated experimentally. Single Cantilever Beam (SCB) tests were performed to access interfacial fracture energy (G_c) of the bi-material laminates and their associated interlayer materials. Simulations mimicking the experiments were also performed. The energy needed to fracture was obtained experimentally and also via stress intensity factor from the simulations. The test results show that good adhesion between the aluminium and fibre reinforced thermoplastics can be achieved using a sulphuric acid anodising surface pre-treatment. Further examination has shown that the edges of the test samples highlighted the presence of significant fibre bridging in the SRPP and plastics deformation in the GFPP.

1 Introduction

Fibre metal laminates (FMLs) are metallic materials consisting of a laminate of several thin metal layers bonded to plies of composite material. This combination allows the material to behave much as a simple metallic structure, but with specific advantages such as a high impact resistance, superior corrosion resistance, improved fire resistance, and weight-savings. In this study, the focus is on fracture mechanics, especially the stress intensity factor and energy absorption, for which FMLs are known to exhibit excellent properties [1–4]. Sinmazelik reviewed the type of the fibre metal laminates, bonding types and applied test methods quite thoroughly [5], while the same research group studied the morphology of the fracture surfaces and their characteristics [6].

Interest in these novel types of material results from the combination of the high interfacial toughness properties of composite plies and the high impact resistance of the metallic layers. At present, epoxy based FML systems such as glass laminate aluminium reinforced epoxy (GLARE) and aramid aluminium laminate (ARALL) are used in a number of load-bearing aerospace applications. Glass fibre reinforced epoxy (GFRP)-based FMLs exhibit excellent impact resistance, superior than that of monolithic aluminium alloys and far superior than that of carbon laminates. Vlot and Fredell [7] observed that GLARE 3 offers a superior impact performance than the 2024-T3 aluminium alloy, an ARALL 2 and a quasi-isotropic carbon fibre reinforced polymer (CFRP)/polyetheretherketone (PEEK) composite. It was also confirmed that the excellent impact performance of GLARE is improved at higher strain rates that occur in the glass fibres, combined with their relatively high failure strain [3,8].

The first generation of thermosetting-based FMLs suffered a number of key limitations including long processing cycles, low interlaminar fracture toughness properties as well as difficulties associated with repair. In an attempt to overcome many of these problems, a number of novel FMLs based on thermoplastic matrices have been developed and tested. Thermoplastic-based fibre-metal laminates offer a number of advantages including very short processing times, ease of forming, improved chemical resistance, excellent repairability and superior interlaminar fracture toughness properties. Cantwell et al. [9–10] and Cortes and Cantwell [11] performed low and high velocity impact tests on the FMLs based on a thermoplastic composite. They found that perforation energy and specific perforation energy of multi-layered

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* Corresponding author. Tel.: +62 87739045399;
E-mail addresses: ruslan@fkm.utm.my (M.R. Abdullah), yunan.prawoto@surya.ac.id, yunan.prawoto@gmail.com (Y. Prawoto), W.Cantwell@liverpool.ac.uk, W.Cantwell@liverpool.ac.uk (W.J. Cantwell).

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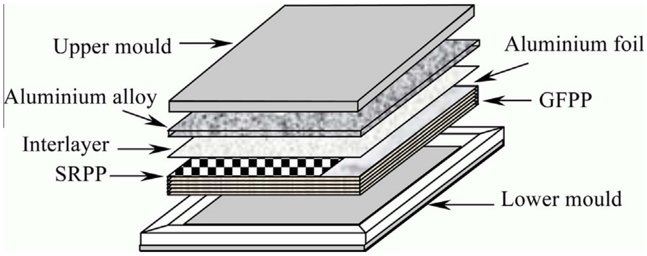

Fig. 1. The stacking arrangement of the aluminium and composite sheets in the picture frame mould.

composite is greater than that offered by monolithic aluminium and a plain composite. Abdullah and Cantwell [12] saw that this hybrid laminates systems offer potential for use in lightweight energy-absorption structures. Impact tests have shown that FMLs based on stronger 2024-T3 alloy offer a superior perforation resistance to those based on a 2024-O alloy. It was observed that the highest specific perforation energy (S.P.E) was offered by a simple sandwich construction based on thick composite core and thin outer aluminium plies.

The aim of the present work is to investigate interfacial fracture properties of a novel FMLs based on lightweight aluminium alloy and a fibre reinforced thermoplastics. Modelling is used to verify the interfacial fracture energy. The work also evaluates whether the previous benefits associated with other fibre reinforced thermoplastic-based FMLs [13,15] are observed in the current systems.

2. Experimental procedure

The laminates investigated in this study were based on 2024-T3 aluminium alloy sheets and two different thermoplastic composite materials, self-reinforced polypropylene (SRPP) and glass fibre reinforced polypropylene (GFPP). These two composite materials were selected since earlier work has shown that when they combined with thin sheets of aluminium alloy, they offer an outstanding resistance to high velocity impact loading. Summary of the materials investigated in this work is given in Table 1.

2.1. Self reinforced polypropylene-based FML

The thermoplastic-based single cantilever beam (SCB) samples were manufactured by stacking one ply of SRPP, eight plies of GFPP and 2 mm thick aluminium substrate (2024-T3) in a picture frame mould. Optimum adhesion between the SRPP and aluminium was ensured by placing a polypropylene interlayer at the bi-material interface as shown in Fig. 1. A starter defect based on a folded aluminium foil with dimensions of 50 × 240 mm and 0.09 mm thick was inserted between SRPP and aluminium alloy. The laminates were then placed in a press and heated to 165 °C at a heating rate of approximately 10 °C/min before being cooled to room temperature at a rate of approximately 5 °C/min. Once the press had cooled to a temperature below 60 °C, the panel was removed from the mould and visually inspected for any defects.

2.2. Glass fibre reinforced polypropylene-based FML

The GFPP-based SCB samples were manufactured by stacking eight plies of GFPP and 2 mm thick aluminium substrate in a picture frame mould. Optimum adhesion between the GFPP composite and the aluminium alloy was ensured by placing a polypropylene interlayer at the bi-material interface. Same starter defect and same heating process were also applied except this time 185 °C.

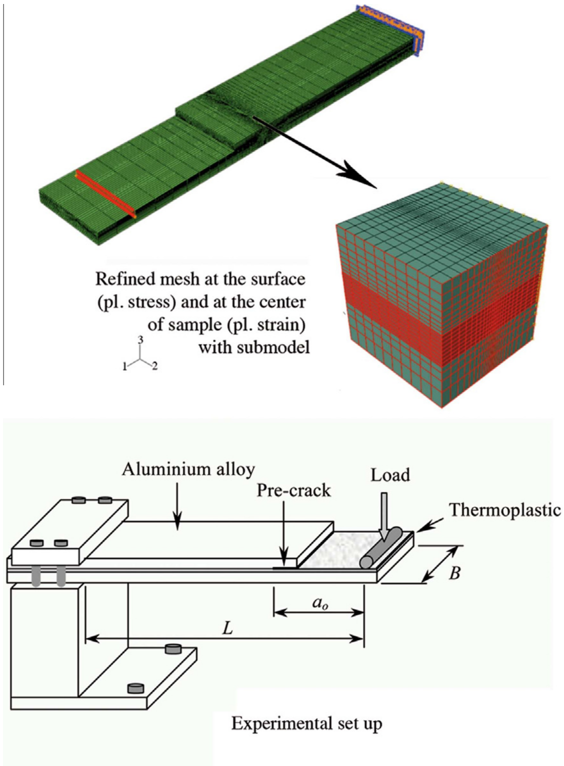

Fig. 2. Sample boundary condition and orientation (left), to mimic experimental set up (right).

For the FMLs based on pre-treated aluminium alloy, prior to laminating process, a sulphuric acid anodisation was applied to the aluminium substrate to ensure optimum adhesion to the composite plies. The purpose of anodising the metal substrate is to create a large and active surface area for the molten polypropylene interlayer to flow into and interlock with the aluminium. In addition, this coating on the aluminium surface can resist hydration of diffused moisture, protecting the base metal from corrosion. In this work, both Gluco and Xiro were used as interlayer materials.

Specimens having length, thickness and width dimensions of 200 mm, 5.40 mm and 20 mm respectively were cut from the panel in order to produce individual SCB samples. The loading arm (L) was 100 mm, the length of the starter defect (a_0) was 40 mm and the width (B) was 20 mm. Prior to testing, the edges of the specimens were painted with thin layer of white correction fluid and marked from the tip of the pre-crack to facilitate the observation of crack advance during the test. The SCB tests were conducted using an Instron 4505 universal test machine. The specimens were clamped at one end in a steel fixture as shown in Fig. 2. Load was applied at a crosshead displacement rate of 2 mm/min to the specimen arm, forcing a crack to propagate along the aluminium alloy-composite interface. Crack propagation along the bi-material interface was observed manually using a magnifying glass and noted every 5 mm from the tip of the pre-crack until the crack had extended approximately 40 mm. Load (P) versus specimen displacement (δ) reading was recorded by the Instron, while crack length (a) reading was taken on a marked scale prepared in advance. The specimen was then unloaded at the same crosshead displacement rate and removed from the test machine. The test was performed on at least three specimens to obtain reliable data.

The interfacial fracture energy (G_c) was determined using an experimental compliance calibration method [14–19], G_c is given by: