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Review

Impact on thermoplastic fibre-metal laminates: Experimental observations

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ABSTRACT

This work investigates a new generation of fibre metal laminates, termed TFMLs, based on an aluminium alloy and a self-reinforced polypropylene (SRPP). Circular plates were studied experimentally under conditions of localized impact loading. It was observed that the TFML plates outperform glass fibre/epoxy based FMLs under impact conditions. Limitations, associated with the metal/polymer interface and the interlayer toughness, are discussed in detail. The response of this material, and its constituents, were characterized over a wide range of strain-rates through the use of innovative equipment and techniques. This is of particular importance, given that the mechanical properties of SRPP are recognized as being strain-rate dependent. This paper presents extensive experimental data that can be used for modelling the response of TFMLs under impact conditions.

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Nomenclature

A schematic of the construction of a fibre-metal laminate (FML) is presented in Fig. 1. Here, the FML (or TFML) configurations are expressed using a shorthand notation, describing the lay-up configuration as *X/Y*, such as 2/1, 3/2 and 5/4. In this case, the number of metal and composite layers are indicated by *X* and *Y*, respectively; following the notation commonly used in the literature on this subject. Given that, the FML outer layers are generally made of metal, the number of composite layers is $Y = X - 1$. In this article, the material configurations are identified according to MXTO-#, where:

M indicates the composite material, this being P for polypropylene fibre based or G for glass fibre/epoxy reinforcement.
X number of metal layers
T thickness of the metal layers, A referring to 0.30 mm thick and B to 0.40 mm thick.
O number of glass fibre or woven PP plies used in each reinforcement block
\# indicates the specimen number

For example: The configuration of specimen P5A14-2 ($X = 5$, $O = 14$) is 5/4, having five 0.3 mm thick metallic layers and four PP-based reinforced block with 14 plies of woven PP

1. Introduction

The aerospace industry is continuously developing new lightweight materials with the aim of improving the structural performance of aircraft. Such structures are frequently subjected to impact loading, such as hail, ballistic impact and even explosions. Composite materials are preferred over conventional metals, due to their high specific strength/stiffness and superior fatigue resistance. More recently, there has been a growing of interest into investigating the possibility of combining composites and more traditional metal alloys to develop so-called hybrid materials, which are a combination of thin layers of metal sheet and fibre-reinforced composite. These materials are known as fibre-metal laminates (or FMLs), Fig. 1, and offer a superior fatigue toughness, failure characteristics and energy absorbing performance when compared to most metals. GLARE® is the commercial name of an FML based on a high-performance aluminium alloy and a glass fibre/epoxy composite. GLARE® was initially developed during cooperation between Delft University of Technology and Stoker-Fokker in the 1980's. It is currently used in the fuselage of the Airbus A-380 [1,2].

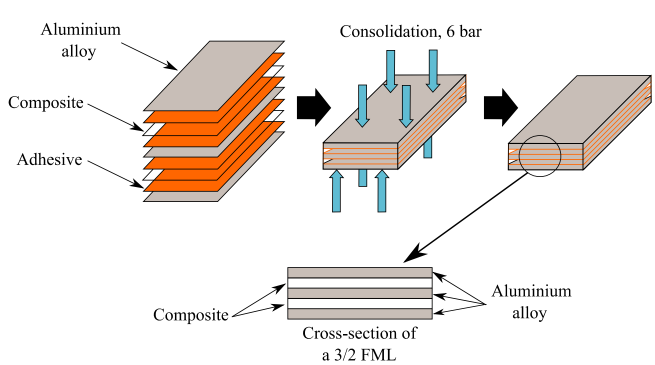

Fig. 1. FML schematic construction, adopted from [8].

Vlot [3,4] highlighted the impressive performance of GLARE© under static, low and high velocity impact loading, especially when compared to aerospace grades of aluminium alloy (such as 7075-T6 or 2024-T3) and carbon fibre/epoxy composites. The reason for ability to absorb impact energy is a combination of the viscous-plastic behaviour of aluminium and the high energy absorption capability of the composite. GLARE© also offers a superior response under high velocity impact loading compared to monolithic aluminium and carbon/epoxy, due to strain-rate sensitivity of the glass/epoxy.

Fleisher [5] investigated lightweight luggage containers based on GLARE© and reported that they are capable of absorbing a bomb blast greater than that used in the 1988 Lockerbie air disaster. Fatt et al. [6] determined the ballistic limit of GLARE© during impact by a blunt cylinder, and derived an analytical approach to predict this threshold. Reasonable agreement was observed with the experimental data and the model was used to estimate the energy absorption mechanisms in the FML panels. It was observed that the use of GLARE© results in a 15% increase in the ballistic limit, compared to 2024 aluminium alloy plates having the same areal density.

Despite the excellent impact performance and fatigue strength of GLARE© (or similar thermosetting-matrix FMLs), it does have drawbacks, associated with its relatively long processing cycle and modest interlaminar fracture toughness characteristics [7]. In an attempt to overcome many of these issues, a range of thermoplastic matrix FMLs, termed TFMLs, were developed at the University of Liverpool [8–12]. Reyes and Cantwell [10] studied TFMLs based on a glass fibre reinforced PP composite, reporting impressive improvements in the processing time, fracture toughness and impact resistance, compared to more conventional thermosetting-based FMLs.

Compston et al. [12] determined the high velocity impact response of a TFML based on a glass/polypropylene composite and concluded that the ballistic limit of this hybrid was up to 49% higher than an equivalent monolithic 2024-T3 aluminium plate. This improvement is significantly higher than the 15% increase yielded by GLARE©, as reported by Fatt [6]. Compston [12] reported lower interfacial fracture toughness between the metal and thermoplastic polymer, than observed in epoxy-based FMLs. However, this effect can also be considered as beneficial to the energy absorption capability of TFMLs. Iriondo et al. [13] performed dynamic mechanical analysis (DMA) tests on TFML samples made from a SRPP named Curv, observing that the elastic modulus is frequency dependent, due to its thermoplastic nature. It was also noted that damping in TFMLs is roughly ten times greater than in either GLARE or monolithic aluminium 2024-T3, suggesting that TFMLs may provide a better performance in vibration-dominated applications.

Abdullah [8] et al. studied the behaviour of a TFML based on polypropylene (PP) fibre reinforcements under low and high velocity impact conditions. Different configurations of TFML were studied and a superior performance of a 4/3 TFML, compared to 2/1 or 3/2 lay-ups was observed. Múgica et al. [16] compared the impact performance of aluminium and magnesium alloy based TFMLs under low velocity impact loading. The authors concluded that the perforation threshold of the aluminium-based TFML was more than double that of the magnesium-based TFML. The blast response of TFMLs was investigated by Langdon et al. [7] and Lemanski et al. [18]. They identified the resulting failure mechanisms in the various laminates, as well as in the monolithic material.

During impact loading, such as that associated with a ballistic or explosive event, the structure is accelerated rapidly, experiencing large deformations and failure. The material behaviour must be fully identified over a wide range of strain-rates and strain levels