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Material Behaviour

Effect of through thickness metal layer distribution on the low velocity impact response of fiber metal laminates

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ABSTRACT

The effect of distribution of aluminum layer through the thickness of fiber metal laminates (FMLs) on their low velocity impact response was studied. The FMLs were prepared using aluminum 2024-T3 layers (0.3, 0.4, 0.6 mm thickness) and glass fiber reinforced epoxy (two layers of 0° and 90° each) through hand layup followed by vacuum bagging. The four different layups considered had metallic layers placed at different locations through the thickness while maintaining the total metal layer thickness constant. The FMLs were subjected to low-velocity impact using a drop weight testing machine. The performance of FMLs was evaluated using different parameters such as maximum force, energy absorbed, damage degree, dent depth and maximum deflection. Among the four FMLs, it was observed that the FML 2/1–0.6 in which the composite layers were stacked together had lower levels of cracking and deformation and recorded the highest force for the same impact energy level, whereas the FML 4/3–0.3 in which two adjacent composite layers having different fiber orientations were separated by metallic layer recorded the lowest force and maximum cracking and deformation. The lateral spread of delamination and interlayer opening was comparatively greater for 2/1–0.6 when compared to 4/3–0.3, indicating that distributing the aluminum layers in the FML can decrease the lateral spread of damage within the FML.

1. Introduction

Composites based on glass fiber and thermosetting resin have good specific strength and stiffness. However, they invariably fail in a brittle manner, and hence have poor performance under impact. Metals, on the contrary, can absorb energy by plastic deformation before failure; however, their specific stiffness and strength are not a match for composites. Fiber metal laminates (FMLs) consisting of metallic sheets and fiber-reinforced composite layers stacked together are expected to have a balanced performance in terms of specific properties and impact resistance. The last decade has witnessed a surge in the research on FMLs and these studies have addressed many aspects of FMLs, ranging from their manufacture to performance evaluation under monotonic tensile loading, fatigue loading and both low and high velocity impact. A brief review of the existing studies relevant to the current study is presented in the following sections.

There are several studies addressing the impact behavior of FMLs consisting of composite layers having glass, carbon or aramid fibers as the reinforcement in a thermosetting or thermoplastic matrix. Vlot et al. [1–4] demonstrated that FMLs made of aluminum sheets and glass fiber reinforced epoxy (GFRP) performed better than a monolithic aluminum sheet having similar areal density as that of the FMLs. Due to their improved fatigue performance, blunt notch strength, corrosion properties and fire resistance, FMLs are finding application in aircrafts [5–7]. A review of the development of FMLs and their applications is presented in Ref. [8]. The improved impact response of FMLs when compared to monolithic metal was attributed to the rate sensitivity of the glass fiber strength [3,6]. Further, delamination between layers permitted membrane type behavior in the FMLs resulting in higher energy absorption by the aluminum layers as opposed to bending type deformation of thick monolithic aluminum sheets [3].

Caprino et al. [9] investigated the low-velocity impact response of FMLs consisting of GFRP and aluminum 2024-T3 layer and observed that the resistance of FML to complete penetration was better than that of composite. The FMLs in their study suffered lesser level of damage when compared to composite at impact energy levels that resulted in penetration. Lalibert'e et al. [10] studied the impact response of three different types of commercially available FMLs each having different number of composite layers. They observed that FMLs having higher fiber content absorbed the least energy and suffered lower level of

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damage. Fan et al. [11] observed that increasing both the number of metal and composite layers increased the specific perforation resistance of the FMLs. Atas [12] investigated the failure mechanisms in FMLs consisting of aluminum and GFRP layers and identified plastic deformation and shear fracture in the aluminum sheets, along with fiber fracture and delamination in the composite layers, to be the primary energy absorbing mechanisms.

Wu et al. [13] investigated the impact response of FMLs made of aluminum 2024-T3 sheets and GFRP. They observed that FML layup has an effect on their impact behavior. Liu and Liaw [14] also studied the effect of layup on the low-velocity impact response of FMLs. They reported that FMLs with cross ply composite layers have better impact resistance than FMLs having unidirectional composite layers. Keeping the FML layup the same, Sadighi et al. [15] observed that increasing the metal layer thickness improves the impact resistance of the FMLs. Yaghoubi et al. [16] investigated the effect of overall thickness of FML on the low-velocity impact response of GFRP-aluminum FMLs. They reported that the threshold cracking energy increases with thickness and thickness also had an influence on the modes of damage suffered by the FML.

Moriniére et al. [17] studied the effect of fiber orientation and position of the metallic layers in the layup on the low-velocity impact response of FMLs consisting of Aluminum 2024-T3 and GFRP. Using their analytical model they showed that distributing the aluminum layers through the layup improved the energy absorption by 9% but the maximum force decreased by 15%. A detailed review on the impact response of FMLs is available in Refs. [18,19]. From the studies discussed above, it can be observed that FMLs based on GFRP have improved impact resistance when compared to either a monolithic metallic layer or a composite layer. Further, the effect of overall thickness, composite layer thickness and layup, thickness of the metallic layer etc. on the impact response has been studied in depth. However the effect of metallic layer position through the thickness on the low velocity impact response of FMLs has not received much attention. To the best of the authors' knowledge, there are no experimental investigations reported in literature addressing systemically the effect of distributing metallic layers, at the same time keeping the total metal layer thickness the same, on the low velocity impact response of FMLs. In this context, this study aims at understanding the effect of distribution of the metallic layers through the thickness on the low velocity impact response of FMLs. Four different FML layups each having the same total metal thickness were prepared using aluminum 2024-T3 sheets of different thickness and GFRP. Low velocity impact tests were performed using a drop impact machine at five different energy levels. The details of the work are presented in the following sections.

2. Experimental details

2.1. FML preparation

Sheets of aluminum alloy, 2024-T3, having thickness 0.3 mm (A3), 0.4 mm (A4) and 0.6 mm (A6) were used. T3 relates to solution heat treated and cold worked condition. The composite layer consisted of a single ply or plies of Epoxy (LY 556) reinforced with uni-directional (UD) glass fiber. The areal density and volume density of glass fiber were 551 g/m^2 and 2.17 g/cc, respectively. The room temperature curing agent HY 951 was used as the hardener. The four different layups considered are designated as 2/1–0.6, 3/2–0.3(O), 3/2–0.4, and 4/3–0.3 and their layups are given in Table 1. In the nomenclature, the first number indicates the number of aluminum layers and the second number indicates the number of composite layers. The next number(s) indicate the thickness of aluminum layer(s) and the letters, if any, indicate the position of the respective aluminum layer. For e.g. 3/2–0.3(O) means, three aluminum layers, 2 composite layers with two 0.3 mm thick outer aluminum layers and one 0.6 mm thick inner aluminum layer whereas 3/2–0.4 means three aluminum layers of each 0.4 mm thickness and 2 composite layers. Each composite layer may have one ply or more than one plies, as indicated in Table 1. In Table 1, [0/90] means two UD plies, one having fiber in 0° orientation and the other having fiber in the 90° orientation laminated together. Further A6 indicates 0.6 mm thick aluminum and so on. In all four FMLs, the total thickness of the metallic layers was 1.2 mm. The FMLs were fabricated using hand layup followed by vacuum bagging. The laminates were cured under pressure at room temperature. A composite laminate having layup of $[0/90]_{2s}$ was also prepared for comparison. Sheets of size of 350 × 350 mm^2 were first prepared and then samples of size 100 × 100 mm^2 for low velocity impact were cut from the sheets using a diamond wafering saw. The fiber volume fraction of the composite layers was determined through ashing as 0.5. More details can be found in Ref. [20].

Table 1
Details of FMLs and composite.

FMLs and composite	Configuration	Total thickness (mm)
2/1–0.6	[A6/0/90/90/0/A6]	3.55
3/2–0.4	[A4/0/90/A4/90/0/A4]	3.60
3/2–0.3(O)	[A3/0/90/A6/90/0/A3]	3.65
4/3–0.3	$[A3/0/A3/90]_s$	3.70
C	[0/90/90/0/0/90/90/0]	3.85

2.2. Test procedure

The impact tests were performed using an INSTRON CEAST 9340 drop tower impact tester. A schematic drawing of the experimental set-up of the low-velocity impact tests is shown in Fig. 1. The specimen holding fixture of the machine had a circular opening of 70 mm diameter, as shown in Fig. 1. The hemispherical steel impactor had a diameter 16 mm with a total mass of 8.132 kg. FMLs and plain composites were subjected to low velocity impact loading at energy levels of 20, 30, 45, 60 and 75 J. The corresponding impact velocities are,

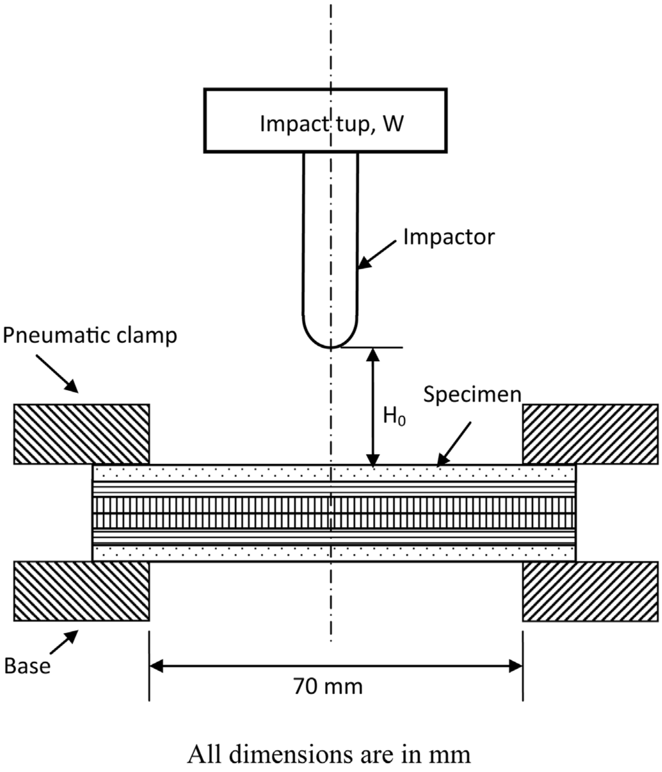

Fig. 1. Schematic diagram of the experimental set-up for impact tests.