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Original Research Article

# Low-energy impact behaviour and damage characterization of carbon fibre reinforced polymer and aluminium hybrid laminates

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ABSTRACT

The purpose of this paper is to investigate the impact behaviour and damage characterization of carbon fibre reinforced aluminium hybrid laminates (Al/CFRP) in comparison to classic carbon fibre reinforced polymer (CFRP) at low-velocity and low-energy impact. Impact damage characteristic with damage initiation and progression, internal failure modes and understanding of the role of the metal layers in the impact behaviour under low-energy were examined and discussed. The damage mechanism of the tested laminates is very complex. There is an internal degradation of the material, with the plastic deformation in case of fibre metal laminates. Characteristic matrix cracks (bending and shearing cracks) running at the fibre–matrix interface in composite layers are the first damage mode. The critical damage mode is delaminations observed between composite layers with different orientation as well as delaminations at the metal–composite interface in fibre metal laminates. For the tested materials, particularly carbon fibre reinforced composites, the absorbed impact energy is mainly connected with elastic response and damage of the laminate. In case of fibre metal laminates the absorbed energy is also connected with plastic deformation of the laminate, occurring especially in the metal layers. High impact resistance of fibre metal laminates indicates that metal (aluminium) layers may prevent delamination propagation and impactor penetration.

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## 1. Introduction

Low-energy impact damage is a major problem in structural applications of composites [1–3]. It is well known that fibre reinforced polymer composites (FRP), particularly these with carbon fibres, are very susceptible to low-velocity transverse impact [4–7]. Most composites are brittle and can only absorb energy in elastic deformation and through damage mechanisms, but not as a result of plastic deformation like metals [8].

In case of low-energy impact, the composites can fail in a wide variety of modes and contain non-visible impact damage (NVID) or barely visible impact damage (BVID), which nevertheless severely reduces the structural integrity of the component [8,9]. Low-energy impact causes damage in the subsurface without deformations and penetration in the composite materials, but leaves an extensive area of failure inside composites [10,11]. Various damages such as matrix cracks, delamination and fibre breakage are observed for impacts [12–14]. Frequently, it is very difficult to detect the damages by visual observation; therefore a significant reduction in the strength and stiffness of the materials is possible [9,12–15].

An interesting material solution is represented by fibre metal laminates (FMLs). FMLs are hybrid materials, consisting of alternating thin layers of metal sheets and fibre-reinforced composite material [16,17]. These laminates possess superior properties of both metals and fibrous composite materials. They are characterized by excellent damage tolerance: fatigue and impact characteristics, low density, high mechanical properties and corrosion and fire resistance [16,18]. GLARE (GLAss reinforced aluminium) composites are the most popular type of FMLs. Nevertheless, the current and future research in the scope of FMLs is focused on generating new laminates, for example ones based on the combination of carbon fibre reinforced polymer and metals (e.g. aluminium and titanium) [19,20].

From the review of available literature, it appears that extensive investigations have been conducted in recent years in order to research the impact behaviour mainly for GLARE composites [21–27]. Most of the earlier works focused on the low-velocity impact at higher impact energy leading to catastrophic damage to the laminate. Because fibre metal laminates are relatively new and their nature is complex, a lot of their characteristics, especially the impact resistance, still remain unclear. Therefore, it is important to understand the behaviour and mechanisms of the impact damage in laminates, particularly these with carbon fibres at low-energy impact.

The purpose of this paper is to investigate the impact behaviour and damage characterization of carbon fibre reinforced aluminium hybrid laminates (Al/CFRP) in comparison to classic carbon fibre reinforced polymer (CFRP) at low-velocity and low-energy impact. Impact damage characteristic with damage initiation and progression, internal failure modes and understanding of the role of the metal layers in the impact behaviour under low-energy were examined and discussed.

## 2. Experimental procedure

### 2.1. Material

The FML panels examined in this study were made of 2024-T3 aluminium alloy sheets (0.5 mm thick) and unidirectional prepregs (Hexcel, USA) based on AS7J high-strength carbon fibre (0.134 mm thick). The nominal fibre content was about 60 vol.%.

In order to ensure better adhesion of composite material, the surfaces of aluminium sheets were anodized in chromic acid (CAA) and coated with EC 3924B corrosion inhibiting structural adhesive primer (3 M, USA).

The lay-up scheme of the FML laminates was 2/1, two outer aluminium layers and one interlayer made of carbon-epoxy prepreg with $[0_2/90_2]$ stacking sequence. For the purpose of comparison, a classic carbon reinforced laminate with the same thickness and $[0_2/90_2]_3$ stacking sequence was used.

The hybrid laminates were produced in the Department of Materials Engineering at Lublin University of Technology by autoclave method (Scholz Maschinenbau, Germany). The cure cycle was carried out at a heating rate of 2 °C/min up to 135 °C and held at this temperature for 2 h. The pressure and the vacuum used were 0.5 and 0.080 MPa, respectively. The laminates were cut to the final size of 150 mm × 100 mm for impact tests.

### 2.2. Low-velocity impact test

The low-velocity impact test was performed at room temperature using a drop-weight impact tester (Instron Dynatup 9340). The impact tests were carried out according to ASTM D7136 standard. A hemispherical impactor tip with a diameter of 38.1 mm and mass of 1.4 kg was used. The velocity of impact was maintained between 1.10 and 2.15 m/s. A range of impact energies 1.5 J, 2.5 J and 5 J was achieved by changing the drop height.

### 2.3. Characteristics of damage

The specimens after impact were examined using both non-destructive and destructive inspection techniques. The automated non-destructive ultrasonic testing system MAUS$^{TM}$, based on single sensor pulse echo, was used to analyse the impacted region and to determine the damaged area. The system is capable of delivering automated scanning with determined resolution in the A, B and C mode (named as A-, B- and C-scan).

After inspection delivery, the microscopic observations of cross-sections were carried out in the impact area by means of optical microscope (Nikon MA200, Japan) and scanning electron microscope (FEI Nova NanoSEM) in order to visualize the internal damage. To ensure better imaging and enable the evaluation of potential internal damage for individual layers of laminates (0/90), the metallographic specimens were prepared at the angle of 45°.

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