The response of hybrid composite structures to low-velocity impact

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1. PURPOSE

Carbon-fibre reinforced composites (CFRPs) are used as structural materials for aerospace applications due to their advantageous specific material properties such as stiffness and strength. In such applications the components are subject to impact by rain, sand, and hail [1]. The impact of hail stones in different velocity regimes can cause serious damage to a CFRP structure. Especially during low-velocity impacts (generally up to 10 m/s) the contact time between impactor and structure is long enough for the entire structure to respond [2, 3]. The resulting damage ranges from intralaminar to interlaminar failure, also known as delamination. Low energy impact or high energy low velocity blunt impact may initiate significant internal damage which is undetectable by visual inspection. This insidious type of damage is referred to as barely visible impact damage (BVID) and is often defined as damage visible within a distance of 1 m, or damage causing a specific permanent indentation [3]. Since it is difficult to detect and decreases the mechanical properties significantly, the damaged structure needs to withstand given load levels within regular inspection intervals. As in future aerospace applications laminarity of surfaces will play an important role, the permanent indentation of a surface by impact disturbing the laminarity also needs to be considered.

An intelligent combination of different types of material can take advantage of their most favourable properties to counteract the damage of impact and erosion without neglecting the lightweight concept. *Stefaniak et al.* showed that residual strength after impact can be increased substantially by hybridisation of unidirectional CFRP laminates with thin steel foils [4].

The aim of the present work is to identify a beneficial combination of several materials to obtain an increased impact resistance and to avoid severe structural damage at usual impact events like hail strike. For that purpose an elastomer, glass-fibre reinforced plastic (GFRP), metal and CFRP are combined. The intention is to find a way to make serious internal damage easier to detect on the structure’s surface. Further, the residual surface indentation after impact needs to be examined in order to relate the impact energy to the reduction of laminarity.

2. EXPERIMENT

2.1. Experimental procedure and failure analysis

A drop tower with a hemispherical steel indentor, having a diameter of 20 mm, was used to conduct the low velocity impact tests. Different weights were employed to generate the required impact energy by setting the suitable drop height. The impact force was measured by a piezo-electric load cell. In order to avoid repeated striking of the indentor on the specimen, the whole carriage was caught after placing the impact.

The extent of the damage was then determined by

1) a depth gauge to measure the depth of indentation,
2) ultrasonic C-Scan analysis of the delamination area, and
3) an optical 3D-scanner to determine the global 3D-distortion of the sample.

2.2. Materials

The symmetric layup of the specimens always consisted of a symmetric, quasi-isotropic CFRP core, optionally covered with a layer of elastomer, followed by layers of GFRP, whereby the resin system of the GFRP prepreg corresponded to that of the CFRP. Steel foils (1.4310) with a thickness of 0.125 or 0.250 mm formed the outer erosion-resistant layer. The size of the flat samples was 100 x 150 mm² according to ASTM-standard for drop-weight impact [5]. The symmetric layup, shown schematically in **Figure 1**, was chosen to avoid process distortions due to the different thermal expansion coefficients of the materials to ensure samples as even as possible.

Four material configurations were tested:

1) thin steel foil (0.125 mm) without elastomer
2) thick steel foil (0.250 mm) without elastomer
3) thin steel foil (0.125 mm) with elastomer
4) thick steel foil (0.250 mm) with elastomer

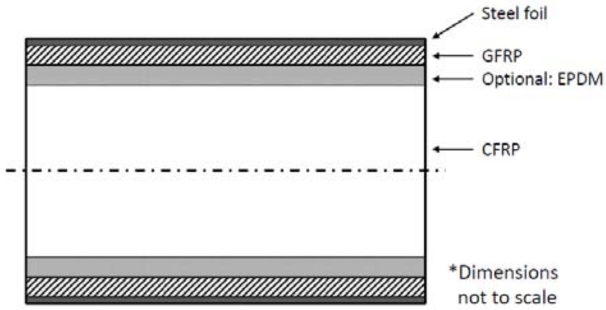

Figure 1. Schematic layup

2.3. Experimental methodology

In the first stage of impact tests energies of typical impact events for aviation applications were tested. After testing, the samples were classified regarding to the occurring damage into (1) ‘cosmetic’ damage not disturbing the laminarity, (2) disturbed laminarity and (3) structural damage.

In the second stage the impact energy was gradually increased starting from 6 J in order to find the kinetic energy at which damage first appears, named failure threshold energy (FTE) [6]. With the utilized indentor geometry at low energy level, failure initiates inside the laminate and is not visible on the surface. Therefore, the amount of damage had to be determined by an ultrasonic C-Scan. For damage detection it was also important to identify the kinetic energy at which the damage merged from BVID to visible damage. Here again the extent of the damage inside the sample was detected. Finally, the threshold value of indentation depth disturbing laminarity was determined by increasing the impact energy incrementally beyond the point of first visible damage.

3. FINDINGS

Preliminary tests showed that the application of a steel foil as outer layer of a hybrid laminate results in an increased resistance to surface damage of low-velocity impacts. The application of a steel foil and its thickness as well as the inclusion of an elastomer show significant influence on the damage extent and the damage mode progression. Since the experiments have not yet been fully completed, further investigations will specify the statements and will be presented at the conference.

4. VALUE

The intention of the current study is to assess the potential of additional protective layers on pure CFRP laminates subjected to low-velocity impact. From this comparison, the benefit of hybrid composite structures can be quantified. In order to successfully apply the proposed hybrid composite on aircraft structures, the occurring damage modes and their order of occurrence are investigated. Further, this study examines if inner failure is always visible on the materials’ surface and otherwise to which extent the point of first damage and first visible damage diverge and how severe the inner damage is at that point.

References

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