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A double-cell foam-filled composite block for efficient energy absorption under axial compression

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ABSTRACT

This paper describes an experimental evaluation of the crashworthiness characteristics of a novel design for cost-effective crashworthy composite glass fibre-reinforced plastic (GFRP) sandwich structures. All the samples are based on the concept of the "double-layered" foam-filled block, i.e. two foam-core sheets which are wrapped by reinforcement woven fabric, that acts as the reinforcement face and meanwhile ties the core layers and faces together, thus preventing catastrophic failure under axial loading conditions. The design, manufacturing and crush testing of rectangular blocks fabricated are described. Special attention is focused on the analysis of the mechanics of the block axial collapse, emphasizing on the mechanisms related to the crash energy absorption during the compression of the composite blocks with and without use of two types collapse trigger mechanism. Experimental results indicated high crushing force efficiency was achieved up to 80%.

1. Introduction

Extensive research works in the recent decades have shown that the use of fibre-reinforced plastic composite (FRP) materials in automotive and aerospace applications may result in significant functional and economic benefits, ranging from increased strength and durability features to weight reduction and lower fuel consumption [1,2]. In particular, researcher's attention has been directed towards the improvement of structural vehicle crashworthiness by using FRP composites in specific vehicle parts as collapsible absorbers of crash energy i.e. as structural members that are able to absorb large amounts of impact energy, while collapsing progressively in a controlled manner [3,4].

For many years, cost-effective sandwich structures have proven applications in the aerospace and automotive industries. Conventional sandwich panel typically consists of two thin, stiff fibreglass facings separated by a lightweight polymer foam-core. They are known to provide extremely efficient lightweight structures. However, under high energy impact loading, they often behave in a brittle and somewhat unpredictable manner. Furthermore, the fibreglass facings have a tendency to debond from the core leading to a sudden loss of all load-bearing capacity and subsequent catastrophic failure [5]. As a novel method using everting means to control failure of sandwich panels has been reported previously by Taher et al. [6]. Longitudinal edges of sandwich faces are disposed with an everting means, characterized of having a groove whereby during an event of crash load, face feeds to everting means along the groove and buckles, thus creating progressive energy absorption. Efficiency of crushing mechanism depends on controlling of faces edge buckling. A set of designs are based on the concept of the "tied-core" sandwich, i.e. the use of additional core reinforcements that act to tie the opposing facings of a sandwich together had been tested by Pitarresi et al. [7].

This paper describes the experimental analysis of a series of novel double-layered composite sandwich structures that have been specifically designed to fail progressively with efficient energy absorption. In addition three different types of trigger mechanism are evaluated.

2. Experimental program

2.1. Conceptual design

During edgewise crushing, the fibreglass facings of conventional sandwich structures have a tendency to debond from the foam-core leading to a sudden loss of all load-bearing capacity and subsequent catastrophic failure.

In the current structure fibreglass was wrapped around two foam layer cores to prevent from core-to-facing debonding, i.e. during axial crashing the debonding tendency is controlled by hoop stresses in stress in fibreglass layers. In these designs, the

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Nomenclature

A	block cross section area	P_{max}	peak load
CFE	crush force efficiency	S	displacement
E	absorbed crash energy	SAE	specific absorbed energy
EPS	energy per stroke	SE	stroke efficiency
L	length of specimen	T	specimen thickness
M	specimen mass	W	specimen width
m_c	crushed block mass	δ	post-crush displacement
P	compressive load	σ_{max}	aximum compressive strength
$\overline{P}$	average crushing load		

middle layer of fibreglass is integrated within the core. Not only does this extra reinforcement provide increased stiffness and strength, but it also acts to tie opposing middles of the opposing facings of the sandwich structure together.

A designation code shows configuration characteristics of test specimen. For example, 12, the first two digit of the block designation 12–40 × 27 × 150V, indicate the block type design; 1 indicate one block in specimen structure and 2 shows double-layered configuration. The next data, i.e. 40, 27 and 150 indicate width, thickness and length in mm, respectively. Also the last character shows trigger type; "V" for bevel trigger or V type, "I" for groove trigger or I type and blank indicates a specimen without triggering modification. An overall picture of the shape and the dimensions of the test specimens are given in Fig. 1.

2.2. Triggering mechanism

As reported by Thornton [4], composite structures generally require a collapse trigger mechanism to promote stable, progressive crushing. Otherwise, sudden catastrophic failure can occur. Generally, collapse trigger mechanisms create a region of locally elevated stress at one end of the block from which failure initiates and then propagates. Two types of collapse trigger mechanism were investigated:

1. A straight cut-out with width and depth 3 and 5 mm, respectively to one end of the specimen that trim middle fibreglass laminate (a so called groove trigger or I type trigger as shown in Fig. 2a.
2. Two chamfer cut-out (5 × 5 mm) to two opposite corners of one end of the specimen perpendicular to intermediate fibreglass reinforcement in the name of bevel trigger or "V" trigger as indicated in Fig. 2b.

2.3. Specimen manufacturing

The main fabrication steps for the keel beams are described in Fig. 3 and consist of

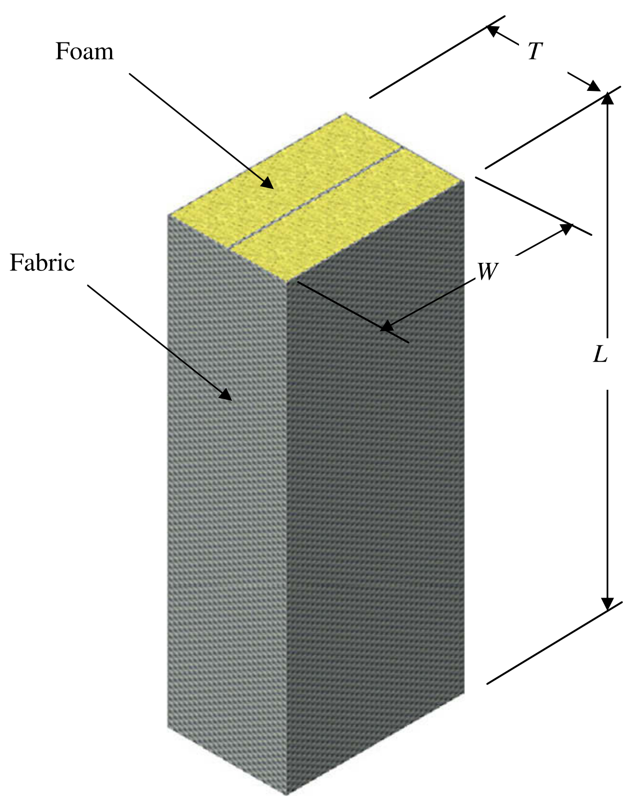

Fig. 1. General layout and dimensions of the Sandwich block tested specimens.

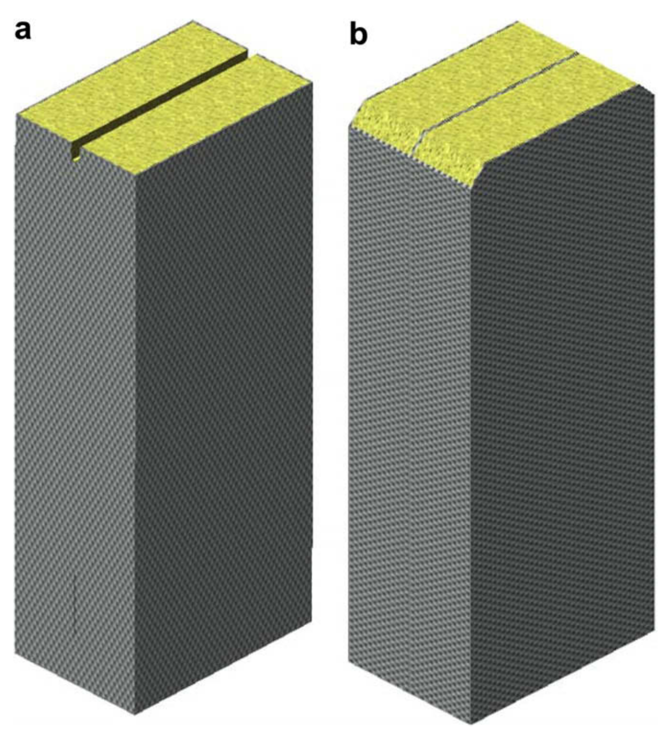

Fig. 2. Different types of end modification as collapse mechanism; (a) groove trigger or I type and (b) bevel trigger or V type.