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Understanding the behaviour of fibre metal laminates subjected to localised blast loading

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Abstract

This paper examines the behaviour of fibre metal laminates (FML's) subjected to localised explosive blast loading. Experiments are conducted on samples of varying thickness and material distribution. Plastic deformation, debonding, delamination, fibre fracture and matrix cracking have all been identified as energy absorption mechanisms. Widespread debonding is particularly evident between layers. Comparison between different plates of similar overall thickness shows no significant improvement in blast performance with increasing number of distinct material layers. This suggests that debonding does not absorb a significant proportion of the blast energy.

Keywords: Fibre–metal laminate; Plate; Blast loading; Failure

1. Introduction

A common method of protecting people and/or objects from the effect of a blast event is to deploy some form of plate like structure between the blast source and the object to be protected. In general, clamped metal plates subjected to *localised* blast loads deform plastically until some threshold impulse is reached. If this threshold impulse is exceeded, tearing occurs at the centre, usually resulting in a small cap or petalled tearing pattern. Langdon et al. [1,2] identified some typical damage regimes of fibre–metal laminates. Delamination and debonding were found through the cross sections of the plates, and rupture of the back face occurred.

Fibre–metal laminates (FML's) are lightweight blast-resistant materials that consist of several composite layers sandwiched between metallic sheets. They were identified as promising materials for lightweight blast resistant applications [1–3]. This study presents the results of blast loading carried out on FML's made from layers of Twintex (woven glass fibres in a thermoplastic resin) and rolled aluminium. Several variables affect the FML behaviour, including plate thickness, plate composition (thickness and distribution of the aluminium and composite layers in the plate), plate area, and loading diameter.

2. Experimental procedure

The fibre metal laminates investigated in this study are manufactured at the University of Liverpool from 0.6 mm thick aluminium alloy (2024-0) and a Twintex composite (woven glass fibres in a polypropylene matrix). Panel manufacture is described more fully by Langdon et al. [4].

Numerous studies have investigated the localised blast loading of flat plates, for example as presented in [1,2,4–9]. The same general procedure has been adopted in this investigation. The plates are clamped between two steel clamping frames, leaving an exposed area of 300 mm × 300 mm. This is mounted onto a ballistic pendulum, by

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Nomenclature

Several plate configurations are tested, which are identified according to AXT YZ-# where

A	refers to aluminium
T	refers to twintex
X	the number of layers of aluminium. The aluminium layers are spaced equally through the thickness of the laminate, with one aluminium layer on the front face and one on the back face
Y	the number of layers of Twintex. The layers of Twintex are all of equal thickness, and each Twintex layer is placed between the aluminium layers
Z	the number of sheets of glass fibre cloth used in each layer of Twintex
#	the plate number

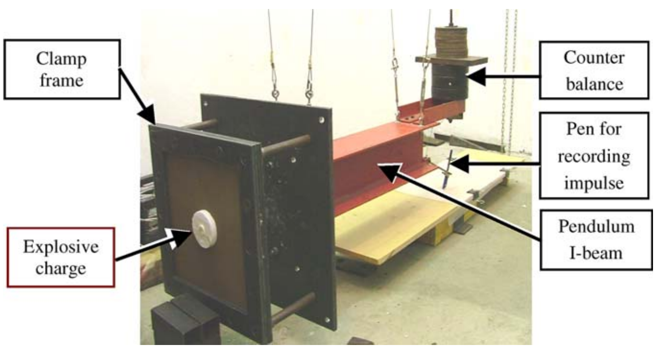

Fig. 1. Ballistic pendulum setup.

which means the explosive impulse is measured. Localised blast loading is obtained by detonating a disc of PE4 plastic explosive on a polystyrene pad in the centre of the plate. The experimental setup prior to blasting is shown in Fig. 1.

3. Observations and discussion

3.1. Front face deformations

The front faces of the plates are often heavily pitted in the region where the explosive is mounted. This can be seen in all front face pictures (Figs. 2–4). The pitting is predominantly a surface effect, and is distinct from the plate deformation that is discussed elsewhere in this paper. The pitting is seen on all the front faces, but its severity appears to be primarily a function of charge mass.

In some cases, an area of the front face undergoes local plastic deformation as a result of the blast impulse, leaving a crater shaped front face deformation, or "ring buckle". This ring buckle is shown clearly in Figs. 2c–d, 3c and 4. Thicker plates have larger bending stiffness, and generally exhibit this cratering more distinctly than thinner plates, which tend instead to exhibit global plate bending.

3.2. Back face deformations

A diamond or cross-shaped permanent deflection is seen on the rear face of the plate, examples of which are shown in Fig. 2. The deformation remains orthotropic if back face tearing occurs, as seen in Figs. 3b–d. The woven Twintex fabric is aligned so that the fibres are oriented parallel to the edges of the plates, and the diamond pattern therefore develops because the wave speed in the fibres is larger than in the resin, allowing the explosive shock wave to travel faster in the fibre direction. Some panels are manufactured with Twintex fabric oriented at ±45° to the edges of the plates. As expected, the deflection pattern on the back faces of these panels is rotated through 45°, as shown in Fig. 4.

3.3. Observation of plate behaviour and damage mechanisms

The differences in composition and structure of FML's and monolithic plates (such as steel) allow energy to be dissipated via different mechanisms. Reyes and Cantwell [10] and Zhu et al. [11] reported that laminated composite materials can dissipate energy through debonding, delamination and matrix cracking.

Different plate behaviours (e.g. front and back face deflections) are characterised by the nominal plate thickness or the number of layers. Plates are divided into the different groups shown in Table 1 according to number of layers to characterise various aspects of plate behaviour [4,7].

Fig. 5 shows photographs of plates of different thicknesses subjected to an impulse of approximately 15 N s. Thinner plates exhibit onset of back face tearing at lower impulses [7] than thicker plates. Thus, for the thicker plates shown in Fig. 5 (A3T28, A4T34) the 15 N s impulse causes large plastic deformation, while for thinner plates (A5T42, A2T12) this causes tearing and subsequent petalling.

The cross sections shown in Figs. 2 and 3, indicate that thin plates (Groups A, B_1) typically show no significant difference between front and back face deflections. For thick plates (Groups B_2, C_1, C_2, D), the front face often exhibits only small deflections – even if the back face deflection is large. Figs. 2c and d show that the back face commonly debonds from the rest of the plate and undergoes large plastic deformation, while the main part of the plate experiences relatively small deflections.

The cross sections presented in Figs. 2–5 show that interlaminar debonding occurs at the aluminium–Twintex interfaces. In general, thinner panels experience global