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IMPACT BEHAVIOR OF IN-PLANE PRE-STRESSED PANNELS

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Abstract

In this paper the behaviour of plates when they are subjected to normal impact under in-plane pre-stressed conditions was studied. Two kinds of lightweight materials were considered: aluminium alloy 7075 and quasi-isotropic glass fibre-reinforced vinylester resin. The residual velocity, the ballistic limit and, in the case of the composite material, the delaminated area, were measured in each test. Unstable cracks, that generate the catastrophic failure of the panel, were observed in the case of the aluminium at pre-stressed load levels lower than those inducing material yielding.

Introduction

Structural components, such as those commonly used in the aeronautic and aerospace industries, may be subjected to impact loads caused by foreign bodies. After impact, the residual strength and other mechanical properties may also decrease as a consequence of the damage to the material. An important structural typology is that of pressurized shell structures such as vessels, aircraft fuselages, etc., in which the structural elements are subjected to in-plane loads. These structures are usually made of materials of high specific mechanical properties, such as aluminium alloys or laminated polymeric composite materials. In addition to the common loading hypothesis, the element may suffer impact loads orthogonally to its surface by accidents or sabotage. This means that in order to check the impact structural integrity of such elements under impact loading, it seems convenient to consider that the element is previously loaded in its plane before receiving the impact load.

Several scientific works consider the behaviour of structural materials subjected to low velocity impact (Cantwell *et al.*,1989; Richardson *et al.*, 1996), and as the velocity becomes much higher (Nunes *et al.*, 2004), but in these works, the specimens were free of load at their edges before testing.

For low velocity impact of pre-stressed components, several researchers reproduce the static loading condition before impact testing, although most of them carry out impact tests on uniaxial pre-stressed specimens (Chiu *et al*., 1997; Zhang *et al.*, 1999). This last preloading condition does not properly reproduce the complex stress-state that appears in practical structural problems. All these researchers checked the effect of the pre-stress on the increase of the maximum force and damage area in laminated composite materials. Kelkar *et al*. (1998) observed that the greater the pre-stress level the larger the maximum force and the damage area.

Few more realistic tests have been made, such as those in which the specimens are statically biaxially pre-stressed. McGowan *et al*. (1999) carried out high velocity impact tests with a gas cannon device on sandwich preloaded panels, and found that, at a determined preloading level, complete rupture of the specimen occurred. However, little is known of the influence of the in-plane biaxial preloading of shells and plates on their response to high velocity impact.

In this paper the influence of the static tensile uniaxial and biaxial specimen preloading on the behaviour of plates under high velocity impact loading was studied. Two kinds of lightweight materials were selected: an aluminium alloy and a polymeric composite material.

Experimental Procedure

The plate specimens were made of aluminium alloy 7075-T6, 1.5 mm thick, and quasi-isotropic glass fibre-reinforced vinylester resin. The laminate thickness was 2.2 mm. Two specimen geometries were used depending on the type (uniaxial or biaxial) of static preloading. For uniaxial preloading, rectangular-shaped specimens (140x200 mm) were used, whereas cross-shaped specimens (200x200 mm) were used for the case of biaxial preloading. The geometry and the shape of the latter specimens were selected, after making full-numerical simulation of the problem, in order to get a uniform stress state in the impacted zone.

To keep the specimens pre-stressed during the impact test, a special experimental device was designed and manufactured, and then it was coupled to a gas cannon set-up. The first device allows holding different static loads in two mutually orthogonal directions. The device has two main components: a frame with two loading cylindrical actuators (one vertical and the other horizontal) that are capable of giving 51 kN. These actuators may work together or independently. The set-up has a hydraulic device that gives and controls the loads applied to the specimen. The static preloads applied to the specimens are given in Table 1.

Table 1

Material	Uniaxial loading (kN)	Biaxial loading (kN)
Aluminium	51	51 in every axis
Quasi-isotropic laminate	51	37.5 in every axis

Once the specimen was preloaded, it was impacted by steel spherical projectiles 12.5 mm in diameter, launched at velocities ranging from 100 m/s up to 350 m/s by one stage gas cannon manufactured by SABRE BALLISTIC. This set-up has: a barrel, a tunnel 2 m long, and a chamber in which the preloading device was placed. During the impact tests, both the projectile striking velocity and the residual velocity were measured by another set-up specially designed in our lab.

After the impact tests, the composite material specimens were inspected by C-Scanning technique to measure the damage area.

RESULTS

Figures 1 and 2 show the relationships between the impact and residual velocities for the two tested materials. Curves were adjusted to the experimental data, consistent with those proposed by Zuckas (1992) and then validated, experimental and numerically, by Kasano (1999). These gave:

$$V_r = \begin{cases} 0.0 \leq V_i \leq V_l \\ A \cdot (V_i^p - V_l^P)^{1/p}, V_i > V_l \end{cases} \tag{1}$$

where: V_r is the residual velocity, V_i the impact velocity, V_l the ballistic limit, and p and A are two empirical adjusting parameters.

From the mathematical expressions of the curves, the ballistic limits were obtained. In the aluminium in axial preloading, the ballistic limit was 105 m/s whereas in biaxial preloading this was 108 m/s. In the laminate the ballistic limits were 123 m/s in the uniaxial preloading case and 106 m/s in the biaxial one.

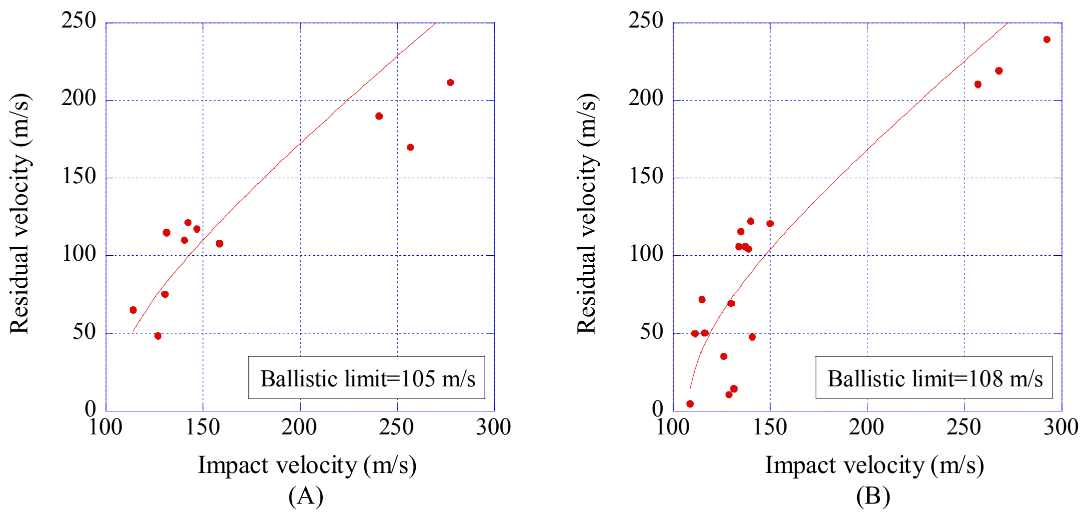

Figure 1 Residual velocity versus impact velocity in aluminium: uniaxial (A) and biaxial (B) preloadings.

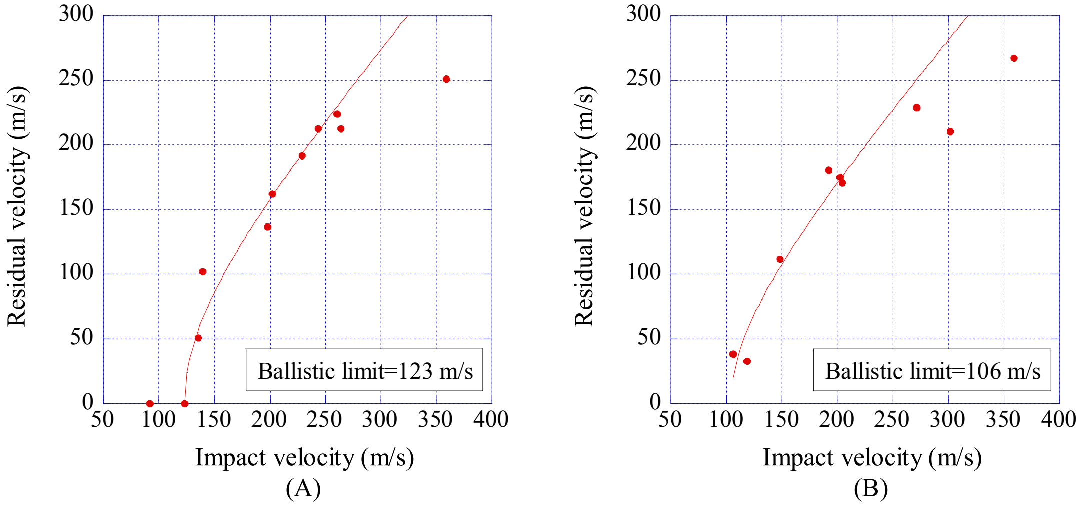

Figure 2. Residual velocity versus impact velocity in laminate: uniaxial (A) and biaxial (B) preloadings.

In the composite material the difference between the ballistic limits is about 14% while in the aluminium it is only about 3%.

Catastrophic failure occurred in the aluminium specimens (Fig. 3) regardless of the type of preloading. However, this kind of failure was not seen in the quasi-isotropic laminates.

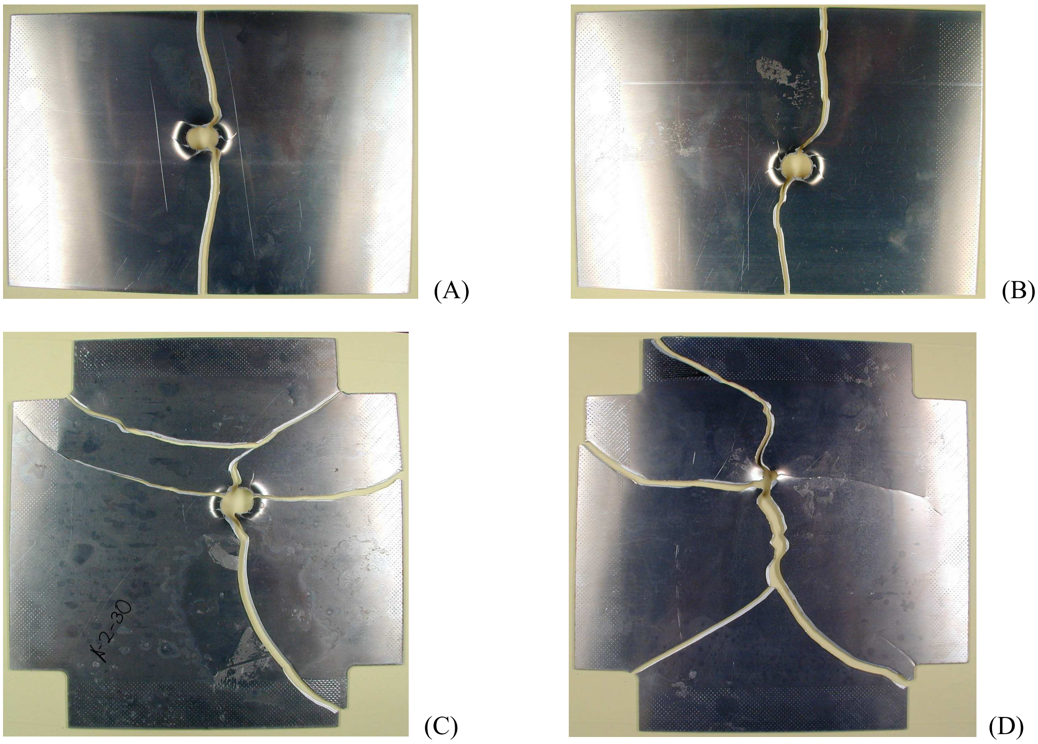

Figure 3. Catastrophic failure of aluminium specimens. (A) uniaxial preloaded specimen and impact velocity of 114 m/s; (B) uniaxial preloaded specimen and impact velocity of 277 m/s; (C) biaxial preloaded specimen and impact velocity of 109 m/s ; and (D) biaxial preloaded specimen and impact velocity of 292 m/s.

C-Scanning inspection of the impacted quasi-isotropic laminate specimens showed the relationship between the impact velocity and the damage area (Fig. 4). At impact velocities below 150 m/s, the damage area increases as the impact velocity increases. This had been shown by López-Puente (2003) in non pre-stressed composite material specimens. Figures 5 and 6 show the images of the C-Scanning inspection.

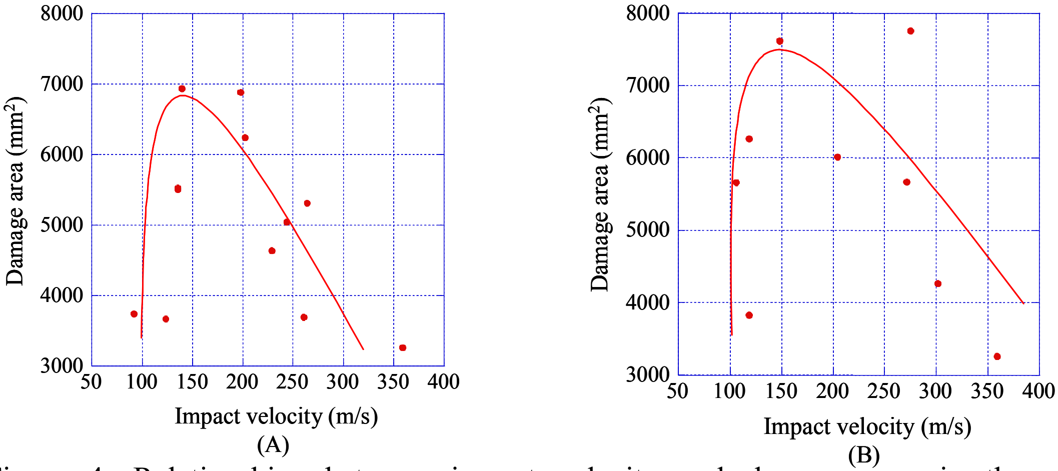

Figure 4. Relationships between impact velocity and damage area in the glass fiber/vinylester resin laminate with: (A) in-plane uniaxially pre-stressed specimens and (B) in-plane biaxially pre-stressed specimens.

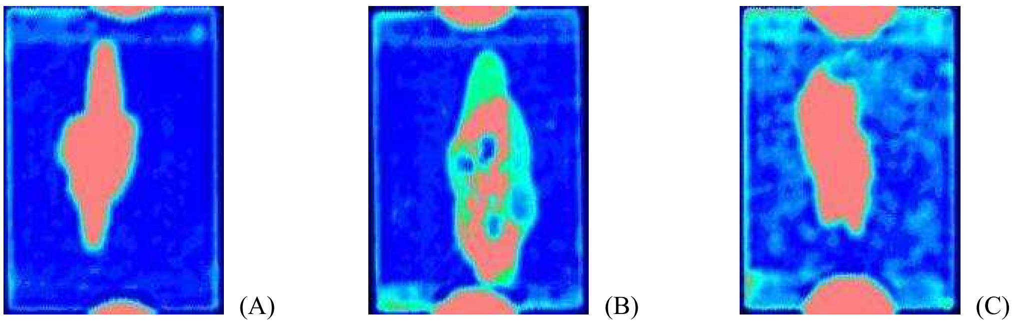

Figure 5. C-Scanning inspection images of the quasi-isotropic laminate uniaxially pre-stressed at impact velocities of: (A) 123 m/s, (B) 140 m/s and (C) de 260 m/s.

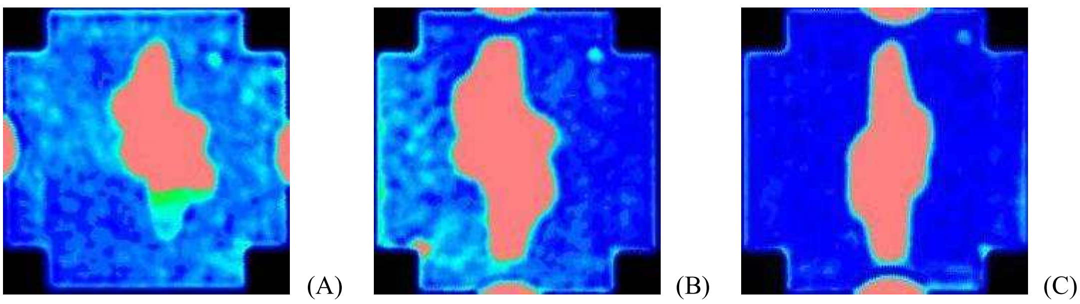

Figure 6. C-Scanning inspection images of the quasi-isotropic laminate biaxially pre-stressed for impact velocities of: (A) 119 m/s, (B) 148 m/s y (C) 271 m/s.

Figures 5 and 6 reveal that at similar impact velocities, the damage area is greater in the biaxially preloaded specimen than in the uniaxially pre-stressed specimen.

Conclusions

The influence of the pre-stressed conditions (uniaxial and biaxial) on the behavior of pannels made of aluminium alloy and quasi-isotropic glass/vinylester composite materials under impact loading has been studied.

In the composite material specimens biaxially loaded, the ballistic limit for the used projectile is lower and the damage area larger than those obtained in the uniaxial pre-stressed case.

In the aluminium alloy coupons, catastrophic failure of the specimens appears in both pre-loading states. Apparently, there is not significant differences between the ballistic limits in both pre-stressed conditions.

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