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Compression after impact of thin composite laminates

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Abstract

The damage tolerance of various lay-ups of thin carbon/epoxy laminates (1.6–2.2 mm thick) is examined by compression after impact (CAI) tests, using a new testing device which adapts to the thicknesses of the specimens and does not require tabs nor any modification of the specimen geometry. The compression stress state was not modified by the presence of the device, as was verified by numerical simulation. With this device, CAI tests were done of different carbon/epoxy laminate lay-ups (quasi-isotropic, cross-ply and woven) and the values of the residual strength and the normalized residual strength of the laminates were obtained as a function of the impact energy. The woven laminate was found to offer the highest residual strength under all the impact energies, and the quasi-isotropic laminate the least loss of normalized strength as the impact energy was raised.

Keywords: A. Carbon fibres; B. Strength; C. Damage tolerance; C. Laminates

1. Introduction

Carbon fiber/epoxy laminates are widely used in aeronautic and aerospace structural components mainly because of their excellent specific mechanical properties. They may suffer damage during their manufacture, assembly, maintenance or service life, caused by different types of impact, of which low-energy impact is considered the most dangerous [1,2], because the damage may escape detection in a routine visual inspection of the impacted surface of the component [3]. The impact energy causing visible damage to the component may be well above that which has a significant effect on the mechanical properties [4,5]. Delamination is probably the most serious problem, given the difficulty of its visual detection and the extent to which it lowers the mechanical properties [6]. The greatest reduction is that of the compression strength [7,8] which may be up to 40–60% of that of an undamaged structural element [9]. So damage tolerance is an important factor in the design of aeronautic and aerospace components made of laminated materials.

Damage tolerance in laminates is usually studied by determining the effect of different impact energies on their residual strength, the compression after impact (CAI) test being the experimental test of components damaged by low energy impact. The global testing process has two steps: in the first, the specimen is subjected to low-energy transverse impact that generates a certain degree of damage inside the laminate; then the damaged specimen is tested in in-plane compression to determine its residual strength. CAI tests must be carried out in a device that avoids global buckling of the impacted specimens, so that failure comes as the delamination progresses with the local buckling of the sublaminates produced by impact.

Several organizations and companies have published recommendations for the CAI test (NASA [10],

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Boeing [11], SACMA [12], CRAG [13]), but there is no universal standard (ASTM or ISO) that would state the specimen geometry and the test variables. Most of the tests to generate laminate damage are done with a drop weight tower testing device [1,14–19] that reproduces the impact of a large mass at relatively low velocity (a few meters per second). The size of the specimen and the clamping system vary from one study to another but the devices and the procedures are similar. However, notable differences are found in the subsequent compression tests of the damaged specimens. The large aeronautic and aerospace companies (NASA, Boeing) normally use thick specimens (>3 mm) with their top and bottom edges clamped, and the lateral edges supported, to avoid failure by global buckling of the specimen which is usually narrow. In the test adopted by CRAG, the specimen is fitted with tabs at each end. These methods call for very large specimens, so a great deal of material would be needed. On the other hand, in many aeronautic and aerospacial applications, the laminates used in structural components are thin (1.5–2 mm) such as those in the cryogenic tanks of H_2 of reusable launch vehicles [20–22] and in the fan blade of a turbojet engine [23]. This means that the data obtained from the above-mentioned tests might be inapplicable to the actual structure since the damage mode depends in part on the thickness of the mechanical component. Prichard and Hogg [9] used these tests with small thin specimens, but other authors [24] have shown that at thicknesses below 2 mm, the same methods can produce local crushing damage in the loading zone and generate erroneous residual strength values. Tabs have been proposed for thin specimens as a method of avoiding this problem [25] and in other studies [24,26], antibuckling plates are used in addition; this avoids global buckling of the specimen but does not prevent the local buckling of the sublaminates generated by the impact. The antibuckling plates have a centre hole so that they do not alter the impact damage surface. The objection to these methods is that specimens with end tabs need grips to be fixed, as in tensile tests, and they have to be narrow, which could mean a change of their geometry before the compression test [27]. Also an accurate alignment of the specimen is required and the use of tabs makes the test more complicated. To avoid these drawbacks, some authors have used loading plates with a slot in which the specimen is placed between antibuckling plates [15]. Other methods use a device that can be adapted to the thickness of the impacted specimens and does not require either lateral guides or antibuckling plates, the specimen being sized to avoid global buckling [28].

There are, then, problems in testing damaged composite materials in compressive conditions. The test methods of aeronautic companies and other organizations recommend the use of large specimens of thickness above 3 mm. This requires a great deal of material and a high cost, and the test specimens do not always correspond to the actual material of the structure. There is no generally accepted method of testing small specimens of less than 3 mm thickness; most proposed methods have to use tabs and narrower specimens, and this implies a change in the specimen geometry in some cases and further complexity in the test.

Several authors have studied the reduction of the compression residual strength, but most have centered on quasi-isotropic laminates [1,4,14–16,19,24,29–31] and a few on other tape lay-ups and woven laminates (two-dimensional fabric) [27,32–35].

In this work, the damage tolerance of different lay-ups of carbon fibre/epoxy laminates, of thicknesses between 1.6 and 2.2 mm, was considered. Two tape laminates (quasi-isotropic and cross-ply) and a woven laminate were tested. The residual strength and the normalized residual strength were obtained and examined to find how these are modified by changes of the impact energy. A new device for the CAI tests of the thin laminates was designed, which avoids the above mentioned problems. Numerical simulation showed that in a uniaxial compression test, the stress is not altered with this new device.

2. Experimental set-up

2.1. Description of the CAI device

The device used to test different thin laminates (1.5–2.2 mm) had to adjust to their thicknesses, and avoid altering their geometry with a narrowing of the specimens that would modify the impact damage. The use of tabs was ruled out to simplify the test.

Considering these requirements and trying to avoid the problems of other investigations, several devices were designed (Fig. 1). One of these, similar to those of the aeronautical groups (SACMA, NASA or Boeing) and to that of Duarte et al. [15], adapted to the geometry of the impacted specimens used in the study, is shown in

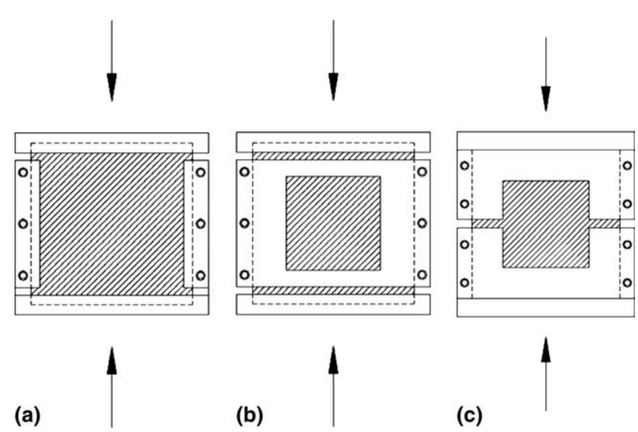

Fig. 1. CAI devices developed.