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Experimental analysis of damage creation and permanent indentation on highly oriented plates

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ABSTRACT

This paper presents an experimental investigation concerning low-velocity impact and quasi-static indentation tests on highly oriented laminates used in aeronautical and aerospace applications. The damage observed in such laminates is very particular. Post mortem analysis were carried out which helped to define an impact damage scenario. Microscopic observations led to explain the mechanism of permanent indentation formation which is a fundamental point of damage tolerance justification. Equivalence between static and dynamic is also discussed.

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1. Introduction

The use of composite materials in aeronautical and aerospace applications has been increasing recently because of their stiffness to weight and strength to weight ratio. During composite structure's life, low-velocity impacts by foreign objects may occur during manufacturing, maintenance, operation, etc, which can largely affect their residual mechanical properties [1]. Even if there is no damage sign on the surface, however, internal defects may already have been created [2]. The minimum damage that can be detected by visual evaluation is the Barely Visible Impact Damage (BVID) [3]. In aeronautical standards, the threshold of detectability after few days of rest and humidity aging is 0.3 mm of dent depth. In this study, the BVID is taken as 0.6 mm after 48 h of relaxation but without humidity aging which can decrease more the depth of the indentation.

Therefore, in order to cope with safety standards, designing and dimensioning composite structure require taking into account damage tolerance [4,5]. Damage tolerance was introduced in 1978 in the civil aviation. This requirement is explicitly expressed by the standard JAR 25.571: "the damage tolerance evaluation of the structure is intended to ensure that should serious fatigue, corrosion, or accidental damage occur within the operational life of the airplane, the remaining structure can withstand reasonable loads without failure or excessive structural deformation until the damage is detected".

In the field of impact damages, the damage tolerance drives to dimension the structure depending on the impact detectability: if the damage is not detectable, practically when the impact indentation is less than BVID, the structure must support the extreme loads and if the damage is detectable, practically when the impact indentation is bigger than BVID, an other criterion must be considered [5]. The last case is not discussed in this paper.

The damage tolerance concept is fundamental because it leads to dimension the aeronautics structures, not only by comparing their strength to the applied external forces but also by taking into account their capacity to keep track of the impact. This capacity to mark during an impact must be considered during the structure design.

Consequently, the damage tolerance has been a subject of investigation for many years. Several authors [6–9] have been studying the response of composite structures to low-velocity impact. They have been trying to give an explanation and to simulate the different damage phenomena appearing during these tests. However, more research studies are still needed to be performed to have better understanding of the damage phenomena developed in these materials during impact but equally to better explain and simulate the indentation phenomenon which is fundamental in damage tolerance design. Paradoxically, in authors knowledge, this indentation phenomenon has not been subject of investigations in the literature and the attempted explanation proposed in this paper might be quite original.

In this paper, a study of the impact behaviour of highly oriented plates, used in special aeronautical and aerospace applications, was carried out. Impact and quasi-static tests were performed to monitor the damage creation and development during these experiments. A comparison between these two tests is also treated with the aim in replacing the dynamic analysis by static one because much more

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data can be obtained from these tests than from an impact one. This subject was investigated by many researchers [10–13]. These authors demonstrated a good behaviour resemblance for these two tests.

2. Experimental setup

2.1. Materials

RTM laminates were manufactured with 12 layers of carbon fibres of the type G30-500 GK HTA-76 produced by Toho Tenax and infused with epoxy resin RTM6 delivered by Hexcel Composite. Two nearly balanced woven fabric layers of 0.2 mm thickness were placed on the upper and lower surface of the plate at the longitudinal direction. Between these two layers, 10 quasi unidirectional (quasi UD) layers of 0.3 mm thickness were draped and aligned along the longitudinal direction (cf. Fig. 1). This quasi UD is a woven fabric with all carbon fibres placed in the warp direction and only holding threads, made of glass, placed in the weft direction .The materials properties of the two different layers were evaluated experimentally and are listed in Table 1.

El_t and El_c are the Young modulus in tension and compression through the fibres directions while Et_t and Et_c are the Young modulus in traction and compression in the transverse directions. σl_t and σl_c are the failure stresses in traction and compression through the fibres directions while σt_t and σt_c are the failure stresses in traction and compression in the transverse direction. τlt, Glt and υlt are the failure shear stress, the shear modulus and the Poisson's ratio in the l–t plane, respectively.

2.2. Low-velocity impact and quasi-static indentation tests

The tested plates were cut into specimen of 150×100 mm^2 in dimensions and impacted with different energies. Low-velocity impact tests were conducted using a guided drop weight tester (cf. Fig. 2). The principle of free fall weight is to drop an instrumented mass (impactor) from a specific height on a specimen held by a support (cf. Fig. 3). The drop weight tester presented in Fig. 2 consists of a main block of 4 kg, a spherical indentor having a 12.7 mm diameter, a piezoelectric force sensor and an accelerometer to measure the impact load and acceleration during the test, respectively. An optical sensor is used in order to evaluate the initial velocity before the impact. All the results are collected by an analogical data acquisition system [14]. Then the force/displacement curve is plotted which gives an idea of impact plates behaviour (cf. Fig. 4). The impact energy is the area occupied by this curve.

Quasi-static tests were performed by an INSTRON testing machine at a displacement rate of 0.5 mm/min with the aim of comparing the behaviour of the indented and impacted plate. The same spherical indentor as the one utilized for impact tests was used. These tests were done at the same maximum displacement attained by the impactor during the dynamic experiments for comparing them. They were performed at different displacements to study and evaluate the creation and the development of the different damages.

Some of the impacted and indented plates were subjected to non destructive controls as X-rays to define the damaged zone obtained after the tests. Afterwards, destructive controls (microscopic observation) were done in order to identify a damage scenario which will be lately developed in the paper.

3. Experimental results

3.1. Force–displacement curve

In Fig. 4, force–displacement curves for plates tested statically and dynamically at two different loading are presented. It can clearly be seen, for the plate tested at the maximum energy, that the force–displacement curve can globally be divided into four big parts. The first part of the graph is linear which represents the rigidity of the non damaged specimen. At around 0.8 mm (A), the linearity is lost which can give an indication of damage initiation. At around 1.4 mm displacement (B), a brutal decrease of the force is observed, however, the force is still increasing until it reaches a maximum between 5 and 5.5 mm depending on the tests (C). Afterwards, this forces starts to decrease awaiting the test end (D). These observations will be detailed in the impact damage scenario paragraph. Moreover this scenario description is more specifically based on data (curves and micrographs) obtained during static tests, in order to benefit from greater clarity of static curves. Afterwards a comparison between static and dynamic cases is treated (cf. Section 3.4).

3.2. Damage scenario

As mentioned before, plates impacted at different impact energies and others statically tested at the same maximum displacement reached during the dynamic experiment were submitted to microscopic observations in order to explain the creation and propagation of the damage during these tests. By visual inspection, three different cracks can be monitored on the surface and the bottom of the specimen (cf. Figs. 5 and 6). These three crack types, named 1, 2 and 3 in the following of the text, are equally visible on the X-rays (cf. Fig. 12) performed on the impacted and indented plates. Later (48 h), the permanent indentation is measured for each tested plates which were later enrobed by an inclusion resin in order to prevent the relaxation of the damaged parts after cutting them. Then two different cuts were done (cf. Fig. 5) to observe

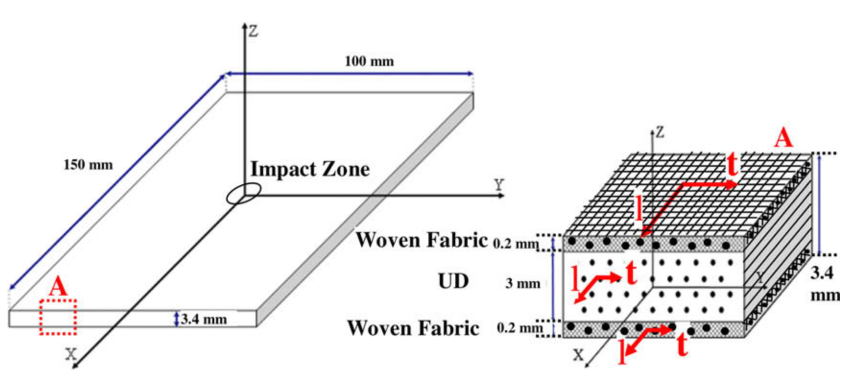

Fig. 1. Plates stacking sequence and dimensions.

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