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Impact response of thick composite plates under uniaxial tensile preloading

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ABSTRACT

This work focuses on the impact response of composite plates 5 mm thick subjected to uniaxial tension preload. Laminated carbon/epoxy with quasi-isotropic stacking sequence $([0/45/90/-45]_2)_S$ samples were used. Doehlert-type design of experiments was proposed to investigate the influence of both preload and impact energy on impact composite responses. Deformation, varying from 300 to 3000 micro-strain, was imposed thanks to a preload device designed for this purpose. Impacts were generated using a home made drop tower. Imposed impact energy was varying from 30 to 214 J. Post-impact damage was characterized by both non-destructive (ultrasound) and destructive (deply) techniques. Influence of the preloading on delamination areas (total and projected) was quantified and found sensitive to the preloading.

1. Introduction

Composite materials are increasingly used in aerospace due to their high stiffness to mass ratio compared to other materials. These materials are known for their vulnerability to low-velocity impact from foreign objects [1–3], such as drop of tools during maintenance for example. Low velocity impact produce internal defects in the form of delaminations and matrix breaking which are difficult to be detected from routine inspection like visual inspection. This type of damages can significantly reduce the residual strength and stiffness of the material, as a consequence they are considered critical for the structures. Impact behavior of composites has been extensively treated in the literature. The state of the art is related in a lot of overviews [4–8]. Nevertheless, most of these investigations focus on composite laminates that are unloaded during impact and generally concern thin structures. A major challenge now is to use composite materials as structural parts. These materials are usually responsible of carrying large loads, either in operation or at rest, and may in some cases have very large thickness. There is a strong interest in investigating the influence of preloads on the impact response of thick composite structures.

In the literature, few studies deal with the impact behavior of preloaded plates or shells [9]. Usually, imposed preloading amount to 6000 $\mu\varepsilon$ for the glass fiber reinforced polyester (GFRP) [10,9] and to 2500 $\mu\varepsilon$ for carbon fiber reinforced polyester (CFRP) [11]. The influence of uniaxial preload on the response on impact damage is reported in references [12,13,11]. In these references, low velocity impact on quasi-isotropic CFRP [12,11] and GFRP [13] plates have been studied and concern thin plates. Uniaxial preload was imposed by hydraulic actuator and vary from 500 $\mu\varepsilon$ to 2400 $\mu\varepsilon$. It was observed that the damaged area and the contact force increased with a tensile preload [12,11]. On the contrary, Mitrevski et al. [13] observed that preload altered the indentation depth (for conical impactor) and did not modify the damaged area.

Saghafi et al. [9], induced compressive uniaxial preload on thin curved panels. In this work, two boundary conditions were tested, free and guided lateral edge. They showed that when the preload increase, the damaged area was higher.

The influence of a biaxial preload is studied in [13,10,14]. The results show that tension/tension biaxial preloads rise the contact force peak for GFRP, while CFRP is found insensitive to preload for at least low energy (less than 10 J) and low preload (less than 1500 $\mu\varepsilon$). Robb et al. [10] performed low-velocity impact tests on GFRP laminated plates. These plates were impacted at the energy of 21.5 J with preload in biaxial tension, biaxial compression and tension compression (±2000 $\mu\varepsilon$, ±4000 $\mu\varepsilon$, ±6000 $\mu\varepsilon$). They showed that the absorbed energy was lowest for a tension/tension configuration. Ghelli and Minak [15] worked on numerical analysis of the effect of membrane preloads on the low-speed impact response of composite laminates. They proved that a uniaxial ten-

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sile preloads increase the peak stresses and this effect was stronger for biaxial preloads.

Kulkarni et al. [16] induced biaxial preloading imposing air pressure on one face of the plate. They showed little preload influence on contact force, which was justified by the effect of the plate curvature induced by pressure. The decrease of contact force due to curvature was previously observed in [17].

Heimbs et al. [18] studied the impact resistance of preloaded composite plate during a hight velocity impact. Carbon/epoxy samples were preloaded in compression and in tension. The experimental tests prove that the damaged area was reduced for tension preloading. Absorbed energy was higher for tension preloaded case than unpreloaded. Garcia-Castillo et al. [19,20] worked on the hight velocity impact resistance of preloaded carbon composite plates. They proved that the ballistic limit was higher and the damage area was lower for biaxial loading than for unpreloaded samples. The maximum impact energy supported by biaxial preloaded samples was 11% higher.

The present work is a part of a research program about the impact behavior of thick preloaded composites. It focuses on plates but another study dealing with preloaded shell is in progress. The objective is to study the influence of preload and impact energy on generated damage. To achieve this objective, a precharge device was designed. An experimental design was set to optimize the choice of test conditions. A home made drop tower device was used to perform impact. The damages generated were qualified and quantified by means of non-destructive techniques (NDT) and destructive techniques. Micrographic and deply techniques have been especially investigated.

2. Material and samples

The material used is an unidirectional carbon composite (UD T700) pre-impregnated with epoxy resin (M10R). Four rectangular plates of dimensions 450 mm ×500 mm and 5 mm in thickness were manufactured. The draping was carried out on a polished steel plate with a flatness of 0.1 mm m^{-1}. To limit preferential delamination [21,22], quasi-isotropic stacking sequence $([0/45/90/-45]_2)_S$ was chosen. Once draped, the plates were put under vacuum (−850 mbar) and inserted into an autoclave operating at 5 bar. The curing cycle is composed of two phases: 85 °C for 45 min and 120 °C for 60 min at heating and cooling rate of 2.6 °C m^{-1}.

Eight samples of size 100 mm × 230 mm were extracted from each plates. To avoid damage initiation associated with maintaining the samples in the preloading device, glass/epoxy tabs were glued. Moreover to improve the contact between the jaws of the preloading device and the sample, aluminum tabs were glued on those glass/epoxy tabs. Finally three drills 10.5 mm diameter were made at both ends to ensure load transmission. Fig. 1 represents a sample.

3. Experimental devices

To carry out experiments, the sample was placed in a preloading device and the impact was generated by a drop tower.

3.1. Preload device

A 60 kN device for imposing uniaxial preload was designed. This device, represented in Fig. 2(a), is composed of a rigid frame; two crossheads connection to the frame; two grips (each connected to one crosshead by a pivot connection); two threaded rods connecting each crosshead to the frame. One of the rod was equipped with a full-bridge strain gages to assess the applied preload as well as the stress in the rod during impact loading. Thanks to the pivot

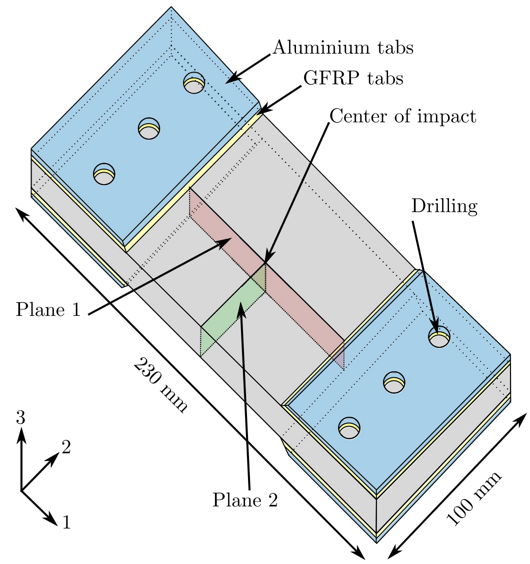

Fig. 1. Detail of a prepared sample with tabs and drilling, and the two planes for micrographic observations.

connection, the bending of the sample was allowed to avoid damage within the grips during impact. The impact took less than one minute after preloading to avoid accommodation of the specimen.

3.2. Home made drop tower

Drop tower device is commonly used to achieve impact loadings. This drop tower has two columns allowing the vertical translation of a mobile. These two columns are maintained by a rigid frame. An anti-rebound device allows a single impact of predefined incident energy. The drop tower, shown in Fig. 2(b), has a maximum capacity of 25 kg falling 2.80 m height. As a consequence, the maximum speed is about 7.4 m s^{-1} and the impact energy of about 700 J.

3.3. Instrumentation

During an impact test, the following values were recorded:

- The contact force between the impactor and the sample using a piezoelectric sensor (capacity 100 kN ± 1%).
- The position of the impactor (using a high speed camera clocked at 10000 image s^{-1} and a laser sensor).
  From these data, the impactor displacement and velocity can be easily derived.
- The tensile preload collected by the instrumented threaded rod.
- The angle of the rotation of the grip thanks to a high speed camera and images analysis.

4. Damage observation and quantification methods

After impacting a composite material, damages classically observed are: fiber breakage, delamination, debonding and matrix cracking (cf. Fig. 3). Damages are usually observed by non-destructive controls (like ultrasonic control) and micrographs (destructive). Few people use quantitative destructive technique to investigate damages. Some authors [23–25] use deply technique which consist on the destruction of the matrix by high temperature. This technique can be used to measure delamination and fiber breaks and can complete ultrasonic control. To observe and quantify them, three non destructive and destructive techniques were employed: