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Contribution of the experimental designs for a probabilistic dimensioning of impacted composites

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Abstract

This work deals with the mechanical response of a simple composite structure subjected to an impact with low velocity and large mass. The main aim is to simulate the dropped tools taking into account scattering of various parameters of the system. The measured mechanical responses were modeled by using empirical polynomial forms resulting from a design of experiments. In a first step, the polynomial of the contact force between the striker and the structure was used by assigning to each variable a statistical distribution. In a second step, a distribution was attributed to the coefficients of the polynomial. Finally, the Monte-Carlo technique was used to calculate a failure probability on the basis of the action—resistance modeling. This work also serves the purpose of helping the engineering and design departments to carry out an accurate reliability analysis on the behavior of impacted composite structures.

Keywords: Polymer–matrix composites (PMCs); Impact behaviour; Statistical properties/methods; Mechanical testing

1. Introduction

Composite materials are often used in the field of structural automotive components because they combine good mechanical performances with a low density.

However, these structures are regularly exposed to accidental low velocity impacts caused by various situations such as tool drops during maintenance operations or low flying objects while in service. This dynamic loading generates various types of damage such as delamination, transverse

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and shear cracking, fracture of fibres and debonding fibre/matrix. Moreover, this damage inside the material cannot be generally seen by a visual observation of the surface. Thus, the main problem is the global performances reduction of structures due to the local material degradation.

It is then important to take into account in the designing of the structures an optimization of their behavior to the dynamic loads. Traditionally, this step is often intuitive and/or empirical because the modeling of the dynamic behavior (falling weight) of composite structures is difficult to express analytically. Indeed, these materials generally present a complex mechanical behavior. Very few are isotropic, their damage is often varied. Moreover, the impact is a multi-parameter phenomenon depending on space and temporal information [1–5]. The main factors are

(1) The impact energy which is calculated from the height and the mass of the projectile [6]. In fact it is often more convenient to consider the couple mass–velocity.
(2) The stiffness of the impacted structure includes two main parts. The first one is the material characteristics such as the stacking sequence [7,8], the components and a possible ageing [9]. The second one is the geometry such as the shape of the structure [10–12] the thickness [13,14],...
(3) The contact type between the projectile and the structure. It concerns essentially the shape of the stricker nose [15,16].

This complex problem can be solved by using design of experiments. This technique allows to minimize the number of tests to do and provides empirical polynomials to model the mechanical responses of the system. In addition, given that the shock is obviously accidental it is natural to introduce in the design procedure a probability of failure of the mechanical system. A large number of problems have been solved by using an algorithm integrating design of experiments and/or reliability method [17–23].

2. Material and structures

The laminate investigated consists of E-glass impregnated with polyester resin. Each layer is a woven-roving with 95% of the fibers in the same direction to obtain a quasi-unidirectional ply. The other 5% are perpendicular to allow the handling of the dry fibres. The coupons were made using the hand lay-up technique.

The fibre volume fraction is approximatively 50%.

The stacking sequence was: three layers in the 0° direction, two layers in the 90° direction and finally three layers in the 0° direction given the following notation: $[0_3, 90_2, 0_3]$.

The composite structures were provided in the form of 300 mm × 50 mm from large plates. The thickness was about 4.8 mm.

This procedure usually used in industry for large structures suggests a scattering of the mechanical properties of the material because it is quite difficult to put all fibres in the right direction.

3. Experimental set-up

The impact tests are carried out using a drop tower (Fig. 1) designed in the laboratory. This device is based on a falling mass. It has an automatic anti-rebound system. The nose of the striker