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Numerical simulations of high velocity impacts of composite fragments

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Abstract

In this work, a numerical methodology to predict the behavior of high velocity impacts of composite laminate fragments against a rigid plate has been developed. In order to model the behavior of the carbon/epoxy laminate, an intra-laminar failure model has been used to describe the ply failure whereas the inter-laminar behavior has been modelled using a cohesive interaction. To validate the numerical model proposed, experimental tests of high velocity impacts of fragments have been performed in a wide range of impact velocities (from 70 to 180 m/s). The comparison showed that the numerical methodology developed predicts adequately the fragment evolution.

Keywords: "composite; fragment; numerical; high-velocity; impact."

1. Introduction

The aeronautical industry is very active in trying to diminish the aircrafts fuel consumption. This fact is relevant both from the airlines point of view (to diminish the cost associated) and from the environmental point of view since the aircraft industry is responsible of 2% of the emissions of greenhouse gases. To achieve this goal, two main strategies are used: diminish the weight of the aircraft structure and increase the efficiency of the engines. The last developments of the two main aircraft manufacturer companies use around 50% of composite materials in its structure (in terms of weight), and it is expected that this percentage will increase in the following decades. Regarding the increase of the engines efficiency, the open-rotors are one of the most promising technologies that will promote a

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relevant step in the aircraft fuel consumption. These engines are right now under development; they consist in two pair of counter-rotating series of composite blades (similar to propellers) that will not be protected with a case, and hence could impact the fuselage if a failure occurs. From the structural point of view, the use of these new engines will impose new challenges, since the aircraft manufacturers should demonstrate that the fuselage could withstand a composite blade impact.

The behavior of composite laminates when acting as impactors has not received relevant attention and only one article from the same authors of the current has been found in the literature [1]. In this work the experimental behavior of composite fragments when impacting at high velocity is studied, in particular it is analyzed how the fragment erosion and the impact force vary with the impact velocity.

The behavior of laminates under high velocity impact has been widely studied from the experimental and numerical point of view. Cantwell published the first works of this subject, highlighting the different failure mechanism that appear in the carbon/epoxy laminates when subjected to high velocity impact of rigid targets [2,3]. In the following decades, many other works have studied the behavior of composite laminates under dynamic conditions from both the experimental and numerical point of view [4-20].

The objective of this work is to develop a numerical model capable to predict the behavior of composite fragments acting as impactors. To this end, a continuum damage mechanics material model has been developed. The validation has been performed by means of experimental tests in which composite laminate fragments were launched against a rigid plate in a wide range of impact velocities.

2. Numerical methodology

In this section the numerical model developed to reproduce the behavior of tape carbon/epoxy is described. The intra-laminar behavior is modelled using a continuum damage approach in which the criteria that initiate the damage are based in the ones proposed by Hashin [21]; the expression were adapted to include a three dimensional stress state. The inter-laminar behavior is modelled using cohesive interactions.

2.1. Intra-laminar failure

The composite laminate is modelled as a linear elastic orthotropic material, until one of the damage initiation criteria is fulfilled. These are based in the ones formulated by Hashin [21], adapted to three dimensions. It is important to highlight that these criteria are function of the effective stresses $\bar{\sigma}$, which are calculated assuming that the material is intact. There are five different damage initiation criteria, which are defined as follows:

- Tensile fiber failure; it is considered when the stress in the fiber direction is positive $\bar{\sigma}_{11} > 0$:

$$e_{ft} = \left(\frac{\bar{\sigma}_{11}}{X_T}\right)^2 \tag{1}$$

  where X_T is the laminate tensile strength in the fiber direction.
- Compressive fiber failure; it is considered when the stress in the fiber direction is negative $\bar{\sigma}_{11} < 0$:

$$e_{fc} = \left(\frac{\bar{\sigma}_{11}}{X_C}\right)^2 \tag{2}$$

  where X_C is the laminate compressive strength in the fiber direction.
- Tensile matrix failure; it is considered when the stress in the matrix direction is positive $\bar{\sigma}_{22} > 0$: