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Discrete modelling of low-velocity impact on Nomex® honeycomb sandwich structures with CFRP skins

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ABSTRACT

Predicting the honeycomb sandwich's response to impact loading is a major challenge in the aeronautical industry. Several papers demonstrated the possible use of non-linear springs to model Nomex's impact behavior. On the other hand, the authors show that the lack of transverse shear consideration constitutes a real limitation. The aim of this study is to overcome this limitation by introducing a compression/shear coupling to take into account the transverse shear. In this approach, the modelling of a low velocity impact test is performed on a sandwich composite with CFRP skins and Nomex® honeycomb. Composite skins are modeled as an elasto-plastic-damage material using a user field surbroutine (Abaqus©). The Nomex core is modeled with non-linear springs integrating a compression/shear coupling behavior. Then, the sandwich response under low speed impact is realized and compared with experimental data leading to a good correlation.

1. Introduction

In the aeronautical industry, sandwich structures with honeycomb cores are commonly used for their high specific stiffness. These structures are also very used as energy absorbers in the case of crash loading. Aluminum honeycombs have been the subject of many studies in order to predict their crash behavior. This allowed access to a fine modelling of the failure modes by buckling and plastic strain of cell walls [1,2]. The use of such models has been successfully applied to the structure designs subject to impact [3,4]. It appears that the buckling failure is mainly related to the ductile behavior of the metal [5]. On other hand, Nomex® honeycomb is made of aramid paper impregnated with phenolic resin leading to a fragile elastic behavior. The geometric variations and the brittle elastic failure of this material make the prediction of crashing behavior particularly complex. It is therefore impossible to use the perfect plastic model, traditionally used for aluminum honeycomb [6]. Aminanda [7] demonstrates that the Nomex® honeycomb buckling is preceded by matrix crack on the wall surface. Roy et al. characterize the materials composing the Nomex®. They obtain, by means of finite element simulations, the same mechanical honeycomb characteristics as those provided by the supplier. Similarly, Chen [8] used a 3D model to represent the perforation of sandwich with Nomex core under impact load. Numerical simulation gives also good agreement with the experimental data. Other studies [9,10] have confirmed that 3D mesoscopic models are enough detailed to describe the entire damage mechanisms occurring in a sandwich structure. However, these approaches require a sophisticated 3D model including a multilayer material leading to a high CPU time. In addition, it appears that the results are very sensitive to geometric variations of the honeycomb cell junctions, called plateau border. Chuang and Huang [11] identify the relative density and the plateau border definition, as the major parameter governing the mechanical properties. In this continuity, thanks to FEA simulations and experimental observation, Yang and Huang confirm that the mechanical properties are dependent to the solid distribution at the border plateau [12,13]. Seeman and Krause [14] have demonstrated that a 3D continuous model allow to reduce the computation time by a factor of 12 compared to a complete mesoscopic representation. This computation time saving induced a degradation of the damage mechanisms representation (especially the peak load representation). To challenge this problem, Aminanda et al. [7] demonstrate the possible use of a non-linear springs network to predict the indentation of a sandwich with a Nomex® honeycomb core. Based on this observation, Castanié et al. [15] model the edges of the honeycomb as a spring with a material behavior taking into account a crushing law with or without peak load (Fig. 1). This law is dictated by the local rotation of the skin. They show that the rotation of the skin around the indenter initiates a transverse shear which bypasses the peak of instability in compression. They are able to predict the indentation,

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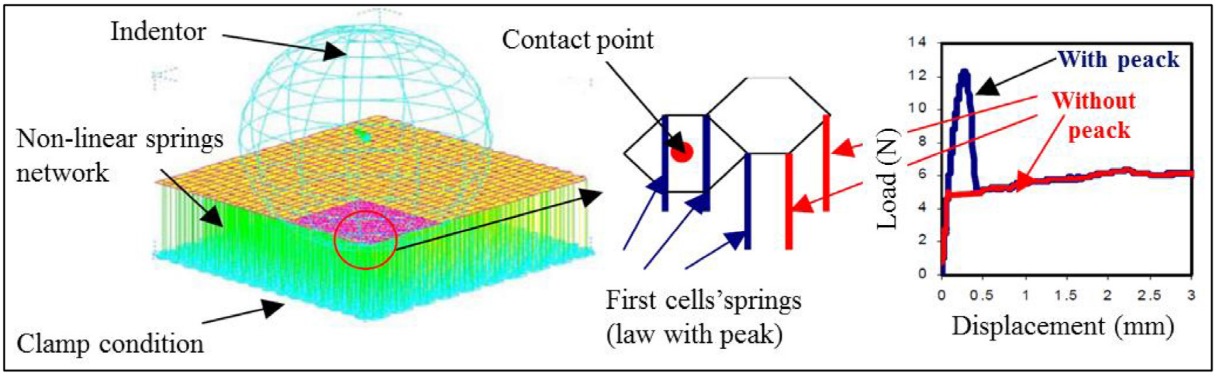

Fig. 1. Nomex® honeycomb indentation model using a non-linear spring network [23].

allowing them to calculate the compressive strength after impact of sandwich panels with metallic skins [16,17]. They obtain a good agreement with their measurements with a low computational time (CPU), which give an interesting compromise between CPU time and phenomena representation. On the other hand, the absence of coupling between compression and shear in the springs, constraint to apply an equivalent nodal force to take into account the transverse shear in order to obtain a good correlation with the experimental data. This limitation constitutes a real obstacle to its use in the mechanical design of the structure with bending and transverse shear. In addition, the study has been carried out on a sandwich with metallic skins, hence, the skin damage and delamination between skin and core are not considered. The absence of skin damage and coupling damage between the skin and the core makes it impossible to apply this model to sandwich using laminate skin.

This discrete model could be a good compromise between the mesoscopic representation of damage and the low computation time of a 3D continuum model. The aim of the present work is to overcome the discrete model limitations by integrating the skin damages, the adhesive damage between skin and core and take into account the damage coupling of the sandwich. This study is carried out on a sandwich composite with CFRP skins and Nomex® honeycomb (Chapter 2). The objective is to model the low velocity impact behavior to give a better understanding of the damage coupling in a sandwich structure.

In this context, the honeycomb is modelled as a spring network with a significant modification. It consists in taking into account the transverse shear and introducing a compressive/shear coupling (Part 3). This coupling allows to model the local shear of the Nomex® induced by the skin rotation. The CFRP damage and delamination phenomena are also taken into account. Then, this model is used to simulate a low velocity impact on the sandwich panel with two different boundary conditions. Numerical and experimental results are compared in order to evaluate the capacity of the model to predict the failure modes (Part 4).

2. Materials and methods

2.1. Materials and manufacturing process

The sandwich is made with CFRP skin and Nomex® honeycomb core. The skins are made with 2/2–12 K twill weave carbon/epoxy prepregs of 200 g/m^2 (reference: EQTC T700 supplied by Structil®). The skins are laminated with two plies at 0° and 45°. In this study, the core is supplied by Hexcel®, two honeycomb references are used (Fig. 2(a), (b)): 64 kg.m^{-3} (HRH 1/8 8.0) and 128 kg.m^{-3} (HRH 3/16 4.0). To make a sandwich structure, it is necessary to position an adhesive film between the skins and the honeycomb core. This is an epoxy film supplied by Structil® (Reference ST 1035). Once the layup sandwich is finished (Fig. 2(c), (d)), the sandwich is cured for 1 h in an autoclave at a pressure of 2 bar at 120 °C. The samples are then cut with a jet of water machine.

2.2. Compression and tensile tests

Shear characterization tests are performed in accordance with ISO 1922. The hypothesis of a homogeneous shear field is generally verified for sandwiches with high dimensional ratio (L/h > 12, indicated by the standard). The honeycombs tested in this study correspond to this case with a ratio of 12.5. Compression characterization tests shall be carried out on specimens with a cross-section of 50 mm × 50 mm in accordance with the aerospace norm IGC 04.25.720.

Quasi-static monotonous tests are controlled in displacement at a speed of 1 mm/min up to 80% of strain. They are used to determine the breaking stress and the initial elastic modulus. In order to identify the loss of elastic property, another test is carried out with a progressive loading-unloading test (called CRP). This test provides information on the evolution of material damage which results in stiffness degradation and irreversible residual strain. All tests are performed on populations of five specimens in the three characteristic directions of the honeycomb: L (span direction), W (wide direction) and Z (thickness direction).

2.3. Drop weight impact test

Many test procedures are used to simulate an impact on a structure; the drop weight impact remains the most commonly used device [18]. The test principle of this drop weight device is to drop a mass, guided by bearing, on a composite plate. Fig. 3(a) shows the drop weight impact device and the boundary conditions applied to the composite plate. This device is intended to make impacts at low velocity (inferior to 10 m.s^{-1}). A hemispherical impactor head with a diameter of 260 mm and a mass of 70.085 kg is used. The impactor is equipped with a load sensor installed between the impactor head and its body. A piezoelectric HBM sensor with a maximum capacity of 120 kN is calibrated to measure the impact load. An accelerometer is used to detect damage event during the impact. A laser sensor measures the initial velocity of the impactor before impact. The displacement and the velocity of the impactor are obtained by a high-speed camera. An additional optical sensor (Keyence LK-H157) is used to measure the displacement in the impact direction of the non-impacted face of the composite plate. This measure of the displacement due to the bending of the plate allows to determine the indentation. Finally, an anti-rebound system prevents multiple impacts after the first rebound of the impactor. The specimens are impacted following two configurations: one with a support plane (Fig. 3(b), the second with bending support (Fig. 3(c)). Three sample are tested for each case and the dimensions are L 360 mm × l 127 mm × t 22 mm. After impact, RX tomography is performed on each specimen to appreciate failure modes and compare with numerical results.