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NUMERICAL STUDY OF AN ARCAN TENSILE COMPRESSION SHEAR TEST IN DYNAMIC: APPLICATION TO BONDED JOINTS

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Abstract. This paper presents a numerical study of the Arcan TCS testing device under dynamic conditions. This test is commonly used to characterize the mechanical behavior of bonded joints subjected to combined quasi-static loadings. In this study, the question of its extensibility to dynamic loadings by the use of an impactor guided in a drop tower is investigated. A dedicated finite element model is built under the plane stress assumption. Stress distributions in the adhesive are analysed through time and space for several configurations.

1 Introduction

Adhesively bonded joints are increasingly used in the transport industry in order to improve the design and reliability of structures of lightweight vehicles (*e.g.* cars, airplanes, *etc.*). Indeed, this assembly process offers an interesting alternative to mechanical and welded joints by providing many advantages such as the possibility to assemble two or more parts made of different materials (*e.g.* CFRP/Honeycomb sandwich), a better strength-to-weight ratio and design flexibility. However, the understanding of the mechanical behavior of these joints under dynamic and combined loadings appears to be a prerequisite to ensure user safety [1, 2].

Nowadays, numerous tests dedicated to the study of adhesively bonded joints are available under quasi-static conditions [3–6] and only a few under dynamic ones [1,5,7]. Among these, the Arcan testing devices developed by Arcan, Cognard, Créac'hcadec *et al.* [8–11] stands out because it allows the study of joints under quasi-static combined loadings while minimizing the edge effects occurring in the adhesive [8, 12, 13].

A numerical study of an extension of the use of this device under dynamic conditions is proposed here. Special attention is paid to the spatial and temporal distributions of the stress fields in the adhesive.a dfsds

2 Tensile/Compression - Shear Arcan test (Arcan TCS)

2.1 Global description

The experimental Arcan TCS test presented in this section (shown in Fig.1) has been developed by Créac'hcadec *et al.* [10, 11] with the aim to provide a reusable and easy to implement specimen dedicated to the characterization of the adhesive in an assembly.

This device is composed of three parts: two metal substrates and an adhesive between them (resp. named A, B and C on Fig.1a). Four holes are machined on each substrates in order to test the bonded assembly under various loading cases. The bonded area is 25.4 (length)×9.54 (width) ×0.2 mm (thickness). During the manufacturing, the two substrates can be fixed together with two screws allowing to control their relative orientations and the thickness of the adhesive. Two circular beaks forming an angle $\alpha = 30°$ with the lap joint (see Fig.1c) are precision machined on the substrates in order to reduce the stress peaks occurring near the edges of the joint, more commonly known as "edge effects".

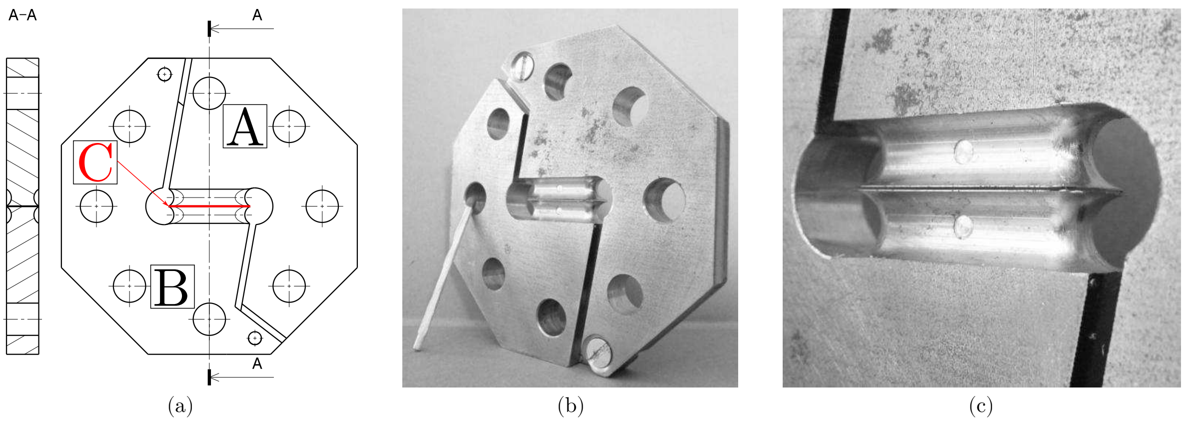

Figure 1: Tensile/Compression-Shear ARCAN Test. (a) Technical drawing. (b) General view of the test specimen [10, 11]. (c) Zoom on the local geometry of the beaks [10, 11].

2.2 Finite Element Model

The 2D Arcan TCS Finite Element Model (FEM) shown in Fig.2 is designed to be faithful to the experimental device presented in the global description section. We consider that the specimen is impacted by a falling mass guided by a drop tower of orthonormal coordinate system: (O, $\underline{x}_0$, $\underline{y}_0$). The resulting axial loading is thus oriented along the direction $\underline{y}_0$ of the gravitational force. The orthonormal coordinate system (O, $\underline{x}$, $\underline{y}$) is attached to the Arcan TCS test specimen and aligned with the adhesive. $\underline{y}$ corresponds to the thickness direction while $\underline{x}$ relates to the overlap direction (see Fig.2a). At last, the angle $\gamma = (\underline{x}_0, \underline{x})$ measures the orientation of the ARCAN device compared with the loading direction.

Boundary conditions (Fig.2a) are applied on two opposite holes and are defined by their orientation γ. Thus, if $\gamma = 0\,°$ (resp. $45\,°$, $90\,°$ and $135\,°$), *i.e.* that the mechanical loading is applied on the noted holes $0\,°$ in Fig.2b (resp. $45\,°$, $90\,°$ and $135\,°$), the loading case will be a tensile test (resp. a tensile-shear test, a shear test and a compression-shear test). In the following, these four cases are referred as $0\,°$, $45\,°$, $90\,°$ and $135\,°$ configurations.

For each hole of the model, a reference point is created at its center and linked through a rigid body relationship to the slave nodes of the half hole (in magenta in Fig.2a). For each configuration, there is a lower reference point (lower RP in Fig. 2a) which can only rotate, and an upper one (upper RP in Fig. 2a) which can both rotate and translate along the direction $\underline{y}_0$ of the drop tower. A concentrated mass of value m [14] is associated to this latter one in order to model the frame and the impactor masses. At last, the initial velocity induced by the fall of the impactor, such as $\|\underline{v}\| = \underline{v} \cdot \underline{y}_0$, is imposed to the upper reference point.

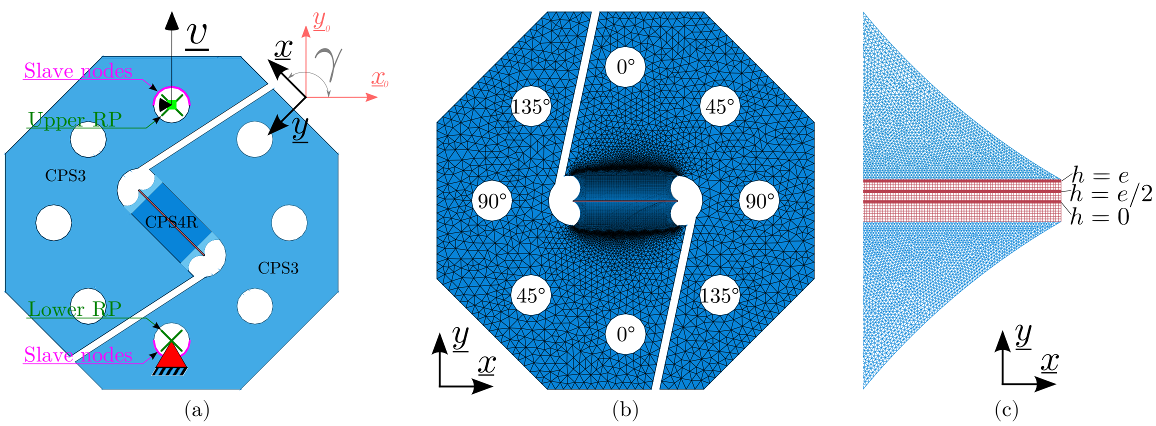

Figure 2: Description of the ARCAN TCS FEM. (a) Boundary conditions. (b) Global mesh. (c) Zoom on the mesh near the right edge of the adhesive joint.

The geometry is meshed with CPS4R elements (4-node bilinear plane stress elements with reduced integration and hourglass control) in the adhesive and a small area in the substrates (resp. in red and dark blue in Fig.2a and c) and CPS3 elements (3-node linear plane stress elements) elsewhere (in light blue in Fig.2a and c, see Fig.2b). A mesh convergence study has been performed to select the adequate element sizes. Thus the FEM contains 401 626 elements (589 268 DOF (2 DOF/node)) with 16 elements in the thickness of the adhesive. With the aim to analyze the stress distributions in the adhesive thickness, $h = 0$, $h = e/2$ and $h = e$ paths are respectively defined in the mid-plane, the 1/4-plane and the plane near the adhesive/upper-substrate border (see Fig.2c).

Considered materials are an aluminium alloy and an epoxy adhesive. $E_a = 1.495$ GPa, $E_s = 70$ GPa, $\nu_a = 0.35$, $\nu_s = 0.34$, $\rho_a = 1\,100\,\text{kg.m}^{-3}$ and $\rho_s = 2\,700\,\text{kg.m}^{-3}$ define respectively the Young moduli, the Poisson's ratio and the density of the adhesive and the substrates.

The numerical analysis is performed under elastic and 2D plane stress assumptions. The finite element solution is obtained using the dynamic/explicit procedure (*i.e.* using the explicit time-integration algorithm) of Abaqus®.

3 Stress distributions in the Arcan TCS specimen

Fig.3 presents the normalized von Mises stresses in the Arcan TCS test specimen for the four possible loading cases. Plots are extracted at an instant t which corresponds to the moment when the maximum stress is reached. Thus, for conf. 0° (resp. 45°, 90° and 135°), $t = 392\,\mu$s (resp. $t = 463\,\mu$s, $t = 776\,\mu$s and $t = 1\,219\,\mu$s). Results are obtained for an impactor with a mass $m = 10$ kg and an initial impact velocity $\|\underline{v}\| = 3.4\,\text{m.s}^{-1}$.

Firstly, it may be noted that the location of the maximum von Mises stress is not the same from case to case. In fact, for the tensile test, the maximum stress seems to be mainly concentrated near the holes used to hold the specimen. For the other tests, the maximum stress is located near the beaks in the connecting radius.

The load path (*i.e.* the path taken by the stress wave) and its shape are also different from one case to another. Thus, the latter follows a straight path for the tensile and tensile-shear tests whereas it is more sinuous for the shear test and completely scattered for the compression-shear test (probably due to wave refraction against the free edges). Also, this one is wider for the tensile test (approximately equal to the overlap length) than for the tensile-shear and shear tests (approximately equal to the half overlap length).

Lastly, stress fields observed for the tensile and tensile-shear tests are homogeneous unlike these observed for the shear and compression-shear ones. In these latter two cases, the stress wave propagates in unused areas of the ARCAN device which results in unwanted vibrations. It is therefore essential to analyze the spatial *vs* temporal stress distributions in the adhesive in order to provide an opinion on the use of this device under dynamic conditions.

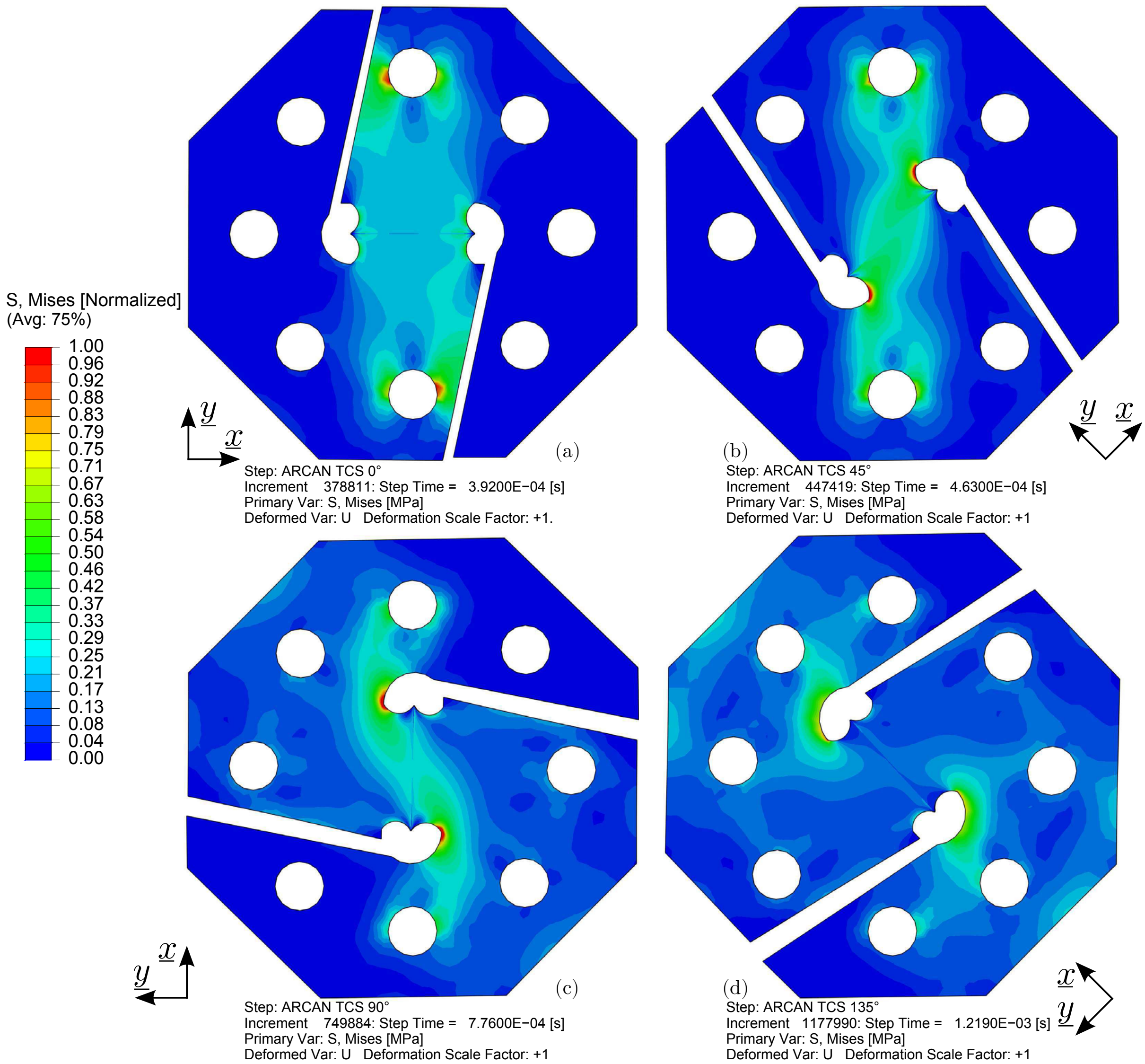

Figure 3: Normalized von Mises stresses in the ARCAN TCS test specimen for four loading cases. (a) Tensile test ($\gamma = 0°$). (b) Tensile-shear test ($\gamma = 45°$). (c) Shear test ($\gamma = 90°$). (d) Compression-shear test ($\gamma = 135°$).

4 Conclusions

The major conclusion of this study arises from the analysis of the von Mises stress fields. Indeed, with the Arcan TCS device, the spatial distribution of the stresses clearly depends on the configuration test. The more direct is the load path from the boundary conditions to the overlap, the more homogeneous are the stresses in the length of the joint. As a result, this non uniform solicitation in the adhesive could lead to a local premature failure. This phenomenon prevents a reliable characterization of the mechanical behavior of the adhesive.

Two main prospects appear from this study: (1) the need of an in-depth spatial *vs* time analysis of the adhesive joint under various boundary and initial conditions, and (2), the development of a vibration analysis approach.

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