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A stress concentration-free bonded arcan tensile compression shear test specimen for the evaluation of adhesive mechanical response

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ABSTRACT

Adhesively bonded structures are increasingly used in the industry: aerospace, aeronautics, automotive and nautical fields. It is thus necessary to characterize the behavior of an adhesive in an assembly from an experimental point of view to a modeling one. The development of reliable models needs very good tests to define the performances of the adhesive used. The modified Arcan test developed by Cognard et al. is an interesting test. However it is difficult to use. The work presented in this paper deals with an evolution of this test called the Arcan Tensile/Compression–Shear Test (Arcan TCS). It simplifies the previous approach taking also into account the influence of the edge effects with the development of a new geometry of the beaks close to the adhesive. It is suited to apply tensile/compression–shear loadings to the adhesive. The test specimen proposed was designed and manufactured to improve the modified Arcan test without reducing the efficiency of the results also including an improvement of the bonding procedure. This new specimen is validated with finite element simulations and tested with an epoxy adhesive to determine the load–displacement behavior and the envelopes at failure.

1. Introduction

Adhesive bonding is widely used in all the main industrial fields as a mean of multi materials assembly [1–3]. This type of assembly is used in aeronautics, aerospace, boating, automotive, medical field and civil engineering. From the point of view of the designer for such important structures, it is necessary to improve the calculation methods based on reliable experimental adhesive tests. The industry thus implements strategies discussing between experimental tests and finite element simulations in order to predict and validate the behavior of such bonded structures. From the adhesive manufacturer point of view or from the industrial user of an adhesive one there is an increasing demand to prove the ability of an adhesive to be used for an industrial application. The choices of the right adhesive need to be justified mainly by finite element analysis. However it is important to notice that these methods have to be based on reliable experimental tests. This paper presents a test suited to characterize the behavior of an adhesive in an assembly taking into account the industrial framework: a test easy to manufacture, easy to be tested in large quantities and interesting to feed numerical models.

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1.1. Normalized single lap shear tests

1.1.1. Presentation of the tests

The design of bonded assemblies need specific test that enable to characterize the behavior of an adhesive in an assembly. Two main normalized tests are widely used by industrial firms: the Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens (SLJ) by Tension Loading (Metal-to-Metal) [4] and the Standard Test Method for Thick-Adherend Metal Lap-Shear Joints (TAST) for Determination of the Stress–Strain Behavior of Adhesives in Shear by Tension Loading [5]. These tests are both manufactured with the bonding of two plates. Thin plates are bonded for the single lap shear test and thick plates for the TAST Test. The control of the adhesive thickness is quite difficult. It mainly depends on the flatness of the plates. After this bonding, the plates are cut to create the geometry of the test specimen (Fig. 1). This cut is not very easy for the TAST test because of the grooves close to the tested overlap. The norm specifies a geometry close to the adhesive. It is very difficult to control this geometry. Sometimes the cut is generated in the substrate; sometimes a thin layer of adhesive is let on the surface of the substrate. This specific geometry has a very important influence on the stress concentrations closed to the adhesive called the edge effects [6] and can thus generate untimely failure. Most of all these tests are limited to “shear” tests.

1.1.2. Non uniform stress distribution and edge effects in shear in the adhesive

The single lap shear test is mostly characterizes by a non-uniform stress distribution in the mid-plane of the adhesive. This test is well known to generate a shear stress and a combination of normal stresses. Lot of analytical models were written to explain this complex stress state [7]. As a consequence it is difficult to have a good shear test in order to have information to develop a law behavior that can easily be implemented in a finite element code. To reduce the deformation of the substrate, the TAST test increases the stiffness of the substrate by an increase of its thickness. The stress state generated is mostly a shear state and is very interesting. However these two tests generate strong edge effects that can be at the origin of cracks that initiate the failure of the test specimen [2,8]. These edge effects mainly depend both on the Young moduli of the adhesive and of the substrates and also depends on the stiffness of the substrates. The stiffness of the substrate interacts also to the stress distribution in the adhesive layer. As a consequence of single lap shear test and TAST test there is an important interaction between the shear test considered SLJ or TAST test and the macroscopic behavior of the adhesive observed.

1.2. Scarf joints

1.2.1. Tensile–shear tests

In order to improve the experimental input data on the behavior of an adhesive in an assembly the scarf joint is widely used [11–15]. The Fig. 2 presents the work of Afendi et al. [9]. For all of these works the principle is the same. Two substrates manufactured with an angle are bonded together. This angle drawn as 45° in the Fig. 2a is generally used for a range starting from an angle of 90° (equal to a tensile test) to an angle of 0° (equal to a shear test). Between these two values the adhesive is loaded in tension–shear. Thanks to this angle, it is possible to apply tensile–shear loadings on the adhesive. From an experimental point of view, it is quite difficult to bond the two substrates. As an example, Afendi et al. used a bonding system to fix and control the bond thickness of the scar joint specimens. This fixture needs the use of two micrometers [10]. The thickness of the adhesive is well controlled. However it is difficult to use it in large quantities because of the use of a bonding fixture. The experimental set up also needs to well master the boundary conditions in order to avoid unwanted loadings.

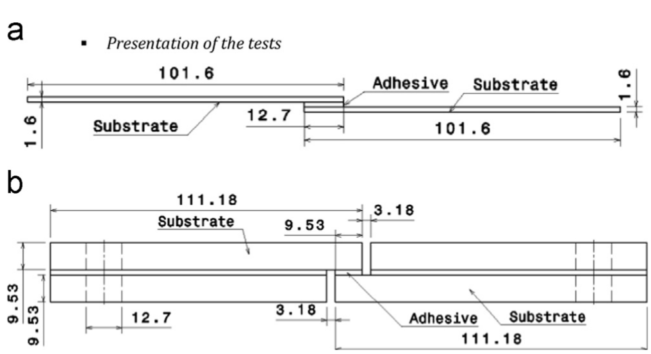

Fig. 1. Normalized tests to characterize an adhesive under shear loadings. (a) Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens (SLJ) by Tension Loading (Metal-to-Metal) [4] and (b) Standard Test Method for Thick-Adherend Metal Lap-Shear Joints (TAST) for Determination of the Stress–Strain Behavior of Adhesives in Shear by Tension Loading [5].

1.2.2. Scarf joints characterized by the edge effects

Lot of work were made to analyse the stress distribution in the mid-plane of the adhesive and in the thickness [16–20]. The stress state in the mid-plane is more uniform than in the single lap shear test. But this test is well known to generate stress concentrations at the end of the substrate. The stress singularities close to the substrate are generally analyzed with finite element simulations in elasticity. The main parameters governing this phenomenon are the Young moduli of the substrate and of the adhesive. The thickness of the adhesive also plays an important role. The thicker the adhesive is, the higher edge effects are. It is possible to reduce this edge effect thanks to specific geometry close to the adhesive such as the ones proposed by Cognard et al. [1]. As a conclusion, scarf joint is a very interesting test but is limited to tensile–shear loadings. The influence of edge effects is also necessary to be considered to propose a reliable test specimen suited to characterize the behavior of an adhesive in an assembly.

2. Modified Arcan experimental device

2.1. Tensile/compression–shear test

The modified Arcan experimental device developed by Cognard et al. [1] enables to load an adhesive in an assembly in tensile/compression–shear loadings. It is based on the work of Arcan et al. [22]. Starting from a test specimen Arcan et al. proposed to use two perforated plates with different holes. Thanks to these holes it is possible to angle the direction of the load regarding the direction of the test specimen. This idea was adapted to bonded assemblies by Gineste [21] during his Ph.D. Fig. 3a presents the experimental set up. In the center there is the bonded test sample (Fig. 3b) fixed to the perforated plates thanks to a clamping system (Fig. 3c). This fixing system preloads the adhesive. Only tensile–shear loadings can be applied to the adhesive and also generates edge effects in the adhesive. In the second step of the development, Cognard et al. proposed to modify the plates in order to enable compression–shear loading in the adhesive (Fig. 3d). Fig. 3e presents the experimental device with in the center of the bonded sample. This test specimen is fixed to the plates thanks to clamping jaws (Fig. 3e). The orientation of the mid-plane of the adhesive regarding the direction of the load is defined by the angle γ. For tensile test $\gamma=0^\circ$ and $\gamma=90^\circ$ corresponds to a shear test. When $\gamma\in\ ]0^\circ;\,90^\circ[$ it is a tensile–shear test. For $\gamma\in\ ]90^\circ;\,135^\circ[$, it is a compression–shear test. This experimental device enables tensile/compression–shear loadings along a proportional path.

2.2. Use of beaks to reduce the edge effects

The test specimens used by Cognard et al. have a specific geometry close to the adhesive that can limit the stress

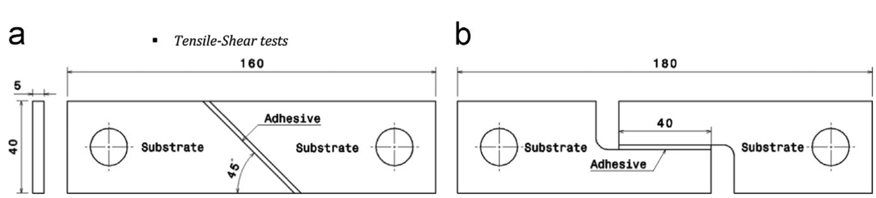

Fig. 2. Geometry and dimensions of adhesive joint specimen [9,10]. (a) Scarf joint and (b) shear joint.