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VIRTUAL TESTING OF METALLIC INSERTS FOR SANDWICH STRUCTURES

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Abstract

In this research, the virtual testing approach is used to study the failure of inserts in sandwich structures. First, a reduced F.E. model of inserts is presented, which includes nonlinear aspects of the materials such as the buckling and collapse of the honeycomb cells, the failure of the potting and the matrix failure of the skins. These model are validated through comparison with real tests showing a good agreement. This work is part of the development of an insert sizing method that could be an alternative to the classical analytical methods.

1. Introduction

Sandwich structures are widely used for helicopters, business jets, satellites, etc. These structures allow to design very lightweights panels and most of the time metallic inserts are used to assembly them.

The most complete reference for this type of inserts is the Insert design handbook of the ESA [1], where an approach to size the inserts is presented. This method consists with calculating the pullout-force that induces the failure of the parts that composes the insert, then, the weakest part causes the failure of the insert. This is based on an analytical model of the sandwich panel that was developed in 1953 [2], which despite the complexity of the equations is very used in the industry.

Also, it is well known that this method overestimates the failure force of the inserts. If the ESA procedure is applied to the inserts of the literature (ref. [3]–[5] for instance), the calculated load is always higher than in the tests by 18% to 32 %. Yet, the values obtained through this method are acceptable but not very accurate.

For this reason, F.E. methods have been proposed as a good alternative for the insert design instead of the analytical approaches [6], [7]. However, the core and insert geometry are not only very complex to model, but also the numerous features that should be included demands a very good expertise or time investment, and even if these models are very accurate, they might be not suitable to be implemented for large scale simulations.

In this context, we propose the implementation of reduced F.E. models for the insert design, which allows to have accurate results without the main disadvantages of the detailed modeling. The model is based on the study presented in [8] and the damage modeling method proposed in [9].

2. Real specimen's description

Three inserts studied in [10] are used as experimental reference. All the three specimens are made using the same materials but the geometry is different as showed in figure 1-a. The core is a Nomex Honeycomb of 3.0 pcf and 20 mm of thickness with a cell diameter of 3.175 mm. The potting is made with the AV-121 B mixed with 10 % of phenolic microspheres. The skins are made of two layers [0,90] of the G0939/145.8 woven with a total thickness of 0.55 mm. All the specimens are submitted to pull-out until complete failure using a metallic support as shown in figure 1-b.

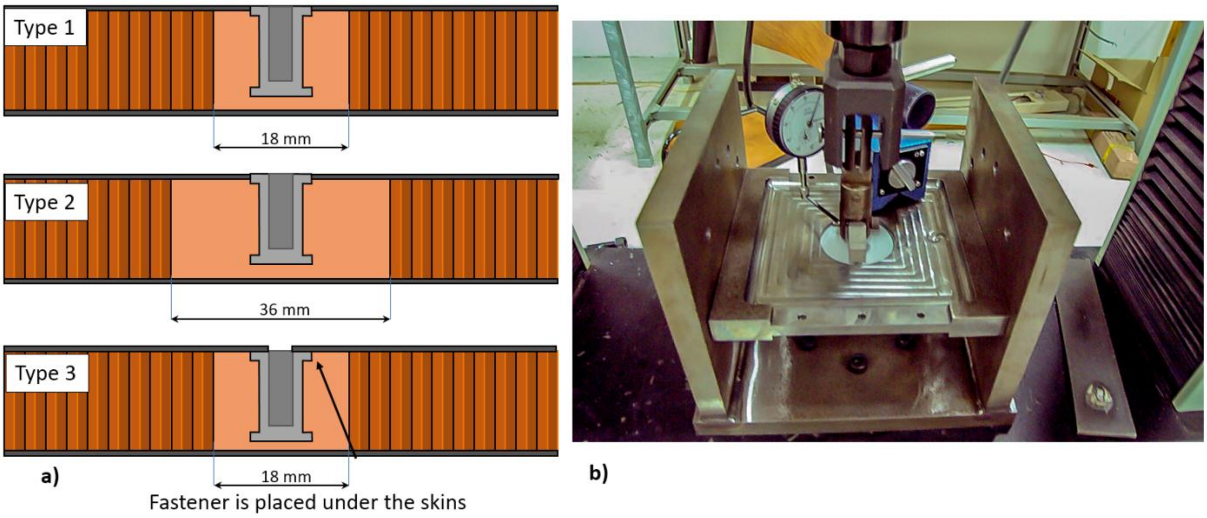

Figure 1. Insert's description of type 1, 2, 3 and testing set up. [10]

3. Virtual model features

The insert specimens are modeled using Abaqus standard. Only volume elements are used to represent the materials. The Z-displacement of the nodes at a radius of 15 mm is fixed to simulate the support of figure 1-b. The displacement is imposed at the center of the fastener as shown in figure 2. Because of the characteristics of the test, it is possible to use symmetry to simplify the model and simulate only one quarter of the specimen.

The behavior of the core, potting and skins included the linear and the post failure behavior. These behaviors laws are obtained through an extensive experimental and numerical analysis (see for example ref. [8]). Some variations of the characteristics of the materials, such as the strength of the core or the potting elastic modulus, are taken into account to define an envelop of possible behaviors. This range is delimited between the best case (the core and potting are stronger due to manufacturing defects and the insert size is higher) and the worst possible case (when the core and potting are weaker and the insert is as his minimun possible size).

Finally, all these characteristics are introduced in the model through an Abaqus UMAT subroutine. These laws are discussed in the following sections.

3.1 Modeling of the core

The experimental reference of the shear behavior of this honeycomb core is in the work of Bunyawanichakul et al. in ref. [10], where a three point beam test is performed. However, even if this test is recommended by the ASTM C393 [11], the method is only accurate to determine the shear modulus and strength of the core, but it doesn't provide coherent values of the nonlinear behavior. This is because the cells in the middle collapse first, and therefore, the behavior curve only reflects the failure of those cells as shown in [8] and [12].

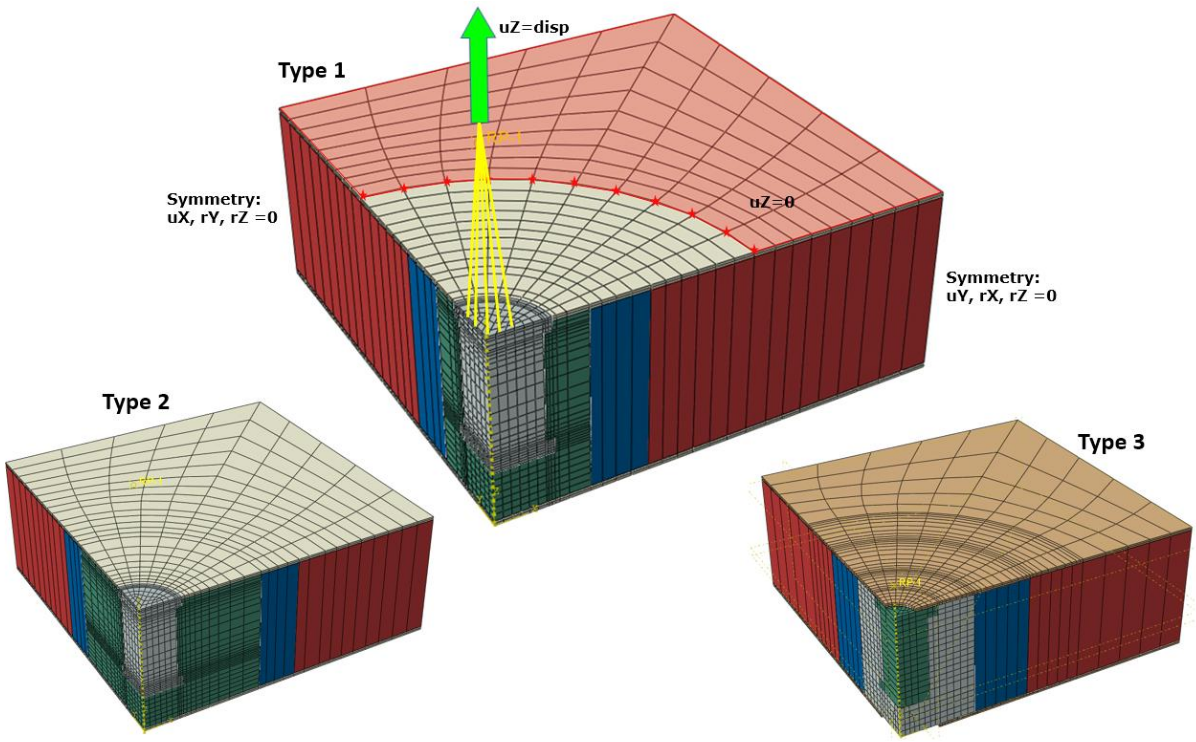

Figure 2. Reduced F.E. models of inserts type 1, 2 and 3.

To estimate the natural complete shear behavior of this honeycomb core, the initial part of the curve provided by Bunyawanichakul [10] is used as initial reference and a typical shear curve of these Nomex cores (ref. [13] and [8] for instance) is scaled to fit the values, including the start of the nonlinear behavior (see figure 3).

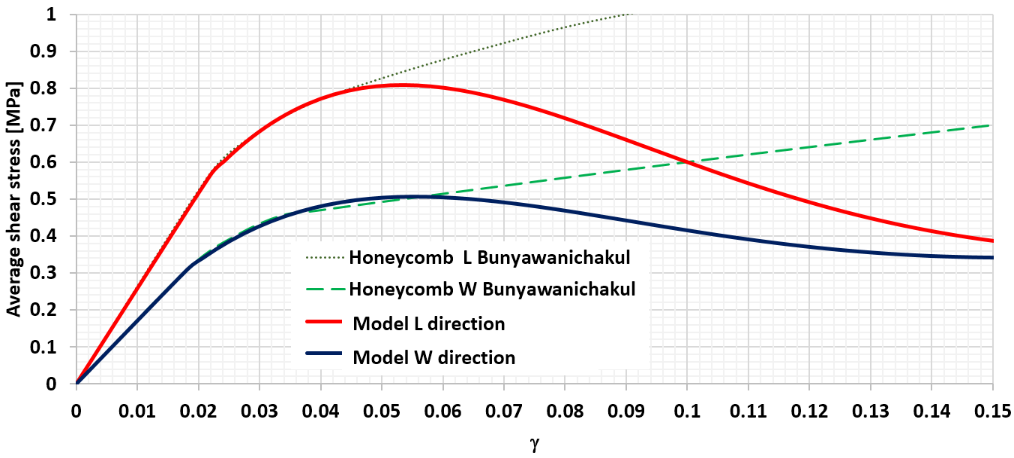

Figure 3. Comparison of the experimental Bunyawanichakul's curves [10] and the curves used as reference for this research.

Once the semi-experimental reference curve is defined, the modeling of the honeycomb core is made following the recommendations of [9], where a CDM (Continumm Damage Mechanics) approach is proposed to include the nonlinear shear behavior of a honeycomb using only one volume elements through the thickness, allowing to obtain accurate results and reducing the computational cost.

Also, as explained in [8], the behavior of the cells near the insert should be about 16 % and 35 % stronger in the W and L directions, respectively, in comparison to the nominal values, but also they should collapse earlier. This is because the honeycomb cells that are closer to the insert are much more stable due to the presence of the potting, and therefore have a different shear behavior. This increment of the shear strength is only considered for the best case and not for the worst case.

For this reason, the core is divided in two sections; the first one which is near the insert (Figure 2 in blue) with an equivalent radius of three cells after the potting, and the second one, the rest of the honeycomb, which is far from the insert (Figure 2 in red color).

The model curves in the L and W directions of the figure 3 are fitted using the CDM approach of ref. [9], including two shear nonlinear stages; initial buckling and collapse, as explained in [8]. Finally, the behavior of both core sections is given in figure 4.

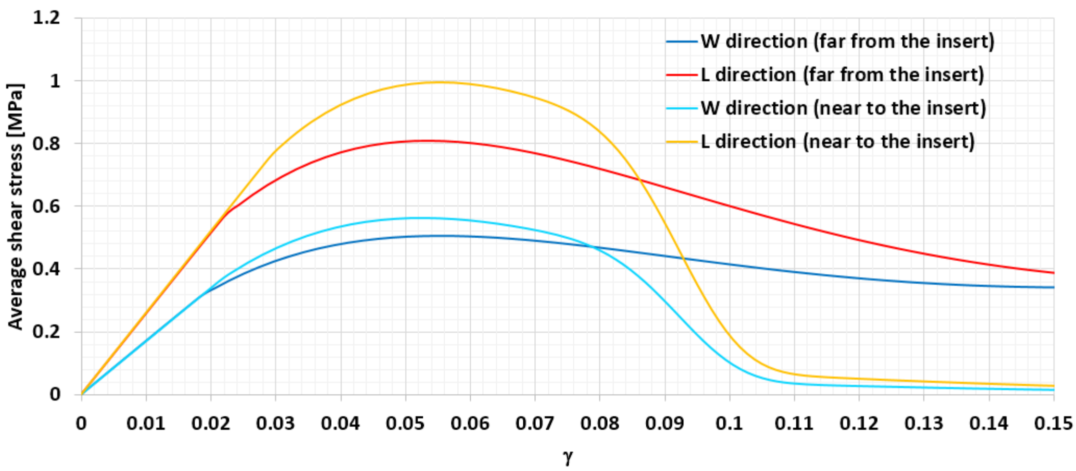

Figure 4. Behavior laws of the honeycomb far and near to the insert. (based in [9])

3.2 Modeling of the potting

The potting is considered as a perfect cylinder. For insert type 1 and 2, the typical and minimum values of the potting effective radius recommended by the Insert design book of the ESA are considered for the worst and best case respectively (see ref [1] and equations 1 and 2).

Concerning the material, the potting behavior is highly nonlinear because of the added microspheres, which transforms the adhesive into a polymer syntactic foam. When this material is submitted to tension, its Young modulus is 1851 MPa and it breaks at 15 MPa, while in compression the Young modulus is 1233 MPa and has an almost perfectly plastic behavior starting at 31 MPa (instead of breaking).

This similar behavior was programed into the UMAT and is given in figure 5a.

$$b_{typ} = bi + 0.5S_c \quad (1)$$

$$b_{min} = bi + 0.35S_c \quad (2)$$

3.3 Modeling of the skins

The elastic modulus of the skins are $E_X = E_Y = 52$ GPa and $E_Z = 5$ GPa in the principal directions, while the shear modulus are $G_{XY} = 32$ GPa and $G_{XZ} = G_{YZ} = 3.5$ GPa. Both superior and inferior skins are modeled as a homogenous material with uncoupled damage laws implemented to take into account the matrix damage in the shear XY, XZ and YZ directions. Once the elastic limits are reached (100 MPa) the stiffness is reduced to 15% of the original value. Both curves are shown in figure 5b.

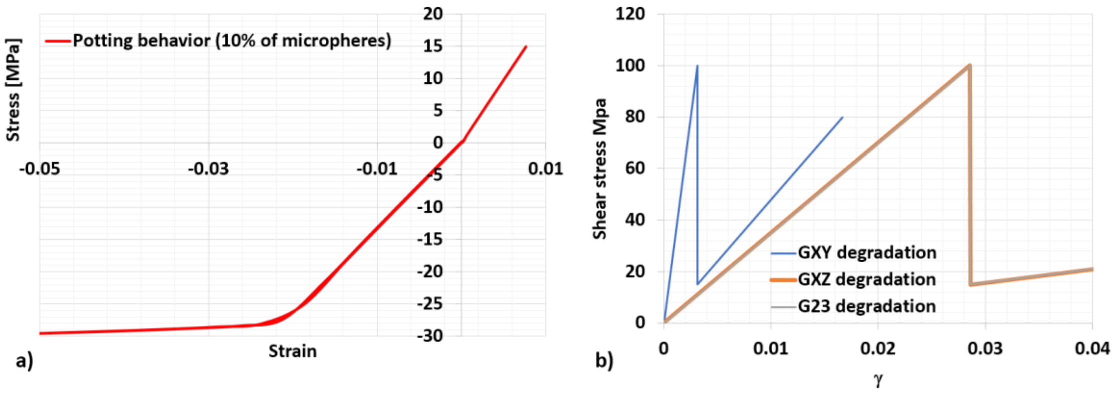

Figure 5. Potting and skin behavior laws

4. Results

The simulations are run with 8 processors, and it takes between 7 to 12 min depending on the insert case and considerations of the materials. This calculation time is very acceptable.

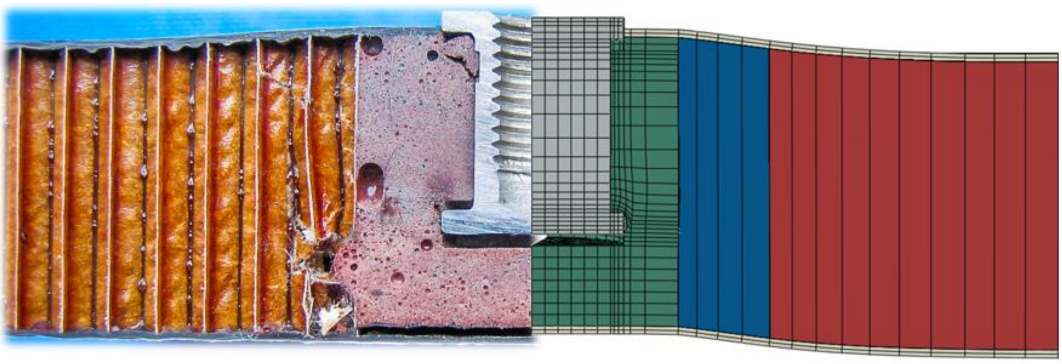

Figure 6. Comparison of the experimental and numerical damage scenario of the insert type 1 after the pull out test.

Also, the numerical and experimental results can be compared. Visually (see figure 6), the failure modes of the real test specimens seems well represented; the shear buckling and collapse of the cells, the plasticity of the potting and the deformation in the skins. The only important failure mode that is not represented is the breaking of the skins/potting interface at the bottom of the insert.

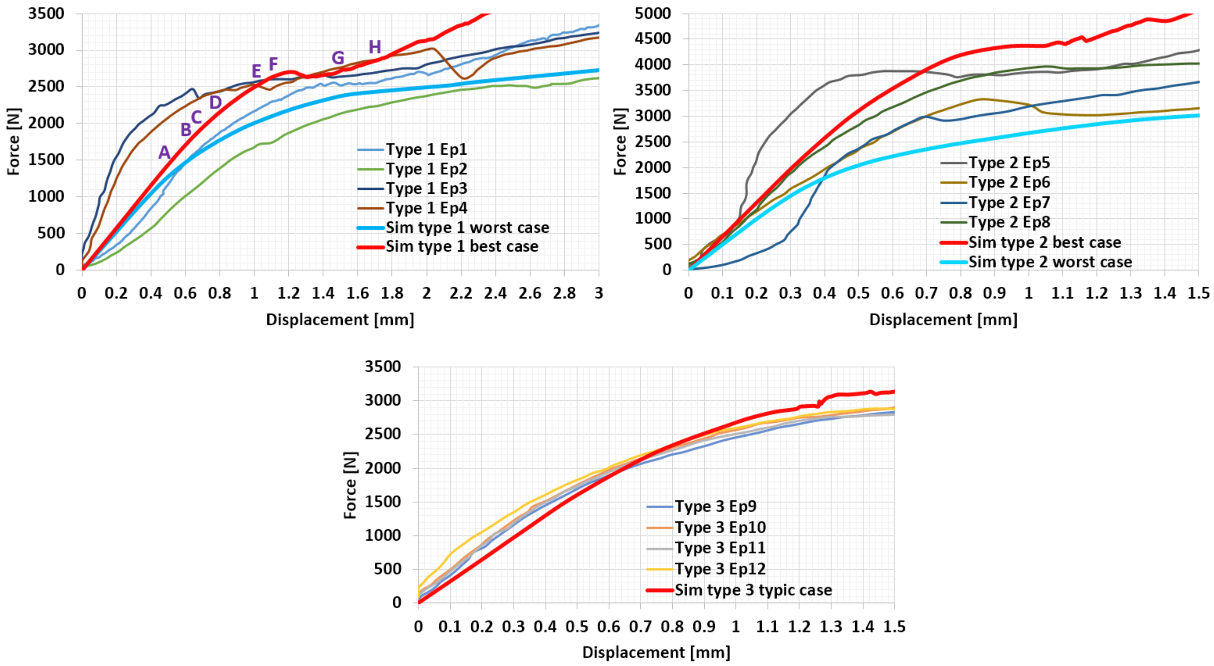

Figure 7. Comparison of the experimental and numerical behavior of the loading curves for the inserts type 1, 2 and 3.

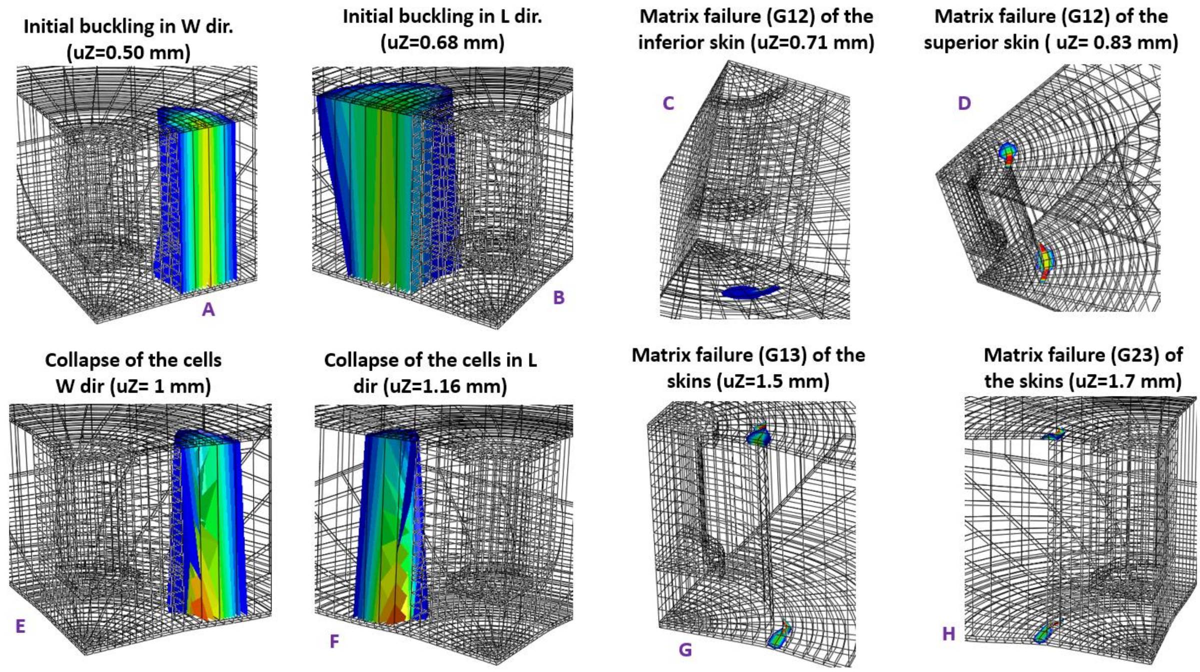

Figure 8. Identification of the failure modes in the insert type 1. (see figure 6)

Concerning the loading curves (see fig 7), for inserts type 1 and 2, the consideration of the best and worst cases seems to describe the range of maximal strength of all the experimental tests; which is relevant. For the insert type 3, only the typical values are considered, showing a good agreement with the experimental results until a displacement of 1.5 mm. After this, the stiffness of the model increased dramatically presumably due to the fact that the fiber failure of the skins is not included in the insert model.

Finally, the method proposed in [9] allows to discern the elastic buckling from the permanent damage of the cells. The same procedure is used to detect the matrix failure of the skins. All these failures are identified in figures 7 and 8 for the insert type 1 and are denoted with the letters from A to H.

5. Conclusions

The proposed method allows to simulate the behavior of inserts at a very low computational cost and to obtain very accurate results. Also, in contrast to the detailed modeling of inserts, this method is easier to implement and allows to easily identify the failure modes introduced in the model as shown in figure 7.

Another interesting aspect is that the consideration of the best and worst cases seems a good method to determine the strength range of inserts.

Finally, although more work is still having to be done in this part, it is shown that the influence of small variations, such as defects, of the parameters of the materials, plays a very important role in the insert behavior and is still to be investigated.

Acknowledgments

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