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A numerical investigation on significant parameters influencing the flatwise compressive behaviour of a Nomex^{TM} Honeycomb

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Abstract

Sandwich panels are structural elements widely used, especially in aerospace field, because their high stiffness with a low weight. However the assessment of a detailed and reliable mechanical behaviour especially in compression is, at present, a key task for a large exploitation in primary structures. Due to the large amount and variance in manufacturing processes, the fitting of precise material model behaviour is in fact not a straightforward process. Geometry, material and technological characteristics furnished by the manufacturers are often not sufficient to build a comprehensive model that is representative of the real product. Therefore, starting from an experimental-numerical experience, based on "virtual test" approach of a flatwise compressive test on a Nomex^{tm} Honeycomb core, a parametrical analysis of the most significant parameters is carried on by means of Finite Element models. The variation influence of several parameters (*wall thickness, dipping thickness, Nomex mechanical characteristic*, etc) is investigated around a reference and optimal solution. The influence of the variation of these parameters on the numerical virtual model of the Honeycomb is reported and finally discussed with the aim to help the tailor process of a material behaviour model.

Keywords: Virtual Tests; FEA; Nomex; Sandwich Panels; Honeycomb

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1. Introduction and motivations

Nowadays a very sensitive task in the transport field is the reduction of structures weight and, directly connected, the fuel saving; this is especially true in the aeronautic field. Generally honeycomb cores for aerospace industry are mainly made by phenolic impregnated Nomex^{TM} paper that, despite some concerns related to condensing water, are very structural efficient in terms of stiffness and weight. However safety issues influence the exploitation of this material in primary structures. Low velocity impacts are in fact widely considered a critical load for this type of structures: the crushing behaviour of the core (i.e. the ability to absorb impact energy) is a key aspect in the design phase. According to these premises, the most reliable approach in the past was to perform large campaign of experimental tests, especially to account uncertainness due to manufacturing process. Nowadays, numerical detailed approaches, called "virtual testing", are gaining importance [1]. Virtual testing consists into the numerical detailed reproduction of experimental tests in order to calibrate and asses the material behaviour. Once the mechanical behaviour has been correctly identified and modelled, for example with flatwise compressive tests, more complex tests, such as impact tests, can be carried out or only simulated. Thus experimental tests can be limited to a preliminary identification process.

Important data about honeycomb cores in Nomex^{TM} can be found in [2] and [3], but some uncertainness remains due to technological history. Technological processes (in particular the dipping in the phenolic resin) are fundamental to characterize the final mechanical behaviour. With the aim to simulate in the future more complex tests, a complete calibration of the mechanical property of Nomex^{tm} honeycomb core (through a complete virtual testing campaign) has been performed by the authors [4]. The results were validated thanking an experimental campaign of compressive test. Therefore starting from this previous numerical investigation, the influence of several parameters in the output of the numerical model is presented in this paper. Parameters like elastic modulus, yielding strength, walls thickness,… can slightly fluctuate due to manufacturing process of honeycomb core and, as a consequence, modify the macroscopical mechanical behaviour (i.e. change the load-displacement curve in a compressive test). Honeycombs made of Nomex^{tm} are very inhomogeneous and besides the properties of Nomex^{tm} sheets are very difficult to estimate also with experimental tests. Hence it's very interesting to evaluate the response of the numerical model (sensibility) using material parameter slightly different from the reference one.

2. Background

The "reference" calibrated material properties of the Honeycomb core under investigation has been obtained by the same authors in [4] using an approach comprehensive of experimental tests and very refined numerical models. Four "stabilized" specimens were tested following the prescription of ASTM C365/C 365M-05 [5]: a square specimen shape (100x100 mm). Tests have been performed with a testing machine MTS Alliance RT/100. A 100 KN MTS axial load cell and a laser device have been used to measure load and deflection data, Fig.1a. The results among the tested specimen are very similar (despite generally there could be a significant variance in specimen properties, this issue has been avoided using specimens belonging all to the same lot), thus one single experimental curve (exp 1) has been chosen as reference for the following numerical analyses, Fig.1b. A numerical FE model able to reproduce the experimental test was developed. Using this model a calibration of mechanical properties of Nomex^{tm} was done. It has been possible to get an optimized set of parameters (starting from literature values): the result of the FE model was the load-displacement curve that better fitted experimental data. This numerical curve is the reference data for the analyses that have been made in present paper.

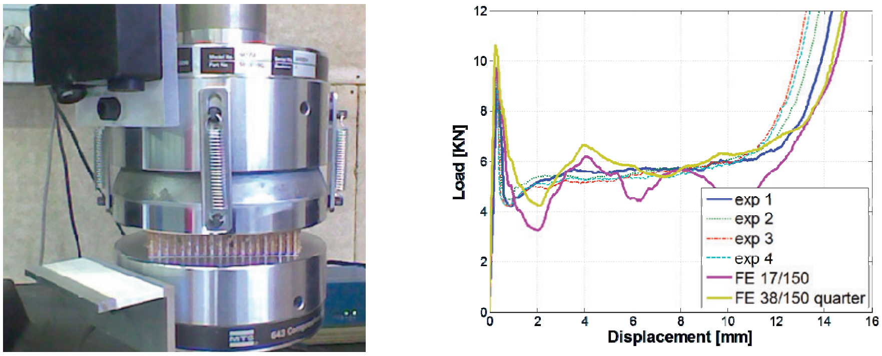

Fig.1. a) Experimental set up of the compressive test. b) Comparison between experimental load displacement curves and FE curves.

3. Numerical model

The FE numerical model is a micro mechanical model which means that each hexagonal cell of honeycomb core has been reproduced with a high detail level, Fig.2a. This kind of approach can be found also in literature [1], [6]. In order to find a compromise between numerical time costs and consistency of the simulation, it has been decided to use a model made of 17 cells instead of the real number of 150. In this way it's possible to evaluate interactions between cells but the required numerical resources aren't too elevated. It can be seen in Fig.1b that differences between FE curve for a quarter of the real tested panel (full model with symmetry condition) and the curve obtained for a group of 17 cells (reduced model) are limited. Comparing with the exp1, the error on the adsorbed energy is 3.73% for quarter and 9.75% for the 17 cells. Also error on peak is similar (7.55% for 17 cells and 14.8% for the quarter). Therefore the use of a reduced model for sensibility analyse is reasonable and it brings to reliable results. The elements used are reduced brick element C3D8R. Mesh dimension is 0.2x0.2mm and there are 4 elements through the thickness. The total number of elements is 687720. Mesh values have been chosen due to a mesh sensibility study made in [4]. Analyses have been made with commercial software Abaqus^{tm} 6.9-1 with an explicit scheme. FE tests cover a range of variation in model parameters of 30%. The reason of the choice of this value comes from authors' sensibility in order to evaluate significantly the effect of tested parameters. Moreover is reasonable to avoid wider variation because in real industrial context a such width variation in parameters (i.e. elastic modulus or yielding strength) can't be tolerated.

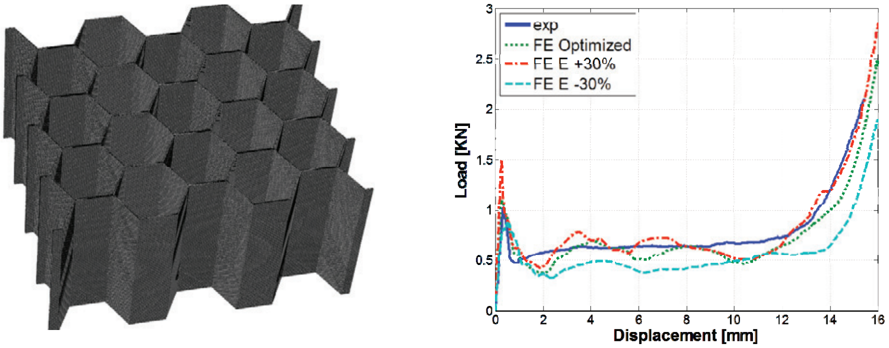

Fig.2. a) Numerical model of honeycomb core. b) Effect of variation of elastic modulus on numerical load-displacement curve.

3.1. Elastic modulus effect

The effect of elastic modulus of Nomex^{tm} on the numerical load-displacement curve has been evaluated comparing it with the optimized one. Two tests have been made with a range of variation of 30% of the elastic modulus value. The optimized value is 1848 MPa while the highest value is 2441 MPa and the lowest is 1315 MPa. The result can be seen in Fig.2b. Elastic modulus mostly affects peak value instead the effect on the plateau isn't so evident. Increasing or decreasing E value affects in a different way the curves from FE models. An increased in E causes an increment of the peak of about 36% and of the adsorbed energy of 12%. Instead with the lower value of E, the peak decreases of 21% and the adsorbed energy decreases of 20%. Perceptual variations have been obtained using as reference the optimized FE curve.

3.2. Yielding effect

The effect of yielding strength of Nomex^{tm} on the numerical load-displacement curve has been evaluated comparing it with the optimized one. The plastic behaviour has been assumed as elastic perfectly plastic. Two tests have been made with a range of variation of 30% of the yielding stress value. The optimized value is 40 MPa while the highest value is 52 MPa and the lowest is 28 MPa. The result can be seen in Fig.3a. Yielding strength mostly affects the plateau value instead the effect on the peak is lower. Increasing yielding strength causes an increment of the adsorbed energy of about 24% while with the lowest value the adsorbed energy decreases of 21%. The effect on the peak is instead very different spacing from an increase of 14% with the highest strength modulus to a very small increment of 0.3% with the lowest yielding. The influence of yielding strength on the FE load-displacement curve, as far as the adsorbed energy, seems to be almost linear. Perceptual variations have been obtained using as reference the optimized FE curve.

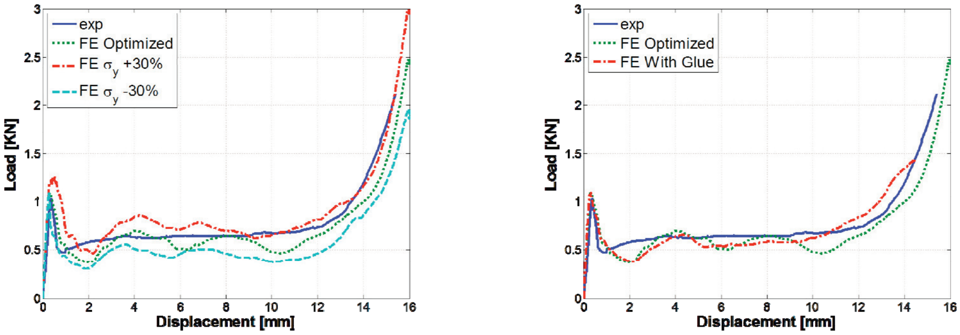

Fig.3. a) Effect of variation of yielding strength on numerical load-displacement curve. b) Effect of glue on numerical load-displacement curve.

3.3. Glue effect

Adhesive glue is used in a zone near the upper and lower skin in order to guarantee the link between honeycomb core and skins. The effect of this parameter has been evaluated using a special Abaqus^{tm} feature called *skin.* The procedure consists into the placing of shell elements over cell walls. These shell elements have also an appropriate thickness profile in order to better reproduce the real glue profile. The effect of glue on the numerical load-displacement curve has been evaluated comparing it with the optimized one. The result can be seen in Fig.3b. The glue effect on peak and adsorbed energy is negligible but modelling glue leads to a significant increment in time costs. Besides the glue skin generates some instability issues in the very final part of the compression.

3.4. Wall thickness effect

Wall cells thickness is a very difficult parameter to evaluate due to the very low Nomex^{tm} paper thickness, combined with the high inhomogeneity of the material. To get reasonable values for thickness an experimental measure using SEM photos has been performed [4]. However the parameter is crucial for a reliable simulation, therefore two tests have been made with a range of variation of 30%. The result can be seen in Fig.4a. Wall thickness affects in a not negligible way both peak value and adsorbed energy. Increasing thickness causes an increment of 37% of adsorbed energy and of 35% of peak value. Decreasing thickness causes a reduction of adsorbed energy of 27% and of peak value of 9%. Perceptual variations have been obtained using as reference the optimized FE curve.

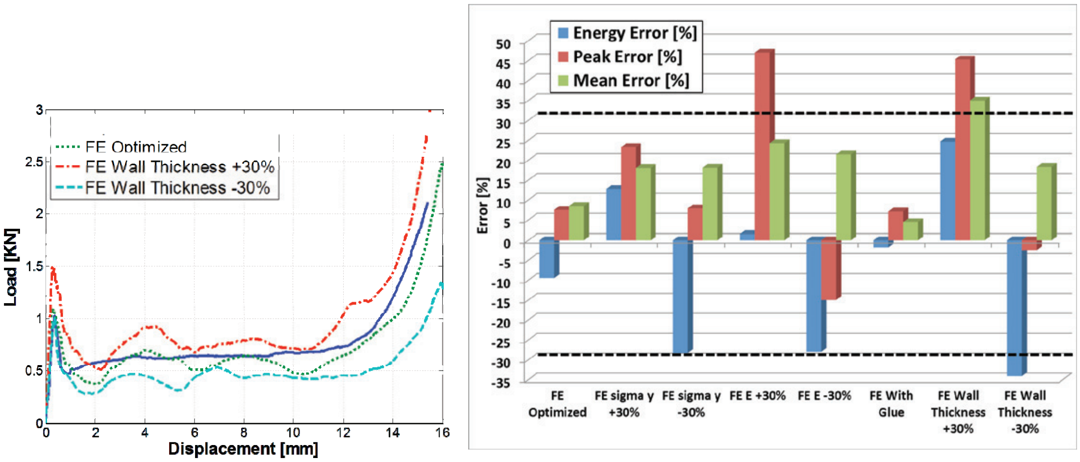

Fig.4. a) Effect of Nomex^{tm} paper thickness on numerical load-displacement curve. b) Perceptual error using various parameters. The reference is the experimental curve.

4. Conclusions

In order to compare the influence of various parameters on the numerical load-displacement curve two different error quantity has been evaluated. The first error refers peak value and it is defined as (1):

$$E_{\%peak}=100*(Peak_{numerical}-Peak_{experimental})/Peak_{experimental} \tag{1}$$

As peak we refer to the first highest value of the load-displacement curve. Perceptual error peak is thus a punctual comparison. In addiction another error quantity has been evaluated in order to estimate the overall difference between numerical and experimental curves over the complete range of displacement. This quantity is the adsorbed energy error. Adsorbed energy can be calculated as the area below each load displacement curve up to the same displacement (14 mm) in each test.

The perceptual energy error is defined as (2):

$$E_{\%energy}=100*(Energy_{numerical}-Energy_{experimental})/Energy_{experimental} \quad (2)$$

It’s interesting also a combination of the two errors described above thus also a mean error between them has been calculated. This error is calculated summing the absolute values of previous errors hence mean error can be considered a synthetic value useful to quantitative compare the effect of different parameters. The overall results can be seen in Fig.4b. Material behavior data used in the each test are provided in Tab.1.

Table 1. FE model parameters

Numerical Test	Elastic Modulus [MPa]	Yielding Strength [MPa]	Single Wall Thickness [mm]	Glue
Optimized	1878	40	0.108	No
FE E+30%	2441	40	0.108	No
FE E-30%	1315	40	0.108	No
FE σ_y+30%	1878	52	0.108	No
FE σ_y+30%	1878	28	0.108	No
FE thk+30%	1878	40	0.140	No
FE thk-30%	1878	40	0.0756	No
FE with glue	1878	40	0.0756	Yes

Looking Fig.4b some important considerations easily arise. Obviously best results are obtained with the optimized configuration. Actually these results are even better with glue. The reason why the optimized configuration isn’t the one with glue concerned especially numerical performance as already described in paragraph 3.3. It’s very interesting to summarize the effect of various parameters on the different part of the curve. In order to change peak value the most influenced parameter is the elastic modulus and with a slight smaller effect also wall thickness. The main difference between these two parameters is that elastic modulus affects less the adsorbed energy than wall thickness. Hence if there is the will to change mainly peak value is better to fit elastic modulus than wall thickness. The influence of yielding strength is almost the opposite of elastic modulus. This means that yielding strength affects mostly the adsorbed energy while its effect on peak is barely negligible. Another important consideration concerns the non-linearity of almost all the parameters on the resulting curve.

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