Determination by experimental and numerical methods of the stress and strain states in perforated plates with square holes placed in a parallel pattern, stressed with uniaxial traction

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Abstract: - The paper presents a comparative study between experimental tests and numerical results obtained with the help of the finite element method with regard to the stress and strain state that appears in a perforated plate with square holes placed in a parallel pattern stressed with uniaxial traction.

Key-Words: - perforated plate, uniaxial traction, Instron tensile testing machine, finite elements method.

1 Introduction

The plane perforated parts are used as strength elements in numerous industrial applications, both in machine manufacturing and in civil engineering. The analytical strength calculus implies big difficulties, both related to mathematics and to the volume of work to be carried out and therefore very often and with results close to reality, the stress state is determined with the help of experimental methods and of numerical methods. A very important characteristic of the perforated plates is the plate's perforated area, area which is calculated with formulas specific for each hole type (hole shape and manner of hole placement on the plate). In the case of the plate studied in the current paper (fig.1), this relationship is the following one:

$$S_P = \frac{100 \times D^2}{p^2} \, [\%] \tag{1}$$

The material discontinuity in the plate's plane, obtained by perforation, has as a first effect the disturbing of the stress field in the stressed plate and the concentration of stresses in certain points on the holes' contour.

Due to the holes' closeness, the disturbance effects mutually influence each other, sometimes resulting in an amplifying, sometimes resulting in a diminishing. Because of the regularity of the holes' placement, the disturbance effects are more intense felt on certain directions. Given the mentioned difficulties, the stress state determination in plane plates and in curved plates has solutions only for certain particular cases.

The studied plate has following dimensions: D = 10 *mm*, p = 16 *mm*, plate thickness g = 0.8 *mm* and the perforated area was S_P =39 %.

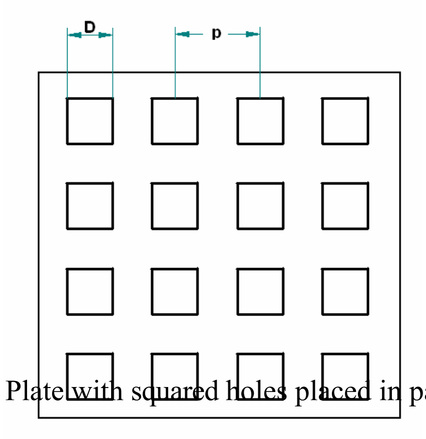


Fig. 1 Plate with squared holes placed in parallel

2 Mechanical tests

Mechanical tests presented in this paper were realized on the universal traction, compression and buckling testing machine INSTRON 4303 from the endowment of the Engineering Faculty of Sibiu, Romania.

The universal traction, compression and buckling testing machine INSTRON 4303 (fig. 2) is a testing device composed of two main systems: a mobile beam and the control system, which applies stretching or compression loads to the material. It can exert a maximal loading capacity of 25 *kN*, controlled through the IEEE-488 interface and the specialized software Material Testing System series

IX. It allows the control of the mobile beam's displacement speed with a precision of 0.5% and the force's recording with a precision corresponding to the ASME 4-E class or to the DIN 51221 class 1. The mobile head's control system allows the programming of the mobile beam's speed and assures the mobile head's position control.

Fig. 2 The universal traction, compression and buckling testing machine INSTRON 4303

The resulting data are specific for the test types for which the machine was realized, thus loads, displacements, stresses, specific strains, energies. During a test, the results appear as instantaneous values of the load and of the displacement or of the stress and specific strain, and at the end of the test, they appear as values registered in peaks or in points specified by the user.

The experimentation program was based on following elements:

- thickness of the chosen test samples g = 0,8 mm;
- sets of six test samples each;
- the speed with which the test sample is stressed is of 0.5 *mm/s*;
- acquired output data are: breaking load [*kN*], breaking elongation [*mm*], maximal stress achieved in the material [*MPa*], relative elongation corresponding to the maximal stress in the material [%];

A testing method was realized in the INSTRON testing machine's own programming language, MATERIAL TESTING SYSTEM, in this stage being determined: the test's type (traction), the material data (test sample shape, material thickness, test sample width, distance between the machine's clamping dies and the distance between the measurement markings), the traction speed, the machine's limits, the machine's acquisition rate (25 points/s), output file type (ASCII or DIF – Data Interchange Format, a file type that can be imported into any software for statistical processing of data), type of output data that will be collected (the software offers to the users about 200 types of data specific for each test type);

Beneath the above-mentioned data, the primary data of such tests are saved (the characteristic curve in coordinates force [*kN*] – displacement [*mm*]). These data are found as point pairs in the aforementioned coordinates in the file for each analysis in ASCII format.

Data that must be input in the software application are:

L_0 - initial length between markings [*mm*];

g_0 - test sample thickness [*mm*];

S_0 – area of the minimal initial cross-section of the test sample [mm^2].

The data acquired from the INSTRON 4303 testing machine are point pairs elongation (Δl) – force (F) in the British measurement units system, i.e. elongation – [*inch*] and force – [*lb*].

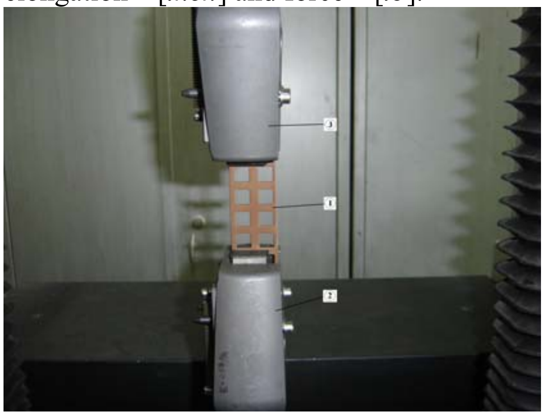


Fig. 3 Test sample made of a perforated metal sheet with squared holes

1- test sample; 2 – fixed clamping die; 3 – mobile clamping die

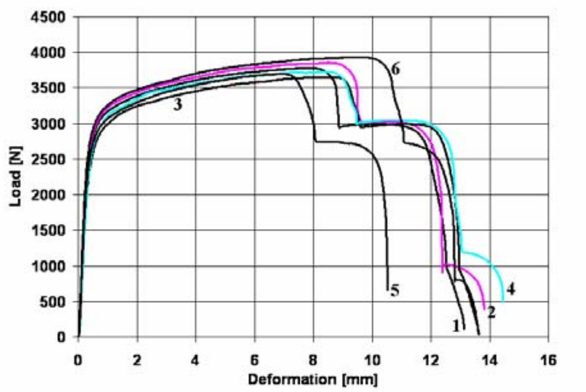


Fig.4 Characteristic tensile stress-strain curves for a metal sheet of 0.8 [mm] thickness with squared holes in parallel pattern, stressed uniaxially.

From the experimentally determined characteristic curves, presented in figure 4, it can be noticed that for each linking bridge between the holes there is a small yield level, which increases with the thickness of the linking bridge, i.e. with the pitch between two consecutive perforations.

The values of parameters determined by means of the mechanical test carried out are presented in table 1 for each of the six studied test samples [3]. Also, the table presents the arithmetic average value for these values and the average square error [6].

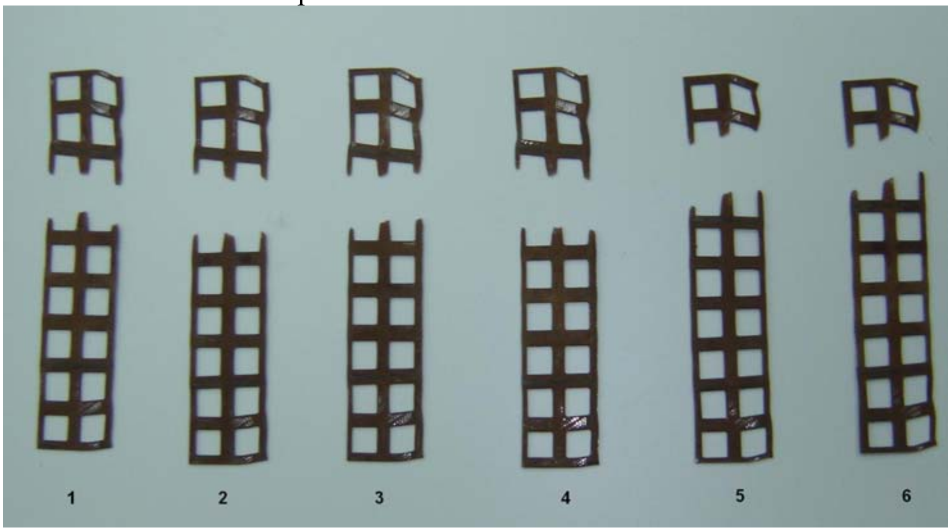


Fig. 5 Set of test samples fractured at their tensile testing

Table 1: Values from experimental determinations

Test sample number	**Hole length**	**Minimal area of the cross-section**	**Breaking load**	**Maximal elongation**	**Maximal stress**	**Maximal specific strain**
	L **[mm]**	S_0 **[mm²]**	F_r **[kN]**	ΔL_{max} **[mm]**	σ_{max} **[MPa]**	ε_{max} **[%]**
1.	10	16.96	5.622	9.94	331.5	16.57
2.	10	16.96	5.918	10.46	348.9	17.45
3.	10	16.96	5.721	10.12	337.3	16.87
4.	10	16.96	5.728	10.13	337.7	16.89
5.	10	16.96	5.820	10.29	343.2	17.16
6.	10	16.96	5.565	9.84	328.1	16.41
Arithmetic average value			5.729	10.129	337.8	16.89
Average square error			0.128	0.227	7.57	0.378
Sum of dispersions			0.052	0.093	3.09	0.155
T_{calc}			1.509	1.388	0.904	1.099
T_{tab}			2.571	2.571	2.571	2,571
Remark:			At the tensile testing of metal sheets with the thickness g = 0.8 *mm*, for a significance threshold α = 0.05, according to SR ISO 5725-1:1997, by applying the Student test it is remarked that there are no aberrant values in the measurement series carried out, because $\mathbf{T_{calc} < T_{tab}}$			

3. Numerical simulation

In the analysis by means of the finite element method in non-linear domain that will be presented in the following, the perforated plate was discretised as a solid deformable body, initially composed of 575 elements of thin shell type (THIN SHELL 163) [5]. The type of associated element is an element with four nodes having 12 degrees of freedom in each node and that can be used only in explicit-type analyses such as the current one. The degrees of freedom associated to each node are represented by: nodal displacements, global rotations, nodal speeds and accelerations. For coordinates, displacements and rotations, bi-linear interpolations are used. The specific strains are calculated from the displacements field and the curvature from the rotations field.

The specific transversal strains are calculated at the middle of the edges and are interpolated in the integration points. In the analysis presented here there were used five integration points on the element's thickness. Due to the manner in which elements are connected, the network consists of 568 nodes, which gives to the system a number of 6816 degrees of freedom [4]. The pre-processor used in this analysis case was LS-DYNA, from the software package ANSYS 8.0

The active elements (the clamping dies of the testing machines) were described by means of components for which certain degrees of freedom were cancelled.

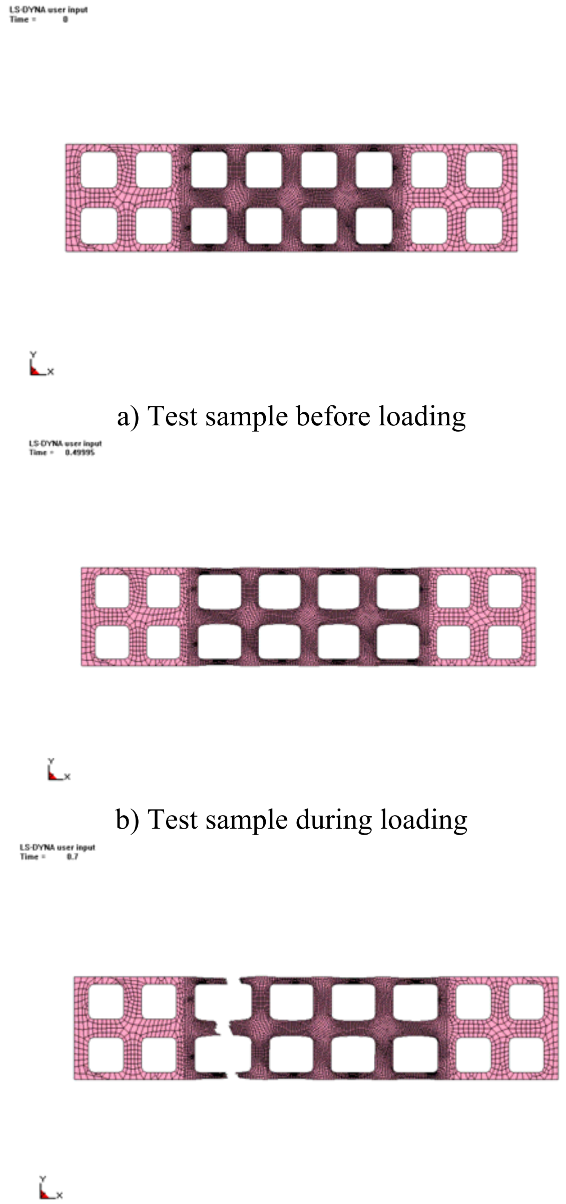
Thus, for components considered to be fastened in the lower clamping die, all degrees of freedom were annulled, while for those considered to be fastened in the upper clamping die, all rotations and translations along the Oy and Oz directions were annulled, remaining only the translation along the Ox axis.

The material type associated to the test sample elements is identical to the one mentioned above, thus keeping all characteristics indicated for this material.

Figure 6 a...c presents the test sample before the test (a), during the test and after breaking (c).

The variation pattern of the equivalent stresses in a node, during testing, is shown in figure 7.

Results obtained following the running of this analysis, namely the variation of equivalent stresses, of equivalent specific strains and of the sample's thinning after the deformation, are presented in figure 8 a...d



a) Test sample before loading

b) Test sample during loading

c) Broken test sample

Fig. 6 Aspect of the test sample at various stages during the experiment

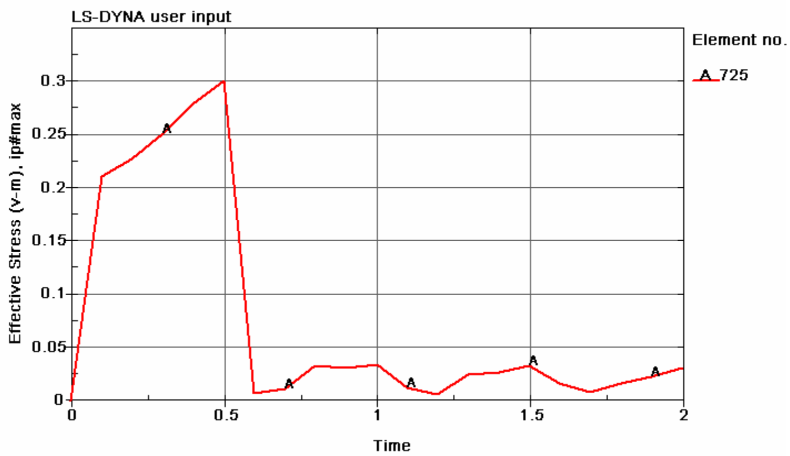
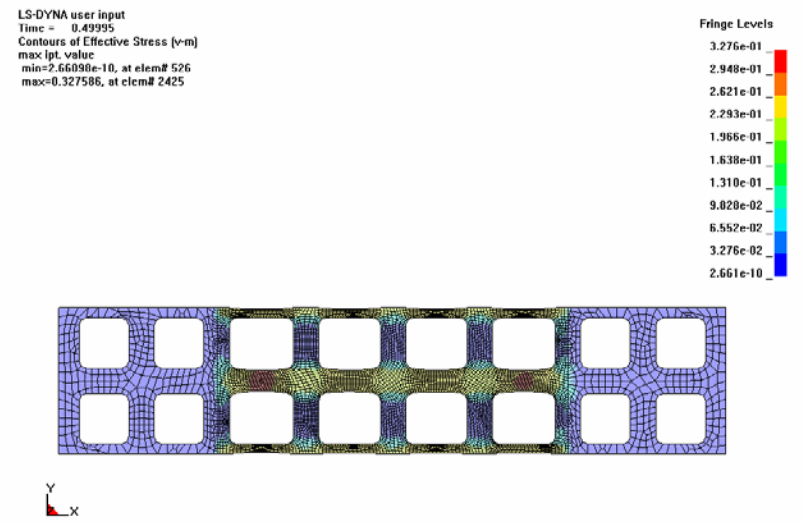
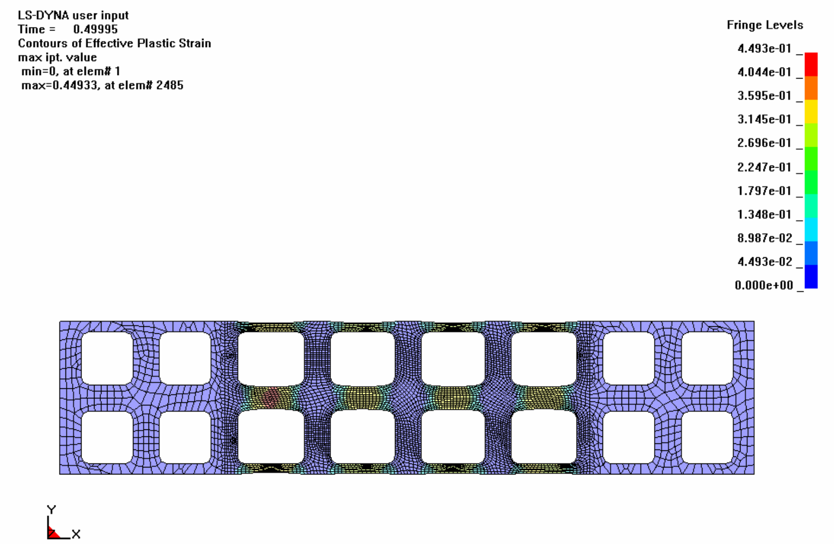


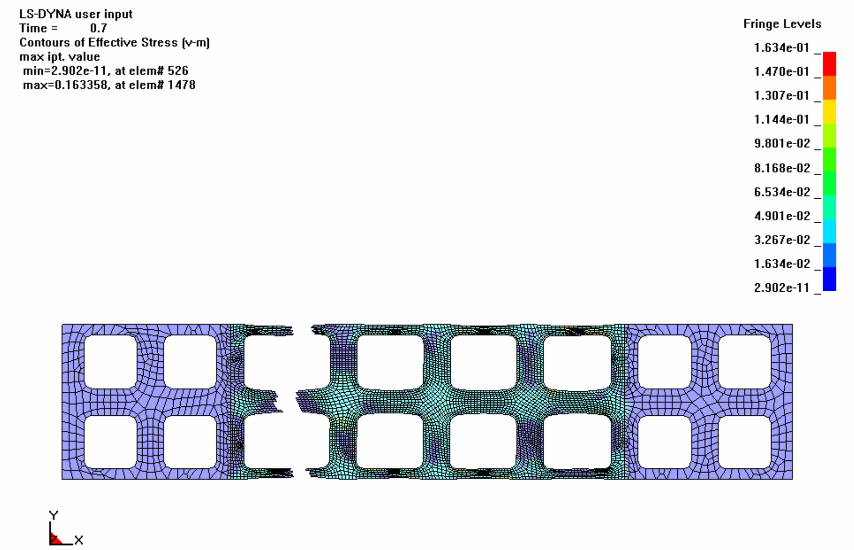
Fig. 7 Variation of the equivalent stress for an element



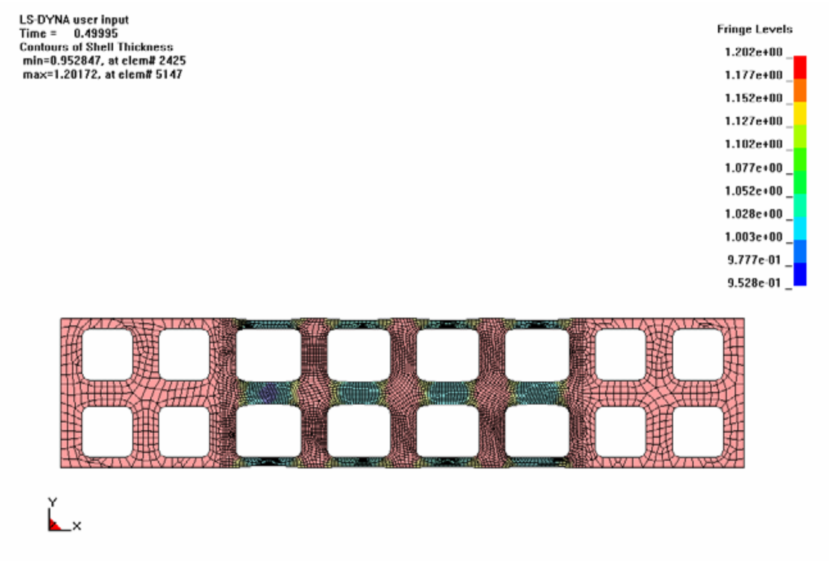
a) Distribution of equivalent stresses at one moment during loading



b) Distribution of specific strains at one moment during loading



c) Distribution of equivalent stresses at the moment of breaking



d) Variation of the test sample's thinning after the deformation

Fig. 8 Numerical results in the plate with square holes (D= 10 mm) placed in parallel

4 Conclusions:

If the average value of the experimentally determined maximal stress (σ_{exp} = 337.8 *MPa*) is compared to the value determined with the help of the finite elements method (σ_{MEF} = 300.3 *MPa*), one can notice only a very small difference between the two values, the error being of about 20.1 %, which leads to the conclusion that determinations made with the help of the finite elements method are very close to reality, so the method can be successfully used for such structures.

Also, if a comparison is made between the manner of fracture of this perforated plate type presented in paragraph 3 and the one obtained after mechanical tests (paragraph 2), one can notice a similitude both with regard to the manner in which structures are deformed, and with regard to the manner in which they break.

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