Computer Tomography Investigation of Defects in Plastic Material Plates

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The purpose of this paper is to show the possibility of finding the location and to describe internal discontinuities in plates made of plastic materials using non-destructive evaluation methods. Their effect on the mechanical behaviour is also evaluated by means of numerical calculus. The technique of computer tomography („CT") is used as a non-destructive evaluation method whereas the numerical calculus is realized by the finite element method.

Keywords: computer tomography, discontinuity, finite element analysis

In engineering, mechanical structures made of materials presenting surface or internal defects are frequently met. These cases are usually encountered in materials obtained by various traditional manufacturing technologies (casting, forging, welding etc.), but also in composite materials.

The presence of discontinuities can weaken the loading capacity of structures, cause failure and endanger the safety in exploitation of the structures [1]. Thus, the investigation of structures and materials using non-destructive evaluation methods is mandatory due to the fact that it offers detailed information regarding the presence, the shape and the dimensions of defects [2-3].

In terms of three dimensional defects in structures, the importance of their detection consists in the possibility of studying their influence on mechanical behaviour over the exploitation of the structure.

By combining modern techniques of nondestructive evaluation, for locating and description of the defects, with modern calculus techniques for the analysis of the stress and strain around defects, conclusions can be drawn regarding the influence of defects on mechanical behaviour and integrity of a structure [2-5].

In this paper, a study realized by CT technique some plastic materials plates with internal defects is described, followed by numerical calculus in which information obtained after X-ray scan in a CT (plate geometry and defects, positioning of defects) is used [6]. This technique is chosen because it allows a complete description of the structure as well as the reconstruction of the volume using specialized software, which can be used in composite elements analysis [7].

In order to exemplify the way in which defects influence the state of stress and strain, numerical calculus is performed for the models investigated using the CT, varying the boundary conditions, but maintaining the loads.

Experimental part

Materials and methods

Specimens Description

In this paper , the specimens are made of plastic materials (epoxy resin) casted in three layers with internal defects imposed.

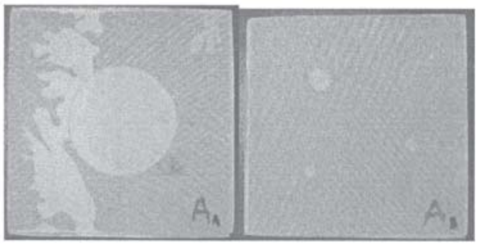

Fig. 1. Specimens

For the present study, there are two square stratified with epoxy resin plates, with a side of 100 mm (fig. 1). The plates are made of three resin layers with 2 mm thickness.

In the middle layer, the following flaws appear:

-in the A1 plate there is one circular flaw, positioned in the centre;

-in the A3 plate there are three circular flaws, randomly positioned.

Computer Tomography

-Functioning principles and equipment

The functioning principles of this method are, as in traditional X-ray, the measurement of the level of attenuation for the electromagnetic radiation that crosses the examined object and the reconstruction of the imagine of the investigated object, using various projections of its cross sections [7-8].

The CT is composed of a sliding table, inside a tunnel, on which the object to be examined is positioned (fig. 2). The table slides back and forth through the tunnel with different speeds. Inside the tunnel case there is an arc-shaped curved frame on which is fixed the X-ray tube which rotates around the object under investigation during the progression of the examined table. In the tunnel, on the same frame, opposite of the source of X-ray, there is an arc-shaped detector. During a complete rotation of the tube, by sending a bunch of fan-shaped X-ray through the investigated object, images of thin sections are acquired. At each rotation, the detector records 1,000 images. A dedicated computer system reconstructs two-dimensional images of the scanned body section [6, 9].

In order to investigate the plates, a spiral CT (helical CT scan) has been used (fig. 3). The spiral CT can rapidly take high-quality images, due to improving technology of image sensors. This system, known also as multidetector CT, was a system type of 4 sections.

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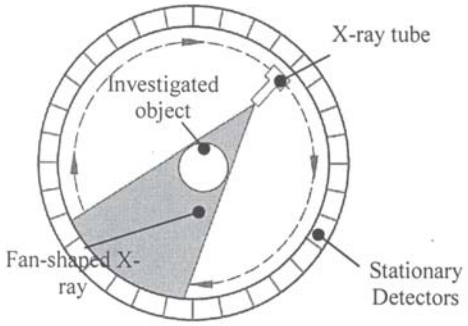

Fig. 2. The functioning principle of CT

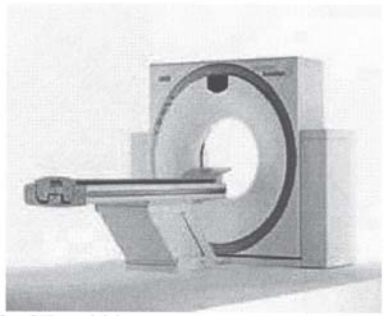

Fig. 3. CT multidetector system type of 4 sections

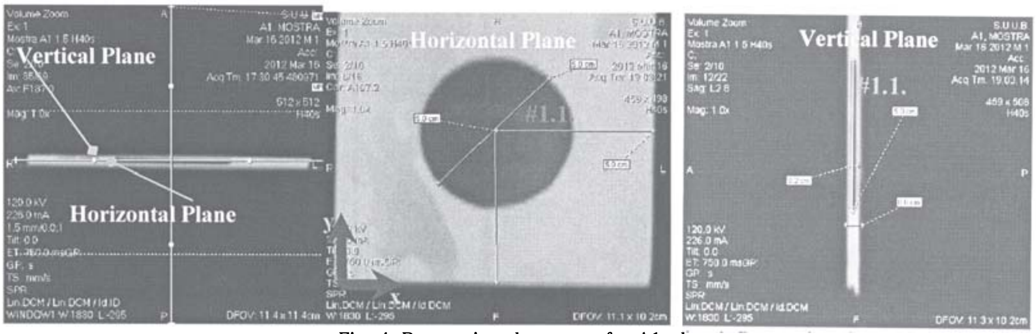

Fig. 4. Processing the scans for A1 plate

Processing the results

Using a specialized software aiming to describe the defects (eFilm Workstation), the CT images obtained after scanning the plates, are processed.

The methodology of processing the images obtained by CT is as follows:

- the section, where on the opening of the flaw is maximum and for which two areas of interest, vertical and horizontal are defined, is chosen of the series of cross sections (axial) obtained from X-ray scan;
- using the defined areas and the dedicated software, the chosen section is reshaped in frontal plane (horizontal) and in sagittal plane (vertical);
- in the frontal section the following are defined:
  shape of the flaw;
  overall dimensions of the plate and the flaw;
  plane positioning of the flaw;
- in the sagittal section the following are defined:
  overall thickness of the specimen;
  depth of the flaw.

In figure 4 and in figure 5, data obtained for A1 plate and respectively A3 plate are shown.

Table 1 presents the obtained results.

The next step consists in the reconstruction of volume of the plates in order to make the finite element model.

Numerical Analysis

The strength calculus for structures made of plastic materials, necessary for establishing the state of stress and strain, represents one of the main problems faced by engineers in this area of expertise. Advantages of using numerical methods are various such as obtaining fast and accurate solutions for problems of great variety and practical importance [10].

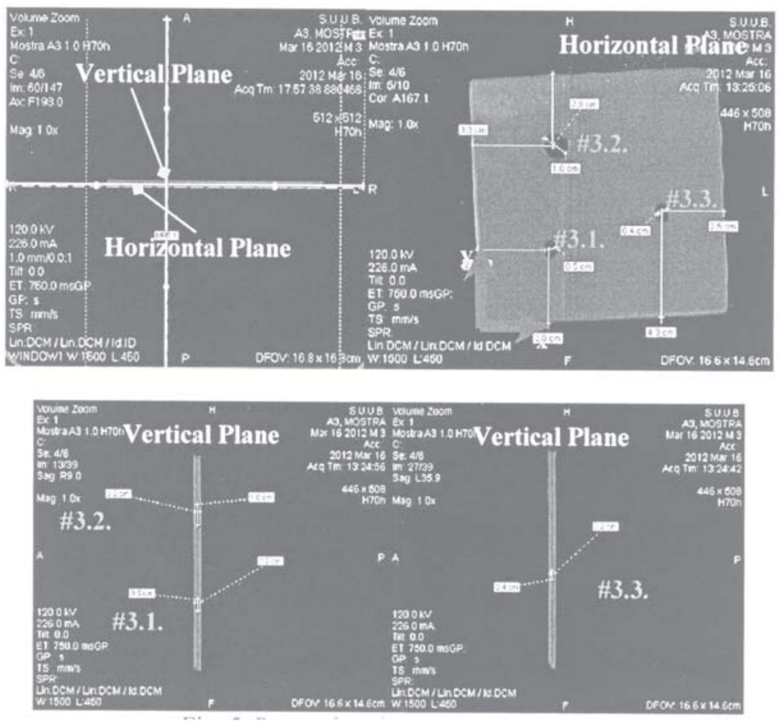

Fig. 5. Processing the scans for A3 plate

Table 1
DESCRIPTION OF THE DEFECTS

	Defect	Size of defect [mm]	Position of the defect		
			Coord. X [mm]	Coord. Y [mm]	Depth [mm]
A1 plate	#1.1.	Φ 50	50	50	0.2
A3 plate	#3.1.	Φ5	30	30	0.2
	#3.2.	Φ10	30	75	0.2
	#3.3.	Φ4	75	43	0.2

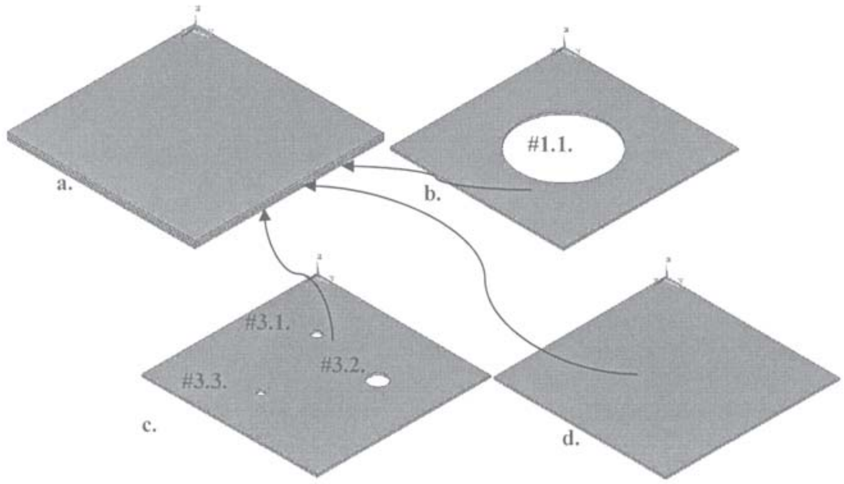

Fig. 6. Calculus models: a. Reconstructed volumes; b. Geometry of the middle layer A1 plate; c. Geometry of the middle layer A3 plate; d. Geometry of the middle layer specimen plate

The numerical analysis performed using the finite element method can provide information regarding the aspects of the way in which the presence of some internal defects can decrease the loading capacity of a structure and can generate delamination phenomena and fracture propagation [11-12].

Calculus models and finite elements analysis

The information obtained by X-ray scanning has been used for creating the calculus models. Three models are defined, two for the investigated plates and one standard model for which the middle layer is continuous. The intended purpose for the standard model has been the possibility to compare stress and displacements values with those obtained for the plates with discontinuities. Calculus models (fig. 6) are performed with tetrahedron finite elements, as they can approximate regular shapes without losing the precision of analysis. Also, they have degenerate compatible form for analysis of models containing curves [13].

In order to exemplify the influence of the defects on its behaviour of structure in service, three numerical analyses for each plate are explained, as follows:

a.model constrained on one side of the contour (fig. 7, a);

b.model constrained on two sides of the contour (fig. 7, b);

c.contour model constrained on all sides (fig. 7, c).

These models are loaded by a pressure on one of the exterior surfaces. The value of this pressure is set to 0.1 MPa.

The material is homogeneous, isotropic and has linear behaviour. Elastic characteristics of epoxy resins of which specimens were built are determined by mechanical tests (tensile testing), and presented in table 2 [14].

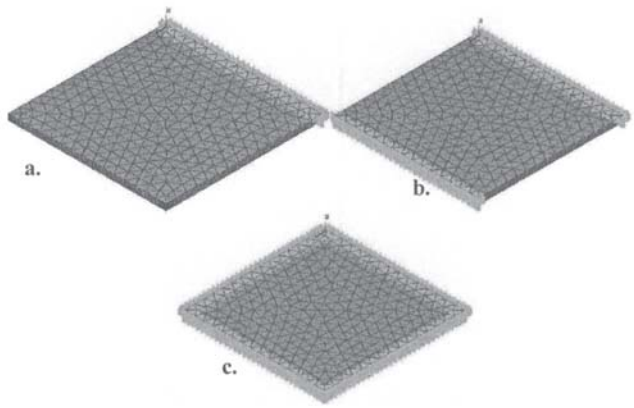

Fig. 7. Modes of loading and boundary for the two plates

- Numerical results

In order to assess the effects of discontinuities, depending on their size as well as their boundary conditions, a comparison of equivalent stress values of the two plates (A1 and A3) was performed. The standard value for this comparison is considered the tensile strength experimentally determined.

As described below, the following parameters are presented in graphical form:

-equivalent von Mises stress for the entire structure (fig. 8 - A1 plate, fig. 9 - plate A3), depending on the used boundary conditions;

-equivalent von Mises stress for middle layers (fig. 10 - A1 plate, fig. 11 - plate A3), depending on the used boundary conditions.

Table 2
VALUE OF ELASTIC CHARACTERISTICS OBTAINED BY EXPERIMENTAL MEANS

Material	Young's modulus [MPa]	Poisson's ratio[-]	Tensile strength [MPa]
Epoxy Resin	3482.2	0.28	28.2

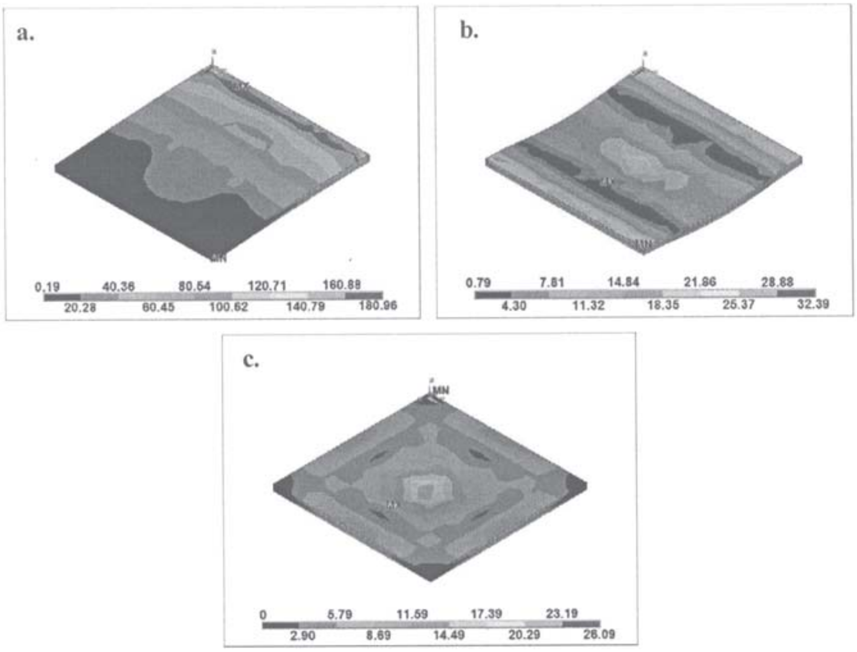

Fig. 8. Equivalent von Mises stress for A1 plate: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained all sides

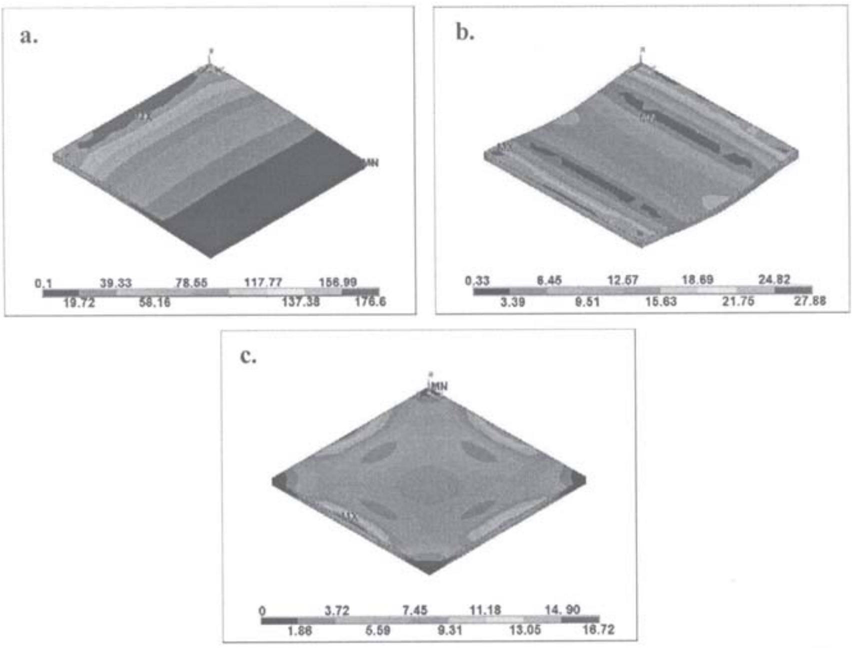

Fig. 9. Equivalent von Mises stress for A3 plate: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained all sides

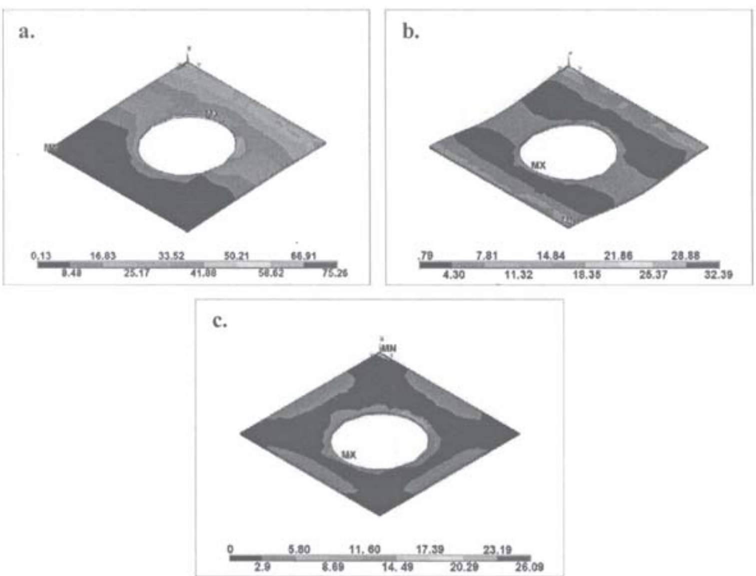

Fig. 10. Equivalent von Mises stress for A1 plate in middle layer: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained all sides

For the quantitative assessment of the discontinuities effects in the two plates, in figure 12 and figure 13 the equivalent von Mises stresses are presented for the entire layer structure and the middle layer of the standard plate.

According to the values presented in the charts described above, the following conclusions can be drawn:

-the worst case scenario is one side boundary condition because it yield high stress values and elevated displacements, $\sigma_{ech\ max}$=180 MPa for A1 plate and $\sigma_{ech\ max}$=176 MPa for A3 plate, due to the high local effects;

-as a result of analysing the equivalent stress values for the three models in the first boundary condition case (plate constrained on one side), the stress of the discontinuity zone has lower values than the one obtained in the constrained boundary. Regarding this, the discontinuities effects of the boundary conditions are negligible;

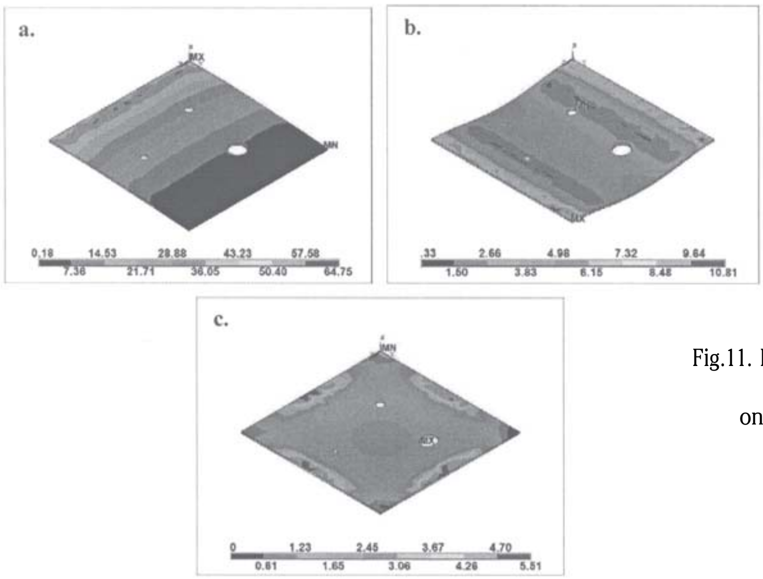

Fig.11. Equivalent von Mises stress for A3 plate in middle layer: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained on all sides

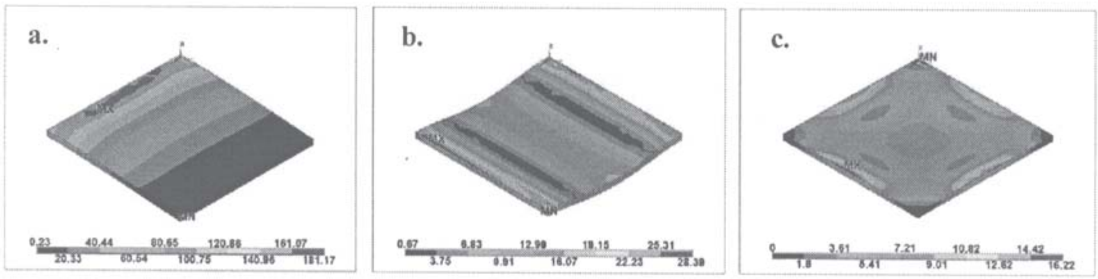

Fig. 12. Equivalent von Mises stress for specimen plate: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained on all sides

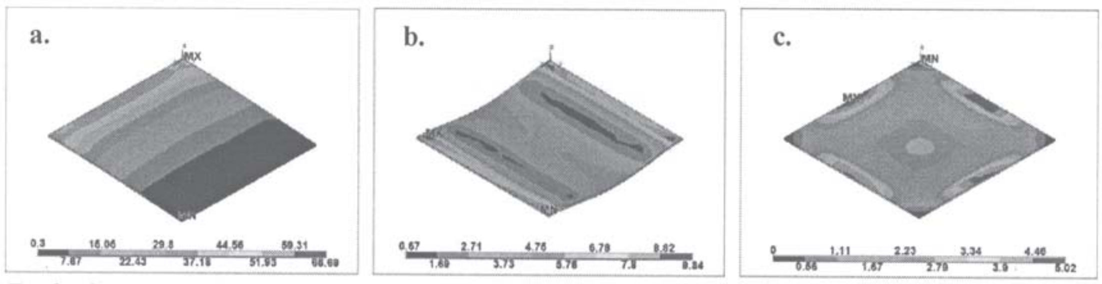

Fig.13. Equivalent von Mises stress for specimen plate in middle layer: a. plate constrained on one side; b. plate constrained on two sides; c. plate constrained on all sides

-the plate with multiple defects (A3 plate) has a higher load capacity than a plate with a single larger defect (A1 plate), for all boundary conditions cases; the numerical values are presented in table 3;

-for this type of loading, the presence of defects in the middle layer, does not create higher values of stress in all three cases of boundary conditions; the numerical values are presented in table 4;

-the maximum equivalent stress for the A1 plate is five times larger than the one obtained in the A3 plate. This shows that the size and position of defects influence the stress distribution throughout the structure, negatively disturbing the mechanical behaviour of the structure;

-these numerical analyses outline the importance of knowledge of the position, shape and size of the defects due to their influence on the loading capacity of the structure.

	Maximum equivalent von Mises stress [MPa]		
	Two sides boundary conditions	Two sides boundary conditions	Two sides boundary conditions
A1 plate Middle layer	75.26	32.39	26.09
A3 plate Middle layer	64.75	10.81	5.51
Reference plate Middle layer	66.69	9.84	5.02

Table 3
EQUIVALENT VON MISES STRESS FOR THE ENTIRE STRUCTURE

	Maximum equivalent von Mises stress [MPa]		
	Plate constrained on one side	Plate constrained on two sides	Plate constrained on all sides
A1 plate	180.96	32.39	26.09
A3 plate	176.6	27.88	16.72
Reference plate	181.7	28.39	16.22

Table 4
EQUIVALENT VON MISES STRESS FOR THE MIDDLE LAYER OF THE STRUCTURE

Conclusions

The study of discontinuities represents an actual problem especially in the case of composite and plastic materials with or without fibre reinforcement.

A nondestructive method of investigation is recommended for the parts made of these materials, in order to establish their structural integrity.

Choosing the right method of nondestructive evaluation represents an important and difficult step and imposes a good knowledge of the existing problem.

The accuracy of the method depends on the type of material and its applicability.

For the analysed plates, the computer tomography was used because of its accurate images and their easy reconstruction into finite elements

The finite element method is the most appropriate way of characterisation the effect of discontinuities over stress and strain distribution and the loading capability of a structure.

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