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Identification of the Stress Fields from the Strain Fields in the Isotropic Materials

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Abstract

The identification of the material properties in sheet metals is usually achieved using uniaxial tests. The main attention of this article is focused on the identification of the plastic behaviour of sheet metals using full field measurement. The results were compared for notched specimen and specimen with a hole. These geometries create a heterogeneous strain fields which were measured during the test using high-speed cameras JAI Pulnix TM – 4000 CL which are used in digital image correlation system. DIC is non-conventional optical method for contactless measurement of spatial deformation and displacement and is more and more applied in experimental mechanics. The benefit of using a heterogeneous strain field in the identification process is that a complex state of stress-strain can be analyzed at the same time and much more information can be obtained in a single test. However, the stress field cannot be directly computed from the test and a suitable identification process has to be developed. The article contains virtual fields method (VFM) adapted for strains and plasticity which has been used to identify the hardening behaviour. The results obtained with the VFM have been compared with the results coming from a standard identification made with uniaxial tensile tests.

Keywords: digital image correlation, plastic deformation, strain fields, stress fields.

Nomenclature	
X_1, X_2 and X_3	parameters to be identified by Camfit
Greek symbols	
$\sigma_{H(k)}$	equivalent stress
$\varepsilon_{eq_{pl}(k)}$	equivalent accumulated plastic strain

1. Introduction

Identification and quantification of the plastic deformation of materials is important in several respects. On one hand, the industry manufactured many components by cold forming, on the other hand, overloading of supporting structural elements leads often to plastic deformation of materials and to their violation (break). Knowing the size and distribution of plastic deformation allows better use of the properties of materials at production of parts, and in their operation. A typical example

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of production of parts by plastic deformation of the material is cold forming of the steel sheet. This process is most commonly used in automotive and consumer industry (and to improve performance moldings in these fields of industry).

Usually the identification of mechanical properties is test by using of uniaxial tensile tests. However in last years, thanks to the development in the full-fields measurement techniques, more complex specimens which generate heterogeneous stress-strain fields can be used to study the behaviour of the material properties during the plastic flow. Then the parameters can be identified using for example an inverse approach which includes FE updating [1-3]. Next identification process is the Virtual Fields Method [4] which has been successfully applied in many applications, including elasto-plasticity [5,6] and large strain plasticity [7]. The use of heterogeneous tests allows getting a lot of information from a single test since different stress-strain conditions are evaluated at the same time. In this article were carried tests on a notched specimen and specimen with a hole. The displacement and strain field was measured using digital image correlation and the results have been used to identify the parameter with VFM. As plasticity model was used Swift hardening law.

2. Experiments

The heterogeneous strain field was obtained using a notched specimen and specimen with a hole, the complete geometries are illustrated in Fig. 1. The specimens were cut in rolling direction from a cold rolled sheet made from isotropic steel. The mechanical properties measured using standard tensile tests are listed in Tab. 1. The value of the Lankford parameter [8], i.e. the ratio of the transverse to the through-thickness strain increment, is measured at different stages of the test. In this article was used the principle of digital image correlation which is based on application of stochastic pattern of the surface of the test object [9]. This pattern was sprayed using a white base colour and spattering a black colour on top. These speckles on the top of surface represent material points of the body. The speckles copy the deformations of the surface and they move together with the surface. Displacement and strains of the points are calculated through correlation of corresponding facets on digital snapshots in state before and after deformation [10], [11], [12]. The VIC-3D commercial software was used for the calculation of strain fields from the displacements.

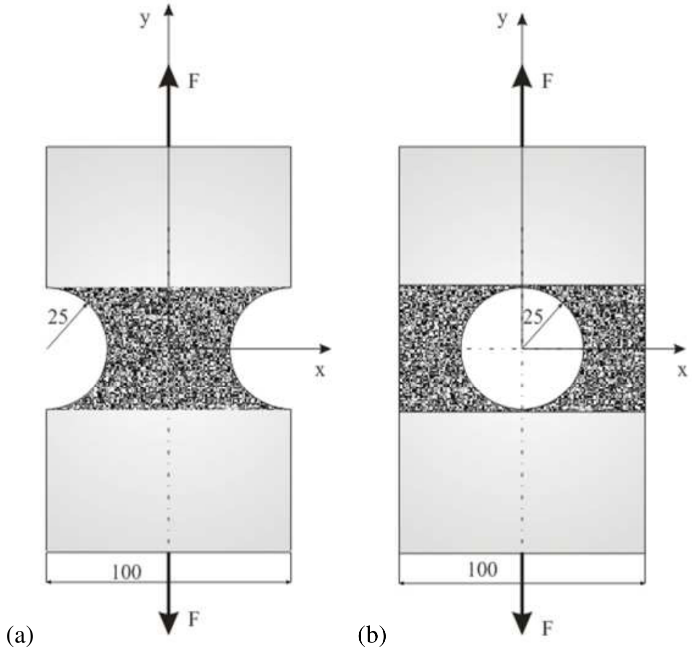

Fig. 1. Geometry of the (a) notched specimen (b) specimen with a hole

Table 1. Mechanical properties of cold rolled steel sheet measured by standard uniaxial tensile tests

Mat.	Dir.	Thick. [mm]	$R_{p0,2}$ [MPa]	R_m [MPa]	A80 [%]	A_g [%]	r	n	r 3%	r 5%	r 10%	r 15%	r 20%
	0°	0,8	229	339	35	20,6	0,9	0,19	0,8	0,9	0,9	0,9	0,9

A	45°	0,8	233	338	35,5	20,2	1,1	0,19	1,1	1,1	1,1	1,1	1,1
	90°	0,8	244	346	35,5	19,8	1,1	0,19	1,1	1,1	1,1	1,1	1,1

The experimental setup is illustrated in Fig. 2, an INSTRON 8801 tensile machine with hydraulic grips was used to perform the tests. A couple of JAI Pulnix TM – 4000 CL cameras, able to acquire 2048×2048 pixels with 10-bit dynamic range, was used to record the images for stereo-correlation. The specimens were tested along the longitudinal direction up to the final break however, because of the occurrence of buckling at large deformations, only the first part of the test was used in this study, where the displacement can be considered as planar.

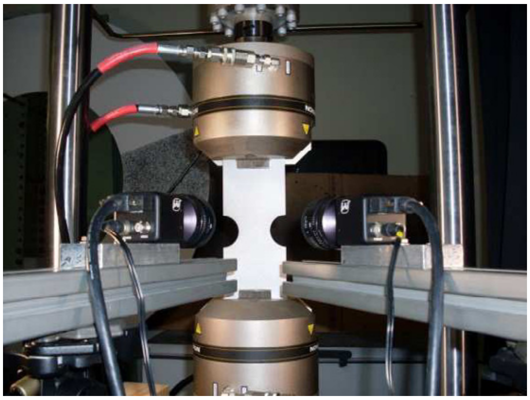

Fig. 2. Experimental setup

The correlation algorithm was run using a correlation window of 27 pixels and a step of 5 pixels between two measurement points. The incremental correlation option was used, i.e. each image is correlated with the previous one and the measured incremental displacement is added to the one measured in the previous step. The results for the strain ε_x, ε_y a γ_{xy} calculated from the displacements were obtained from the Vic 3D and for displacement 3,8 mm are shown in Fig. 3 and Fig. 4.

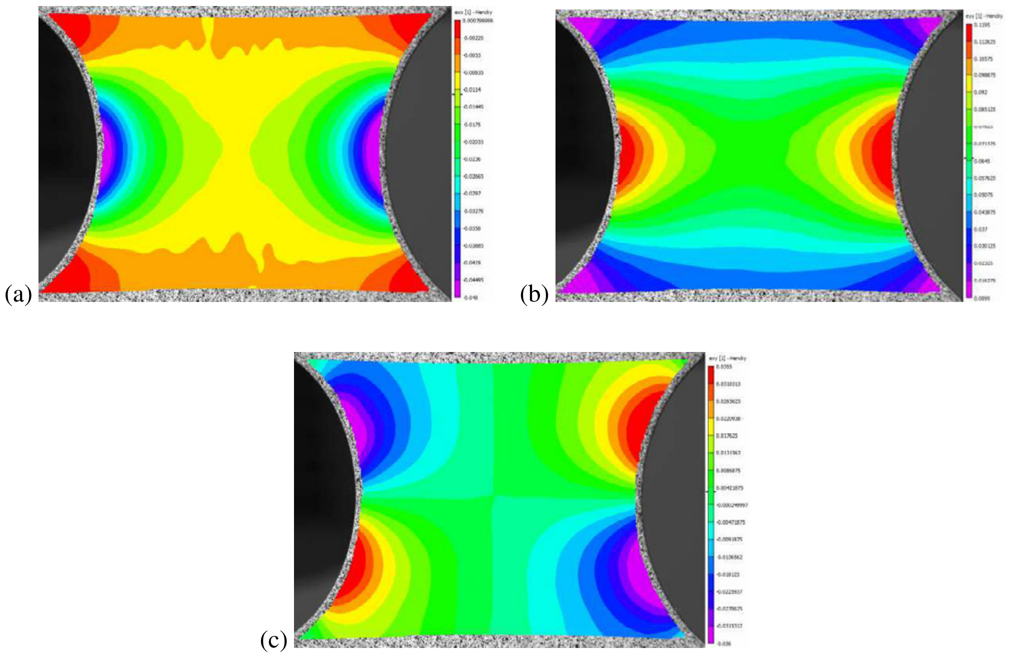

Fig. 3. The strain (a) ε_x, (b) ε_y and (c) γ_{xy} obtained from the Vic 3D for notched specimen

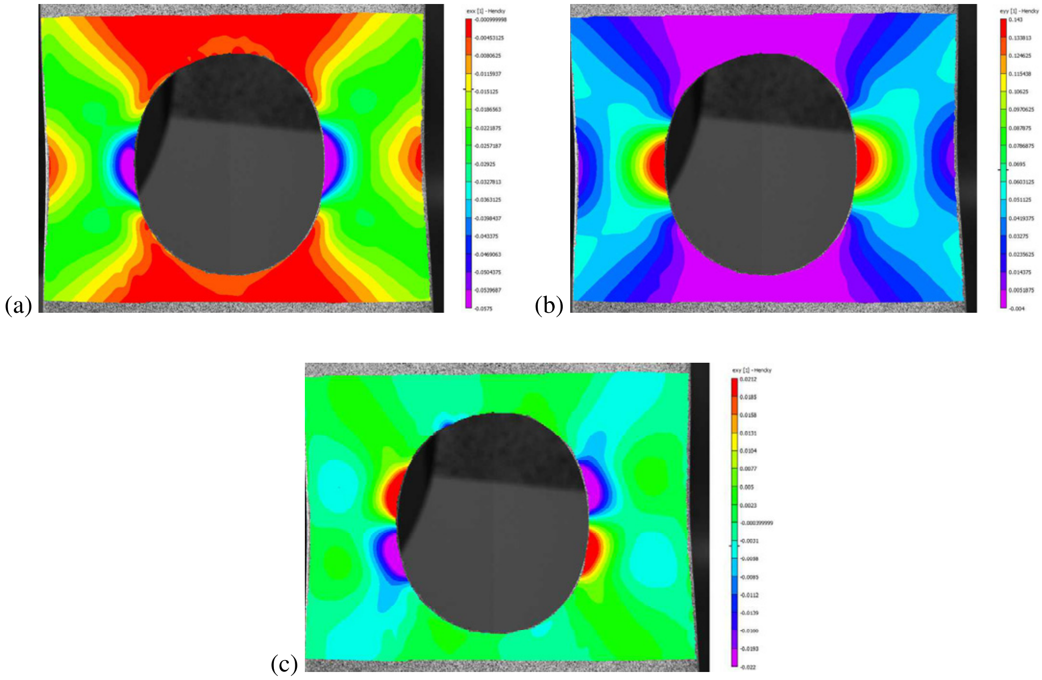

Fig. 4. The strain (a) ε_x, (b) ε_y and (c) γ_{xy} obtained from the Vic 3D for specimen with a hole.

The strain localization is clearly visible due to the notches and the hole. The tests are rather heterogeneous and look suitable to be used with VFM in order to identify the constitutive parameters of the isotropic model.

2.1. Identification of the constitutive parameters in elastic and elastic-plastic range

Camfit [13] is a GUI Matlab based software implementing the Virtual Fields Method. It can deal with linear elasticity (isotropic and orthotropic) as well as simple elasto-plasticity. Camfit uses displacements as input. The program then generates a mesh with triangular elements (Fig. 5) generated over a field of interest selected by the user.

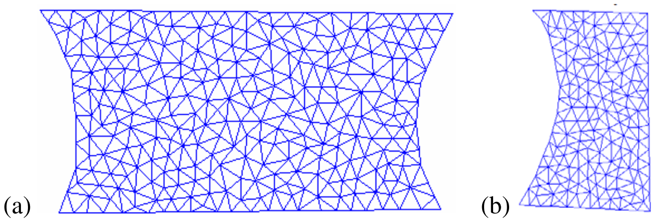

Fig. 5. Mesh with triangular elements for (a) notched specimen, (b) specimen with a hole.

The reconstructed displacements u_x and u_y for notched specimen and specimen with a hole are shown in Fig. 6.

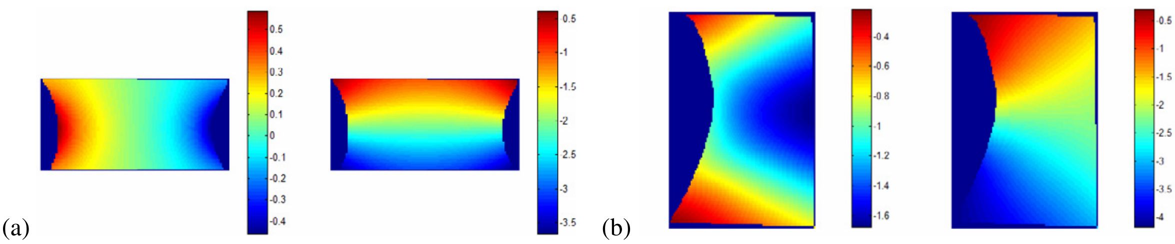

Fig. 6. Reconstructed displacements u_x and u_y for (a) notched specimen, (b) specimen with a hole

The strain fields ε_x, ε_y and γ_{xy} were calculated from the displacements u_x and u_y by Camfit and the results for notched specimen and specimen with a hole for displacement 3,8 mm are shown in Fig. 7.

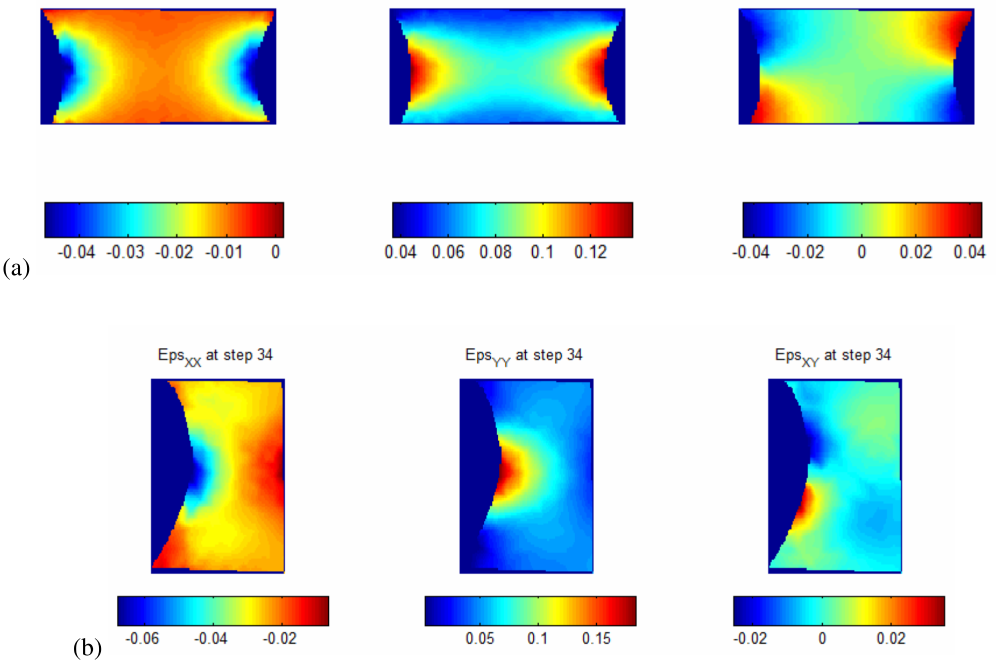

Fig. 7. The strain ε_x, ε_y and γ_{xy} obtained from the Camfit for (a) notched specimen, (b) specimen with a hole

In elasto-plasticity, Camfit uses only one constant virtual strain field, as defined previously depending on the test configuration. This can also be seen as the difference between averages, normal or shear force, measured and recalculated from the strains and the constitutive parameters. The program first identifies the isotropic elastic constants, as we can see in Fig. 8. This enables to define an elastic range for the test, thanks to a plot which reports external and internal virtual work. If linearity is correct, then the elastic range was well defined. Otherwise, it should be changed to arrive to acceptable linearity.

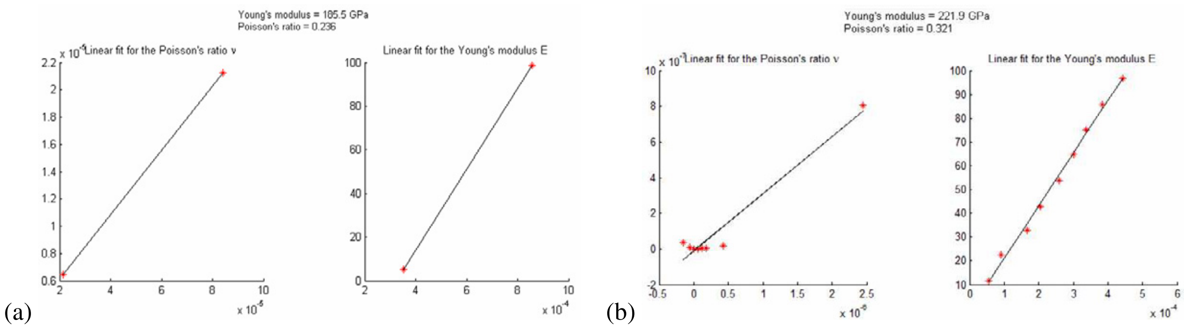

Fig. 8. Parameters obtained in elastic range by Camfit for (a) notched specimen, (b) specimen with a hole

The second stage concerns the plastic parameters and four isotropic hardening models are available based on a simple Prandtl-Reuss model. In this case the power law model was chosen and the results are shown in Fig. 9.

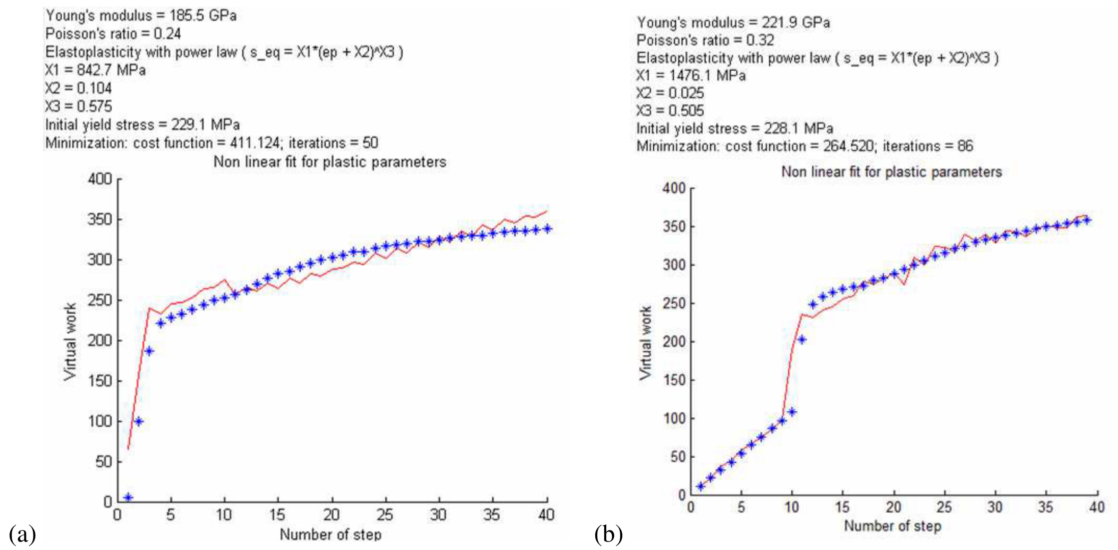

Fig. 9. Parameters obtained in elasto-plastic range by Camfit for (a) notched specimen, (b) specimen with a hole

2.2. Stress field identification from strain field using the VFM

The plastic parameters obtained by Camfit were used on calculating stress fields. The hardening law is described by using a Swift law:

$$\sigma_{H(k)} = X_1.\left(X_2 + \varepsilon_{eq_{pl}(k)}\right)^{X_3}, \tag{1}$$

where $\sigma_{H(k)}$ is the equivalent stress, $\varepsilon_{eq_{pl}(k)}$ is the equivalent accumulated plastic strain and X_1, X_2 and X_3 are the parameters to be identified.

The stress fields obtained from strain fields calculated by Matlab [14] for notched specimen and specimen with a hole for displacement 3,8 mm are illustrated in Fig. 10 and Fig. 11, respectively.

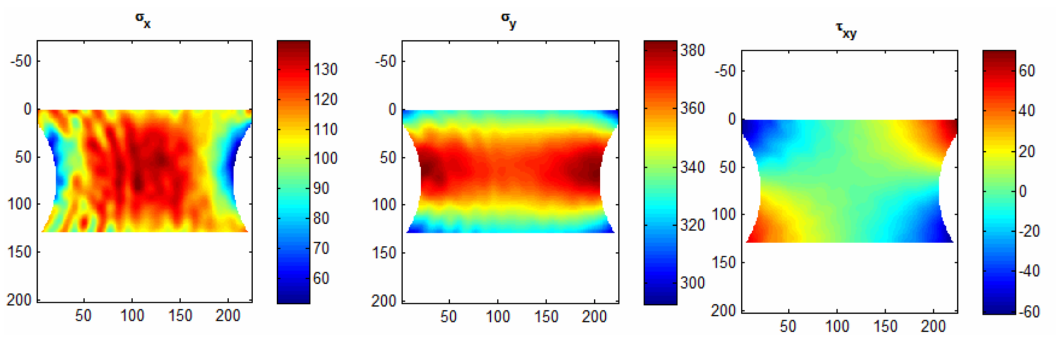

Fig. 10. The stress fields σ_x, σ_y a τ_{xy} obtained by Matlab for notched specimen

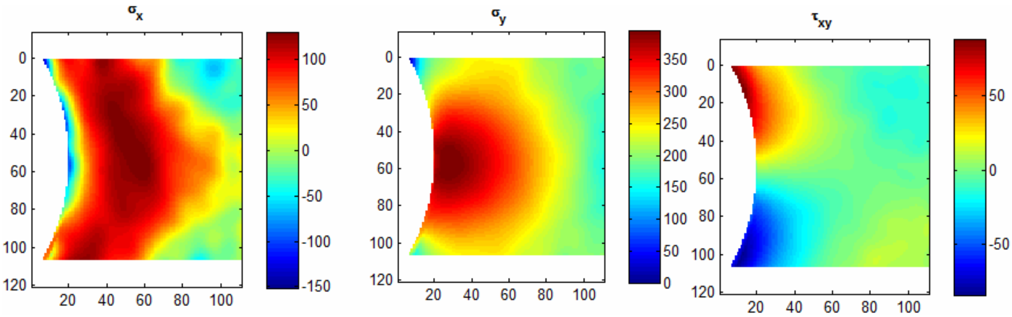

Fig. 11. The stress fields σ_x, σ_y a τ_{xy} obtained by Matlab for specimen with a hole

2.3. Results and discussion

Measurement results obtained Camfit are listed in Tab. 2. By two tensile tests performed before these experiments some material properties were obtained, these are listed in Tab. 1. The results of yield stress obtained by Camfit were compared with the results of tensile tests. We can see good agreement between the yield stress obtained by Camfit and yield stress obtained by tensile tests.

Table 2. Identified parameters

Camfit								Tensile tests	
		Parameters of elastic range		Parameters of plastic range (Power law)				Yield stress [MPa]	
Shape	Dir.	E [GPa]	μ	X_1	X_2	X_3	Yield stress [MPa]	Test1	Test2
U	0	185,5	0,24	842,7	0,104	0,575	229,1	229	228
O	0	221,9	0,32	1476,1	0,025	0,505	228,1	229	228

3. Conclusion

This paper presents an example of identification of an isotropic model using full-field measurements and the Virtual Fields Method. As we can see in the presented results, the application of digital image correlation method of measurement is suitable for analysis of plastic deformation on the object's surface. The molded samples, which allow the localization of stress is preferable to use for the analysis of large plastic deformation. Material properties of isotropic materials were obtained using standard tensile tests and were compared with results of an experimental procedure to identify the material properties of specimens on which was used Camfit. Comparison of the values for yield stress of the material, we can see a good agreement with those obtained by Camfit.

Acknowledgements

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