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Identification of Material Parameters of an Orthotropic Metal Sheet

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Abstract: Identification of constitutive equation parameters of orthotropic specimens is a highly demanding task requiring a full field measurement of the strain fields. This measurement is done using a Digital Image Correlation technique. The material parameters are identified by employing the Finite Element Method Updating and the Virtual Field Method alternatively.

Keywords: Virtual field method, Finite element method updating, Constitutive equations parameters, Orthotropic material Introduction

1. Introduction

Metal sheet materials are commonly taken as isotropic continuum for evaluation of their mechanical and fracture behaviour. It is often assumed that the influence of the metal sheet grain structure originated from the material manufacturing can be neglected for numerical calculations although rolling technology produces significantly shaped grains. The assumption about isotropic material behaviour is often justifiable but cannot be adopted a 'priory without relevant experimental measurement. It is noteworthy that an apparently relevant material parameter can be obtained if the isotropic material behaviour is assumed and the experimental measurement is done using only one smooth tensile specimen.

The tensile tests, using two specimens cut along and perpendicularly to the grain orientation, have to be done to ensure whether the orthotropic material structure can be neglected. For this purpose, let's suppose a linear elasticity (generalized Hook law) and plane stress state in this work. Generally for orthotropic materials, three elements (due to symmetry) of the well known material stiffness matrix D in the equation (1) can be determined using the above mentioned two smooth specimens and the standard experimental techniques (i.e. strain gauges or extensometers). A fourth element can be measured using Iosipescu shear test for instance.

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$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & 0 \\ D_{12} & D_{22} & 0 \\ 0 & 0 & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix} \tag{1}$$

The strain component $\varepsilon_{xy} = 0$ moreover D_{11}, D_{12} and D_{22} are dependent only on two parameters, the modulus E and the Poisson number ν in the case of the smooth isotropic specimen tensile loaded.

Nowadays full field non contact optical methods like the Digital Image Correlation (DIC) [1] allow determining all stiffness matrix parameters using only one specimen. Identification of the material parameters can be done alternatively using the Finite Element Method Updating (FEMU) or the Virtual Field Method (VFM).

2. Finite Element Method Updating

The FEMU method [2] is based on the iterative computation of displacement fields which is compared with the measured displacement field varying the constitutive parameters. The identified constitutive parameters are the ones which minimize the distance between the computed and the measured displacement fields. the least square method was used in our work for this minimization (as a modification of the "displacement gap cost function"). Values of the constitutive parameters are selected randomly from the limited range. Nodes of the Finite elements should be generated in the same positions on which the displacement field was measured.

3. Virtual Field Method

An alternative to the FEMU is the Virtual Fields Method [3, 4] (VFM). It requires the availability of full-field data. The stress fields are derived as a function of the unknown parameters and the identification is achieved by making these stress fields verify the principle of virtual work with virtual fields (i.e. test functions) chosen a priori. The principle of virtual work to the experimental data is applied with as many virtual fields as there are unknown parameters, such as to build up a linear system of equations involving the unknown parameters.

It was proved that all the FEMU approaches are equivalent to the VFM when full-field data are available for the identification. It was shown that sensitivity to noise is systematically higher for FEMU than for VFM [4].

4. Experimental

A flat EN 10 204 Al-alloy specimen with asymmetric notches was manufactured from 1 mm thick metal sheet, draft shown in Fig. 1. The shear strain is presented in the region between notches during tensile loading thanks to the specimen geometry. The specimen was continuously loaded in longitudinal (horizontal) direction with constant grip displacement velocity 0.4 μm/sec until plastic strain occurred. A random speckle was prepared by airbrush on the specimen surface. The central part of the specimen was recorded by a 15 MPixel Canon EOS 500D digital camera with SIGMA macro lens each 10 seconds.

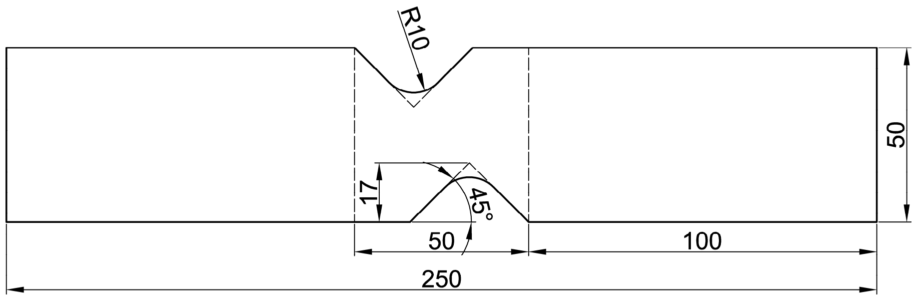

Fig. 1. Draft of a flat EN 10 204 Al-alloy specimen with asymmetric notches. Length units given in mm.

The recorded sequence of the images was processed by our own DIC software based on the cross-correlation cost function [5]. The regular orthogonal grid of 44×27 points, where the displacement vectors are measured, was defined in the reference image. Points outside and on the border of the specimen were rejected. The specimen image with depicted measuring points is shown in Fig, 2. Each grid point is at the centre of one template with dimensions 61×61 pixels. The positions of the templates during loading were searched using DIC tools. The resultant displacement field evolution was used as input for the search of constitutive equations parameters.

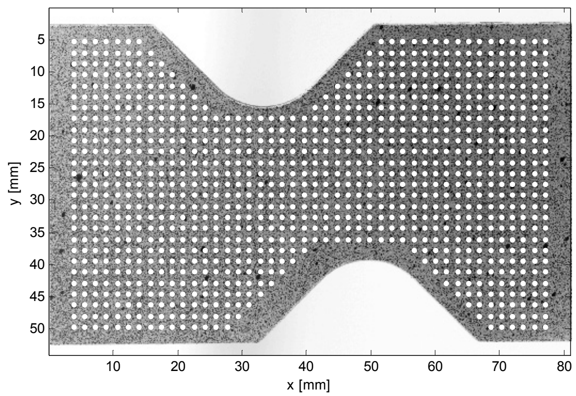

Fig. 2. The view of the evaluated part of the specimen surface with reference orthogonal grid.

The strain field ε_{xx} calculated by the DIC software is depicted in Fig. 3. It is clearly visible that some parasitic bending occurred possible due to slipping of the specimen in self-locking grips. Plastic strain already occurred at this loading level.

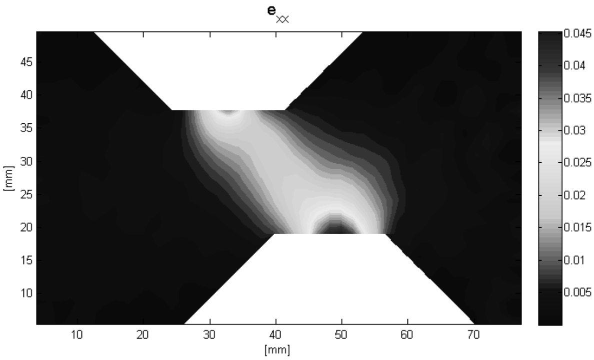

Fig. 3. Strain field ε_{xx} calculated by the DIC software.

5. Computation of the constitutive equation parameters

5.1. Finite Element Method Updating results

The rinite elements mesh with nodes in the same places as measuring grid was generated. The mesh was expanded into boundaries of the whole specimen where the planar elements PLANE were employed. The loading was modelled by adding planar elements with much higher stiffness at the ends of the model. The constitutive equations parameters for elastic isotropic material were iterative computed together with the unknown loading eccentricity.

Results are listed in Table 1. It was proven that the FEMU method is quite sensitive for white noise as mentioned in [4]. Consequently, the results are strongly influenced by the selection of the reference points and the number of iterations. It seems that a lower number of reference points brings more stable results (compare the calculated Poisson number for 25 and 50 points selected). Thus it is not possible to choose which parameters are valid at this moment using the experimental results mentioned above. Orthotropic behaviour of the specimen was not studied by this method from this reason.

Table 1. Constitutive equation parameters computed by the FEMU method

	25 points selected		50 points selected		100 points selected	
Number of iterations	1000	500	1000	500	1000	500
E [GPa]	103.8	103.8	106.8	106.6	119.5	109.8
Poisson ν	0,42	0,42	0,23	0,014	0,307	0,39
Eccentricity [mm]	3,57	3,57	2,93	2,92	3,96	3,54
Criterion	0,000008	0,000008	0,000018	0.000018	0,000031	0,000032

5.2. Virtual Field Method results

The Virtual Fields Method software CamFit [6] was used for our purposes; see www.camfit.fr for more details about this software. The displacement field evolution of the specimen central part calculated by the DIC method was used as input. It is not necessary to expand the measuring grid to cover the whole specimen and loading conditions as mentioned for FEMU. This simplification can be taken as an important advantage of this method.

The constitutive equations parameters for elastic isotropic material were computed for a data set where loading was linear as indicated from the loading record. The resultant elastic modulus E and Poisson were linearly fitted using this data set. Final results are: $E = 98.4$ GPa and $\nu = 0.399$.

Furthermore, the nanoindentation method was applied to ensure the validity of these results. The measured reduced modulus is $E_r = 114.5$ GPa. The corresponding elastic modulus was calculated to be $E = 106$ GPa using the Poisson number $\mu = 0.399$. This result is in relatively good agreement with the value obtained by the VFM (and by the FEMU using 25 reference points).

The constitutive equation parameters for orthotropic material obtained by the CamFit software are listed in Table 2.

Table 2. Material stiffness matrix *D* elements calculated by CamFit

D_{11}	D_{12}	D_{22}	D_{33}
126 730	76 581	263 810	28 499

It was proven that the studied material is strongly orthotropic as concluded from the material stiffness matrix D elements calculated by the CamFit software (compare elements D_{11} and D_{22}).

6. Conclusions

It was shown that constitutive equation parameters for a thin sheet metal can be calculated using only one specimen.

It was proven that the FEMU method is quite sensitive for white noise. Consequently results are strongly influenced by the selection of reference points and number of iterations.

On the other hand, the VFM software CamFit calculates the searched parameters very reliably and stands robust against white noise which is naturally present in the experimental data. Result for E was independently verified by the nanoindentation method. It was proven that the studied material is strongly orthotropic as concluded from the material stiffness matrix D elements found by the CamFit software.

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