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Calibration of Material Parameters during Billet Straightening

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Abstract. This contribution deals with the use of image digital correlation method for the determination of displacements, strains and stresses field on the 3-D mechanical part – a billet resulting by division from continuous casting process. Results of the measurement are used for the verification of identification method for the online determination of mechanical parameters of the material from billet bending. The motivation for this task is the preparation of the experimental algorithm for the automated evaluation of the part curvature and the proposal of the intervention for curvature adjustment so that the resulting shape suits to tolerance requirements for the product given.

Introduction

Straightening of semi-finished products – billets resulting by division from continuous casting process, is required by further subscribers. The as straight billet as possible within tolerances given by the size of semi-finisher products is required. The straightening process is made manually at present. That means that the billet is manipulated by manually controlled machines. The straightening process is controlled by the machinist and is based on his experiences. It is obvious that the productivity and accuracy of the straightening process is in hands of the operator. The development of the automated straightener is currently in progress.

However, such device needs to identify automatically material properties of straightened semi-finished product so that the controlling program could carry out adequate and effective straightening interventions. The approach can be twofold. The first one loads parameters of the straightened material from the database. The second approach identifies material properties online during the straightening process. The first approach seems to be easier however it is prone to errors – wrong material, inaccurate values of material parameters, etc. For this reason, the second approach of automated parameters identification is being developed.

The straightening process is further predicted online. Based on the optimization algorithm, interventions of the straightening machine using action members – straightening rollers are proposed.

In following chapters, the experiment and related activities leading to the proposal of identification algorithm for obtaining material properties and further development of optimization SW is described.

Experiment

The experiment itself was carried out in premises of the company KOMA – Industry Ltd., Ostrava – Vítkovice, Czech Republic. The straightening machine for billet adjustment was used. The straightening machine was fitted with sensors for measurement of displacements and forces. The measurement of forces is based on the record of pressure rates in working rolls of the straightening machine. For evaluation of the cylinder displacement the incremental encoder is used. The accuracy of sensors is given by requirements of the praxis and similar displacement and pressure sensors will be used for the automated straightening machine designed.

The image digital correlation method was used for the measurement of displacements of the straightened billet. The digital image correlation method is the optical method which uses the sequence of images in which the changes are identified [1]. On the base of changes identified, the field of displacements, strains and stresses can be evaluated. The digital image correlation method is not tied only to problems of mechanics of solids, but it can also be used in other areas of science and technology. The device Mercury RT 2x2.3Mpx@40Hz was applied in the measurement. The software Mercury RT made by the company Sobriety Ltd. was used for the evaluation of images obtained.

The mechanical part measured is depicted in Fig. 1 (left). Transverse dimensions of the billet used in the experiment were 200 x 200 mm. The material of the billet was steel 34CrMo4. The straightening process itself is performed so that the billet measured is pressed against rests and is formed using the ram. The straightening ram itself is placed symmetrically in relation to both rests. The chosen results obtained from the measurement and subsequent evaluation are depicted in Fig. 2.

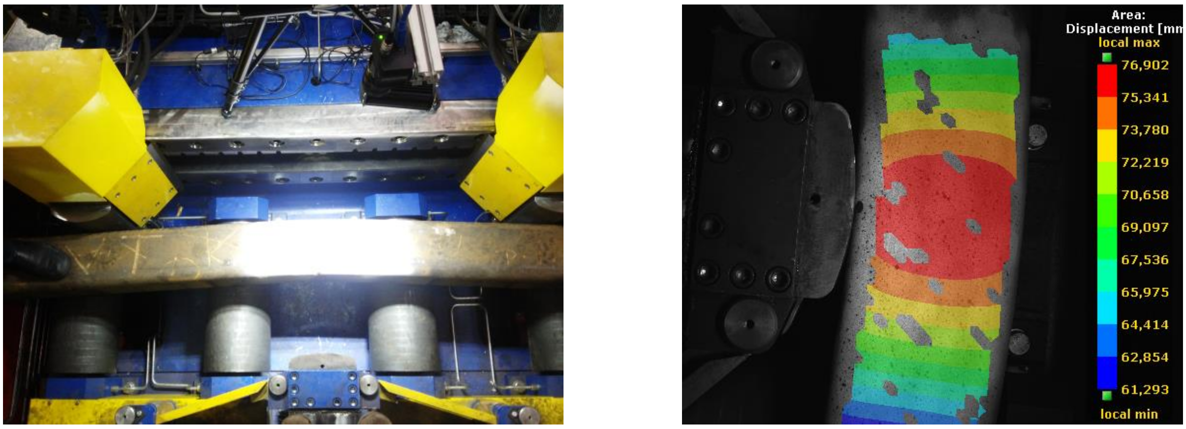

Fig. 1 – The part measured placed in straightening machine (left). DIC measurement results – total displacement [mm] (right).

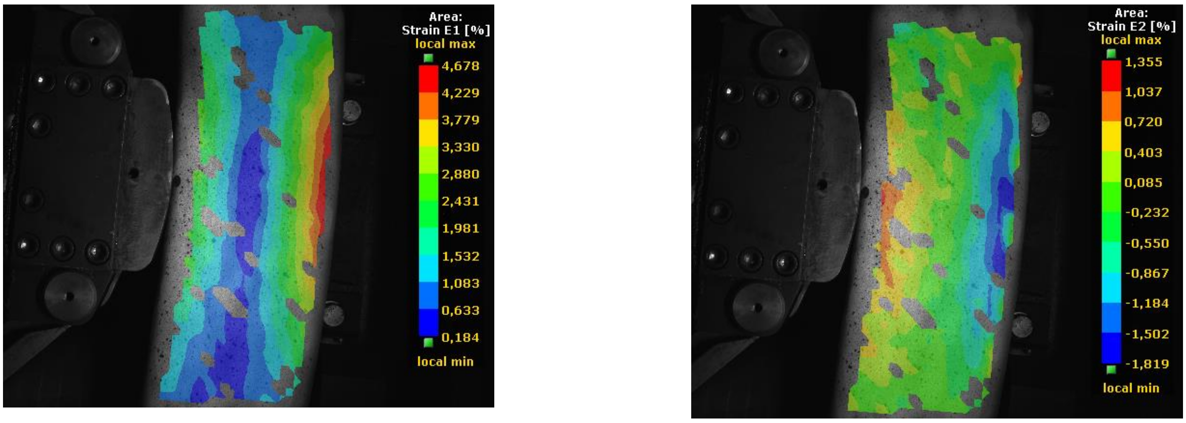

Fig.2 – DIC contours of first principal strain (left), DIC contours of second principal strain (right).

Further, specimens determined for standard material tests in the laboratory were taken from the testing billet. The sampling was performed in the location which was not influenced by previous straightening attempts. The sampling was realized both in transverse and longitudinal direction of the testing billet. The record from the conventional tension test is depicted on Fig. 3.

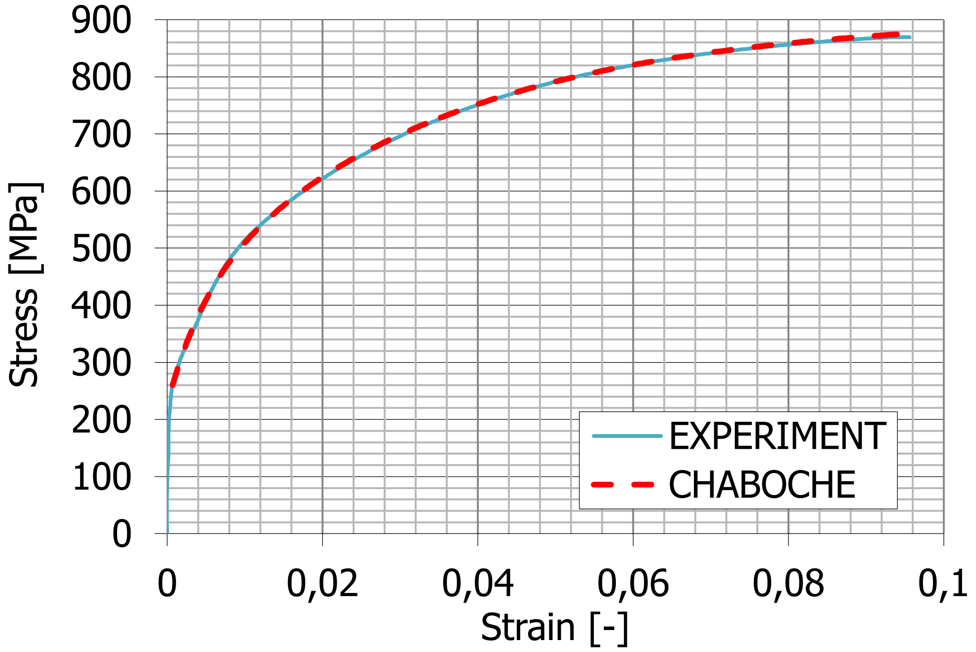

Fig. 3 – Stress-strain curve of 34CrMo4 steel from tensile test and its description by Chaboche model

Simulation

The automated straightening process should be realized in several phases. Firstly, the initial shape of the straightened billet is detected. Secondly, material properties are identified. Followingly, the optimization simulation of the straightening process is realized. On the base of its results the straightening operations themselves are performed. This procedure will be done in closed loop until the billet is straightened to the tolerance required. This straightening process will be also carried out in the second plane.

The identification of parameters will be performed at the beginning of the straightening and will be repeated on the base of need – for instance in case of long straightening time and "cooling down" of the billet.

The identification is carried out on the base of reverse approach using own solver. This approach is being tested at present. Since the development of own solver is not finished yet the commercial FEM solver ANSYS was used.

For the description of the stress-strain behavior, the Chaboche model with two backstress parts was used.

$$\alpha = \alpha_1 + \alpha_2 \qquad (1)$$

For the simplicity, this constitutive model is described for uniaxial loading, i.e. in scalar form. The evolution rule of Chaboche for the backstress [2] is given by differential equation

$$d\alpha_i = C_i d\varepsilon_p - \gamma_i \alpha_i dp \qquad (2)$$

where C_i and γ_i are material parameters, $d\varepsilon_p$ is the increment of plastic strain and dp is an increment of accumulated plastic strain. All material parameters fitted on data for examined steel are stated in the Table 1.

Table 1 Cyclic plasticity model parameters

Material Parameters
E=197GPa; ν=0.3 $\sigma_Y = 226MPa$; $C_{1-2} = 36907, 15180\ MPa$ $\gamma_{1-2} = 214, 30$

The FEM model was created using BEAM188 finite elements. The appropriate macro was used so that parameters of the model could be easily changed. The refinement of the finite element mesh was realized in the surrounding of the loading force so that the development of the plastic deformation could be correctly described. The span of rests was assumed the same as in real case - 1560 mm. The maximal deflection specified in the middle corresponded to the experimentally determined value, approx. 77 mm.

Results in the form of contours of axial deformation and axial stress in the surrounding of loading applied is depicted in Fig. 4. The good agreement with the experiment is obvious from Fig. 2.

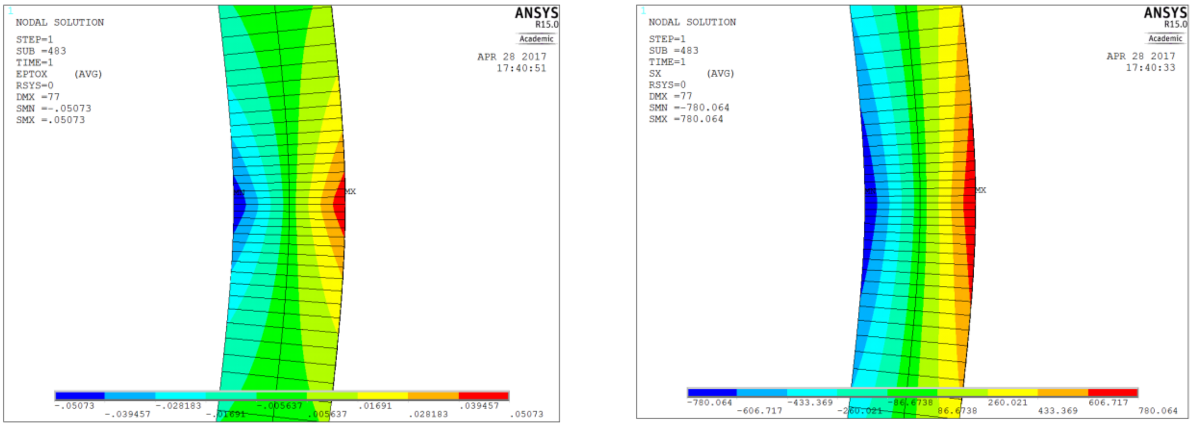

Fig.4 – FEM contours of axial strain (left), contours of axial stress (right).

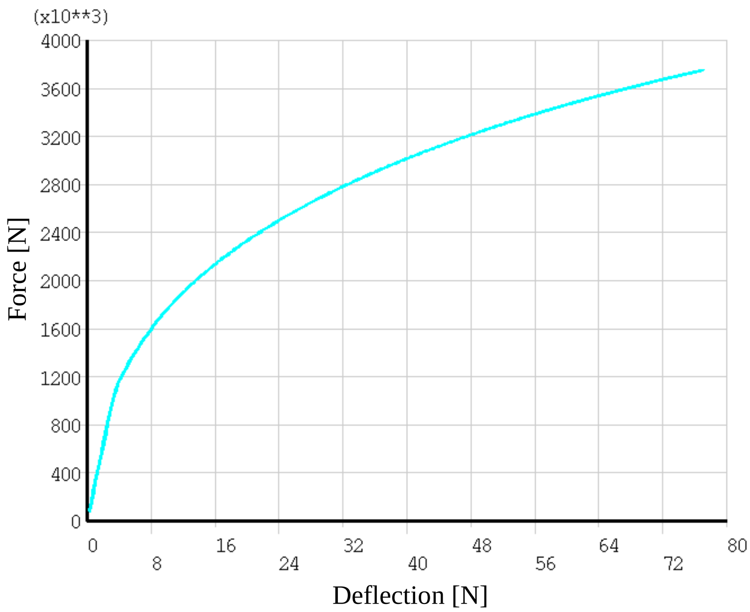

Fig.5 – Dependency of force on deflection obtained by FEM.

Based on the FEM simulation, the dependence of the force on the maximal deflection of the beam was evaluated as well – see Fig. 5. Only the maximal force of 4.17e6 N was known from the experiment. Its value was obtained from the working pressure.

Conclusions

The measurement of displacements and strains on the testing billet using the image digital correlation method was performed. Results are used for the verification and adjustment of the identification algorithm of material properties. The algorithm has been developed based on the billet material tension tests performed. The billet straightening process using the three-point bending is significantly different from the straightening of metal sheets and belts [3]. The straightening optimization can be realized through the modification of design, e.g. for circular rods [4], or through the adjustment of technology using sensors. In our case, the last mentioned case was used. The development of the subsequent straightening algorithm for the expert system is temporary in progress.

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