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CU-ETP COPPER MONOTONIC TENSILE TEST MODELING IN LS-DYNA SOFTWARE USING HARDENING AND DAMAGE MODELS

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Abstract

This paper deals with modeling of monotonic tensile test of Cu-ETP copper in numerical environment using finite element method. The research aims to verify the capabilities of LS-Dyna software in terms of modeling the strain hardening and damage of the material. The numerical analyses were proceeded by experimental tests to determine the materials constants of isotropic hardening model and constant required for modeling of material's damage. Determined material constants were implemented into LS-Dyna environment using MAT_Damage_3 material model. The specimen model was built using eight-node hexahedrons. Both in case of experimental and numerical tests, the controlled parameter was displacement of the specimen. Obtained strain-stress curves were analyzed and conclusions were drawn.

Keywords: *finite element method, strain hardening modeling, damage modeling, LS-Dyna, Cu-ETP copper*

1. Introduction

Computer simulation programs based on Finite Elements Method (FEM) use many different material models. Starting from simplest linear models, through bilinear or non-linear, to more complex including hardening and damage modeling during the analysis. A proper choose of material model and determination of included material constants is very important due to the quality of obtained calculation results.

In this paper the *MAT_DAMAGE_3 material model implemented in LS-Dyna environment was verified. This model belongs to the group of material models including hardening and damage of the material. The verification consisted of modeling of monotonic tensile strength test strain-stress curve for Cu-ETP [1] copper in LS-Dyna environment. The chemical composition of the material is given in Tab. 1.

Tab. 1. Chemical composition of Cu-ETP copper

Cu	Bi	O	Pb	Others
≥ 99,9	≤ 0,0005	≤ 0,04	≤ 0,005	≤ 0,03

2. Hardening and damage models in LS-Dyna

Beside the basic material properties such as density, Young’s modulus, Poisson’s ratio or ultimate tensile strength, the *MAT_DAMAGE_3 model includes also hardening model and damage model based on the Lemaitre’s model.

LS-Dyna in each calculation step calculates and cumulates damage on the basis of stress and strain values obtained from FEM analysis. The cumulation of damage is given by [2]:

$$\dot{D} = \begin{cases} \left(\frac{Y}{S}\right)^t \dot{\varepsilon}_{pl} \text{ if } r > r_d \text{ and } \frac{\sigma_m}{\sigma_{eq}} = -\frac{1}{3}, \\ 0 \quad \text{in other case} \end{cases} \tag{1}$$

where σ_m/σ_{eq} is the stress triaxiality, σ_{eq} is von Mises equivalent stress, r_d is damage threshold, S and t are material constants [3] and Y is strain energy density release rate given by:

$$Y = \frac{1}{2}\boldsymbol{\varepsilon}^{el} : \boldsymbol{D}^{el} : \boldsymbol{\varepsilon}^{el}, \tag{2}$$

where $\boldsymbol{D}^{el}$ represents the fourth-order elasticity tensor and $\boldsymbol{\varepsilon}^{el}$ is elastic strain [4].

The model describes material’s behavior until damage $D = D_c$, where D_c is the critical value of damage corresponding to appearance of crack of length of an order from 0.1 to 0.5 mm. The *MAT_DAMAGE_3 requires determination of S, t, D_c and r_d material constants.

3. Experiment

The aforementioned material constants was determined from monotonic tensile test conducted according to [5]. The test was conducted using specimens’ geometry of which is shown in Fig. 1. The tensile test graph is shown in Fig. 2. Basic mechanical properties obtained from test are given in Tab. 2.

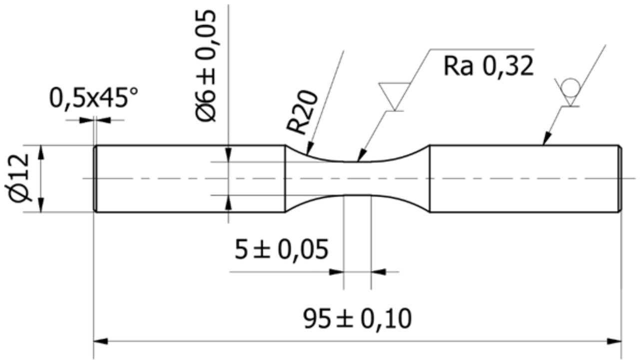

Fig. 1 – Specimen’s geometry

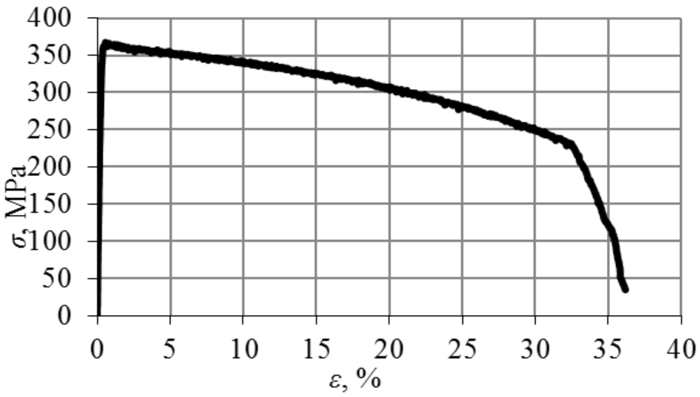

Fig. 2 – Monotonic tensile strength test graph

Tab. 2. Basic mechanical properties of Cu-ETP copper

$R_{p,02}$, MPa	R_m, MPa	A, %	E, GPa
360	367	36,16	131

4. Material constants determination

On the basis of monotonic tensile strength test obtained it is possible to determine material constant for one of the hardening models and for damage model. Since the analysis concerns monotonic tensile test isotropic hardening model was selected. To determine the constants, the strain-stress graph was divided into elastic (Fig. 3) and plastic (Fig. 4) parts.

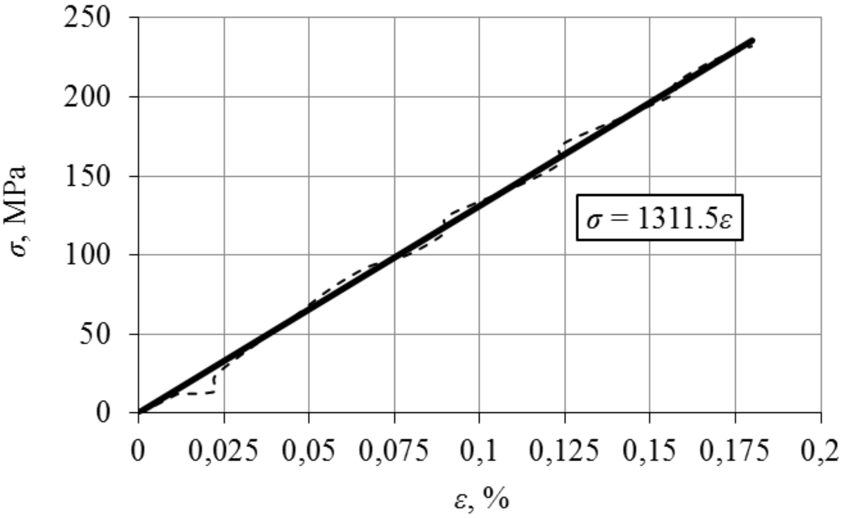

Fig. 3 – Young's modulus determination

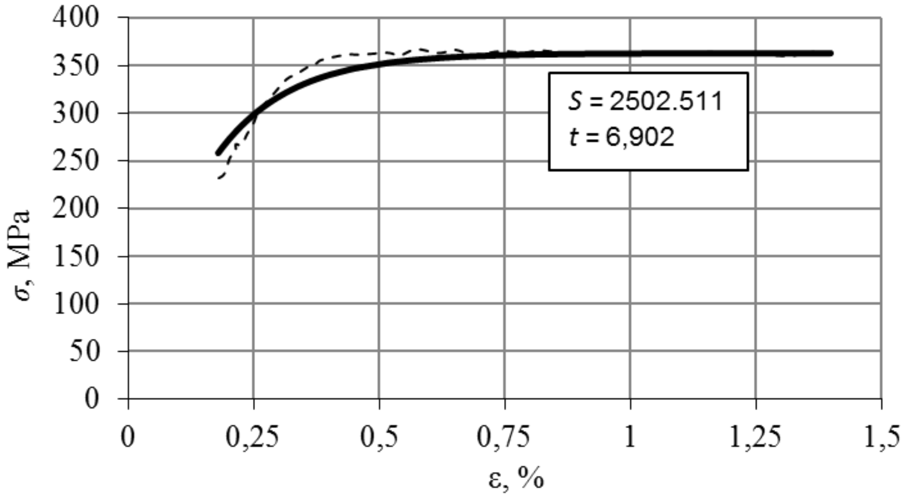

Fig. 4 – Material constant determination

The elastic part of the graph allowed for determination of Young's modulus and yield stress. Data shown using dashed line was approximated using curve given by equation $\sigma = 1311.5\varepsilon$ (solid line). Taking into account the percent scale of the strain axis Young's modulus was determined as $E = 1.3115 \cdot 10^5$ MPa. The plastic part of the graph was approximated by the curve describing hardening model (2). The values of determined constants are: $D_c = 0.36$, $r_d = 0.021$, $S = 2502.5$ and $s = 6.9$.

5. FEM model

The numerical analysis was conducted using LS-Dyna software. The software is used for FEM analyses based on explicit solver. In order to conduct the analysis, the specimen model was created (Fig. 5). The finite elements mesh consist of 2770 nodes and 2324 elements of SOLID type. Each of these elements is eight nodal hexahedron. In LS-Dyna environment elements are described as fully integrated S/R solid [4]. During the analysis the *CONTROL_HOURGLASS with parameters set to IHQ = 4 and QH = 0,1 keyword [4] was also used.

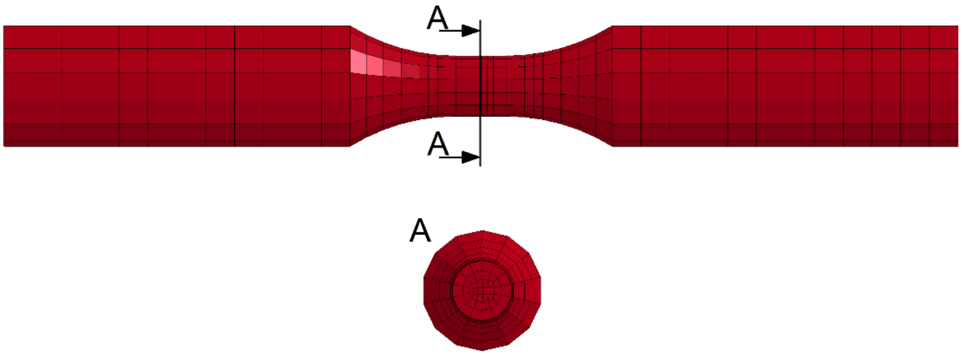

Fig. 5 – Finite elements model of the specimen

All degrees of freedom of the nodes of the left specimen grip part was taken to fix it. In order to set the kinematic loading *BOUNDARY_PRESRCIBED_MOTION_SET keyword was used [4]. Displacement rate was defined using *DEFINE_CURVE_FUNCTION keyword. It corresponded to displacements achieved on the servohydraulic testing system. The displacement was applied to the nodes of the right grip part of the specimen.

6. Analyses results

In the Fig. 6 monotonic tensile test charts obtained from experiment and LS-Dyna are comparted. Total strains used for determination of the chart were read directly for analysis history of the model's elements and the stresses were determined on the basis of reaction forces in the specimen's axis direction, in the grip part of the specimen. In the Fig. 7 necking and fracture of the specimen obtained from experiment and LS-Dyna are compared.

In the elastic range experimental and calculated charts shows high compliance. Similarly good results were obtained for hardening model. Determination of correct values of damage model constant wasn't fully achieved. Hence, the full compliance of the charts also wasn't achieved.

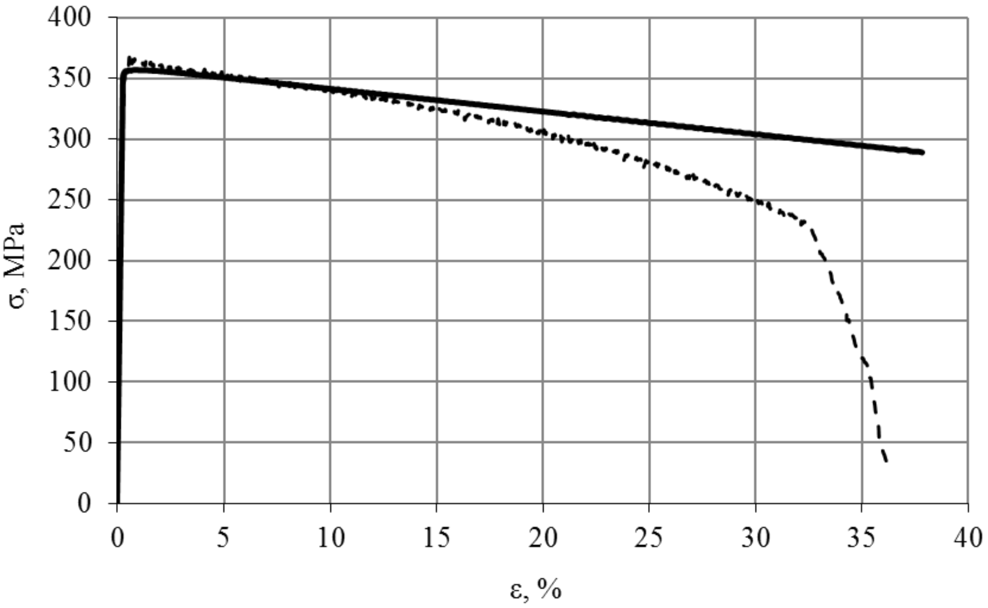

Fig. 6 – Comparison of tensile test charts obtained from experiment (dashed line) and LS-Dyna (solid line)

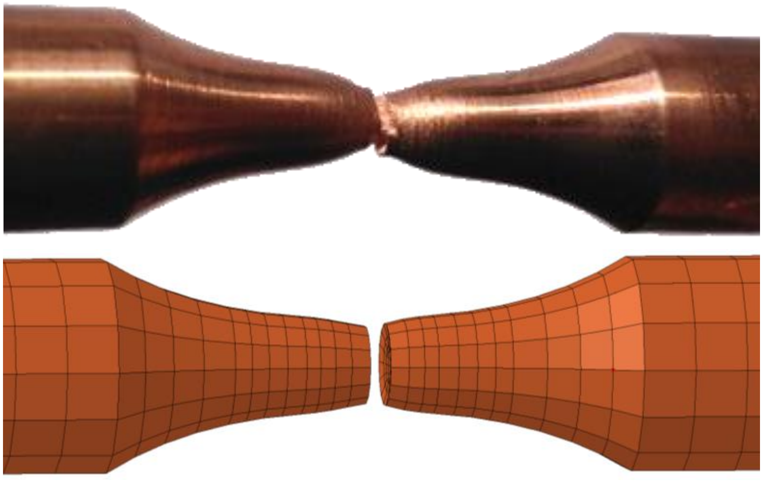

Fig. 7 – Necking and fracture comparison for the specimen and FEM model

7. Conclusions

The analyzed material doesn’t show a clear yield stress. Hardening of the material is present only for a very small range of strain, hence its modeling is very difficult. After a number of isotropic hardening model calibration trials included in *MAT_DAMAGE_3, only a moderate accuracy was achieved.

Similar evolution of strain-stress curve was achieved for ca. 10% of total strain. Further analyses concerned modeling of damage using Lamaitre’s model. Despite the wide range of material constants values modifications a high agreement of numerical model with experimental test wasn’t achieved for high strains.

In order to be able of modeling materials, for which yield stress value is very close to ultimate tensile strength value using *MAT_DAMAGE_3 in LS-Dyna further research is needed to elaborate the method of damage model material constants determination.

References

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