STUDY OF FEM MODEL FOR TENSION AND COMPRESSION TEST FOR ALUMINUM ALLOYS SAMPLES IN ORDER TO SET MATERIAL DATA

Beata Zduniak, Andrzej Morka, Roman Gieleta

Military University of Technology, Department of Mechanics and Applied Computer Science
Gen. S. Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.: +48 22 6837610, fax: +48 22 6839355
e-mail: bzduniak@wat.edu.pl, amorka@wat.edu.pl, rgieleta@wat.edu.pl

Abstract

The purpose of this paper is to conform an available material data for aluminum alloy material (PA11). This task was filled with the aid of computer modeling techniques, which are based on Finite Element Method (FEM), and our own experimental tests of quasistatic tension/compression material samples. For this kind of research FEM is most commonly used, but there are also other numerical methods that can be applied. The idea of FEM is the division of the given continuous area into a finite number of sub-areas (finite elements) connected with one another in nodal points and approximation of solution inside the finite elements using interpolation functions and function values in nodes. Numerical analysis was performed with the LS-Dyna commercial software. Reconstruction of conditions of experiment required application of implicit method of numerical integration in time, so called implicit solver. At this stage of work the aluminum alloy PA11 with respect to Johnson-Cook model was researched. A further work for finding a good material data for WHA, U12A steel for other constitutive models will be performed. A good agreement of the numerical and experimental results is received. Other material data used in modeling, which were not determined by experiment, assumed according to literature sources.

Keywords: numerical analysis, material data, Johnson-Cook model, PA11, FEM

1. Introduction

The purpose of this paper is to conform an available material data for aluminum alloy (PA11). This task was filled with the aid of computer modeling techniques, which are based on Finite Element Method (FEM), and our own experimental tests of quasistatic tension/compression material samples. Numerical analysis was performed with the LS-Dyna commercial software. Reconstruction of conditions of experiment required application of implicit method of numerical integration in time, so called implicit solver.

2. Preparing of a mesh model

A cube, which has length of edge equals 10mm, was considered in this numerical task. A numerical model was universal and easy in implementation. The brick solid element topology with one integration point, in which length of edge equals 0.5 millimetres, was applied. The total number of elements per single case exceeded 8000, what reduced time of calculations. Space discretization of the analyzed problem was prepared by means of the Patran 2007 r5 Software. The built model of mesh is shown in Fig. 1.

3. An initial and boundary conditions

Experiment assumptions were reconstructed by application of suitable boundary conditions. Translation degrees of freedom in the direction of x-axis, on left-side of cube were constrained.
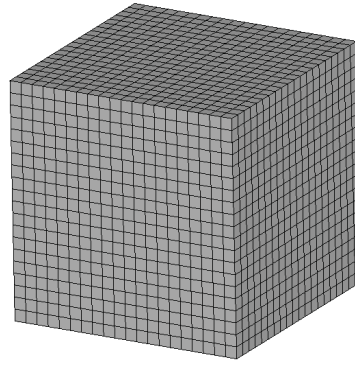
Fig. 1. A 3D view of the mesh and geometry for simulations of tension/compression tests
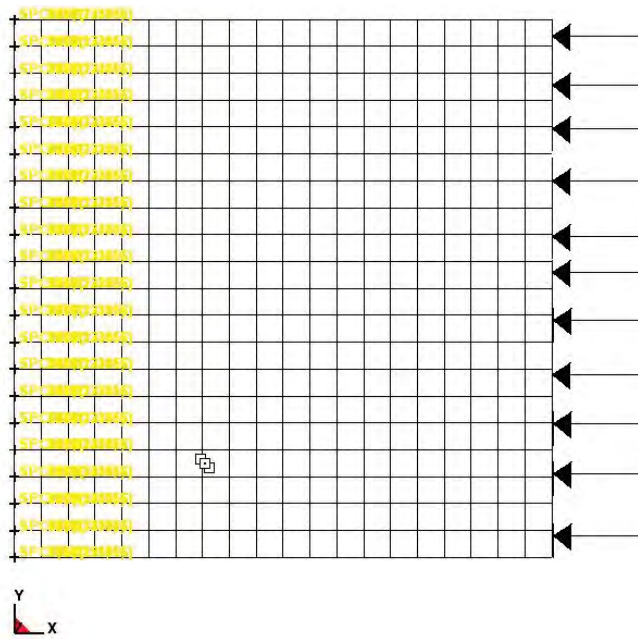

Fig. 2. A scheme of boundary conditions

A pressure to parallel face was applied. The pressure grows linearly in time from 0 to 1 ms and assumed maximum value, $p_{0\ max}$, achievement.

4. Preparation of the preliminary material parameters

A set of preliminary material parameters was collected by literature review. The Johnson-Cook constitutive model (MAT_JOHNSON_COOK) was assumed in this task. The name of material card for mentioned constitutive model implemented in LS-Dyna version 971 is included in the bracket. In Johnson-Cook model, yield stress is described as:

$$\sigma_y = \left(A + B\bar{\varepsilon}_p^n\right)\left(1 + c\ln\dot{\varepsilon}^*\right)\left(1 - T_*^m\right), \tag{1}$$

where A, B, C, n, m are material constants,

$\bar{\varepsilon}_p$ - effective plastic strain,

$\dot{\varepsilon}^* = \dfrac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0}$ - normalized effective plastic strain rate with respect to reference strain rate $\dot{\varepsilon}_0$,

$T_* = \dfrac{T - T_r}{T_m - T_r}$ - normalized temperature.

Plastic stress is dependent on plastic strain, plastic strain rate and temperature. An equation of state in form $p(\rho, E)$ is requisite, in this model, where ρ – density of material, E – internal energy per volume unit.

The Gruneisen equation of state was chosen, because this equation assures accurate describing of the material state around the Hugoniot adiabate. This equation is described below:

$$p = \begin{cases} \dfrac{\rho_0 C^2 \mu [1 + (1 - \frac{\gamma_0}{2})\mu - \frac{a}{2}\mu^2]}{[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu+1} - S_3 \frac{\mu^3}{(\mu+1)^2}]^2} + (\gamma_0 + a\mu)E \\[4mm] \rho_0 C^2 \mu + (\gamma_0 + a\mu)E \end{cases}, \qquad (2)$$

where C, S_1, S_2, S_3 describe dependency between velocity of shock wave and particle velocity. The most common is linear dependency, in experimental research: $D = C + S_1 u$, where D – velocity of shock wave, u – a particle velocity. γ_0 – Gruneisen coefficient defined as:

$$\gamma_0 = \frac{\alpha K_s V}{C_p} = \frac{\alpha K_T V}{C_V}, \qquad (3)$$

where α – linear coefficient of thermal expansion, K_s, K_T – adiabatic and isothermal bulk modulus, C_p, C_V – specific heat at constant pressure and volume, $V = 1/\rho$ – specific volume, and $\mu = \dfrac{\rho}{\rho_0} - 1$.

Parameter a is the correction coefficient of first order for volume. Preliminary parameters for Johnson-Cook model for aluminum alloy found in the literature are shown in Tab. 1.

Tab. 1. Preliminary parameters for Johnson-Cook model [1]

Material	aluminium alloy
Symbol	7075 T651
ρ [kg/m^3]	2768
G [GPa]	26.2
E [GPa]	
v [-]	
A [GPa]	0.3365
B [GPa]	0.3427
N [-]	0.41
C [-]	0.01
m [-]	1
T_{melt} [K]	877.6
T_{room} [K]	294
$\dot{\varepsilon}_0$ [s^{-1}]	
c_p [J·kg^{-1}·K^{-1}]	875.6

5. Verification of material data for aluminum PA11

An experimental plot (Fig. 3) presents dependence of stress-strain for quasistatic tension test of PA11.

Tab. 2. Preliminary data for Gruneisen equation of state [2]

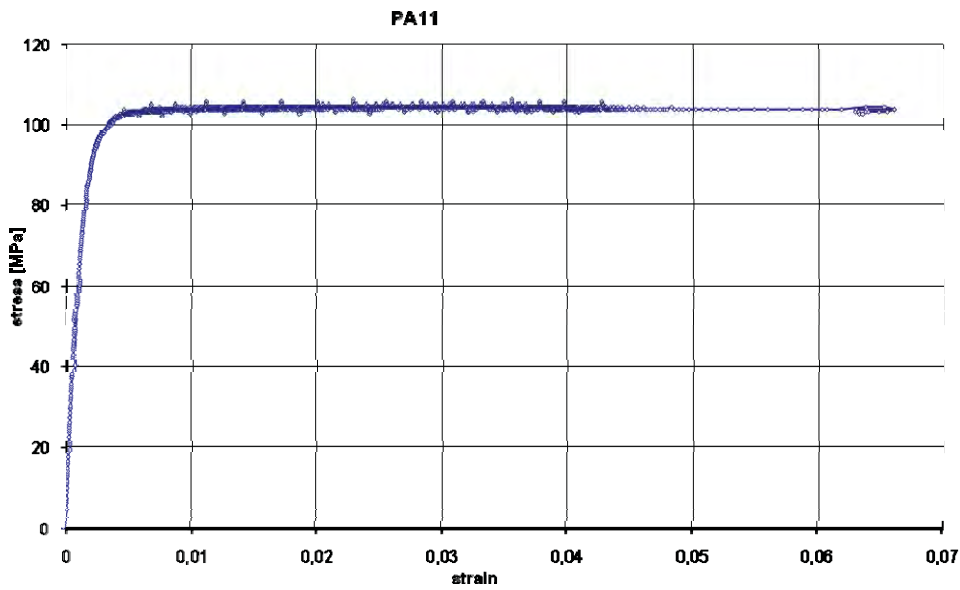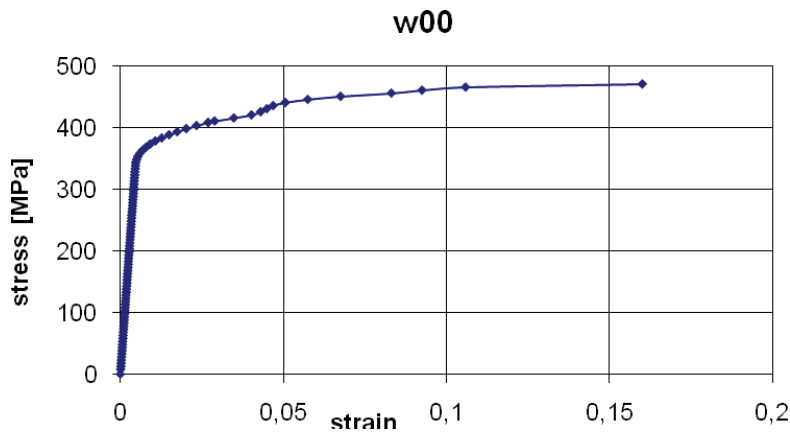| Material	aluminium
Symbol	Al
ρ_0 [kg/m^3]	2713
C [m/s]	5240
S_1 [-]	1.4
S_2 [-]	0
S_3 [-]	0
γ_0 [-]	1.97
A [-]	0.48

Fig. 3. Dependence of stress-strain for PA11

Fig. 4. A stress-strain plot received for numerical model with preliminary set of Johnson-Cook data, $p_{0max} = 500$ MPa

The preliminary set of Johnson-Cook data according to Tab. 1 and 2 leads to stress-strain curve as showed in Fig. 4. Modification of these material data is necessary (A, B, n parameters). The least square method was used to carry out the curve fitting procedure. A value of static yield stress - parameter A in equation (1) was assumed to 100 MPa according to curve shape, in Fig. 3. Finally the values of parameters in demand are equal respectively: $A = 100$ MPa, $B = 9.7$ MPa, $n = 0.21$, Fig. 5.
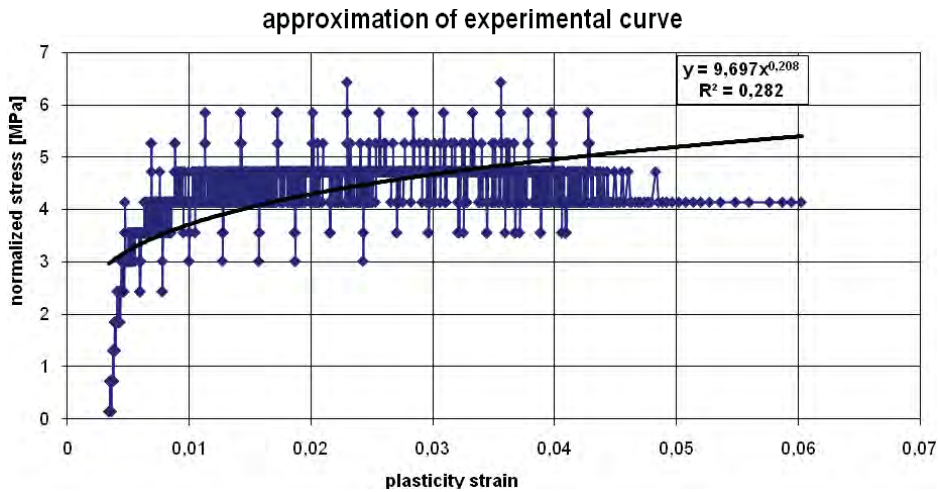
approximation of experimental curve

$$y = 9.697x^{0.208}$$
$$R^2 = 0.282$$

Fig. 5. Selected constants for Johnson-Cook model. Stress normalized to A = 100 MPa

A Young modulus was appointed for numerical simulation of tension of PA11 sample from Fig. 6. Value of Young modulus is about 73.5 GPa. This parameter equals 68.5 GPa in experimental result. Relative error achieves 7%, it is acceptable error in this kind of problem.
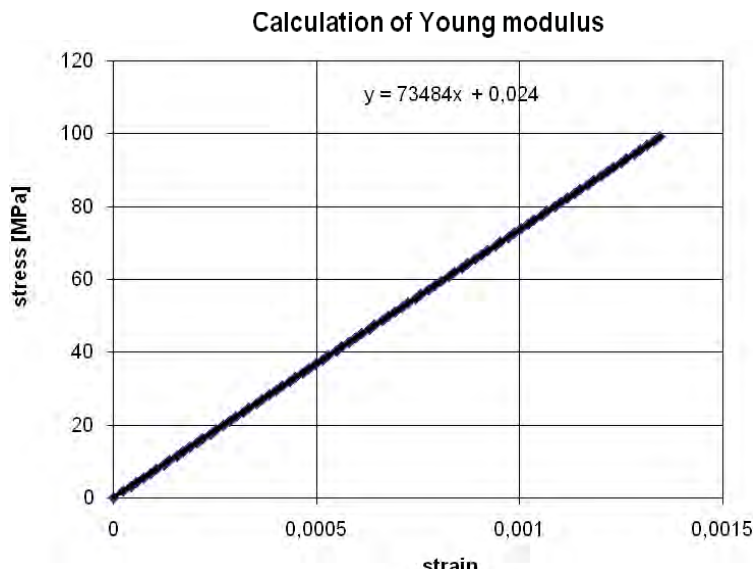
Calculation of Young modulus

$$y = 73484x + 0.024$$

Fig. 6. Calculation of Young modulus for simulation of tension of PA11 sample

Comparison of stress-strain curves from experimental and numerical tests is shown in Fig. 7. These curves have similar shape and values of static yield stress are consistent. A perfect-plasticity curve is used to comparison, Fig. 7 also. This model of plasticity is the best for mapping of behaviour of real material for studied aluminum alloy at large strain values.

6. Conclusions

The purpose of this paper is to conform an available material data for aluminum alloy material (PA11). At this stage of work the aluminum alloy PA11 with respect to Johnson-Cook model was researched. A further work for finding a good material data for WHA, U12A steel and other constitutive models will be performed. A good agreement of the numerical and experimental results is received. Other material data used in modeling, which were not determined by experiment, assumed according to literature sources.
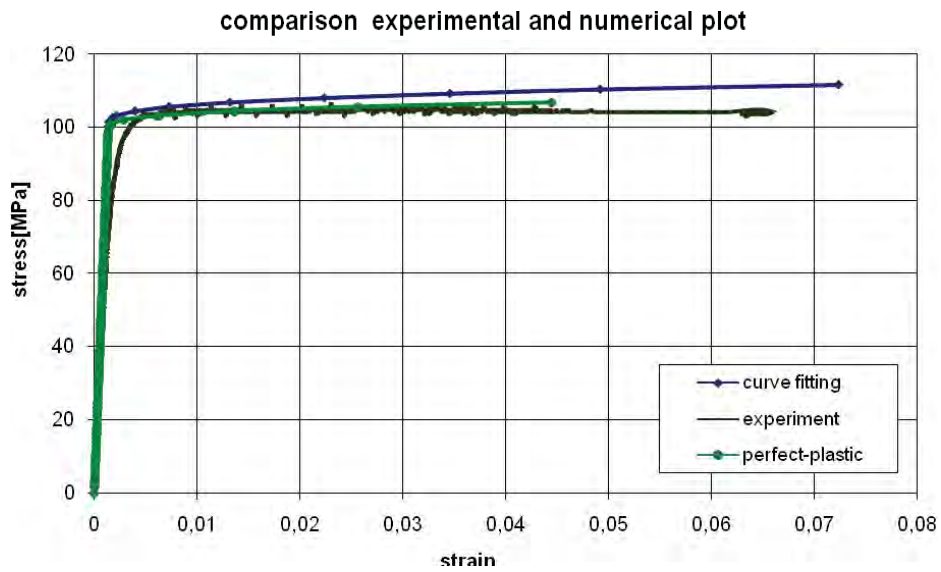
Fig. 7. Comparison of stress-strain curves for numerical and experimental results for tension test

Acknowledgements

References

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[2] Raftenber, M. N., *A shear banding model for penetration calculations*, International Journal of Impact Engineering, Vol. 25, pp. 123-146, 2001.