MODELING OF DISCONTINUOUS DEFORMATION IN Al-6%Mg ALLOY

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ABSTRACT

We describe a procedure for modeling the structural inhomogeneity of a material by the finite element method. We consider the material as a composite consisting of an elastoplastic matrix and brittle inclusions (dispersoids). The finite element model is based on experimental data on the concentration of inclusions and their geometrical sizes. The proposed finite element model describes well the discontinuous deformation of Al-6%Mg alloy.

KEYWORDS

Modeling of heterogeneous structure, finite element method, discontinuous deformation.

INTRODUCTION

Diagram of structural materials deformation in some tension is of discontinuous character. It is known about the effect of low-temperature discontinuous deformation of the materials, which is associated with the initiation of strain that results from pulse impact, either thermal or mechanical [1, 2].

Composite materials, which failed by multiple cracking mechanism, have got pulverized strain diagram [3]. Such diagrams are associated with the destruction of fibers in various cross sections of material. With the destruction of fiber, loading perceived by it is transmitted to the matrix, and on the tension chart there appears tooth, proportional to the load magnitude. On further deformation, local strengthening and growing tension in the matrix occurs, which causes the destruction of fibers' segments in other cross sections.

Also known Portevena - Le Chatelier effect of breaking fluidity, which is associated with plastic deformation by twinning, or with a sharp increase of mobile dislocations number due to their exemption from consolidation of impurity atoms [4, 5]. Dislocation can be fixed by atmospheres of atoms impurities, second phase particles or in other way [6].

In work [7] it is investigated the relationship of discontinuous deformation under tensile of Al-6%Mg alloy with the second phase dispersed inclusions destruction. The dependence of instantaneous values of strain increments and the size distribution of dispersed phases is obtained.

To get a real picture of stresses and strains distribution with taking into account the discontinuous rate in modeling structural elements by finite element method (FEM), material should be viewed as a heterogeneous one [8]. Besides, elastic plastic deformation chart of such material, obtained from the FEM, must be consistent with experimental chart.

This work hasaimed to develop methods of simulation of structural components influence on Al-6%Mg alloy deformation with ANSYS software applying, work of which is based on use of FEM.

SPECIMEN, MATERIAL AND TESTING

In the tensile stress-strain diagram of smooth cylindrical specimens at a temperature of 20°C, there appear strain jumps due to the cracking of disperse inclusions of the secondary phase and scattering of dislocation clouds [7].
We studied the number of disperse inclusions in the cross section of specimens and their cracking after plastic deformation in the longitudinal direction by the method of transmission electron microscopy of thin foils on a TEM-125K microscope. The dispersoids of length from 0.2 to 5 μm and diameter from 0.08 to 0.15 μm were stretched in the direction of forge-rolling. Their number in the matrix of the α-solid solution of Mg in Al in cross section is about 3×10^6 / mm^2 [7].
After stretching in the longitudinal direction, the dispersoids crack (Fig. 1a) into 2 – 7 fragments depending on the initial form factor α (the ratio between the length and width of an inclusion) till it reaches a value of 3.4. The dispersoids with initial $\alpha \leq 3.4$ are not destroyed.

Fig 1: Destruction of disperse inclusions in the longitudinal direction, ×30000

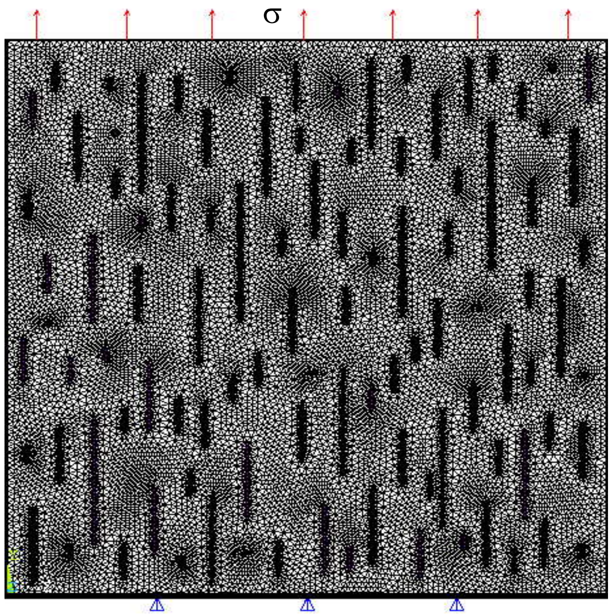


Fig. 2: FEM model of the Al-6%Mg alloy

The data obtained were used for finite element simulations of discontinuous deformation rate in Al-6%Mg alloy.

EVALUATION OF THE RESULTS

Finite-element modelling

Our computations by this method were carried out with the help of the ANSYS program package, version 9.0. The computational model was based on experimental data on the number of inclusions according to the histograms of their distribution depending on the initial form factor [7]. The number of inclusions in the model was n = 100. According to experimental data, for the cross section area $S_2 = 10^{-8}$ m^2, the total area of inclusions is $S_1 = 5.42 \cdot 10^{-10}$ m^2.
We assumed the following:
(a) the ratio between the area S_1 of inclusions in the cross section and the area S_2 of this section is equal to the ratio of the area S_3 of inclusions in the longitudinal section to its area S_4 : $S_1 / S_2 = S_3 / S_4$; we find from here $S_3 = 1.84 \cdot 10^{-11}$ m^2 and $S_4 = 3.39 \cdot 10^{-10}$ m^2 ;

(b) the diameter of all inclusions in the model is identical d = 0.115 μm (averaged value), and their length is *l* = α d ;
(c) the inclusions are rigidly adherent to the matrix.
Taking into account these assumptions and the histogram of the number of dispersoids depending on their form factor α [7], we determined the number of inclusions n, their lengths, total area in the longitudinal cross section of the model S_3, and the sizes of the computational model.
We took the computational model in the form of a square, and then $S_4 = a^2$, where a = 1.842 · 10^{-15} m is the model size.
We assigned the coordinates of placement of the inclusions inside the model according to the two-dimensional normal distribution. As the basis of the finite-element grid, we took an eight-node plane element **plane 82**, which has the properties of plasticity and creep, can increase its rigidity under loading, and also admits large displacements and strains. The number of elements in the model was 115,731.
Our computations were carried out in the elastoplastic region by using the iteration calculation of strain growth and redistribution of the stress field in the matrix and inclusions, with regard for the kinematic hardening of the material. We applied the forces to the upper horizontal boundary of the model, fixed vertical displacements (along the Y axis) at the lower boundary, and limited the latter (Fig. 2).
Calculations made in elastic-plastic formulation, using an iterative computation of strain growth and stress field redistribution in the matrix and inclusions, taking into account the effect Baushinhera and cinematic effect of strengthening the material [9]. Efforts were applied the upper horizontal line of the model, but the bottom line was fixed and vertical movement (axis Y) was limited (Fig. 2). It has been considered that the inclusions are deformed only elastically and elasticity modulus of the first kind is bigger than that of the matrix (Fig. 3). Mechanical properties of structural components of models were taken the same as characteristics of Al-6%Mg alloy. Total mechanical characteristics of the interaction matrix (Fig. 3, curve 2) and inclusions (Fig. 3, curve 1) correspond to material deformation diagram (Fig. 3, curve 3). Mechanical characteristics of inclusions and Al-6%Mg alloy are given in [10, 11]. Mechanical properties of matrix Al-6%Mg alloy without inclusions were determined by iterative calculations by known deformations of inclusions and the total material. The parameters of estimation are compliance of total material deformation presented by the finite-element model, experimental data [12].
We believe that the destruction of the model takes place when the normal stresses, occuring in the model are higher or equals failure tension. Fracture stress for the matrix and inclusions σ fm σ finc are different and determined by their mechanical characteristics. In particular, according to the strain diagrams (Fig. 3), for the matrix fracture, stress is of σ fm = 825 MPa, and for the inclusions – σ finc = 1100 MPa.

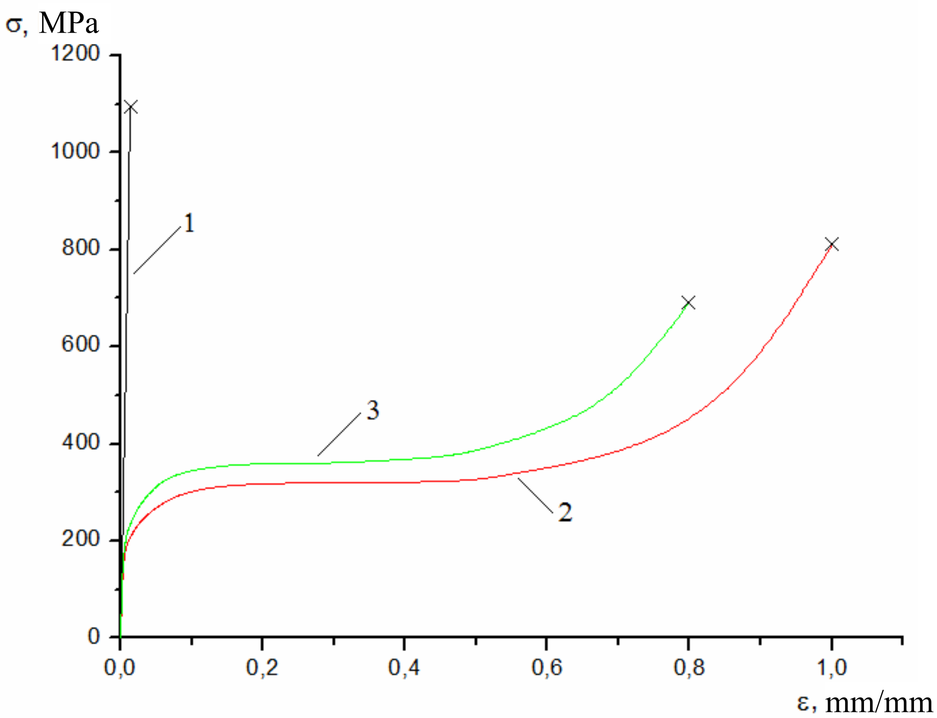
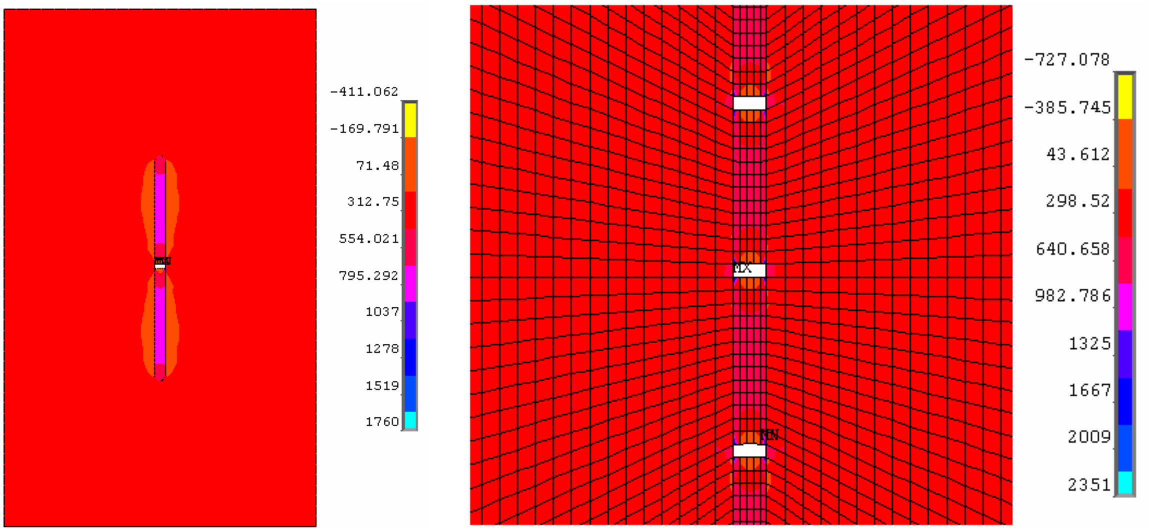


Fig 3: Diagrams of inclusions deformation (1), matrix (2) and total diagram (3) of Al-6%Mg alloy deformation.

The distribution of normal stresses under the critical load shows that the model will begin to fail at the middle part of an inclusion, where the maximum normal stresses arise. We modeled the destruction of elements of the finite-element model in the ANSYS program package with the use of the procedure **kill element**. It determines the elements corresponding to the accepted fracture criterion. Under the critical stresses, the inclusion under consideration fails completely, forming two fragments with a form factor lesser by half than the initial (Fig. 4a).



a b

Fig 4: Inclusion failure: a – failure of inclusion into two parts, b – fragment of the finite-element net of the model under failure of inclusion into four parts

After cracking of an inclusion into two parts (Fig. 4a), the plastic strains and normal stresses are redistributed. The maximum normal stresses are now observed at the middle part of fragments. Here, the critical breaking stresses arise again, and the fragments crack in half. The formed four fragments (Fig. 4b) have approximately equal but lesser by half form factors. Stresses in the matrix are always lower than the critical.

Similar computations for the model with numerous inclusions (Fig. 2) show that the critical breaking stresses in the matrix and inclusions do not arise if the model is loaded with nominal stresses up to 229 MPa. There were no jumps in the stress-strain diagram, which was constructed in parallel at each step of iterations. Under stresses of 229 MPa, the inclusions with the greatest form factor $\alpha = 43.5$ were destroyed according to the scheme for the model with a single inclusion, and the first strain jump appeared in the stress-strain diagram (Fig. 5).

The next inclusion (with the form factor $\alpha = 40.5$) was destroyed under a stress of 230 MPa, and one more strain jump appeared in the diagram (Fig. 5). The inclusion with the form factor $\alpha_3 = 37.5$ was destroyed at $\sigma = 235$ MPa and induced the next strain jump (Fig. 5). Several inclusions with identical form factors cracked simultaneously.

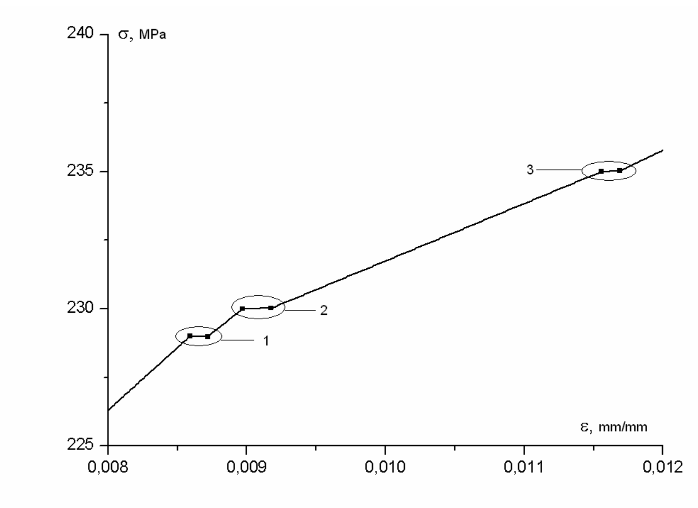


Fig. 5: Appearance of jumps in the stress-strain diagram of AMg6 alloy as a result of destruction of the inclusions with the form factors $\alpha_0 = 43.5$ (zone 1), 40.5 (zone 2), and 37.5 (zone 3).

Figure 6 A demonstrates fragment of the calculation model during destruction of the inclusions with shape ratio α 12 = 10.5 (loading applied to the model is 285 MPa).

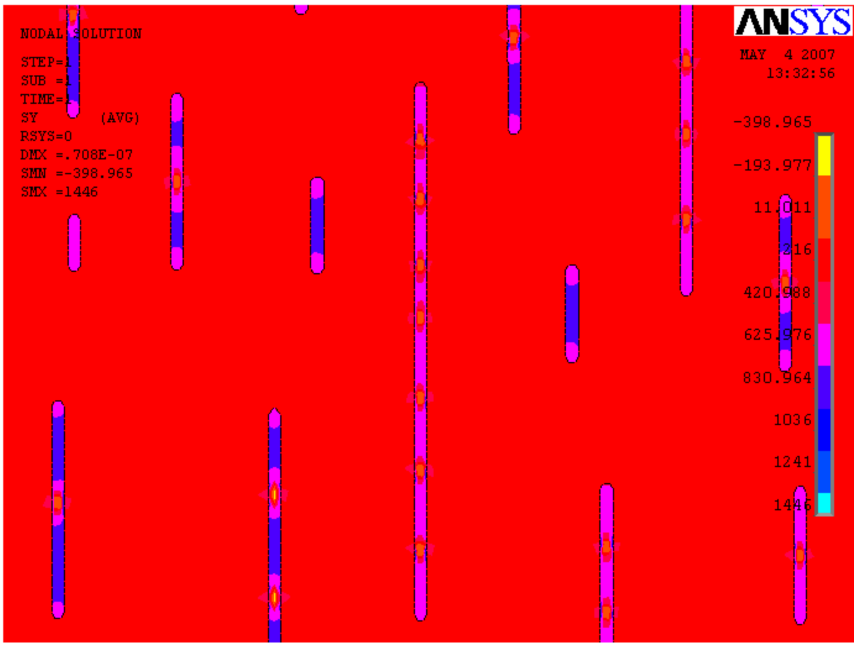


Fig. 6: Fragment of the calculation model during inclusions failure.

Figure 7 presents a three-dimensional histogram of inclusions destruction of particular shape ratio depending on the load, applied to the model.

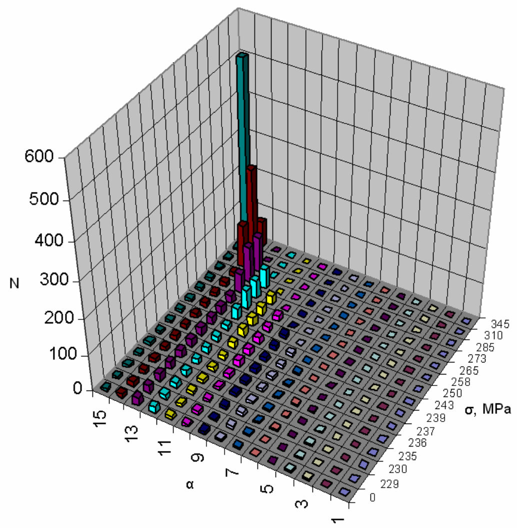
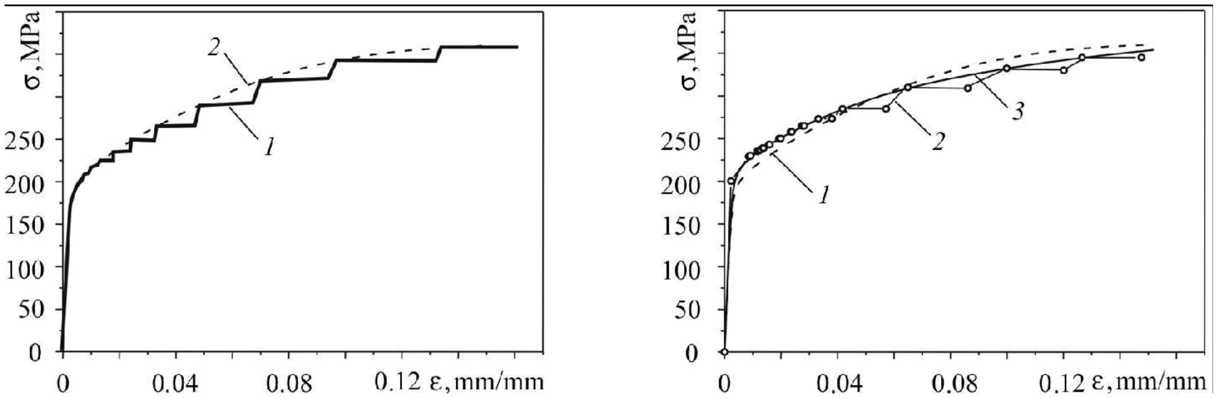


Fig. 7: Histogram of dyspersoids fracture under the load of calculation model.

For reproducing the stress-strain diagram, we applied loads from 229 to 345 MPa to the computational model by iterations with a step of 1 MPa. Choice of the minimum level of stresses (229 MPa) was connected with the beginning of destruction of the inclusions in the model, and the maximum value (345 MPa) was determined by the mechanical characteristics of the modeled composite material. The calculated jump-like diagram for AMg6 alloy (Fig. 8b) is in good agreement with the experimental one (Fig. 8a).



a b

Fig. 8: Stress-strain diagram for AMg6 alloy: (a) experimental data (1) and approximation over the upper envelope (2); (b) approximation over the upper envelope of experimental data (1), FEM computations (2), and approximation of the FEM data (3).

SUMMARY AND CONCLUSIONS

Using the finite element method, we have studied the influence of destruction of inclusions in a heterogeneous material on its jump-like deformation under uniaxial tension. We have obtained a calculated jump-like stress-strain diagram for AMg6 alloy, which is in good agreement with experimental data.

When applying force to the estimated model of heterogeneous material in the middle part of the inclusions, marginal normal stress occurs, and as a result they are failed into two fragments with simultaneous redistribution of deformations and stresses in the model.

On the basis of the developed procedure, one can carry out a linear or a nonlinear analysis of the stressstrain state and fracture of constructional materials with regard for the properties of their structural components.

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