16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Application of the discrete element method to ductile materials subjected to dynamic loads

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Abstract: Dynamic loads accompanying metal forming processes are demanding with regard to numerical simulation. During the deformation process there comes to an interaction between several physical phenomena, where deformation and temperature are the dominant fields. The use of the finite element method in the case of large deformations is problematic and is associated with the fulfillment of the conditional requirements, which will allow to obtain convergence of calculations. One way to overcome these limitations is to use the discrete element method. In this work the possibility to use this method for dynamic analysis was presented. The mathematical model used in simulation takes into account coupling the mechanical field with the thermal field. Due to the large deformation of the material in the presented work, considerable attention was paid to plasticity and the evaluation of flow function used.

Keywords: discrete element method, dynamic load, thermo-plasticity.

1. Introduction

The work of Cundall and Strack [1] is considered the beginning of the formulation of the discrete element method. In its original form it was dedicated to granular materials. In subsequent stages, this method was adapted to other types of materials, mainly used in geomechanics. Currently using this method it is possible to simulate the evolution of the microstructure in materials or to analyze the crack propagation [2-4]. Another advantage of this method is the simplicity of the equations that describe the interactions between the elements. These equations are based on Newton's dynamic laws, thanks to which we can determine the position of the particle in successive time steps

$$m_i \frac{\mathrm{d}\boldsymbol{v}_i}{\mathrm{d}t} = F_{ij} \tag{1}$$

$$I_i \frac{\mathrm{d}\boldsymbol{\omega}_i}{\mathrm{d}t} = \sum_j \boldsymbol{M}_{ij} \tag{2}$$

By applying the method of discrete elements to the analysis of solid material, we are forced to replace the material continuum with a set of particles for which the set of mathematical equations has been supplemented with appropriate constitutive models. In the general concept, the material model has isotropic properties, but some modifications to the equations also allow the introduction of anisotropy [2].

2. Numerical modelling and discussion

The constitutive equations that determine the strength of the interaction of particles with each other are assigned to a point located on the contact plane. In this work, the existence of a plane stress state was assumed at the point where the only stresses are σ_x and τ_{xy}. This assumption simplifies the formulation of the flow function and increase the computation time of the algorithm related to the estimation of the plastic deformation. For computational reasons, phenomena related to phase changes of the material were omitted in the paper. Therefore, the energy dissipated during the process is completely converted into thermal energy.

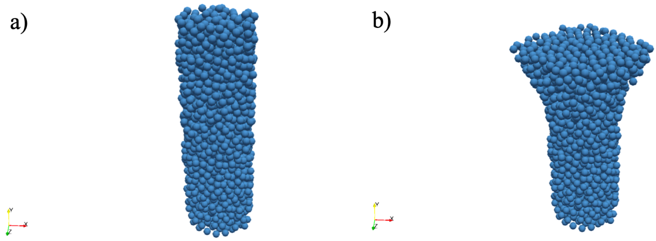

Fig. 1. Test of deformation in dynamic compression of aluminum sample. Initial geometry a) and deformed sample b).

The dynamic load, which may be related to the metal forming process, leads to intensive plastic deformation of the material in the area where the force is applied (Fig. 1.). This effect is counteracted as the speed of the punch is reduced. It was also noted that the number of particles used for volume discretization influenced the results. This is also confirmed by the works of other authors [3-4].

3. Concluding remarks

The analyzed case allows for the formulation of the following conclusions. The use of the discrete element method enables simulation of the metal forming process taking into account large deformations and the accompanying dissipation of energy in the form of thermal energy, under the basic formulation of constitutive equations. The use of the presented method of volume discretization affects the obtained results. It is necessary to carry out further work to eliminate this problem.

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