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ANALYSIS OF KINEMATIC STATE PARAMETERS BY SIMULATION AND EXPERIMENTAL METHOD

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ABSTRACT
In this paper determined Kinematic state of a workpiece at bulk metal forming in open dies of axisymmetrical elements from aluminium alloy in hot state. Strain rate tensor components are determined, as partial displacement rate component derivations. It is necessary to determine initial and final point displacements for a relatively short observed interval with a constant velocity. The regression analysis of all kinematic parameters of the bulk forming process obtained by experimental method is performed. A numerical simulation of bulk forming process is performed in this paper. The simulation is performed in DEFORM 2D programme. Results obtained by using simulation and experimental methods, as well as model results obtained by regression analysis are compared and showed in suitable diagrams.
Keywords: Kinematic state, Bulk metal forming in open dies, Strain rate, Displacement rate, Displacement, Physical Discretization Method

1. INTRODUCTION
In the processes of deformation, the bulk metal forming in open dies is particularly distinguished for its complexity. Due to the complexity of the problem using of theoretical, experimental and numerical approaches is required.
Determination of the points displacement within the deformation zone has been analysed by number of autors from different points of view, depending on the type of deformation process, state of stress and other features.
Strain, stress and kinematic analysis of bulk metal forming in open dies is carried out in the papers. Improvement of the methods in these papers can be achieved by determination of cross-section displacement of points of a workpiece. In this paper displacement of points are determined by measured coordinates of points of digitalized picture of meridial cross-section of workpiecs after deformation. Workpieces are made out of segments, thus they are physically discreted, so that such a method is said to be the Physical Discretization Method (PDM) [1,2].

2. STRAIN RATES
The normal strain rate components are partial derivations of the displacement rates. Strain rate tensor components in cylindrical coordinate system are [3]:

$$\dot{\varepsilon}_r = \frac{\partial v_r}{\partial r}, \dot{\varepsilon}_\theta = \frac{v_r}{r}, \dot{\varepsilon}_z = \frac{\partial v_z}{\partial z}, \dot{\gamma}_{zr} = \frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} \tag{1}$$

The effective strain rate is a quantitative measure of the total strain rate, and defined by the formula:

$$\dot{\varepsilon}_e = \frac{\sqrt{2}}{3}\sqrt{(\dot{\varepsilon}_r - \dot{\varepsilon}_\theta)^2 + (\dot{\varepsilon}_\theta - \dot{\varepsilon}_z)^2 + (\dot{\varepsilon}_r - \dot{\varepsilon}_z)^2 + \frac{3}{2}\dot{\gamma}_{rz}^2} \tag{2}$$

There are two types of deformation states:

- Steady deformation (drawing, rolling, forward extrusion),
- Unsteady deformation (backward extrusion, bulk metal forming in open dies).

In unsteady processes, it is necessary to determine the interval at which end it is possible to determine the kinematic state of the volume of the workpiece. In order to determine the kinematic field, it is necessary to determine displacements of points of the cross-section experimentally, at the beginning and at the end of the observed interval. Based on the obtained displacements of points of the meridial cross-section and duration of the interval, it is possible to determine the components of displacement rates according to the formulas:

$$\left. v_r = \frac{r_0 - r}{\Delta t} = \frac{\Delta r}{\Delta t}, \quad v_z = \frac{z_0 - z}{\Delta t} = \frac{\Delta z}{\Delta t} \right\}. \tag{3}$$

The assumption for displacement rates determination is the constant deformation velocity.
Based on the displacement rates, it is possible to determine the strain rates for the points of meridial cross-section (1). Partial derivations are determined for sufficiently small values of coordinates and time: Δr, Δz, and Δt, according the following formulas:

$$\frac{\partial v_r}{\partial r} = \frac{\Delta v_r}{\Delta r}, \frac{\partial v_z}{\partial z} = \frac{\Delta v_z}{\Delta z}, \frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} = \frac{\Delta v_r}{\Delta z} + \frac{\Delta v_z}{\Delta r}. \tag{4}$$

3. PHYSICAL DISCRETIZATION METHOD (PDM)

The basis of the PDM is discreted segmental workpiece that comes from groove-like plates. The workpieces made this way, allow that after the completion of deformation, and suitable preparation of workpieces, to determine the displacements [1,2].
With the given complexity of the bulk metal forming in open dies process, relevant researches are concretized in the family of stepped axisymetrical workpieces .
For the experiment the aluminum alloy AlMgSi0,5 is used, which chemical composition is given in Table 1.

Table 1. Chemical composition of materials used in experiment

Fe%	Si%	Ti%	Cu%	Zn%	V%	Cr%	Mn%	Mg%	Ni%
0.207	0.477	0.01	0.09	0.068	0.004	0.01	0.1	0.493	0.02

Experiments have been performed at the temperature of hot forming of the alloy: t=440 °C. Deformation is achieved in constant deformation velocity: v=2 mm/s.
For bulk metal forming in open dies, tools made of steel for work in a hot state Č.4751 are used. Deformation process is performed by the tools moving in cylindrical guide that provides their coaxiality during the process. The cylindrical guide has the role of "chamber" in order to maintain isothermal process. The guide is heated with dies and workpieces to working temperature.
During the attempt of practical realization of the idea of discretization of workpieces, they are made in different ways [1].
For the analysis of kinematic state in unsteady deformation process, such as bulk metal forming in open dies, it is necessary to determine state of strain of the workpiece, which includes measuring of the displacements of the points in two close moments. Due to that two workpieces are deformed to flash height: h_{va}=3 mm, and the final h_{vb}=h_v=1 mm. These values are obtained in empirical way [2].
Numerical values of the points of deformed mesh lines are part of the input data for determination of the state of strain. Data processing is done by using a computer program made in MATLAB.

Based on the values of the coordinates of cross-section points of radial and axial lines of the non-deformed and deformed mesh, the displacement of points in the radial and axial directions are determined. Thus, the displacements are:

$$u_{rb} = r_{pb} - r_{p0}, u_{zb} = z_{pb} - z_{p0}. \quad (5)$$

The basis of the kinematic analysis is the determination of displacement rates. At the beginning of the adopted interval of deformation the process stops. Digital image of cross-section obtained at the beginning of the observed interval of deformation with provided axial and radial lines is given in Figure 1**.**

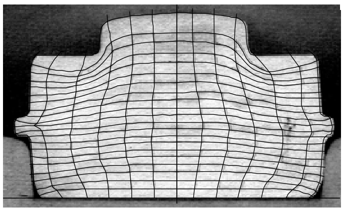


Figure 1. Deformed mesh lines at the beginning of the observed interval

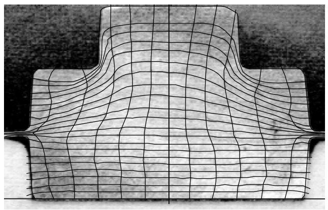


Figure 2. Deformed mesh lines at the end of the process

Based on the values of the coordinates of cross-section points of non-deformed and the deformed mesh, at the beginning of the observed interval, the displacement points in the radial and axial directions are determined. Thus, the displacements are:

$$u_{ra} = r_{pa} - r_{p0}, u_{za} = z_{pa} - z_{p0}.. \quad (6)$$

Increment of nodal points displacements of the deformed mesh is determined as the difference of displacements at the end and at the beginning of the observed interval:

$$\left.\begin{aligned} \Delta u_r &= u_{rb} - u_{ra} = r_{pb} - r_{pa} = \Delta r \\ \Delta u_z &= u_{zb} - u_{za} = z_{pb} - z_{pa} = \Delta z \end{aligned}\right\}. \quad (7)$$

Provided that the deformation velocity is constant: v=2 mm/s, and increment of the tool movement Δz=2 mm, the increment of time shall be: $\Delta t = \Delta z / v$=1 s.
According to the formula (3) it is possible to determine the displacement rates in nodal points of deformed meshes. Displacement rates value of other points are approximated by cubic interpolation.
For obtained displacement rates points of cross-section it is possible to determine partial displacement rates derivations per radius and per height, according to that all components of strain rate tensor are obtained (1). 3D diagram of the effective strain rate is given in Figure 3.

4. NUMERICAL SIMULATION (FEM)

Numerical simulation by Finite Element Method in this paper is carried out using the software DEFRORM-2D. The simulation is performed in all points of the experimental plan. The value of friction factor used in the simulations was obtained by DEFORM calibration diagram. The yield stress is experimentally determined [4,5].
The final appearance of workpiece with a mesh of finite elements with dies is given in Figure 4. The database stores all the strain, kinematic and stress parameters of deformation. In order to display the changes of kinematic parameters in 2D, the numerical values of all parameters are obtained from the database.

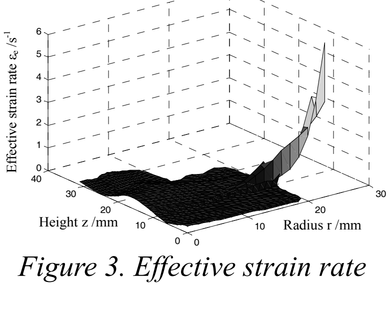


Figure 3. Effective strain rate

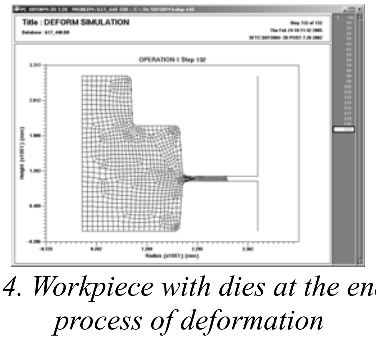


Figure 4. Workpiece with dies at the end of the process of deformation

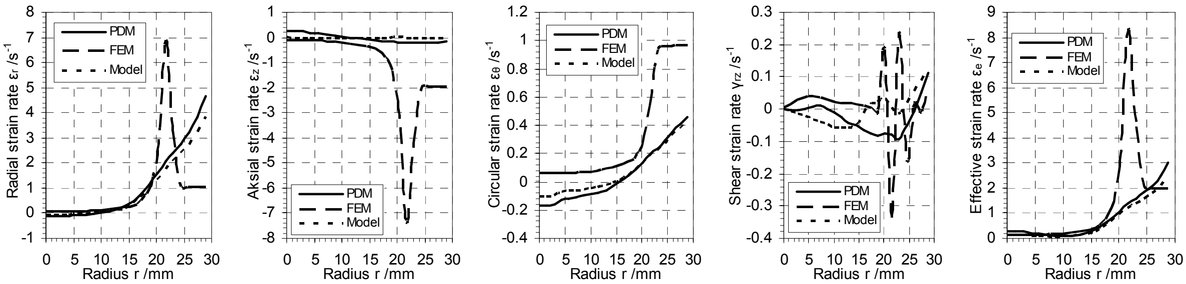
5. REGRESSION ANALYSIS

Regression analysis is conducted with the aim of obtaining mathematical models of values of kinematic parameters. In this paper, but most gave unsatisfactory results. Results with high correlation coefficient were obtained by using the equation of the second degree, which is composed of linear members, members of the interaction factors and the square members. Such a model for the four input factors, as is the case in modeling of kinematic parameters, has the form [6]:

$$y = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i<j}^{4} \beta_{ij} x_i x_j + \sum_{i=1}^{4} \beta_{ii} x_{ij}^2 \tag{8}$$

6. COMPARISON OF KINEMATIC PARAMETERS

3D diagrams of kinematic parameters are good for visual display, but are not suitable for quantitative analysis of value. For this purpose, it is possible to obtain 2D diagrams in all meridial cross-sections of workpiece. Figure 5. shows all the components of strain rate tensor and the effective strain rate that were obtained by FEM and PDM, and regression analysis.



a) Radial SR (b) Axial SR (c) Circular SR (d) Shear SR (e) Effective SR

Figure 5. Strain rate components in the parting line of workpiece

7. CONCLUSIONS

This paper is a contribution to determination of kinematic state of workpiece in the bulk metal forming process in open dies. Based on the kinematic analysis of the bulk metal forming process, the following conclusions are provided:

1. Kinematic state of a workpiece during the process of deformation can be successfully determined by the described Physical Discretization Method PDM.
2. There are differences of kinematic parameters obtained by FEM and PDM simulation, which means that they require improvement.
3. Improvement of PDM can be achieved by reducing the geometrical parameters of groovy-like plate from which the workpieces are made from.
4. Applied regression analysis provides good results and present differences are the result of repeating the central point of the experimental plan.
5. Increasing the accuracy of results can be achieved with using statistical methods on a larger sample.

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