

MODELING OF STRAIN IN BULK METAL FORMING PROCESSES

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Abstract: To determinate strain parameters, a numerical simulation of bulk deformation in open dies of an axi-symmetrical work piece was carried out in numerical FEM systems. DEFORM-2D software package meant for analyzing plane and axi-symmetrical deformation is used in numerical simulation. A graded convex shape of die work piece dimensions and distribution of node points whose dislocations are followed in deformation process have been adopted. Numerical simulation consist of three phases. A numerical experiment is carried out in the first phase, and point movement at the end of deformation process for the accepted coordinate points in a non-deformed state are obtained. Based on these data on point dislocation, state of strain parameters are determined. This numerical experiment relates to the process continuity. The second phase relates to the numerical experiment realized for the same initial conditions, but bulk deformation process is observed in deformation phases, and strain parameter are determined in each of them, based on which the parameters at the end of deformation process are obtained. The third phase relates to the state of strain parameters determined by DEFORM-2D itself, and they refer to the same initial conditions.

Keywords: STRAIN, STATE OF STRAIN, FEM, NUMERICAL SIMULATION, FEM, BULK DEFORMATION PROCESS

1. Introduction

Within deformation process, bulk metal forming is specially characterized for its complexity. To be successful at projecting any technological procedure by deformation process, it is of great and importance to know the parameters state of strain. The best way is testing on real object, being quite expensive one and demanding a lot of time for investigation, so numerical experiments that are cheaper and quickly realized have been more applied lately [1-9].

Recently, thanks to a rapid development of computer engineering, a numerical approach of solving problems has become of great importance. Finite Element Method (FEM) has been used as the most powerful one. Based on this model several commercial software packages for numerical simulation of bulk deformation process have been made. One of the most known software packages for numerical simulation of bulk deformation process have been made. One of the most known software packages is DEFORM, whose producer is Scientific Forming Technologies Corporation (SFTC), where simulation and the obtained results presented in this paper have been carried out [1-14].

2. Basic Parameters of Numerical Experimental Investigations

DEFORM-2D software package will be used for numerical simulation. Bulk metal forming in open die process implies a lot of problems both from the point of view of geomtry and technological condition. An element shown in Figure 1. is observed in the paper with next conditions:

- Material is an aluminium alloy AlMgSi0.5.
- Investigation is carried out at hot forming temperature of $T=440^{\circ}\text{C}$.
- Deformation is obtained by a small constant forming velocity of $v=2\text{ mm/s}$.
- Strain hardening curve parametres are $c=30.34434$ an $n=0.097808$ for AlMgSi0.5 aluminium alloy and temperature $T=440^{\circ}\text{C}$.
- Friction factor is $m=0.114$.

Tool shape is gradually convex (Figure 1.). It consists of two dies, upper and lower ones. The upper part of die consists of two degree heights whereas lower one has one height degree (level) [1].

Work pieces are cyllindrical, of diameter $d_0=33.56\text{ mm}$. Height h_0 is determined by the conditions of constant work piecs volume before and after pressing process for adopted die dimensions given in Figure 1. and it amounts to $h_0=33.94\text{ mm}$. An adopted mesh of a half of axi-symmetrical work piece in given in Figure 2. [1] total number of node points is 154. Point coordinates whose

displacement will be followed in numerical experiment and whose strain state parameters will bu determined are given in Figure 3.

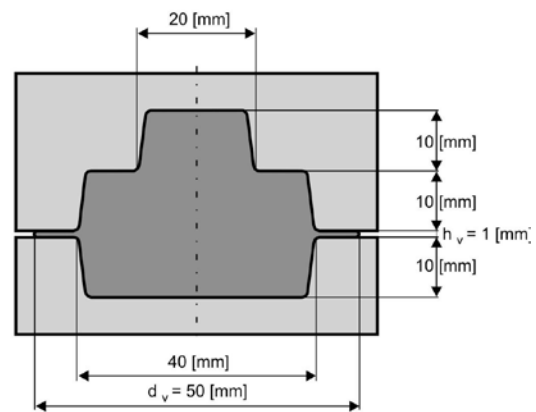


Fig. 1 Workpiece within die [1]

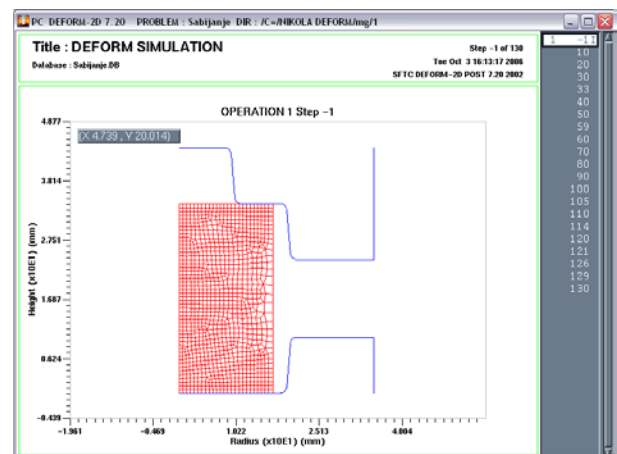


Fig. 2 Adopted mesh of a work piece [1]

3. Numerical Simulation

Numerical experiment for process continuity

To carry out a numerical simulation, it is necessary to put gradually some known data into DEFORM module Pre Processor.

First step is putting info the field of *Simulation Controls* the data connected to the choice of system units, geometry display step number, step recording, values of stroke per steps, as well as values of SMAX process stoppage.

Table 1: Simulation Controls [1]

Simulation Parameters	Units UNIT	☒ SI
	Geometry GEOTYP	☒ Axisymmetric
Step Controls	Number of simulation steps	NSTEP=1000
	Step increment to save	STPINC=10
	Primary die	PDIE(1)=1
	Steps by	☒ Stroke
	Stroke per step	DSMAX=0.1 mm
Stopping Controls	Primary die displacement	SMAX=0, 12.94 mm

In the second step, in the field of *Material Properties* the data connected with a work piece material, namely the values of hardening curves, are input. In the third step, in the objects field, the data connected with the geometry of upper and lower dies, work piece, as well as the values of upper die movement speed are input.

Table 2: Objects [1]

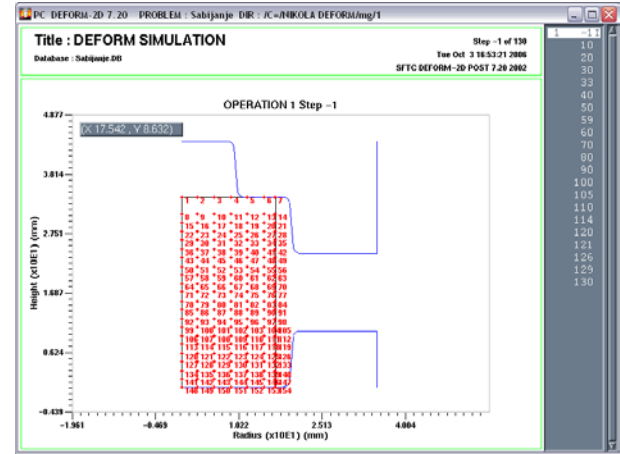
Name: Upper die ☒ Rigid	Geometry		X mm	Y mm	R mm
		1	0	43.94	0
		2	9.300732	43.94	1
		3	10	33.94	1
		4	19.300732	33.94	1
		5	20	23.94	1
		6	35	23.94	0
		7	35	43.94	0
	Movement controls		Speed: 2 mm/s		
		Angle: -90°			
Name: Lower die ☒ Rigid	Geometry		X mm	Y mm	R mm
		1	35	0	0
		2	35	10	0
		3	20	10	1
		4	19.300732	0	1
		5	0	0	0
Name: Work piece ☒ Plastic	Geometry		X mm	Y mm	R mm
		1	0	0	0
		2	16.78	0	0
		3	16.78	33.94	0
		4	0	33.94	0
	Mesh	Number of mesh elements			MGNELM=1000

In the fourth step, in *Inter Objects* field, the data connected with the relations of a die and a work piece as well as friction factor values are input. For other parameter values, there been taken *default* DEFORM-2D software package.

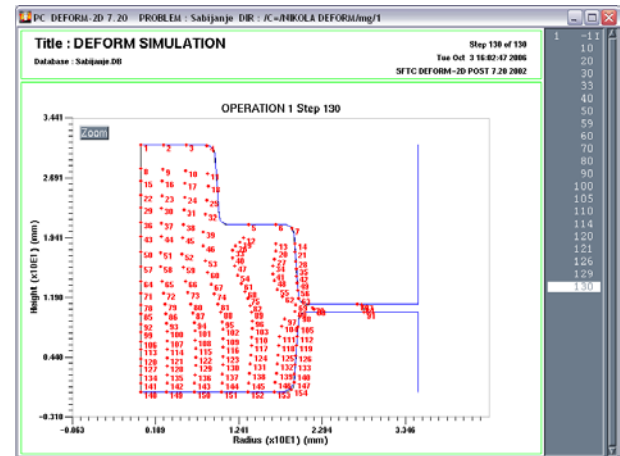
After inputting data and generating a mesh of finite elements, an initial data base for an initial step is formed and it is marked by -1. By forming the data base, all the necessary conditions analyze deformation process are obtained namely by entering *Simulation* module, DEFORM simulation is to be performed [1].

The simulation done, the results obtained may be interpreted in Post Processor module in both graphical and data forms. After simulation process starting, numerical calculation for the stroke per step DSMAX=0.1 mm, are made, at which each tenth step is kept within data base. When the parameters of the finite element mesh reach their critical values, an automatic *remeshing* is done.

For the given simulation example, *remeshing* was done five times, and the process was finished at 13th phase. A final look of the workpiece in the 13th phase with the mesh of finite elements is given in Figure 4.

**Fig. 3 Adopted arrangement of node points in non-deformed state [1]**

To compare data, it is necessary to input info sub-module *Point Tracking*, the adapted node points r_{p0} and z_{p0} , and their arrangement is given in Figure 3. After inputting coordinates of node points in the 13th or final phase, and their arrangement is given in Figure 4. By *Data Extract* order, coordinates of node points at the end of deformation phase i.e. in 13th phase r_{p13} and z_{p13} are obtained [1].

**Fig. 4 Point arrangement in 13th phase obtained by DEFORM simulation**

Based on the obtained node point coordinates at the end of deform process, data processing is done by means of a programme made in MATLAB. Input data are: node point coordinates at the beginning r_{p0} and z_{p0} and at the end of deform process r_{p13} and z_{p13} .

$$\left. \begin{aligned} u_{r13} &= r_{p13} - r_{p0} \\ u_{z13} &= z_{p13} - z_{p0} \end{aligned} \right\} \quad (1)$$

Based on movements of points u_{r13} and u_{z13} partial movement derivation per radius and height are calculated: $\partial u_r / \partial r$, $\partial u_r / \partial z$, $\partial u_z / \partial z$ and $\partial u_z / \partial r$. Using such obtained partial derivations it is possible to determine components of small deformations [6]. By applying a relation of relative and logarithmic strain (2), values of logarithmic strain are obtained to comparisons with numerical values of FEM simulation [1-11].

$$\varphi = \ln(1 + \varepsilon) \quad (2)$$

The values of effective logarithmic strain are given in the form of a three-dimension diagram in Figure 5.

Numerical experiment per steps

The data obtained by numerical simulation, due to a great number of possibilities DEFORM-2D programme package possesses, relate to a complete bulk deformation phase may be reached by means of the generated data base. When numerical experiment in phases is concerned, the idea was to determine strain in each phase of numerical experiment. To determine the values

wanted, we get the needed data on radial and axial coordinates, adopted node points in each step out of DEFORM *Tracking Point* module. Point dislocations are given by the following expression.

$$\left. \begin{aligned} u_{ri} &= r_{pi} - r_{pi-1} \\ u_{zi} &= z_{pi} - z_{pi-1} \end{aligned} \right\} i = 1, 2, \dots, 13 \quad (3)$$

Based on dislocation of points u_{ri} and u_{zi} , $i = 1, 2, \dots, 13$ partial dislocation derivations for radius and height: $\partial u_r / \partial r$, $\partial u_r / \partial z$, $\partial u_z / \partial z$ and $\partial u_z / \partial r$ in each step are calculated. Out of these partial derivations, relative deformations are obtained, where, by using (2) the logarithmic strains φ_{ri} , φ_{zi} , $\varphi_{\theta i}$, γ_{rzi} and φ_{ei} , $i = 1, 2, \dots, 13$ at the end of each step of bulk deformations are obtained [1-11].

Logarithmic strain values in the 13th step (at the end of bulk deformation) are calculated on the base of (4).

$$\varphi_r = \sum_{i=1}^{13} \varphi_{ri}, \varphi_z = \sum_{i=1}^{13} \varphi_{zi}, \varphi_{\theta} = \sum_{i=1}^{13} \varphi_{\theta i}, \gamma_{rz} = \sum_{i=1}^{13} \gamma_{rzi}, \varphi_e = \sum_{i=1}^{13} \varphi_{ei} \quad (4)$$

Effective logarithmic strain values obtained per steps are given in the form of a three-dimensional diagram in Figure 6.

DEFORM results

An important results that can be achieved by numerical simulation, apart from geometry change and dislocation of the points observed, is also strain distribution in each point of plane and axi-symmetrical deformations. DEFORM-2D software package has an advantage if compared to other software packages in the field of bulk deformation, so it gives strain values in each step for the observed node points for the adopted node points r_{p0} and z_{p0} at the beginning of the process in non-deformed state. *Point Tracking* submodule enables generation of *Point tracking Graphs*, as well as showing of the obtained results in both graph and data forms. Effective logarithmic strain obtained by DEFORM simulation is given in Figure 7.

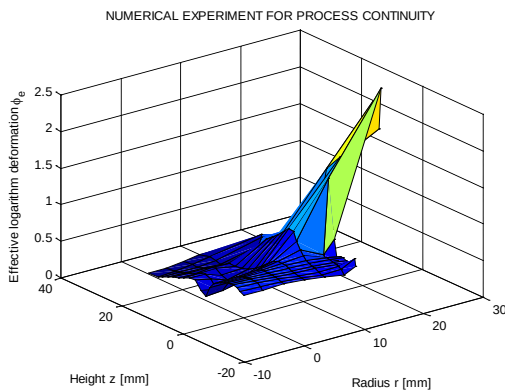


Fig. 5 Effective logarithmic strain φ_e obtained by numerical experiment for process continuity [1]

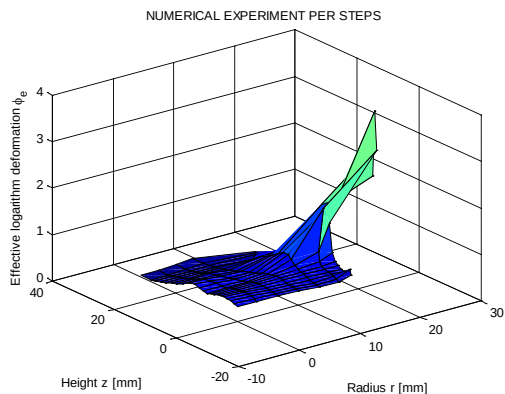


Fig. 6 Effective logarithmic strain φ_e obtained by numerical experiment per steps [1]

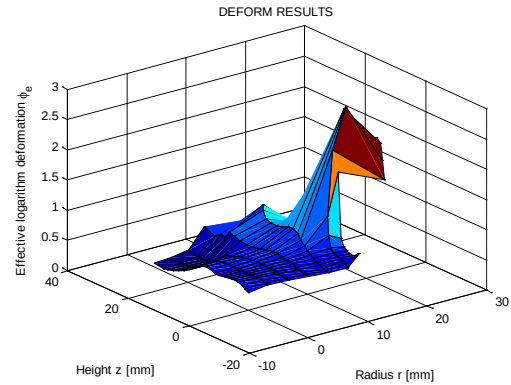


Fig. 7 Effective logarithmic strain φ_e obtained by DEFORM [1]

4. Analysis and Comparison of Obtained Results

On the base of previously given space diagram and state of strain parameter values derived from numerical experiment, an analysis and comparison of the obtained data have been made. For complete analysis and comparison, a programme was made in MATLAB given average diagrams in a meridial plane of a workpiece for any cross-section. The splitting plane cross-section corresponds to a grade plane of a workpiece and of height value $z = 10.5 \text{ mm}$.

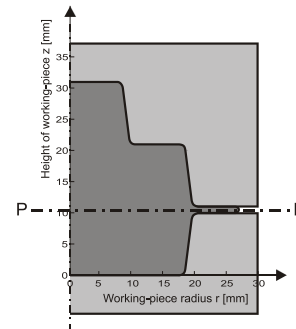


Fig. 8 Characteristic cross-section in meridial plane for a half of axi-symmetrical workpiece

Two-dimension logarithmic strain diagrams for all three cases investigation approaches are given in meridial plane of workpiece for a characteristic splitting plane cross-section are given in Figure 9. to Figure 13.

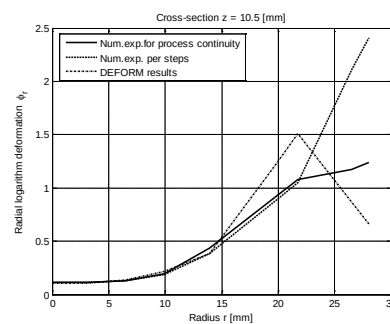


Fig. 9 Radial logarithmic strain φ_r for cross-section P-P

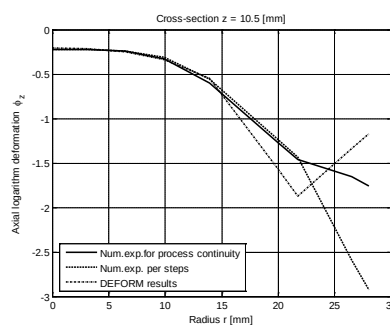


Fig. 10 Axial logarithmic strain φ_z for cross-section P-P

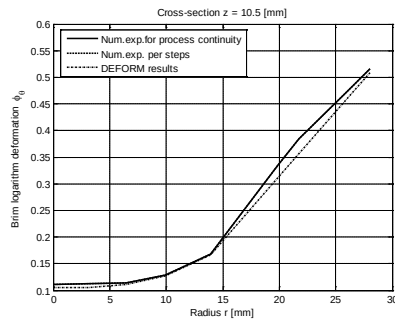


Fig. 11 Brim logarithmic strain ϕ_{θ} for cross-section P-P

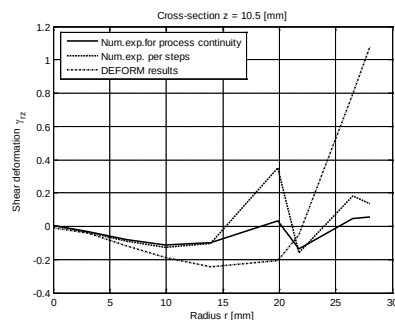


Fig. 12 Shear strain γ_{rz} for P-P cross-section

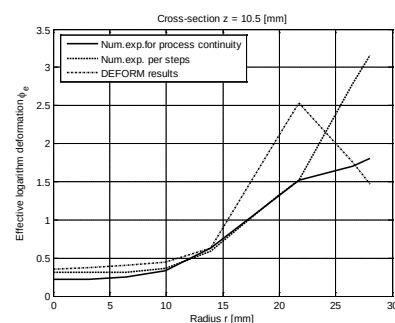


Fig. 13 Effective logarithmic strain ϕ_e for P-P cross-section

At all the three investigation approaches, for all strain parameters, two value zones are evident: flash zone and zone corresponding to interior part of die (die zone).

Comparing logarithmic strain component shear strain and effective logarithmic strain, at all the three investigation approaches of stepped convex die shape, it is evident that components are of similar change character and the values obtained are of the same value order. Maximum values are obtained in the flash zone with all the three investigation approaches, i.e. when high strain values are in question, it is evident the logarithmic strain values calculated per steps in the flash zone are higher than the ones calculated for process continuity. Deviations are evident with DEFORM results where extreme values at one fourth of the flash zone appear at flash.

5. Concluding Consideration

State of strain of stepped convex workpieces at bulk deformation in open dies has been determined in the paper. State of strain has been analyzed and compared. Investigation process consist of three steps: numerical experiment for process continuity, numerical experiment per steps and DEFORM results.

To carry out numerical experiment, DEFORM-2D software package is used, this being made on the base of elasto-plastic formulation of the finite element method and may be used in bulk deformation in open die simulation process, followed by a great number of deformation. The application of the programme for carrying out the process needs defining a set of input parameters

connecting, above all, with: geometry, material, boundary conditions and working regimes. After the numerical experiment is carried out, the obtained results are stored on PC computer hard disk, this enabling their further computer processing. To use the obtained results successfully, programmes were made within MATLAB programme language. Based on the obtained coordinates of node point dislocations, by using MATLAB programmes, state of strain parameters given in three-dimensional diagram shape are determined.

Comparison and analysis of the obtained results are made, and conclusions are the following:

- Differences obtained by using an investigation approach relate mostly to the way of determining parameters. At numerical experiment for process continuity, strains were determined by model of small deformations for the whole deformation process. At numerical experiment per steps, strains are determined by dislocation per steps, where total strain is obtained as a sum of strain obtained for some steps. At DEFORM results, strains are determined by mathematical apparatus using DEFORM-2D.
- At discretization process per steps of bulk deformation in open dies and determination of strain parameters in all phases, a more successful modelling of real process is achieved.
- A strong expansion of computer engineering and software nowadays make it possible for body discretization and process discretization to be a way to greater accuracy in engineering investigations.

6. References

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