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NUMERICAL SIMULATION OF BULK METAL FORMING PROCESS

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ABSTRACT
Research of stress state of bulk metal forming in open dies has been presented in the paper. A numerical simulation for the given conditions was carried out by using DEFORM-2D software package: for process continuity according to deformation phases and applying DEFORM results. By using the mentioned methods, in a relatively simple way, results were achieved and graphically interpreted in the paper. An analysis and comparison of the obtained results for convex and concave dies were done.
Keywords: Stress, Numerical Simulation, Visioplasticity, FEM, DEFORM-2D

1. INTRODUCTION
Bulk deformation, by its complexity, is specially treated within deformation process. To successfully projecting of any technological deformation treatment procedure, strain state parameters are of great importance. Computer system development made bulk deformation process construction and simulation possible and offered to a customer a great variety of analyzing results obtained, as well as on insight into all activities to provide instantaneous and reliable data on all parameters taking part in deformation process.
Due to a rapid computer technique development, a numerical approach to solving problems has been adopted lately. The *Finite Element Method* - FEM has been used as the might's numerical method, more commercial software packages for numerical bulk deformation process simulation have been made. One of the most known software packages is DEFORM, being produced by *Scientific Forming Technologies Corporation* (SFTC) [2], where simulation and the results obtained that are presented in this paper have been carried out.

2. INPUT PARAMETERS OF NUMERICAL RESEARCH
Bulk forming process in open dies includes a wide class of problems, both from the aspect of geometry and technological condition. The elements given in Fig. 1. and Fig. 2. have been analysed in the paper.

- Experimental material is aluminium alloy AlMgSi0,5.
- Investigation is carried out at temperature of hot treatment $T = 440\ ^oC$.
- Deformation is realized at low constant deformation velocity, $v = 2$ mm/s.
- Hardening curve parametres are $c = 30.34434$ and $n = 0.097808$ for AlMgSi0,5 aluminium alloy and temperature $T = 440\ ^oC$.
- Friction factor is $m = 0.114$.

- First tool form is stepped and convex (Fig. 1.). It consists of two dies, upper and lower ones. The upper die consists of two steps of heights, whereas lower one contains one step.
- Another shape of tool is stepped and concave (Fig. 2.). It consists of two dies, upper and lower ones. The upper part of the die consists of two height levels, where one is with degree, whereas the other one is of one height degree.

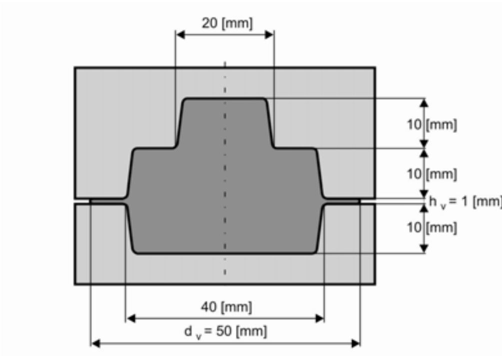

Figure 1. Workpiece in a die for stepped convex die shape

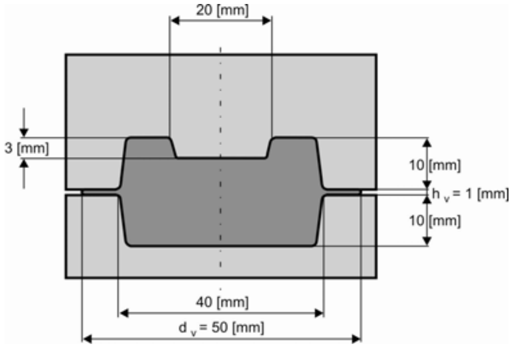

Figure 2. Workpiece in a die for stepped concave die shape

Workpieces are cyllindrical, of diameter d_0=33.56 mm. Height h_0 is determined out of the constant workpiece bulk conditions before and after pressing process for adopted die dimensions that are given in Fig. 1. and Fig. 2. and it amounts to h_0=33.94 mm for convex tool shape, and h_0=29.58 mm for concave tool shape.

Point coordinates, whose displacement will be followed in numerical experiment and whose stress-strain states parameters will be determined, are given in Fig. 3. and Fig. 4. Total number of node points for convex die is 154, whereas for concave one-it is 140.

3. NUMERICAL SIMULATION

Based on the numerical simulation [4], node coordinates per deformation phases are obtained, representing input parameters for determining stress-strain state.

Point arrangement at the end of deformation process for convex die shape is given in Fig. 3., whereas for concave one, it is given in Fig. 4. By *Data Extract* order node coordinates in each phase of bulk deformation are obtained [2].

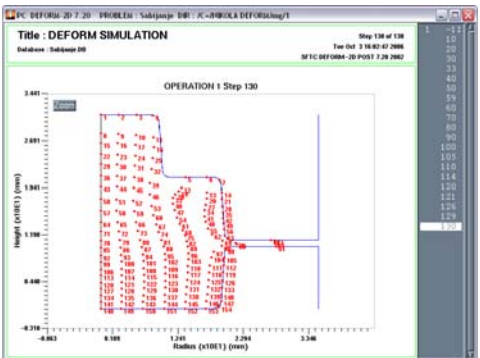

Figure 3. Point arrangement in 13th phase obtained by DEFORM simulation for convex die

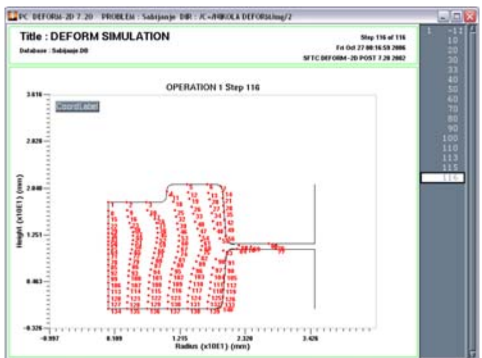

Figure 4. Point arrangement in 12th phase obtained by DEFORM simulation for concave die

3.1. Numerical experiment for process continuity

Strain and kinematic parameters are determined on the base of the obtained node coordinates at the end of deformation process, i.e. point dislocation. Out of the numerical simulation data, strain components and strain rate are obtained [3, 4].

Stress is determined by using visioplasticity method. Data are processed in MATLAB. Input data are: node coordinates at the beginning r_{p0} and z_{p0} and at the end of deform process r_{pk} and z_{pk}, k=13 for convex die (Fig. 3.) and k=12 for concave die shape (Fig. 4.), hardening curve parameters c and n, as well as the results derived from strain φ_r, φ_z, φ_θ, γ_{rz} and φ_e and kinematic analyses $\dot{\varepsilon}_r$, $\dot{\varepsilon}_z$, $\dot{\varepsilon}_\theta$, $\dot{\gamma}_{rz}$ i $\dot{\varepsilon}_e$ [4]. The method is based on obtained axial σ_z, stress component, by solving a basic equation of visioplasticity [1], where main problem is to determine integration constant C. The only points where it is possible to determine axial stress component values are points for maximum radius value at the wreath level (Fig. 1. and Fig. 2.). These values are determined out of radial stress components in these points being equal to zero: σ_r=0. Other strain and kinematic parameters are know, where effective stress is determined along with corresponding hardening curves for effective deformation value.

If we mark the first part of the solution of the basic visioplasticity equation with $\Delta\sigma_{zv,}$ then we may writhe:

$$\sigma_{zv}\Big|_{\left(\substack{z=z_v\\ r=r_{\max}}\right)} = \Delta\sigma_{zv}\Big|_{\left(\substack{z=z_v\\ r=r_{\max}}\right)} + C_1, \tag{1}$$

then:

$$C_1 = \sigma_{zv}\Big|_{\left(\substack{z=z_v\\ r=r_{\max}}\right)} - \Delta\sigma_{zv}\Big|_{\left(\substack{z=z_v\\ r=r_{\max}}\right)}. \tag{2}$$

As the basic visioplasticity equation is not determined for radius value of *r=0 [mm]*. The curve extra poles in square function of this shape:

$$\sigma_z = ar^2 + b, \tag{3}$$

Coefficients a and b are determined out of the system of two linear equations with two unknowns for stress values in the second and third cross-section points of $z=z_v$.

The value of sub-integral function is known because all strain and kinematic parameters as well as effective stress are known. Integrating this function along r , an undetermined integral is obtained. Due to an unknown radial stress in other points, it is not possible to determine the integration constant. For this reason, based on the second system balance equation, it follows [1]:

$$\sigma_{z0} = -\int_0^z \left(\frac{\partial \tau_{rz}}{\partial r} + \frac{\tau_{rz}}{r}\right) dz + C_2. \tag{4}$$

If the first member of the previous expression is marked with $\Delta\sigma_{z0}$ then it may follow:

$$\sigma_{z0}\Big|_{\left(\substack{z=z_v\\ r=0}\right)} = \Delta\sigma_{z0}\Big|_{\left(\substack{z=z_v\\ r=0}\right)} + C_2, \tag{5}$$

thus:

$$C_2 = \sigma_z\Big|_{\left(\substack{z=z_v\\ r=0}\right)} - \Delta\sigma_{z0}\Big|_{\left(\substack{z=z_v\\ r=0}\right)}. \tag{6}$$

In this way axial stress component values in the workpiece axis symmetry are obtained, i.e. for *r=0 [mm]*, this practically meaning the possibility of determining integration constant for all the values of z height.

Integration constant is determined by:

$$\sigma_z\Big|_{\left(\substack{z\\ r=0}\right)} = \Delta\sigma_z\Big|_{\left(\substack{z\\ r=0}\right)} + C, \tag{7}$$

thus:

$$C = \sigma_z\Big|_{\left(\substack{z\\ r=0}\right)} - \Delta\sigma_z\Big|_{\left(\substack{z\\ r=0}\right)}. \tag{8}$$

It is possible to determine normal stress values in all the points of meridial cross-section of a work piece in a previous by described way. Other stress components are determined by using Levy-Mises equations [1].

Effective stress values at the and of deformation process in the observed points of meridial cross-section of a workpiece are given in the form of three-dimension diagram in Fig 5. and Fig. 6.

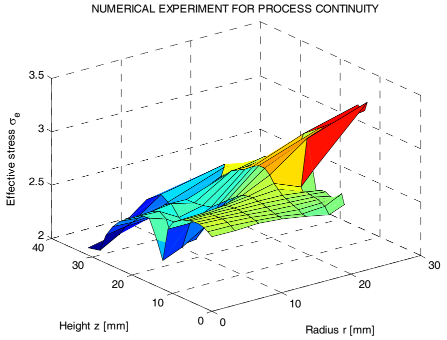

Figure 5. Effective stress σ_e daN/mm^2 for convex die shape

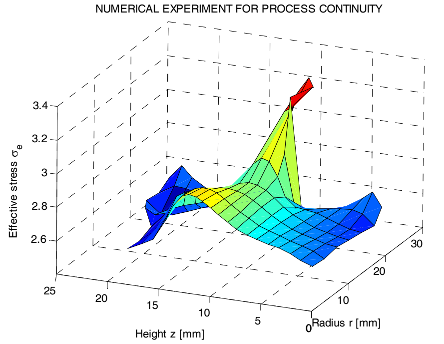

Figure 6. Effective stress σ_e daN/mm^2 for concave die shape

3.2. DEFORM results

Stress change values in each phase of the observed process, for adopted node points for convex and concave die shaps, direcly from DEFORM-2D software package are obtained.
The values of such effective stresses at the end of deform process are given in Fig. 6. and Fig. 7.

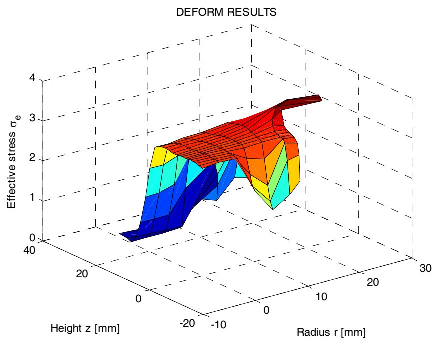

Figure 6. Effective stress σ_e daN/mm^2]for convex die shape

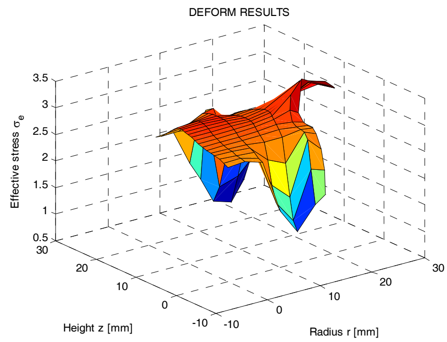

Figure 7. Effective stress σ_e daN/mm^2 for concave die shape

4. CONCLUSION

Stress state differences obtained by using some procedures are primarily related to the way of strain state parameter determination. At numerical experiment for process continuity, strains are determined by the model of small deformations for the whole deform process. At DEFORM results, strains are determined by mathematical device using DEFORM-2D. On the base of the results of the stress presented in this paper and analysis made, it may be concluded that it is more suitable to use stepped deformation numerical experiment in numerical deformation process simulations for the said conditions. Thus, stepped discretization seems to be necessary in research process. A strong expansion of engineering and software now days makes it possible for body and process discretization in engineering research to had to a greater accuracy.

5. REFERENCES

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