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NUMERICAL SIMULATION IN BULK FORMING PROCESS

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ABSTRACT

Investigation of stress-strain state of bulk forming in open dies has been presented in the paper. By numerical simulations it is possible, by discretization of the process per deformation phases, to determine deformation parameters in all phases. Logarithmic strain tensor components are determined by meridial point cross-section per deformation phase displacements, where a total strain is calculated as a sum of strains obtained in deformation phases. Stress tensor component is determined by the method of higher theory of plasticity.
For numerical simulation, DEFORM-2D software package is used, meant to analyze plane and axi-symmetrical deformations. A stepped concave die shape is adopted, as well as working-piece dimensions and node point distribution, whose displacements are fallowed during deformation process. Numerical simulation consists of three phases.
In the first phase numerical experiment is carried out, where, for adopted point coordinates in non-deformed state, point displacements at the end of deformation process, are obtained. Stress-strain state parameters are determined on the base of these data at displacement points. The second phase relates to numerical experiment that is carried out for the same initial conditions, but bulk deformation process is observed in deformation phases. In each phase, stress-strain parameters are determined, based on which parameters at the end of deformation process are obtained. The third phase concerns stress state parameters, determined by DEFORM-2D, and they are related to the same initial conditions.
Key words: *bulk forming, numerical simulation, DEFORM-2D*

1. INTRODUCTION

As a result of a rapid development of computer engineering in the field of metal forming a number of different numerical methods has been developed and used so far. Finite Elements Method - FEM has been used as the most powerful numerical method. Based on this method, several commercial software packages for numerical process simulations have been developed. Among them, one of the most famous software package is DEFORM, produced by *Scientific Forming Technologies Corporation* (SFTC), which has been used in this work.

2. INPUT PARAMETERS OF NUMERICAL INVESTIGATIONS

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 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 parameters are $c=30.34434$ and $n=0.097808$ for *AlMgSi0,5* aluminium alloy and temperature $T=440$ [^oC].
- Friction factor is $m=0.114$.
- Tool is of stepped concave shape (Fig. 1.). It consists of two pieces, upper and lower ones. The upper die piece consists of two height degrees where one is with degree, whereas lower one consists of one height degree.

Working-pieces are cylindrical, of diameter $d_0=33.56$ *[mm]*. The height h_0 is determined out of the working-piece constant volume before and after pressing process for adopted die dimensions given in Fig. 1, and it is $h_0=29.58$ *[mm]*.
Point coordinates, whose displacement will be followed in numerical experiment and whose stress-strain state parameters will be determined, are given in Fig. 5. The adopted network of the half of the axi-symmetrical working-piece is given in Fig. 2. Total node point number is 140.

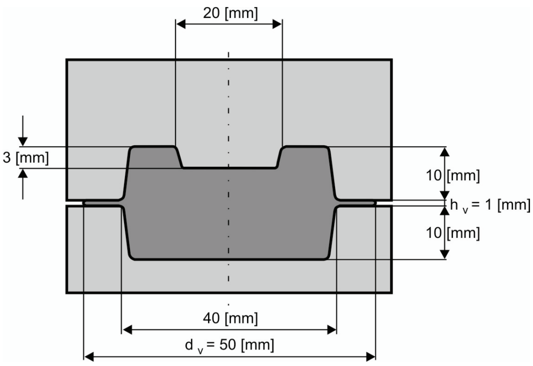

Figure 1 - Working-piece within dies

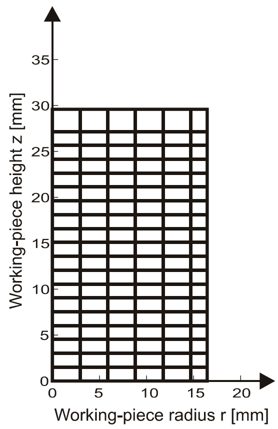

Figure 2 - Adopted network of the halt of axi-symmetrical working-piece

3. NUMERICAL SIMULATION FOR CONCAVE DIE SHAPE

For the adopted tool geometry (Fig. 1.) and adopted working-piece geometry (Fig. 2.), as well as for known friction and hardening curve factors, numerical simulation has been carried out, where the data input into DEFORM's module *Pre Processor*, are given in Table 1. Default values of DEFORM-2D software package are taken for other values.

Table 1. Input data of DEFORM simulation for concave die shape

<table>
<tr><td rowspan="2">Simulation Parameters</td><td colspan="3">Units UNIT</td><td colspan="2">☑SI</td></tr>
<tr><td colspan="3">Geometry GEOTYP</td><td colspan="2">☑Axisymmetric</td></tr>
<tr><td rowspan="5">Step Controls</td><td colspan="3">Number of simulation steps</td><td colspan="2">NSTEP=1000</td></tr>
<tr><td colspan="3">Step increment to save</td><td colspan="2">STPINC=10</td></tr>
<tr><td colspan="3">Primary die</td><td colspan="2">PDIE(1)=1</td></tr>
<tr><td colspan="3">Steps by</td><td colspan="2">☑Stroke</td></tr>
<tr><td colspan="3">Stroke per step</td><td colspan="2">DSMAX=0.1 [mm]</td></tr>
<tr><td>Stopping Controls</td><td colspan="3">Primary die displacement</td><td colspan="2">SMAX=0, 11.58 [mm]</td></tr>
<tr><td rowspan="10">Name: Upper die
☑Rigid</td><td rowspan="8">Geometry</td><td></td><td>X [mm]</td><td>Y [mm]</td><td>R [mm]</td></tr>
<tr><td>1</td><td>0</td><td>29.58</td><td>0</td></tr>
<tr><td>2</td><td>9.7202</td><td>29.58</td><td>1</td></tr>
<tr><td>3</td><td>10</td><td>32.58</td><td>1</td></tr>
<tr><td>4</td><td>19.300732</td><td>32.58</td><td>1</td></tr>
<tr><td>5</td><td>20</td><td>22.58</td><td>1</td></tr>
<tr><td>6</td><td>35</td><td>22.58</td><td>0</td></tr>
<tr><td>7</td><td>35</td><td>32.58</td><td>0</td></tr>
<tr><td colspan="3" rowspan="2">Movement controls</td><td colspan="2">Speed 2 [mm/s]</td></tr>
<tr><td colspan="2">Angle -90°</td></tr>
<tr><td rowspan="6">Name: Lower die
☑Rigid</td><td rowspan="6">Geometry</td><td></td><td>X [mm]</td><td>Y [mm]</td><td>R [mm]</td></tr>
<tr><td>1</td><td>35</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>35</td><td>10</td><td>0</td></tr>
<tr><td>3</td><td>20</td><td>10</td><td>1</td></tr>
<tr><td>4</td><td>19.300732</td><td>0</td><td>1</td></tr>
<tr><td>5</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="6">Name: Working-piece
☑Plastic</td><td rowspan="5">Geometry</td><td></td><td>X [mm]</td><td>Y [mm]</td><td>R [mm]</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>16.78</td><td>0</td><td>0</td></tr>
<tr><td>3</td><td>16.78</td><td>29.58</td><td>0</td></tr>
<tr><td>4</td><td>0</td><td>29.58</td><td>0</td></tr>
<tr><td>Mesh</td><td colspan="3">Number of mesh elements</td><td>MGNELM=1000</td></tr>
<tr><td rowspan="3">Upper die -
- Working-piece</td><td colspan="4">Contact relation CNTACT</td><td>☑Master-Slave</td></tr>
<tr><td colspan="4">Friction model FRCFAC</td><td>Shear</td></tr>
<tr><td colspan="4">Friction</td><td>FRCFAC=0.114</td></tr>
<tr><td rowspan="3">Lower die -
- Working-piece</td><td colspan="4">Contact relation CNTACT</td><td>☑Master-Slave</td></tr>
<tr><td colspan="4">Friction model FRCFAC</td><td>Shear</td></tr>
<tr><td colspan="4">Friction</td><td>FRCFAC=0.114</td></tr>
</table>

Finite element network forming process and data base generation are valid for the initial step "-1", (Fig. 3.). During deformation process, remeshing was done four times, and the process ended in 12th phase. After simulation process starting, numerical calculations for *DSMAX* stroke per step value are done, and each tenth step is saved in data base. After the numerical simulation is done, a final working-piece look is obtained in 12th phase with a deformed mesh (Fig. 4.).

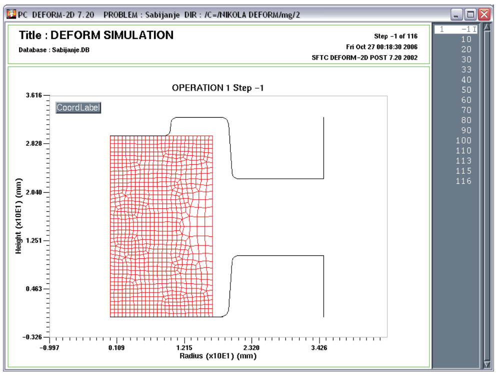

Figure 3 - Working-piece with a deformed network in mesh with dies

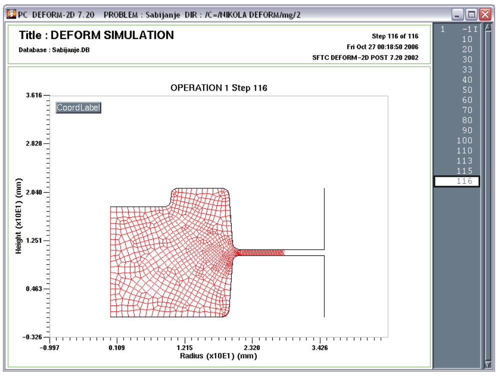

Figure 4 -. Working-piece at the end of deformation process

To compare the results, it is necessary to input the adopted node points r_{p0} and z_{p0}, into *Point Tracking* sub-module, and their distribution is given in Fig. 5. After inputting node point coordinates of non-deformed state into *Point Tracking* sub-module, node point coordinates per phases are generated. The distribution of point in 12^{th} or final phase is given in Fig. 6. Using *Data Extract* order, node point coordinates per phases are also obtained at the end of deformation process, namely in 12^{th} phase r_{p12} and z_{p12}.

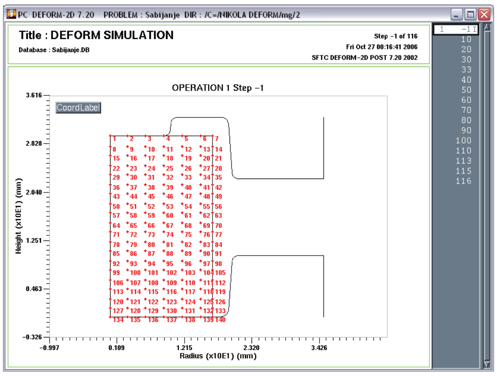

Figure 5 - Adopted distribution of node point in non-deformed state

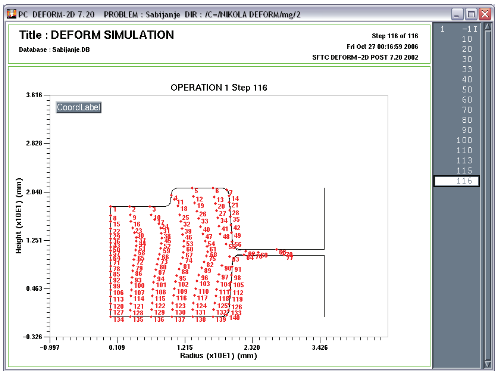

Figure 6 - Point distribution in 12^{th} phase obtained by DEFORM simulation

3.1. Numerical experiment for process continuity

Deformation parameters have been determined by the obtained node points at the end of deformation process. Data have been processed in MATLAB (v. 7.0). Input data are point coordinates at the beginning r_{p0}, z_{p0} and at the end of deform process r_{p12}, z_{p12}, (Fig. 5. and Fig. 6.). Point displacements are expressed by:

$$\left.\begin{aligned} u_{r12} &= r_{p12} - r_{p0} \\ u_{z12} &= z_{p12} - z_{p0} \end{aligned}\right\} \tag{1}$$

Using displacements point u_{r12} and u_{z12}, partial displacement statements per radius and height are calculated: $\partial u_r/\partial r$, $\partial u_r/\partial z$, $\partial u_z/\partial z$ and $\partial u_z/\partial r$. Based on these statements, components of small strains may be determined [6]. Using relations of relative and logarithmic strains (2) logarithmic strain values are obtained to be compared to the values of numerical FEM simulation.

$$\varphi = \ln(1+\varepsilon) \tag{2}$$

Effective logarithmic strain values are given in the form of three-dimensional diagram in Fig. 7.

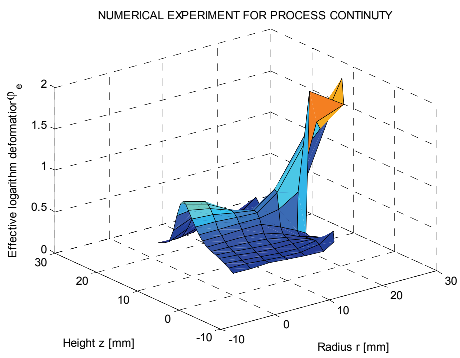

Figure 7 - Effective logarithm strain φ_e

To determine strain rate components, it is necessary to determine displacement speeds, based on point displacements at the beginning and at the end of final deformation interval, provided strain rate is constant. For tool stroke increment *Δz=2 [mm]* and deformation velocity *v=2 [mm/s]*, time increment is *Δt = 1 [s]*. For the adopted increment, node point coordinate values are obtained from the *Point Tracking* sub-module in 10^{th} phase, representing the beginning of the observed interval.
Point coordinates at the end of deformation process, namely at the end of the observed interval are marked by "12" in index.
Input data are taken from working-piece deform analysis, namely: r_{p0} and z_{p0}, r_{p12} and z_{p12}, as well as the obtained node points r_{p10} and z_{p10}.
Thus, displacements are:

$$\left.\begin{aligned} u_{r10} &= r_{p10} - r_{p0} \\ u_{z10} &= z_{p10} - z_{p0} \end{aligned}\right\} \tag{3}$$

Displacement increment is:

$$\left.\begin{aligned}\Delta u_r &= u_{r12} - u_{r10} = r_{p12} - r_{p10} = \Delta r \\ \Delta u_z &= u_{z12} - u_{z10} = z_{p12} - z_{p10} = \Delta z\end{aligned}\right\} \tag{4}$$

Further, displacement velocities in node points of the deformed network are determined (phase 12) where partial displacement speeds per radius $\partial v_r/\partial r$, $\partial v_z/\partial r$ and height $\partial v_z/\partial z$, $\partial v_r/\partial z$, are determined, based on which strain rates are obtained. In this way we come to radial, axial and angular deformation velocity components, whereas rim velocity is determined as a ratio between radial displacement velocity and radius.

Effective strain rate values are given in the form of three-dimensional diagram in Fig. 8.

Stress is determined by using the method of higher theory of plasticity. The method is based on obtaining axial stress component σ_z, by solving the basic equation of plasticity [6]. Input data are: node point coordinates at the beginning r_{p0} and z_{p0} and at the end of the process r_{p12} and z_{p12}, hardening curve parameters *c* and *n*, as well as the results out of deformation φ_r, φ_z, φ_θ, γ_{rz} and φ_e and kinematic analyses $\dot{\varepsilon}_r$, $\dot{\varepsilon}_z$, $\dot{\varepsilon}_\theta$, $\dot{\gamma}_{rz}$ and $\dot{\varepsilon}_e$.

Effective stress values are given in the form of three dimensional diagrams on Fig. 9.

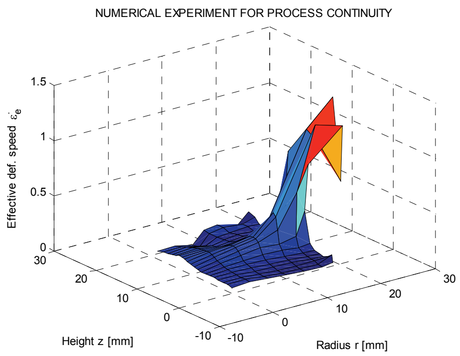

Figure 8 - Effective strain rate $\dot{\varepsilon}_e\ [s^{-1}]$

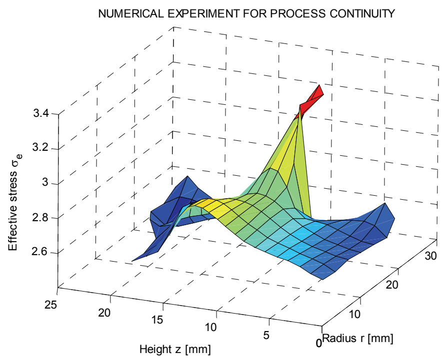

Figure 9 - Effective stress σ_e [daN/mm^2]

3.2. Numerical experiment per phases

With numerical experiment per phases, displacements per phases are determined first, after that final value of strain, strain rate and stress are obtained by known procedures and methods. Based on the obtained node point coordinates per phases, data are processed by a programme made within a programme language MATLAB (v. 7.0). Input data are: node point coordinates at the beginning r_{p0} and z_{p0} and per phases: r_{pi} and z_{pi}, $i = 1,2,...,12$. Point displacements are expressed by.

$$\left.\begin{aligned}u_{ri} &= r_{pi} - r_{pi-1} \\ u_{zi} &= z_{pi} - z_{pi-1}\end{aligned}\right\}\ i = 1,2,...,12 \tag{5}$$

Where logarithmic strain are obtained φ_{ri}, φ_{zi}, $\varphi_{\theta i}$, γ_{rzi} and φ_{ei}, $i = 1,2,...,12$ at the end of each phase of bulk forming.
Logarithmic strain values in 12[th] phase (at the end of bulk deformation process) are calculated by (6).

$$\varphi_r = \sum_{i=1}^{12} \varphi_{ri} \ , \ \varphi_z = \sum_{i=1}^{12} \varphi_{zi} \ , \ \varphi_\theta = \sum_{i=1}^{12} \varphi_{\theta i} \ , \ \gamma_{rz} = \sum_{i=1}^{12} \gamma_{rzi} \ \text{i} \ \varphi_e = \sum_{i=1}^{12} \varphi_{ei} \tag{6}$$

Effective logarithmic strain values obtained per phases are given in the form of a three-dimensional diagram in Fig. 10.

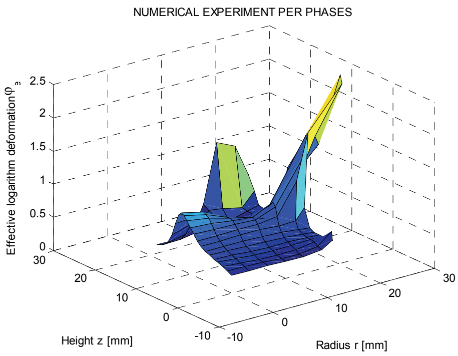

Figure 10 - Effective logarithmic strain φ_e

To determine strain rate tensor components by numerical experiment per phases, it is necessary to know logarithmic strain values in each deformation phase. By interpolation to cube polynom, it is possible to determine logarithmic strain increment for a given time increment, namely logarithmic strain rate.
By differentiating the expression (2) per time *dt*, a relation of relative and logarithmic strain rate is obtained.

$$\dot{\varepsilon} = e^{\varphi} \cdot \dot{\varphi} \tag{7}$$

For adopted deformation velocity *v=2 [mm/s]*, in 12[th] phase for time increment *dt=0.1*, relative strain rates are determined.
Effective strain rate values in the observed points of meridial working-piece cross-section are given in the form of a three-dimensional diagram in Fig. 11.
Stress is determined by using the method of high plasticity. Input data are: node point coordinates at the beginning r_{p0} and z_{p0} and at the end of deformation process r_{p12} and z_{p12}, hardening curve parameters *c* and *n*, as well as the results obtained by deformation φ_r, φ_z, φ_θ, γ_{rz} and φ_e and kinematic $\dot{\varepsilon}_r$, $\dot{\varepsilon}_z$, $\dot{\varepsilon}_\theta$, $\dot{\gamma}_{rz}$ and $\dot{\varepsilon}_e$ analyses.
Effective stress values are given in the form of a three-dimensional diagram in Fig. 12.

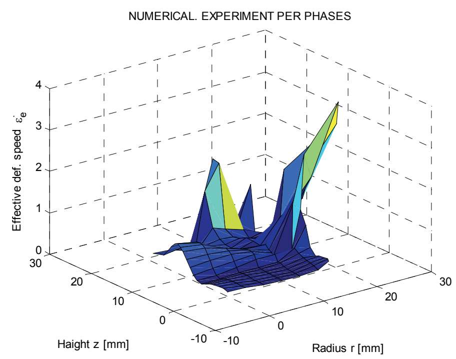

Figure 11 - Effective strain rate $\dot{\varepsilon}_e\ [s^{-1}]$

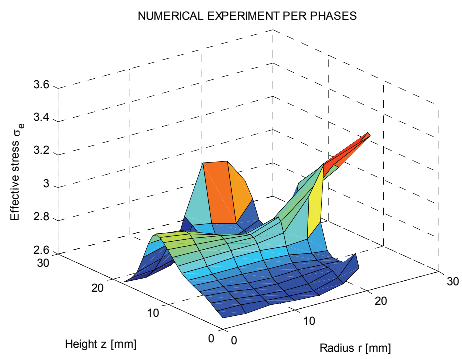

Figure 12 - Effective stress σ_e *[daN/mm²]*

3.3. DEFORM results

For concave die shape deformation change, speed and stress values in each phase of the observed process for the adopted node points are obtained directly out of DEFORM-2D software package. Values of these components at the end of deform process, effective logarithmic strains, effective strain rates and effective stress are given in Fig. 13. to Fig. 15.

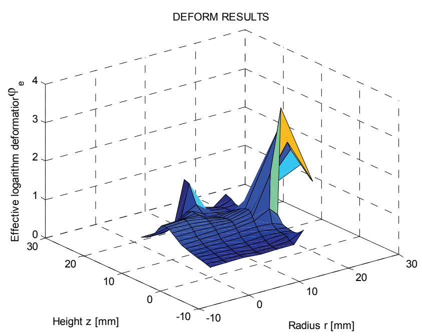

Fig. 13. DEFORM effective logarithm strain φ_e

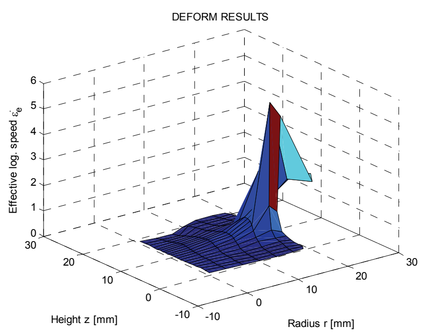

Figure 14 - DEFORM effective strain rate $\dot{\varepsilon}_e[s^{-1}]$

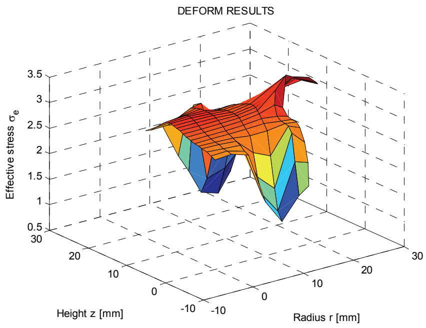

Figure 15 - DEFORM effective stress σ_e [daN/mm^2]

4. CONCLUSIONS

Numerical simulations of bulk deformation process have been carried out in the current paper, by using finite element method, as well as the programmes based on plasticity theory. The numerical experiments carried out simulate the conditions of a real object. Stress-strain deformation state parameters of a working-piece in open dies of axi-symmetrical elements have been determined. Numerical simulation is performed for a stepped concave die shape and it consists of three phases: numerical experiment for process, numerical experiment per phases and DEFORM results.

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NUMERIČKE SIMULACIJE KOD PROCESA ZAPREMINSKOG DEFORMISANJA

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REZIME

U radu je data simulacija naponsko deformacionog stanja zapreminskog deformisanja u otvorenim kalupima, po procedurama koje predstavljaju određene metode. U numeričkim simulacijama moguće je diskretizacijom procesa po fazama deformisanja, odrediti deformacione parametre u svim fazama. Komponente tenzora logaritamskih deformacija određuju se na osnovu pomjeranja tačaka meridijalnog presjeka po fazama deformisanja, a ukupna deformacija se izračunava kao suma deformacija dobijenih u fazama deformisanja. Dok se komponente tenzora napona određuju metodom visioplastičnost.

Za numeričku simulaciju koristi se softverski paket DEFORM-2D, koji je namijenjen za analizu ravanskih i osnosimetričnih deformisanja. Usvojen je stepenasto konkavni oblik kalupa, dimenzije pripremka i raspored čvornih tačaka čija se pomjeranja prate tokom procesa deformisanja. Numerička simulacija se sastoji iz tri etape:

U prvoj etapi se izvodi numerički eksperiment gdje se za usvojene koordinate tačaka u nedeformisanom stanju dobijaju pomjeranja tačaka na kraju procesa deformisanja. Na osnovu ovih podataka o pomjeranju tačaka određeni su parametri naponsko deformacionog stanja. Ovaj numerički eksperiment se odnosi na kontinuitet procesa.

Druga etapa se odnosi na numerički eksperiment, koji se realizuje za iste početne uslove, ali se proces zapreminskog deformisanja posmatra u fazama deformisanja i u svakoj fazi se posebno određuju naponsko deformacioni parametri, na osnovu kojih se dobijaju parametri na kraju procesa deformisanja.

Treća etapa se odnosi na parametre naponsko deformacionog stanja koje DEFORM-2D odeređuje, a odnose se na iste početne uslove.