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FINITE ELEMENTS METHOD APPLICATION TO STUDY THE ORBITAL FORMING PROCESS

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Abstract: *This paper presents the results of researches, done by using finite elements method, in order to find the deformation status and to evaluate material yielding characteristics during volumetric forming process. Thus, numerical modelling done by using finite elements analysis soft FORGE-2, completes the information given by physical experiments and allows the establishment of best constructive solutions referring to the active elements.*

Key words: *numerical modelling, orbital forming, oscillatory die.*

1. INTRODUCTION

The use of unconventional volumetric forming process with an oscillatory die has proven its large applicability because of equipment capacity to conduct the deformation pressure into preferential directions, depending on worked piece's geometry. The concentration of plastic deformation effort onto a restricted zone from worked piece's frontal surface allows the appearance of deformation status into the desired directions, working force reduction up to 80%, the increasing of maximum deformation degree at a single phase.

Contact point between the superior die and the worked piece's material choose is done by modifying equipment's kinematics. Superior die endpoint is considered placed in the origin point of a Cartesian reference system (Fig. 1,*a*). Referred to this oscillation (rotation) point, where an axis (straight-line with a fixed point) passes by, superior die kinematics can be defined through three different simple motions:

- Nutation (θ) – axis rotation into a plain including the oscillation point;
- Precession (φ) – axis rotation around a fixed straight line passing by the oscillation point;
- Spin (ψ) – the rotation of a rigid, the superior die, around the axis having a fixed point.

According to those presented in Fig. 1,*b*, if the superior die must realise an oscillatory motion, together to the worked piece, it is necessary that the driving mechanism (with eccentricities e_1 and e_2) drives the spindle into double precession motions (ω_1 and ω_2). If $\omega_2 = 0$, shaft axis inclination angle is constant and equal to the complement of die angle at its peak. Shaft rotation motion (ψ) around its axis is the result of friction forces existing between worked piece's frontal surface (2) and superior die surface (1).

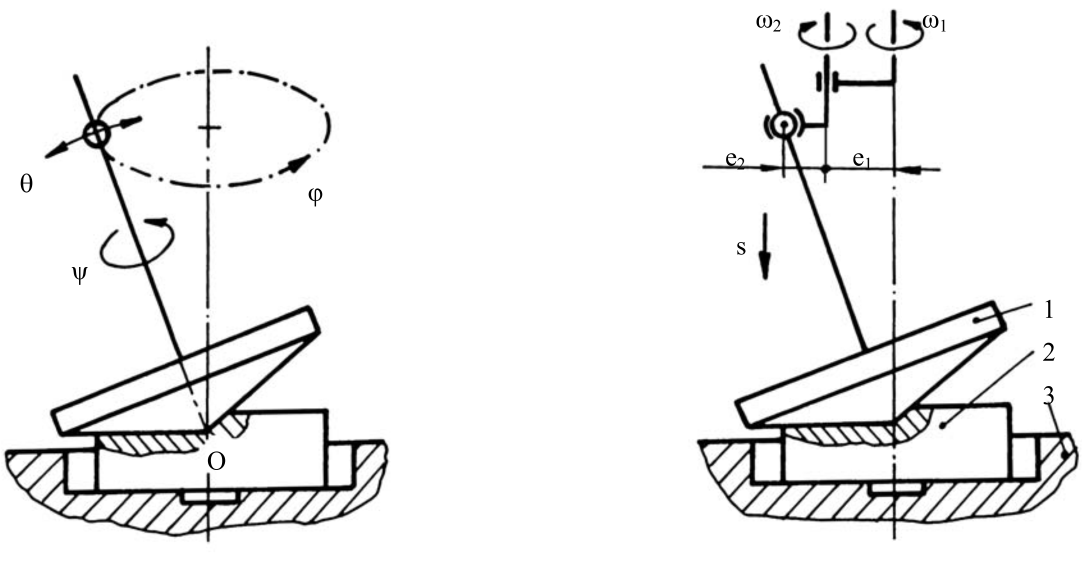


Fig. 1. Forming process kinematics, when using an oscillatory die.

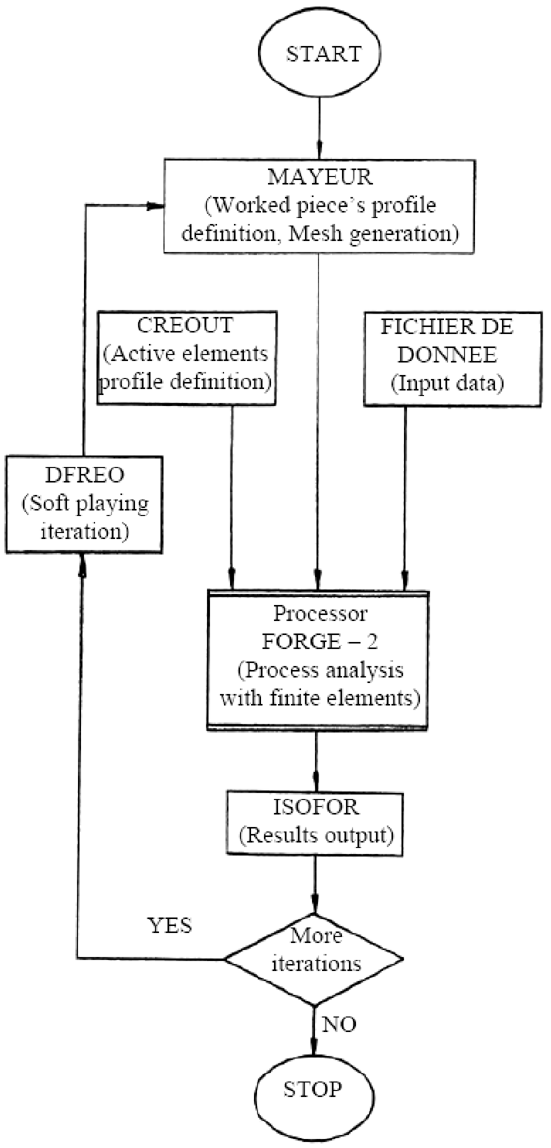


Fig. 2. Finite elements FORGE-2 soft structure.

2. NUMERICAL MODELLING SOFT STRUCTURE

To find the deformation status, to do the evaluation of worked piece's material yielding characteristics and to choose for active elements the best constructive solutions, computer aided simulation may also be used, together or instead of experimental methods.

Finite elements method enables to evaluate both deformation and tension fields. The experiments are necessary for adopted solutions final validation. To realise numerical modelling of deformation process, if using an oscillatory die, finite elements soft FORGE–2 was used, its structural schema being presented in Fig. 2.

Pre-processor is consisting from three modules: MAYEUR, CREOUT and FICHIER DE DONNEE. Within MAYEUR program worked piece's geometry is described and there is also a possibility to choose between manual or automatic mesh generation. CREOUT module allows describing active elements geometry and also kinematics parameters definition. Information concerning worked piece's geometry, active elements profile, meshes parameters, deformed material characteristics, nature of contact between tool and piece, the way of displaying and stocking the results are collected by FICHIER DE DONNEE program. Its structure is consisting from modules where the variables are introduced through key-words.

After running the data by FORGE-2 soft, simulation results are gathered by ISOFOR post-processor. If more iteration has to be made, through DEFREO module, the history of material deformations and worked piece's geometry after current iteration are conserved and the new position of the tools to realise the next sequence is re-defined; then the upper presented modules of the soft are run again. The cycle is repeated until worked piece's imposed geometrical parameters are reached.

3. NUMERICAL MODELLING PHYSICAL BACKGROUND

Tensions and deformations calculus, by using FORGE-2 soft is done according to the following Physics laws:

a) Equilibrium equation - which establish the fact that deformed materials obey to Dynamics fundamental principle

$$div\ (\sigma)=0, \qquad (1)$$

if neglecting volumetric and inertia forces;

b) Plastic incompressibility – which can be expressed, if neglecting volume variations, like

$$div(v) = tr(\dot{\varepsilon}) = 0\ . \qquad (2)$$

The used behaviour law, Norton-Hoff, expressed in tensors shape

$$S = 2 \cdot k\left(T, \bar{\varepsilon},...\right) \cdot \left(\sqrt{3}\dot{\bar{\varepsilon}}\right)^{m-1} \cdot \dot{\varepsilon}\ , \qquad (3)$$

connects tensions deviator tensor S, to deformation speeds one $\dot{\varepsilon}$, through the use of thermo-mechanical consistency factors, $k\left(T, \bar{\varepsilon},...\right)$ and deformation sensitivity, m.

Numerical modelling is also based on Tresca type friction law

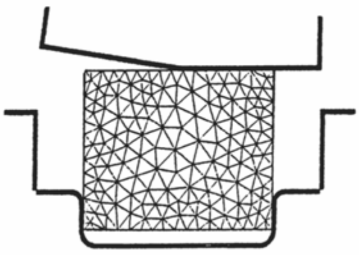
$$\tau = -\alpha \cdot k\left(T, \bar{\varepsilon},...\right)^{*} \cdot \left(\Delta v^{p-1}\right)^{*} \cdot \Delta v\ , \qquad (4)$$

where α means the friction ratio; p – deformation sensitivity at sliding speed; Δv – difference between bodies displacement speeds.

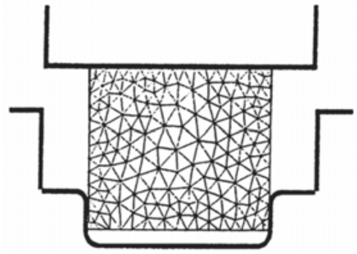
The non-linear system of equations as resulted after assembling, is solved by FORGE-2 soft by using Newton-Raphson iterative method.

4. RHEOLOGICAL PARAMETERS AND MESH CHARACTERISTICS

Numerical simulation enables, after finding deformation status and evaluating material yielding characteristics, to adopt active elements best constructive solutions. During numerical experiment, the evolution of conventional



a



b

Fig. 3. Workpiece active elements and mesh: *a* - oscillatory die forming; *b* - conventional volumetric forming.

volumetric forming process characteristics was analyzed compared to those corresponding to orbital forming by an oscillatory die.

Because orbital forming process is completely defined only in three-dimensional space, numerical simulation aimed the case when superior die makes only the nutation motion, θ. Thus, the study of orbital forming process with an oscillatory die was completely defined through the plain status of tensions and deformations from the nutation plain.

The following values were adopted in the case of rheological parameters:

- material consistency ratio, $k = 34 \cdot 10^3$;
- material sensitivity at cold hardening ratio, $n = 0.001$;
- speed deformation sensitivity coefficient, $m = 0.1$;
- sliding speed sensitivity coefficient, $p = 0.1$;
- friction ratio, α = 0.2 - in the case of conventional forming and in the case of orbital forming:

$\alpha = 0.02$ (between workpiece and superior die);

$\alpha = 0.2$ (between worked piece and inferior die).

To do numerical simulation, onto worked piece surface a plain mesh consisting from curved triangular finite elements was drawn, by using MAYEUR module (Fig. 3); its parametric characteristics were: size 2, curve 0.15, mesh precision 0.04, mesh homogeneity 0.35.

5. NUMERICAL MODELING RESULTS

By numerical simulation, following process parameters variation manner was highlighted:

- equivalent tension, $\sigma_{ech} = \sqrt{\frac{3}{2}\Sigma\sigma_{ij}^2}$, [MPa];
- generalised deformation, $\bar{\varepsilon} = \int \dot{\bar{\varepsilon}} dt$;
- hydrostatic pressure, $p = -\frac{1}{3}\Sigma\sigma_{ij}$, [MPa];
- generalised deformation speed, $\dot{\bar{\varepsilon}} = \sqrt{\frac{2}{3}\dot{\varepsilon}_{ij}^2}$, [s^{-1}].

6. CONCLUSIONS

Conform to experimental results, equivalent tension values specific to forming process when using an oscillatory die (Fig.4) are by far smaller than those in the case of conventional volumetric forming (Fig.5).

Generalised deformation diagrams (Fig.6 and 7) show quite equal extreme values for both manufacturing processes, but material involving degree in forming is visible smaller in the case of conventional flatting.

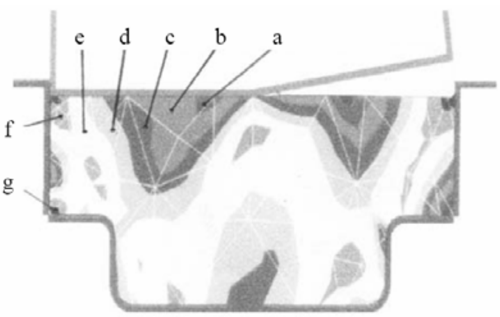


Fig. 4. Equivalent tension diagram specific to orbital forming process by using an oscillatory die; isovalues, [MPa]:
a - $\sigma_{ech} < 5263$; *b* - $5263 < \sigma_{ech} < 5714$;
c - $5714 < \sigma_{ech} < 6166$; *d* - $6166 < \sigma_{ech} < 6617$;
e - $6617 < \sigma_{ech} < 7068$; *f* - $7068 < \sigma_{ech} < 7520$; *g* - $\sigma_{ech} > 7520$.

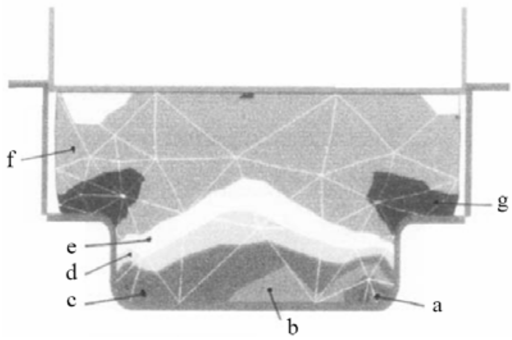


Fig. 5. Equivalent tension diagram specific to conventional forming process; isovalues, [MPa]:
a - $\sigma_{ech} < 3323$; *b* - $3323 < \sigma_{ech} < 4085$;
c - $4085 < \sigma_{ech} < 4847$; *d* - $4847 < \sigma_{ech} < 5609$;
e - $5609 < \sigma_{ech} < 6372$; *f* - $6372 < \sigma_{ech} < 7134$; *g* - $\sigma_{ech} > 7134$.

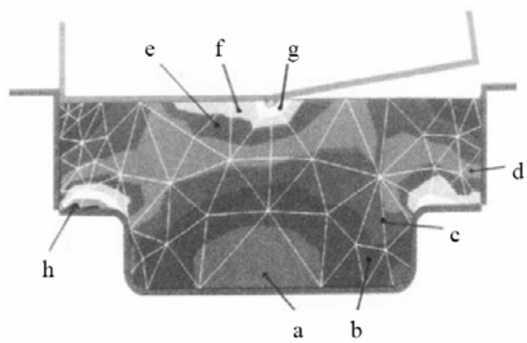


Fig. 6. Generalised deformation diagram specific to orbital forming process by using an oscillatory die; isovalues:
a - $\varepsilon < 0.234$; *b* - $0.234 < \varepsilon < 0.392$; *c* - $0.392 < \varepsilon < 0551$;
d - $0.551 < \varepsilon < 0.710$; *e* - $0.710 < \varepsilon < 0.869$;
f - $0.869 < \varepsilon < 1.028$; *g* - $1.028 < \varepsilon < 1.187$; *h* - $\varepsilon > 1.187$.

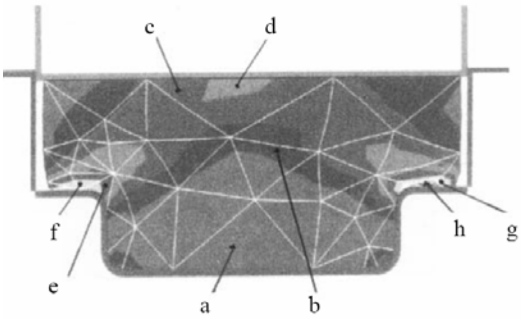


Fig. 7. Generalised deformation diagram specific to conventional forming process; isovalues: *a* - $\varepsilon < 0.193$; *b* - $0.193 < \varepsilon < 0.383$; *c* - $0.383 < \varepsilon < 0.573$; *d* - $0.573 < \varepsilon < 0.763$; *e* - $0.763 < \varepsilon < 0.953$; *f* - $0.953 < \varepsilon < 1.144$; *g* -$1.144 < \varepsilon < 1.334$; *h* - $\varepsilon > 1.334$.

Hydrostatic pressure distribution (Fig. 8 and 9) is more homogeneous and takes smaller values if forming by an oscillatory die. Maximum hydrostatic pressure is reached just under the punch, at a distance of $R/3$ from worked piece's axis.

Nodal speeds field, in the case of conventional forming, is relative symmetrical and includes the vectors oriented after directions inclined at 45 deg referred to workpiece axis direction. When forming by an oscillatory die, speed vectors module is smaller and their direction shows a material displacement tendency to the zones opposite to oscillatory die active flank, in the case of increment registered on the diagram.

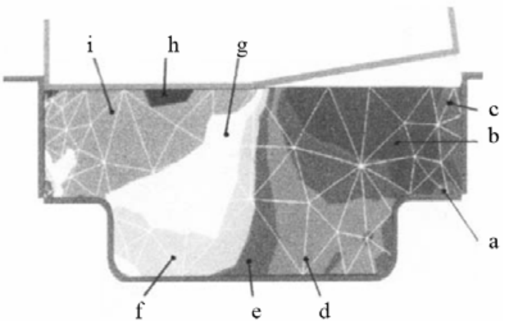


Fig. 8. Hydrostatic pressure distribution diagram specific to forming process by using an oscillatory die; isovalues, [MPa]: *a* - $p < 227$; *b* - $227 < p < 428$; *c* - $428 < p < 630$; *d* - $630 < p < 831$; *e* - $831 < p < 1033$; *f* - $1033 < p << 1234$; *g* - $1234 < p < 1435$; *h* - $1435 > p > 1637$; *i* - $p > 1637$.

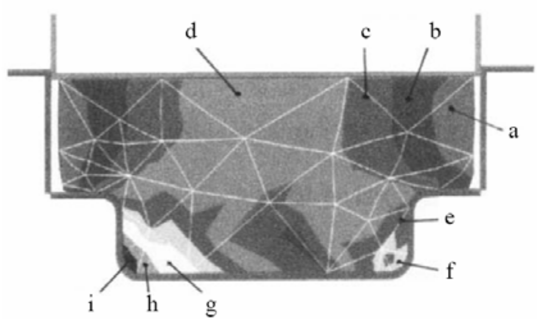


Fig. 9. Hydrostatic pressure distribution diagram specific to conventional forming process; isovalues, [MPa]: *a* - $p < 458$; *b* - $58 < p < 639$; *c* - $639 < p < 820$; *d* - $820 < p < 1001$; *e* -$1001 < p < 1182$; *f* - $1182 < p < < 1362$; *g* - $1362 < p < 1543$; *h*- $1543 < p < 1724$; *i*- $p > 1724$.

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