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ON MODELING THE METAL FORMING PROCESSES

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ABSTRACT

The modelling process of the bulk metal forming, being characteristic of the axysymetric element family is done in this paper. Three methods are used: Finite Element Method (FEM), Upper Bound Elemental Technique (UBET) and Plan Experimental Method (PEM). The changes of the force and piecework geometry, given in the parallel diagram, have been followed. Based on the results obtained it has been concluded that the methods mentioned may be relatively well applied to the forming analysis of the given process.

1. INTRODUCTION

The field of investigating both geometrical and mechanical parameters at open die forging is actual and not still researched. The very complexity of the problem imposes the necessity of using interrelated approaches: theoretical, experimental and numerical ones. A special attention is to be pained to a class of axysymmetric elements, being used very often.

The basic task of metal forging process design is to predict the load, the metal flow and the profile changes. With a good knowledge of the deformation and loads, it is possible to make the optimal design of the process parameters such as the number of deformation stages, the thermal treatment between each stages. Recently, many analytical and numerical methods have been developed for the solution of a wide variety of forging processes.

Then follows the strain of a step-down axysymmetric element modelling in a wide extend of deformation. The modelling was carried out:

- by applying the programme packet based on an elasto-plastic theory of the Finite Element Method (FEM),
- by Upper Bound Elemental Technique (UBET),
- by applying an Plan Experimental Method (PEM).

2. THEORETICAL BASIS

2.1. FEM formulation

An FE analysis of a deformation problem obtains an approximate solution by considering the displacement of only a finite number of points, or nodes, of the work piece. The work piece is partitioned into a finite number of elements interconnected at the nodes. The value of any quantity that is a function of position, such as the displacement of a particle, may be found at an arbitrary point of an element by interpolation between the nodal values of the function. This allows the principles of stress continuity and force equilibrium to be used to construct a set of equations for the element, relating nodal force and nodal displacement. These are called the element-stiffness equations. Since the geometry of the work piece, the boundary conditions and the material properties may all change during a metal forming processes, the relationship between nodal force and nodal displacement is highly non-linear. The analysis must therefore be divided into a number of small but finite increments of deformation and time, so that in each of these the incremental governing equations may be taken to be linear.

The finite-element program used here is based on that for three-dimensional analysis [6,8] which is suitable for general large-strain metal-forming problems. Yield is based on Von-Mises criterion, and plastic flow on the Prandtl-Reuss relationship. The formulation also includes strain hardening.

Let Δf_{Ii} be the i-th Cartesian component of the change in force at the I-th node of a given element during an increment of the analysis, and let Δd_{Ii} be the i-th Cartesian component of the corresponding change in displacement of that node from its reference position. The element stiffness equations may be written as:

$$\Delta f_{Im} = \left(K^{(\varepsilon)}_{ImJn} + K^{(\sigma)}_{ImJn} + K^{(\phi)}_{ImJn} \right) \Delta d_{Jn} \tag{1}$$

where the implied summation is carried out overall the nodes of the element for a repeated uppercase subscript, and over the three Cartesian components for a repeated lower-case subscript. The three inside the parentheses are called, respectively, the deformation-stiffness matrix, the stress-increment correction matrix and the constant-dilation correction matrix.

2.2. UBET method

The initial step in use of this methods is to divide the deformation zone into generalized rectangular and triangular elements examples of which are shown in Fig.1.

If a sufficient number of such elements are used, the shape of the body can be described accurately. Each of these element types has a general solution which incorporates a parallel velocity field together with tangential velocity discontinuities on its surface.

Thus together, the elements compose a very general type of velocity field for the whole workpiece. Here the ringlike elements which constitute annular rings are used for the case of axisymmetric problems.

The next step is to determine the axial and radial strain in the ringlike elements. A characteristic rectangular element together with the procedure to calculate the strain and power dissipation is given in the literature [1,2,3]. Other types of elements can be dealt with in a similar way.

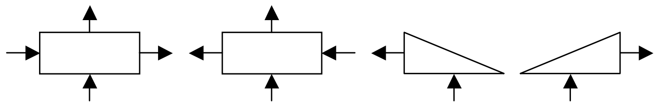


Fig.1. Sections of typical ringlike elements

This procedure is realized through the use of a microcomputer based program written in MATLAB which presents a graphical display of the information following the calculations. With this program, the yield stress is defined as a function of strain and therefore the flow stress is taken different value in different area inside the deformation body.

During the optimization of the velocity field in an increment, the velocity on the free surface which is supposed to be constant for the increment defines the direction and the magnitude of the material flow. The current profile of the body is used to define the information for next increment.

2.3. *Plan Experimental Method (PEM)*

As the process of bulk forming in the open dies is a wide term, both from the aspect of the billet's geometry and technological conditions, the following was accepted:

1. A family of stepped axisymmetric elements with two steps height on one side and one step height on the other side of a graded die plane (D=40 [mm]) (Fig.2).
2. The material investigated is the lead whose chemical composition is given in Table 1.
3. The research is done at room temperature.
4. Deformation is obtained at velocity of: v =10 [mm/min].

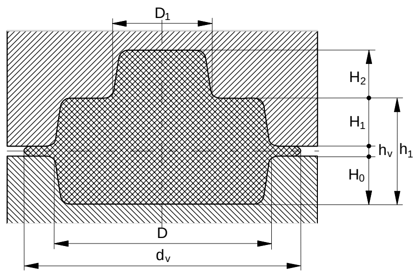


Fig.2. Workingpiece in seizure with die in final phase

Table 1. Lead chemical composition

Fe%	Si%	Ti%	Cu%	Zn%	V%	Cr%	Mn%	Mg%	Ni%
0.47	0.423	0.082	0.29	0.391	0.001	2.143	0.248	0.627	-

5. No lubrication is done during the process.

By metal yielding modeling it is needed to obtain the functional dependencies of output values defining the workingpiece geometry compared to the input ones - independent variable. The die and workingpiece geometrical factors as well as deformation degree and working temperatures are taken for input factors.

A complete more factors first order orthogonal plan with factor varying at two levels is accepted for the experiment plan. A degree function is accepted as of reacting to output parameters (2).

$$Y = a_0 \cdot X_1^{a_1} \cdot X_2^{a_2} \cdot \ldots \cdot X_k^{a_k} = a_0 \prod_{i=1}^{k} X_i^{a_i} . \tag{2}$$

Input factors to be observed are:

- Die geometrical factors investigated, for generality of the results, are expressed by dimensionless relations of the typical die dimensions and basic diameter D (Fig. 2)

$$X_1 = \frac{H_2}{D}, X_2 = \frac{H_1}{D}, X_3 = \frac{D_1}{D}, \tag{3}$$

where,

H_1 - first degree upper die height
H_2 - second degree upper die height
D_1 - second degree upper die diameter, and
D - basic die diameter

- The billet's geometry factor is a relation between the initial billet's diameter and basic die diameter:

$$X_4 = \frac{d_0}{D}, \tag{4}$$

where,

d_0 - billet's diameter.
The input factor level variations are given in Table 2.

Table 2. Input factor level variations

Input factors	Lover level	Basic level	Upper level
X_1	0.2	0.245	0.3
X_2	0.15	0.23	0.35
X_3	0.4	0.49	0.6
X_4	0.75	0.82	0.9

- The process factor is a reduced degree of deformation expressed as a relation between an instantaneous tool stroke and its total stroke, expressed by the formula

$$X_5 = \varepsilon^* = \frac{h_0 - h}{h_0 - h_1}, \tag{5}$$

where,

h - immediate height reached by the upper die points getting into contact with the billet at the beginning of die forging (Fig.3). At the initial phase $h=h_0$.

$h_1=H_0+H_1+h_v$ - final height reached by the upper die points getting into contact with the billet at the beginning of die forging (Fig.2).

h_v - flash height (Fig.2).

Such a defined reduced degree of deformation ε* may take the values ranging only from 0 to 1, i. e. $\varepsilon^* \in [0,1]$.

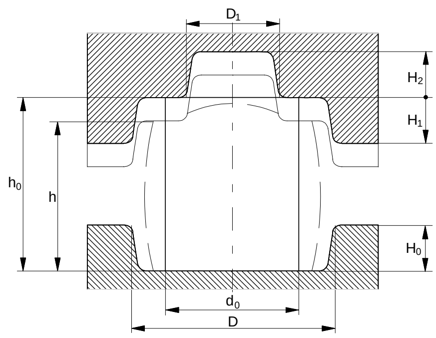


Fig.3 Working piece seized with die in the course of deformation

A relation between an relative degree of deformation and reduced degree of deformation ε* is expressed by:

$$\varepsilon = \varepsilon^* \left(1 - \frac{h_1}{h_0}\right). \tag{6}$$

A repeating system in the central plan point $n_0=4$ times is accepted. The number of the experimental points is: N=32+4=36.

Measuring at the above mentioned the experimental procedures were done by a precise analog-digital measuring equipment connected with an information measuring system, consisting of sensor unit, measuring bridge, transitional unit, A/D card and computer, illustrated by a block diagram in Fig.4.

At modeling contour, only the free part of the contour is modeled, namely the part which is not in contact with die, as the part being in contact with die is defined geometrically based on the known die geometry (Fig.5).

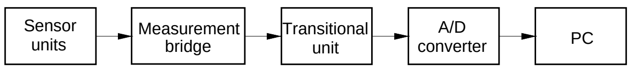


Fig.4. Information measurement system block diagram

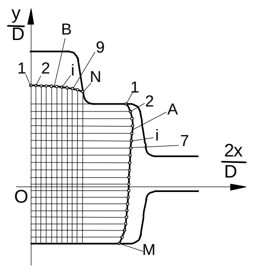


Fig.5 Free workingpiece contour. A - side; B - head

3. RESULT MODELING

Because of the axisymmetric shape of the body a section shown in the Fig.6 is considered.

Based on the theory presented in point 2, a program package for elastic-plastic analysis by a method of finite elements (EPFEP3 - Elastic-Plastic Finite-Element Program for 3 Dimensions) was made. The package was supported by a powerful graphical result presentation. Out of the many results obtained, those referring to the sample contour modelling are presented [9].

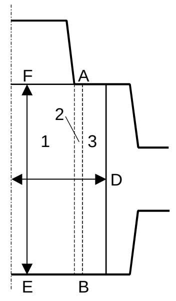
Finite element mesh had 300 elements and 852 nodes. Step of deformation was 0.2 mm. Sight of the mesh of the body at the beginning of deformation is given in Fig. 6a.

The division of the body, what depend on expected deformation, is clearly shown. View after high deformations (42.37% reduction of the height) is shown in the Fig.6b.

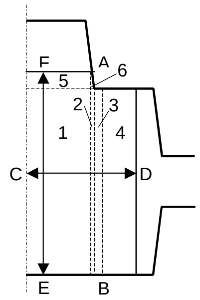
Because parallel velocity fields are assumed on the boundary surface, the workpiece geometry could be described by the plane contours. With this UBET program, it is possible to follow the flow pattern of the workpiece change by the plane contours. As the studied die forging process is a nonsteady state and complicated deformation process, several stages have to be included to complete a full modeling process. Hence a number of standard elements were divided for every stage of the deformation and each stage was performed by increments. Such particular stages of the deformation are described through the example in Fig.7.

a) b)

Fig.6 Spacious view of divided body: a) on the began deformation, b) after high deformation



a) The first stage of deformation



b) The second stage of deformation

Fig.7 Description of the deformation stage

As the first stage, the deforming material is divided into only 3 rectangular ring elements, shown in Fig.7a. The position of the neutral surface line AB where radial velocity is zero was determined by the minimization of the power dissipation. In the next stage (Fig.7b), more elements have to be used because the material flows towards the upper cavity and the left side of the die. Here 5 rectangular and one triangle ring elements were used to define the whole workpiece. The neutral surface line AB was also determined as before. This stage was performed by some increments until the material flow reached the left end of the cavity of the die. During each increment the velocity field was supposed to be constant and this defines the contours of the workpiece used as input information for the next increment. Other stages can be implemented in the same way.

An example of the signal from the inductance sensor in radial and axial direction of the device for contour recording is given in Fig.8.

A change in contour for single reduced degree of deformation, for the billet in the central plan point is given in Fig.9.

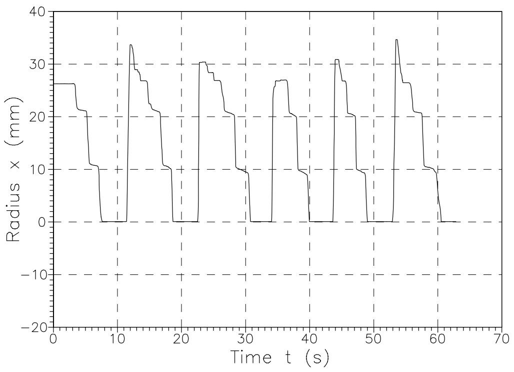


Fig.8 Signal from the inductance sensor in radial direction

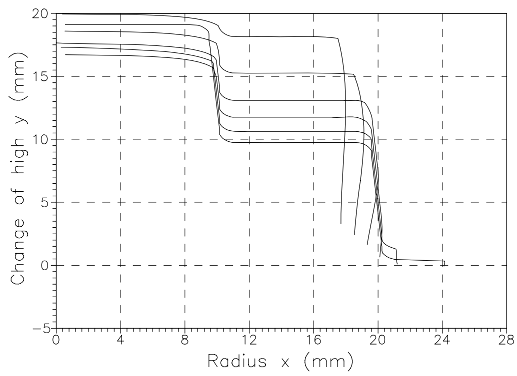


Fig.9 Change in upper workingpiece contour

When all the values of the abscissa of all the points for all the reduced degree of deformation observed are determined, the diagrams of the radius change expressed by the relation 2x/D presented in Fig.10 are obtained.

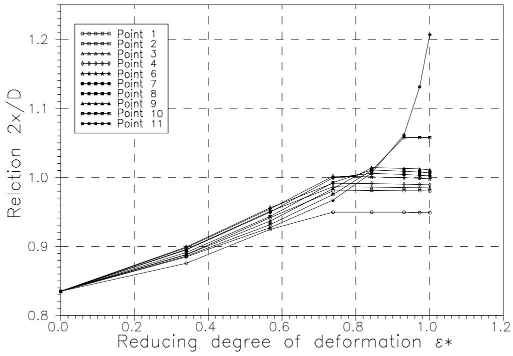


Fig.10. Change in side contour point radius

In the above described way the experimental data in the matrix plan are obtained, namely 2x/D output function values in the observed side contour points, based on which is possible to get the models in the function of the input factors observed. However, as it may not be possible to obtain adequate models in all the points for the whole interval of a reduced degree of deformation from 0 to 1 (X_5=ε*=0÷1), a discrete set of points of this factor is accepted and the radius change modeling is done within then. The interval of the reduced degree deformation factors is divided into ten points, starting from the value ε*=0.1, with step Δε*=0.1, up to the value ε*=1. The models are determined in all the obtained points of the reduced degree of deformation.

Model parameters are obtained by regression analysis, whereas their significance and the model adequacy of all the side contour points, for values of the reduced degree of deformation, are estimated by dispersion analysis.

The model parameter value (2) if the radius change, side contour in the function of the die geometrical factors and workingpiece geometrical factors, in the 7^{th} contour point, for the accepted values of the reduced degree of deformation, are presented in Table 3.

Table 3. Model parameters for point 7 of side contour

ε*	a_0	a_1	a_2	a_3	a_4
0.1	0.9832	-0.0056	-0.0052	-0.0182	1.0266
0.2	0.9706	-0.0102	-0.0101	-0.0374	1.0112
0.3	0.9589	-0.0139	-0.0153	-0.0530	0.9663
0.4	0.9489	-0.0165	-0.0209	-0.0639	0.8966
0.5	0.9408	-0.0181	-0.0270	-0.0696	0.8055
0.6	0.9349	-0.0187	-0.0338	-0.0700	0.6958
0.7	0.9312	-0.0182	-0.0412	-0.0656	0.5702
0.8	0.9294	-0.0169	-0.0492	-0.0565	0.4310
0.9	0.9296	-0.0147	-0.0576	-0.0433	0.2805
1	0.9471	0	-0.0664	-0.0265	0.1208

The changes of the force, mean radius of the side contour and mean front contour height in the function of a reduced deformation degree ε* are given in Fig.11, Fig.12 and Fig.13.

MKE and PEM methods are characterized by a relatively high accordance at geometry change parameters' modelling, whereas the changes in the force modelling increase as the deformation increases.

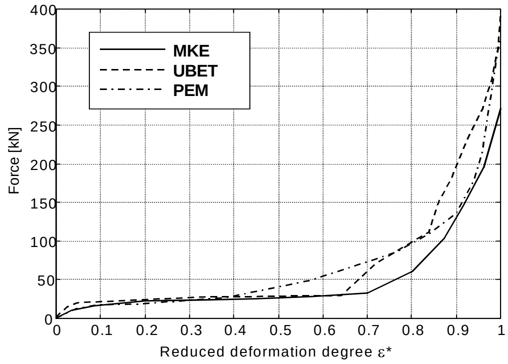
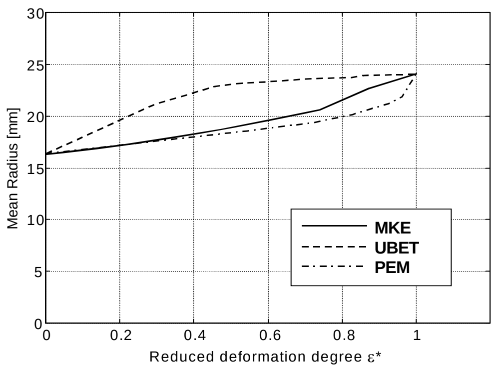


Fig.11 Force in the function of a reduced deformation degree



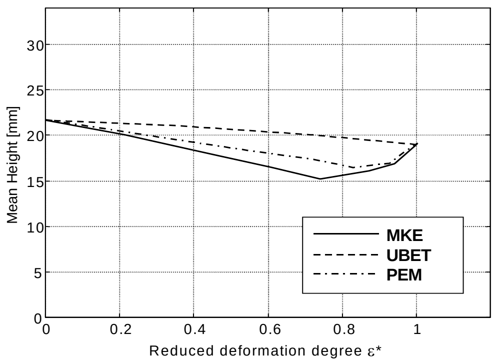


Fig.12 Mean radius of the side contour in the function of a reduced deformation degree

Fig.13 Mean height of the front contour in the function of a reduced deformation degree

4. CONCLUSIONS

The processes of die forging are followed by a high geometrical and physical non-linearity, this conditioning special difficulties at their analysis.

In this paper, the FEM, UBET and PEM methods have been applied and compared to analysis axisymmetric die forging processes.

The changes of the force, mean radius of the front contour and mean height of the front contour in the course of the deformation process are considered in the analysis.

From the results obtained, it is evident that, not with standing the objectively existing limits, the methods considered may relatively successfully be applied to a deformation process analysis within the given conditions.

5. REFERENCES

[1] Bramley, A.N., and Osman F.H., "The upper bound method , in Numerical Modeling of material Deformation Processes: research, development and application", Ed. by Hartley P., Pillinger I. and Sturgess C.E.N., pp 114-130, Springer-Verlag, 1992.

[2] Lugora, C.F., Osman, F.H., and Bramley, A.N., "UBET analysis for asymmetric forging", Proc.Int.Conf. Comput.Plast.:Models Software and Appl., pp. 1005-1014, Barcelona, 1987.

[3] McDermott, R.P., and Bramley, A.N., "An elemental upper bound technique for general use in forging analysis", Proc. 15th MTDR Conf., pp 35-47, Birmingham, 1974.

[4] Osman, F.H., Bramley, A.N., and Ghobrial M.I., "Forging and Perform design using UBET", Adv. Technol. Plast., Part I, pp. 563-568, 1984.

[5] Plančak, M., Bramley, A.N., and Osman, F.H., "Odredjivanje deformacione sile u procesima zapreminskog deformisanja pomocu UBET metode", Zbornik radova Instituta za proizvodno masinstvo, pp. 45-57, Novi Sad, 1990 (in Serbish).

[6] Hartley P., Pillinger I., Sturgess C. (Eds.): Numerical Modelling of Material Deformation Processes, Springer-Verlag , London, 1992.

[7] Pillinger I., Hartley P., Sturgess C.E.N., Rowe G.W.: Thermo-Mechanical Modelling of Metalforming Using the Finite-Element Method, Comput.Plast.Models Software and Appl: Pros.Int.Conf., p.p. 1073-1085, Barcelona, 1987.

[8] Rowe G,W., Sturgess C.E.N., Hartley P., Pillinger I.: Finite-element plasticity and metalforming analysis, Cambridge University Press, Cambridge, 1991.

[9] Vukčević M.: Finite Element Modelling of Forging Processes, Report, University of Birmingham, Birmingham, 1992.

[10] Janjić M., Vukčević M., Domazetović V.: Axisymetrical Element Contour Modelling at Die Forging. Journal for Technology of Plasticity, Volume 22, Number 1-2, Novi Sad, 1997.

[11] Domazetović V., Vukčević M., Janjić M.: Modeling of the Die Forging Processes. ICIT'97 - International Conference on Industrial Tools, Maribor, Slovenia, 1997.

[12] Korn G., Korn T.: Mathematical handbook, Mc Graw-Hill Book Company, New-York, 1968.

[13] Tihomirov V. B.: Plan and Analysis of the Experiment. Easy Industry, Moskva, 1974.

[14] Vukčević Milan: Modeling of the metal forging processes, International congress mechanical engineering technologies '97. Septembar 1997.

O MODELIRANJU PROCESA ZAPREMINSKOG DEFORMISANJA

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ABSTRACT

U okviru obrade deformisanjem se svojom složenošću posebno izdvaja zapreminsko deformisanje, što je, prije svega, uslovljeno činjenicom da je pri ovom vidu obrade materijala posebno teško pomiriti dva kriterijuma: korektnost i jednostavnost rešenja. I pored napora velikog broja istraživača može se reći da ne postoji definitivno prihvaćen metod, niti pak definitivna rešenja čak ni najjednostavnijih postupaka u obradi zapreminskim oblikovanjem.

Složenost problematike je uslovila neophodnost korišćenja međusobno povezanih pristupa: teorijskog i eksperimentalnog. Posebno je aktuelna primjena na klasu osnosimetričnih elemenata koji se veoma često koriste.

U radu je deformaciona analiza familije stepenasti osnosimetričnih elemenata u širokom rasponu deformisanja. Modeliranje je izvršeno korišćenjem:

- *programskog paketa zasnovanog na elastoplastičnoj teoriji metode konačnih elemenata (FEM),*
- *metode gornje granice (UBET) i*
- *metode eksperimentalnog plana (PEM).*

Modelirana je promjena sile srednjeg radijusa bočne konture i srednje visine čeone konture.

Iz dobijenih rezultata se zaključuje da se korišćene metode mogu relativno uspješno primijeniti za deformacionu analizu razmatranih uzoraka. Metod konačnih elemenata i metod eksperimentalnog plana karakteriše relativno visoka saglasnost u modeliranju geometrijskih parametara, dok se kod modelskih rezultata sile javljaju odstupanja koja rastu sa porastom deformacije.