研究速報

Extrusion of Rectangular Sections and Angeles

—Three-Dimensional Analysis by Rigid-Plastic FEM-2—

押出し加工の塑性変形特性

—剛塑性FEMによる3次元変形解析-2—

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1. INTRODUCTION

In the present paper a three-dimensional rigid-plastic finite element code, COPRESS System[1)] is again applied to the analysis of extrusion process. This time the computational examples are extended. The cross sections of the products are varied from rectangular to angle sections. The aspect ratio of them is varied also in a very wide range. As in the previous work the extrusion process is assumed to be carried out from round billets through flat-faced dies. Besides the prediction of the average extrusion pressure, the effect of the aspect ratio and the eccentricity of the die on the metal flow is studied. Results on the velocity and stream lines distribution are presented.

2. COMPUTATIONAL MODELS OF RECTANGULAR AND ANGLE SECTIONS

COPRESS System is a computer code based on the rigid-plastic FEM formulation whose history and theory is well documented[2)] and for conciseness is not repeated here.

Using COPRESS System, extrusion of rectangular and angle cross-sections products from round billets through flat-faced dies is simulated as shown in **Fig. 1**. The extrusion process conditions under which the computations are carried out are the same as in[1)]. Also, the stress-strain relationship of the material of the workpiece is given in[1)].

Tables 2 and 3 show the dimensions of the product for rectangular and angle cross-section products, respectively. The geometrical complexity of the product, i.e. cross-sectional shape of the die exit, is defined by the aspect ratio, DXE/DYE and the angle α.

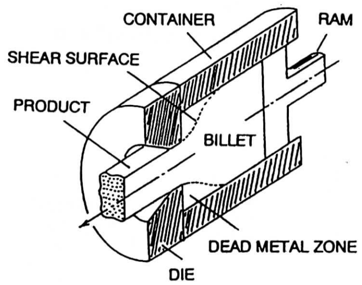


Fig. 1 A-3 D extrusion process throuth a fllat-faced die.

Table 1 Extrusion process conditions for computation.

(i)	Container length:	DZC=100 mm
(ii)	Container radius:	R_O= 50 mm
(iii)	Bearing length:	Z_B= 30 mm
(iv)	Punch velocity:	V_{Zc}= 10 mm/s
(v)	Friction coefficient:	μ= 0.1

Table 2 Computational models of rectangular sections from round billets.

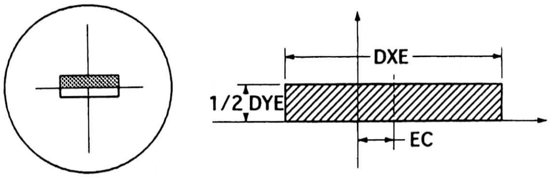
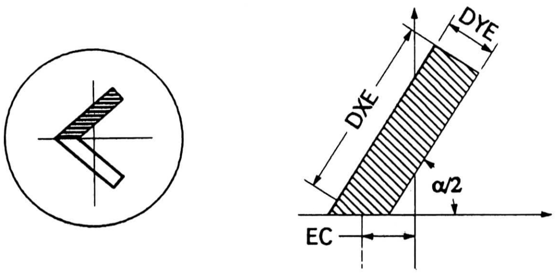


Table 3 Computational models of angle sections from round billets.



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For rectangular sections, the eccentricity of the die is varied from 0 to $3/5R_0$ with variations of $1/5R_0$. In some cases, because of the geometry of the tooling, it is not possible to simulate eccentricities larger than $2/5R_0$. For angle sections, it is interesting to determine the optimum eccentricity of the die in order to get the minimum extrusion pressure. Therefore, the eccentricity of the die is varied from $-3/5R_0$ to $2/5R_0$. It is noted that in order to compare the effect of the section shape and the aspect ratio on the characteristics of the flow of material, the extrusion ratio (cross-sectional area of the billet/cross sectional area of the extruded product) is kept constant for each of the sectional shapes described above.

Fig. 2 and **3** show a typical finite element layout for rectangular and angle sections used for FEM calculations, respectively. The FEM model includes a total of 1176 eight-node brick elements for the container section. In bearing and extruded product sections, the number of elements varies in according with the geometrical complexity of the cross section. In both figures are shown the complete models, but in actual calculations only one half of the geometry is considered due to the symmetry.

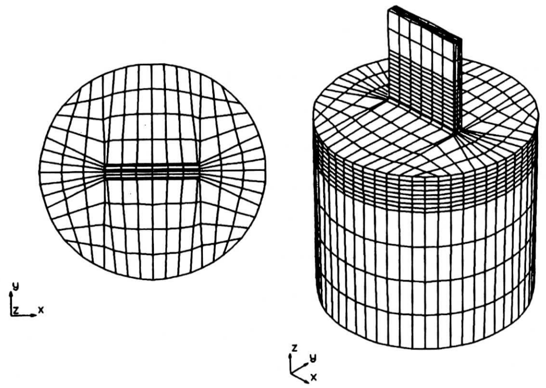


Fig. 2 Finite element mesh of working material for computation of rectangular sections: (a) top view; (b) 3-D view.

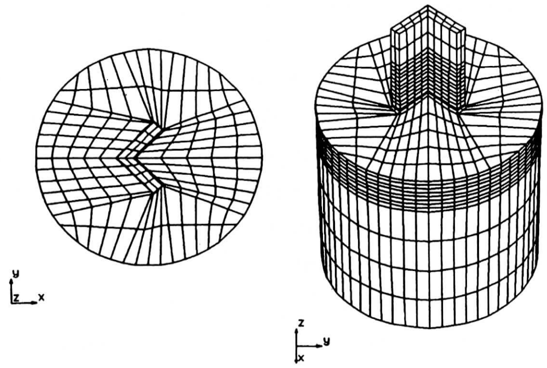


Fig. 3 Finite element mesh of working material for computation of angle sections: (a) top view; (b) 3-D view.

3. RESULTS AND DISCUSSIONS

3-1. Results on average extrusion pressure

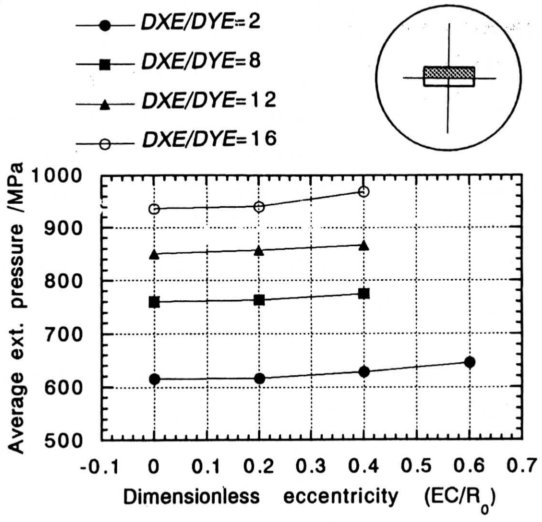
The energy computed can be converted to the average extrusion pressure (P_{Av}) by using the relation given by Eq. (1).

$$P_{A}v = \frac{\phi}{\pi R_O^2 V_{Zc}}$$

where ϕ is the functional corresponding to the FEM formulation given in [1, 3] and expresses the total extrusion power. R_0 is the container radius and V_{Zc} the ram speed.

Extrusion of rectangular sections: For this kind of products the plots of the average extrusion pressure variation with the eccentricity of the die, shown in **Fig. 4**, indicate an important increment when the aspect ratio DXE/DYE is decreased. However, the eccentricity of the die shows a slight influence on the extrusion pressure.

Extrusion of angle sections: It is well known that the pressure required to extrude a given section depends on material variables and geometric variables. Among other variables, in die design, the position of the die opening with respect to the billet axis also affects the pressure required.



(a) Rectangular

Fig. 4 Variation of average extrusion pressure with aspect ratio and eccentricity of the die exit for rectangular sections.

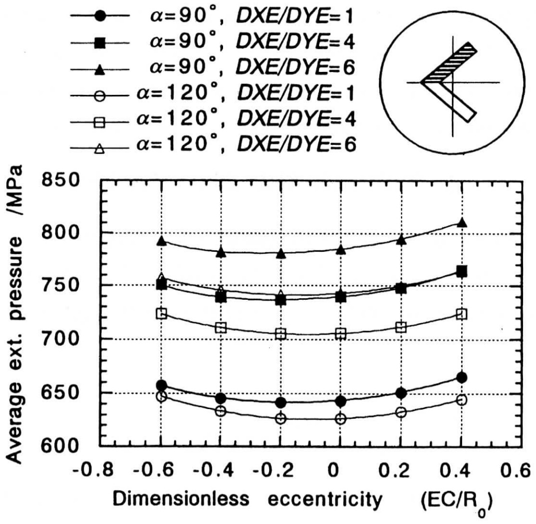


Fig. 5 Variation of average extrusion pressure with aspect ratio and eccentricity of the die exit for angle sections.

Therefore, it is important to determine the eccentricity of the die at which the pressure required is minimum. **Fig. 5** shows the variation of the average extrusion pressure with the eccentricity of the die for angle sections. From this plots or by using an interpolation technique, it is possible to determine the optimum eccentricity for a given section.

As would be expected, the comparison among the predicted extrusion pressure for each of the cross-sectional shapes shows higher values for 90° angle sections and for products with high aspect ratio values. This trend can be explained by the functional in the FEM formulation[1),2)] and equation (1) as a consequence of the increase of internal power of deformation due to the more drastic change of the flow direction inside the plastically deforming zone.

For angle sections, the plots also indicate that a minimum value of extrusion pressure is reached at some die eccentricity. This value may be defined as the optimal die eccentricity in terms of extrusion pressure.

3-2. Results on velocity and streamline distribution

The general trend of the velocity distribution is similar for each of the analyzed cross-sectional shapes. A typical example is given in **Fig. 6** where the velocity component V_Z is plotted in all the volume.

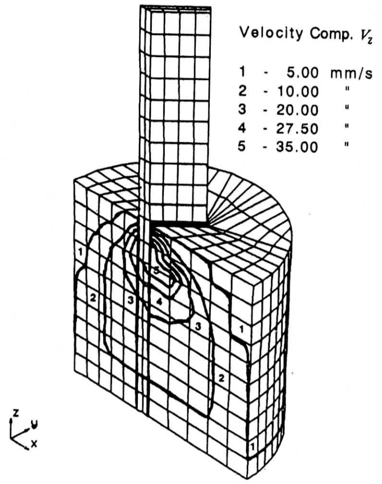
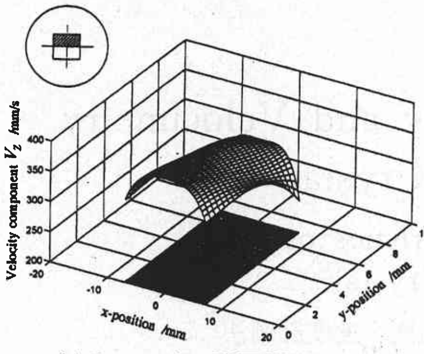


Fig. 6 Distribution of the velocity component V_z.

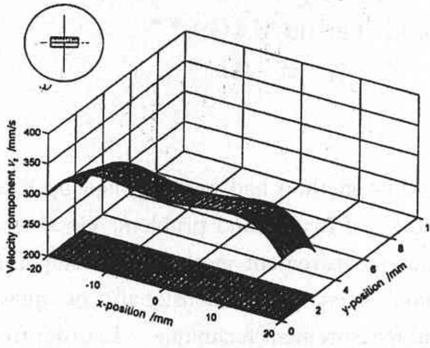
Other important features of the velocity distribution can be better appreciated in three-dimensional plots, as shown in **Fig. 7**. In these plots, the nodal points velocities corresponding to the die entrance plane are plotted as function of the nodal point coordinates, making possible to see a three-dimensional surface representing the velocity distribution for a specific plane.

At every position the axial velocity V_Z decreases or increases due to the frictional retardation at the die surface or to the contribution of the preferential tendencies of the metal flow, namely, at locations far from the die wall where the frictional effects has no longer an important effect. The velocity distribution tends to be more uniform at aspect ratios near 1 and for rectangular sections. The nonuniformity in the velocity distribution increases with the aspect ratio. Higher aspect ratio causes higher located deformations, the components V_X and V_Y decrease which in turn leads to the lowering of the axial velocity V_Z on account of material incompressibility. Also, such a nonuniform velocity distribution is expected to produce greater grid distortions.

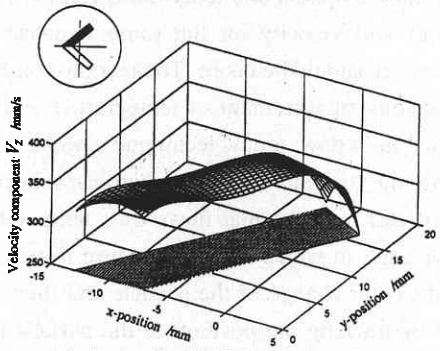
For high aspect ratio rectangular sections, an interesting feature is observed in the velocity distributions, for example, with reference to **Fig. 8 (a)**, it is clearly seen that the velocity distribution shows a double peak, that is, smaller values are located at central positions. However, when the *DXE*/*DYE* decreases, this tendency lessens. This effect can be explained by observing the stream lines patterns show in **Fig. 9**, where detailed differences of material flows are more clearly indicated. In top views, it is possible to appreciate the preferential tendencies of the material flow. As might be expected, for *DXE*/*DYE*=2 case there is some degree of stream lines concentration at the center of the cross-section, therefore, higher velocities. On the contrary,



(a) Rectangular: *DXE/DYE*=1, *EC*=0



(b) Rectangular: *DXE/DYE*=8, *EC*=0 mm



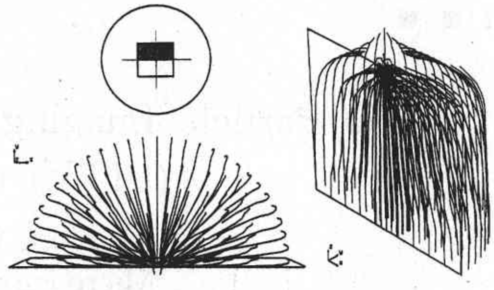
(c) Angle: *DXE/DYE*=8, *EC*=-15 mm

Fig. 7 Distribution of the velocity component V_z at the entrance of the die..

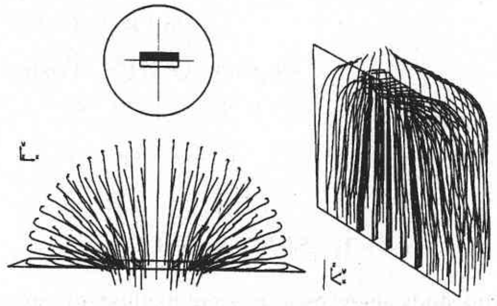
for *DXE/DYE*=8 case, **Fig 9 (b)**, the highest concentrations of stream lines are located towards the lateral positions of the die, which corresponds to the double peak of the velocity distribution.

4. CONCLUSIONS

In this paper, COPRESS System was applied to the simulation of three-dimensional extrusion process. By employing the system as an effective tool, a comprehensive investigation into the deformation characteristics was carried out. Extrusion of rectangular and angle sections was simulated and its flows characteristics were summarized and discussed in terms of velocity and stream lines distributions patterns. Although the die geometry is still simple, the investigation illustrates quantitatively the effect of geometrical complexity on the deformation mechanics for rectangular and angle sections. It is concluded that COPRESS System is indeed an effective tool which provides useful information on the detailed deformation characteristics for various process variables. In order to ascertain the accuracy of the solutions presented in this work , however, an extensive research work is still needed in order to evaluate the effect of the other important variables on the metal flow during three-dimensional extrusion.



(a) Rectangular: *DXE/DYE*=1, *EC*=0



(b) Rectangular: *DXE/DYE*=8, *EC*=0

Fig. 8 Stream-lines distribution.

References

1) M. Kiuchi et. al.: Proc. 1994 JSTP Spring Conf., (1194), 228.
2) M. Kiuchi et. al.: Seisan-Kenkyu, 46, (1994), 51.
S. Kobayashi, S. Oh and T. Altan: Metal Forming and the Finite Element Method, Oxford University Press,(1989).