研究速報

Finite Element Analysis of Velocity Distribution in Bearing during Extrusion of Rectangular Sections

(Combination of Numerical Analysis and Die Design − 1)

矩形材押出し加工時のダイスベアリング部での塑性流動のFEM解析

(数値解析技術とダイス設計との結合−1)

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Introduction

Theoretical analysis of extrusion process commonly have two objectives: the determination of the required forces, and the orediction of metal flow.

In the previous papers[1)~4)], the average extrusion pressure and metal flow characteristics extrusion processes of some three-dimensional products were presented. However, results on the velocity distribution in the bearing, which are important for die design, were not presented. Moreover, this kind of data have not been found in the available literatures. This paper describes the application of the FEM code COPRESS[5)] to the analysis of the velocity distribution in the bearing during extrusion of rectangular sections from round billets through flat-face dies. Results of the simulations clearly show the effect of the die shape and the die land, as well the guiding effect of the die land. Moreover, the results show the influence of the bearing length on the pattern distribution of the axial velocity. Thus, this study is expected to:

- increase the fundamental understanding of the extrusion process ,
- provide scientific basis for die design and extrusion processes design , and
- assist in the rational extrusion process controls for defect-free extrusion operations.

Method of Analysis

The method used in the present study is based on the rigid-plastic formulation. The eight node isoparametric element was used to discretize the variational principle functional which yields a set of nonlinear algebraic equations. The Newton-Raphson iteration method was introduced to obtain the solution of the equations. In the present investigation, the Gaussian quadrature formulas were used for volume integrations. For evaluation of deformation energy terms, 2×2×2 integration points were used. On the other hand, the center point was used for the dilatational terms, in order to avoid the over-constraint caused by a higher order integration. Also, the boundary terms were evaluated by the same formulae. In the present work, 5×5 integration points were used. It was observed, that this integration scheme yields a stable convergence behavior in the Newton-Raphson iteration procedure.

The integration scheme implemented in COPRESS was one-point integration and the suppression of the unrealistic hourglass modes was intended by using a stabilizing matrix[1)~4)]. However, because of that there is no constraints at the exit of the die, the hourglass mode was showed up in the extruded product section. Therefore, under this integration scheme to study the behavior of the axial velocity distribution in the searing. Another drawback showed up was the overestimation of the extrusion force, it was about 20% higher respect to the value calculated by the selective reduced integration, SRI. As a conclusion it became clean that for the purpose of this work the SRI should be adopted.

Results and Discussions

The FEM program developed and applied in the last

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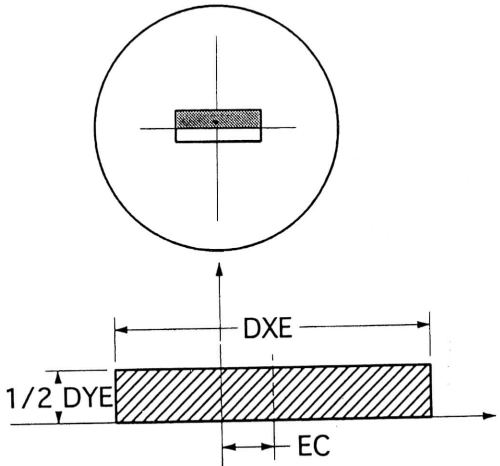

DXE (mm)	*DYE* (mm)	*DXE/DYE*
14.14	14.14	1
20.00	10.00	2
40.00	5.00	8

Fig. 1 Computational models of rectangular sections from round billets.

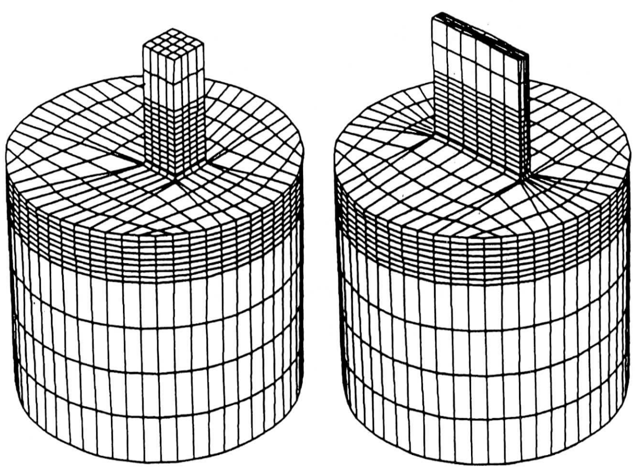

Fig. 2 Finite element mesh of workpiece, a) $AR=1$, $EC=10$ mm, b) $AR=8$, $EC=0$ mm.

papers[1)~5)] is capable of simulating general three-dimensional extrusion processes. In according with the purpose of this new investigation, simulations of rectangular sections were conducted. This section is relatively simple, but clearly shows the usefulness of the computer code and the results are easy to visualize. The geometry of the simulated sections and the positions of the die opening with respect to the billet axis are given in **Fig. 1**. Depending on the geometrical complexity, the number of elements and nodal points varies. A typical mesh, shown in **Fig. 2**, consists of 1344 elements interconnected a 1854 nodal points.

In according with the purpose of the present work, the solution is considered accurate enough when the velocity error norm is less than 0.00001. As a result, about 80 iterations with $\alpha=0.7$ as the deceleration coefficient are needed. Each simulation requires about 5 hours for execution time on a SUN SPARC 10/51.

Summary of process conditions in simulations is as follows:

Material: a rate dependent material, with the flow stress given by

$$\bar{\sigma} = 118\dot{\bar{\varepsilon}}^{0.13} \quad \text{[MPa]}$$

Container length:	C_L	100 mm
Container radius:	R_0	50 mm
Bearing length:	Z_B	5, 7.5, 10, 12.5, 15 and 30 mm
Ram speed:	V_{Zc}	10 mm/s
Coef. of Coulomb friction	μ	0.1
Eccentricity of the die	EC	0, 10 and 20 mm.

A primary requirement in the design of the section-extrusion process is that the extruded material should exit from the die without twisting or bending. This requirement is satisfied if the die shape and the bearing length are such that the extruded material at the die exit has, across its cross section, a uniform velocity in the axial direction. Then, in according with this, the following is to characterize the axial velocity field in the bearing.

Having obtained the velocity distribution at some cross-secitions in the bearing a parameter is needed to characterize its "width" or variability around the central value, that is, a measure of the nonuniformity. For this purpose the standard deviation of the velocity field was chosen. The formulae used for this calculations is given by Eq. 1

$$SDV = \sqrt{\frac{\sum_{i=1}^{N}(V_Z^{(i)} - V_Z^{Ave})^2}{N}} \tag{1}$$

where N: number of nodal points in a given cross-section.
V_Z^i: axial velocity at node i in a given cross-section.
V_Z^{Ave}: average axial velocity of a given cross-section.

The average extrusion pressure, P_{AV}, is calculated by Eq. (2)

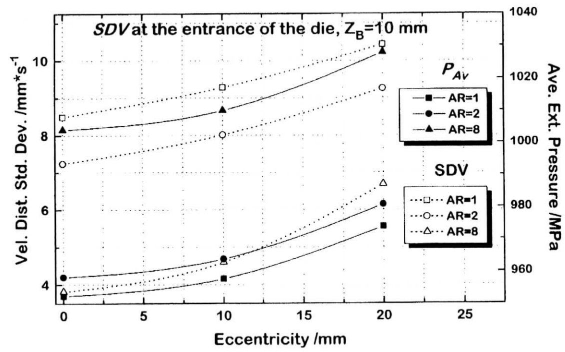

Fig. 3 Variation of P_{AV} and SDV with the EC and AR.

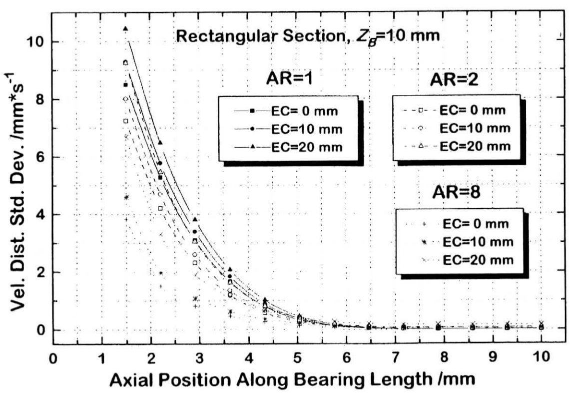

Fig. 4 Variation of SDV with AR, Z_B=10 mm.

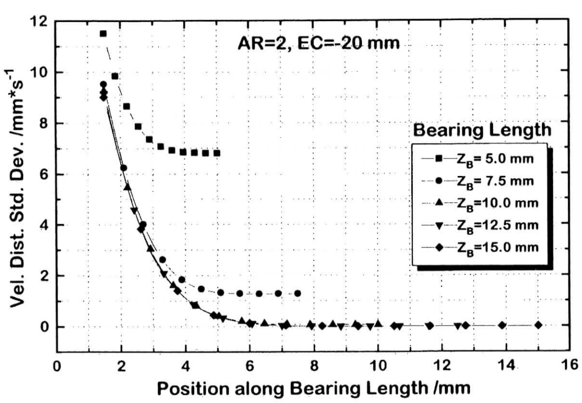

Fig. 5 Variation of SDV along the bearing length.

$$P_{Av} = \frac{\phi}{\pi R_0^2 V_{Zc}} \qquad (2)$$

where: ϕ: total energy calculated by the variational principle formulae

R_0: container radius

V_{ZC}: ram speed

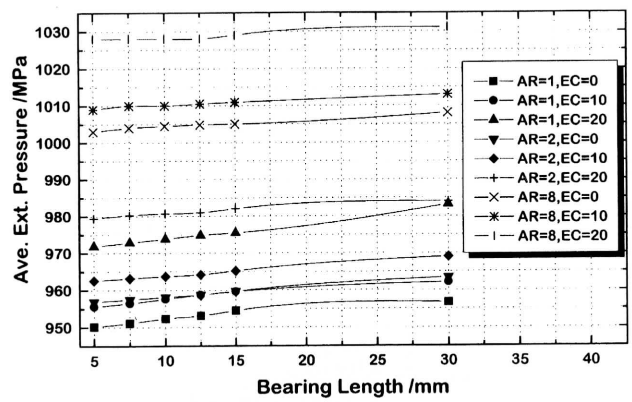

Fig. 6 Variation of P_{AV} with Z_B.

Fig. 3 shows the variation of the average extrusion pressure, P_{AV}, and the standard deviation of the velocity field, SDV, corresponding to the cross sectional plane at the die entrance with the eccentricity of the die. As would be expected, P_{AV} increases with the aspect ratio AR[1], however, SDV is lower for higher AR sections.

Fig. 4 shows the variation of SDV along the axial position of the bearing for 10 mm bearing length cases. It is observed that although the section with higher AR has lower SDV from the entrance of the die until certain position, it needs longer distance to become uniform. In these cases, since the die bearing has enough guiding effect, all sections came out with uniform axial velocity.

Fig. 4, also, could suggest that the optimal bearing length is approximately 6.5 mm, however, as previously mentioned the excess in length acts as a guide for maintaining straightness. Then the optimal bearing length will be more than 6.5 mm. Excess in bearing has a positive benefit, but the extrusion load increases and the manufacturing cost also.

In order to investigate into the optimal bearing length, four cases were simulated: Z_B=5, 7.5, 10, 12.5 and 15 mm all of them for a rectangular section with AR=2 and EC=20 mm. **Fig. 5** shows the results. When Z_B is 5 mm SDV at the exit of the die is still very high, as a consequence the extruded product comes out without straightness. For 7.5 mm bearing length case SDV is significantly decreased, but this length is not long enough to accomplish with the requirement, SDV is about 1.2 mm/s at the exit of the die. SDV becomes zero for cases when Z_B=10, 12.5 and 15 mm. However, the average extrusion pressure, showed in the **Fig. 6**, increases with the bearing length. Therefore, it can

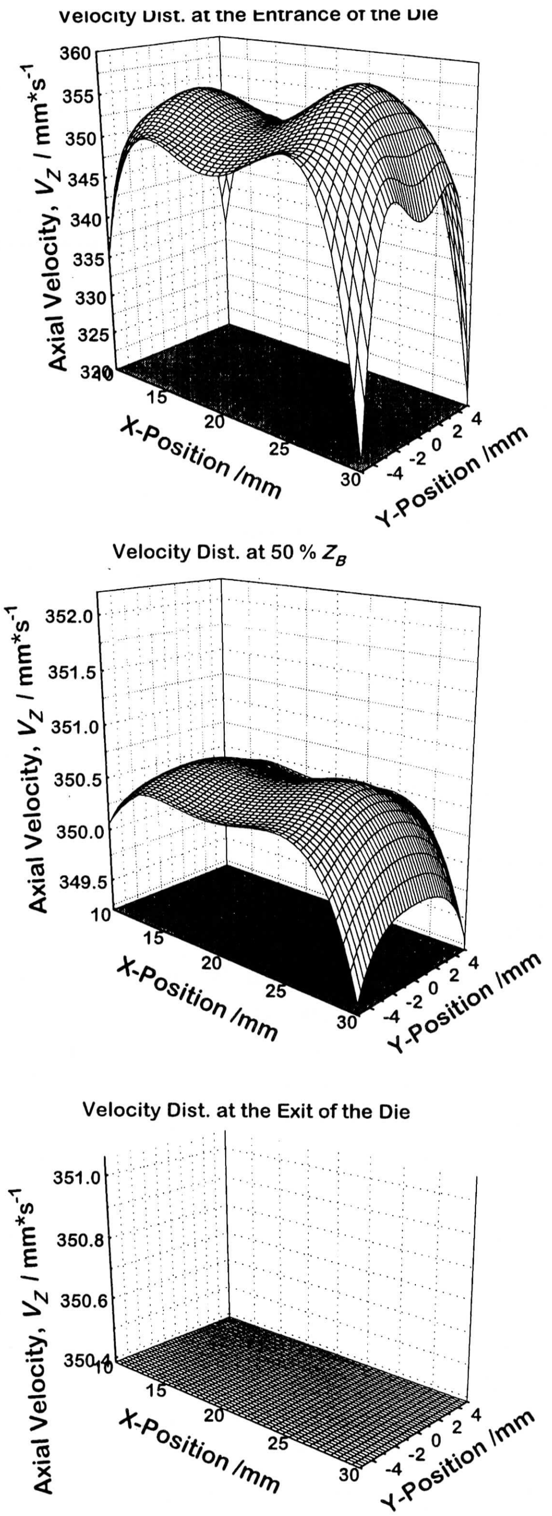

Fig. 7 Axial velocity dist.: AR=2, EC=20 mm, Z_B=10 mm.

be concluded that the optimal bearing length for this section is 10 mm in terms of straightness and extrusion force.

Previous results are reinforced and better illustrated in Fig. 7. It shows the axial velocity distribution for the bearing length determined as optimal, three plots are presented: at the entrance of the die, at 50% of bearing length and at the exit. At the entrance, the velocity field is highly nonuniform, but at the exit of the die it is uniform enough to get a straight product.

Conclusions

A study on the metal flow behavior in the bearing during extrusion process was carried out by the application of finite element techniques.

The results show how the characteristics of the metal flow are influenced by some process parameters, like bearing length and eccentricity of the die opening. From them: it is possible to increase the understanding of the extrusion process, provide better scientific basis for die design and extrusion processes design and assist in the rational extrusion process control for defect-free extrusion operation.

In this work the simulated sections are quite simple, however, the results provide basic understanding for the further and research into more complex sections and characterization of influences of other process parameters.

Finally, it was shown that optimal bearing length and optimal die opening position can be successfully predicted by FEM techniques. (Manuscript received, October 20, 1995)

References

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