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# METAL FLOW ANALYSIS IN EXTRUSION DIES

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**Abstract** Metal forming by extrusion is widely used in industries. Presently streamlined dies are used for extrusion. In these dies the smooth flow of metal is ensured and hence formation of dead metal zone is avoided. In this paper an attempt is made to analyse the variation of velocity components ($V_x$, $V_y$, $V_z$) of the extruded metal along the die length. The analysis is done for the streamlined extrusion dies designed based on the firth order polynomial equation. The analysis is also carried out for various reduction ratios.

## INTRODUCTION

The extrusion process is carried out conventionally by shear faced die. But the shear faced extrusion dies suffer from more redundant work attributed to formation of dead metal zone. Dead metal zone results from the resistance offered by the die surface to the extruded metal. Extrusion dies are presently modified as streamlined extrusion dies. Fig.(1). In these dies [1] the smooth flow of metal is ensured and hence formation of dead metal zone is avoided. This results in reduced extrusion pressure for the given reduction ratio. In this paper an attempt is made to analyse the variation of velocity components ($V_x$, $V_y$, $V_z$) of the metal getting extruded along the die length with the help of computer. The analysis is done for the streamlined extrusion dies designed based on the fifth order polynomial equation. The analysis is also carried out for various reduction ratios.

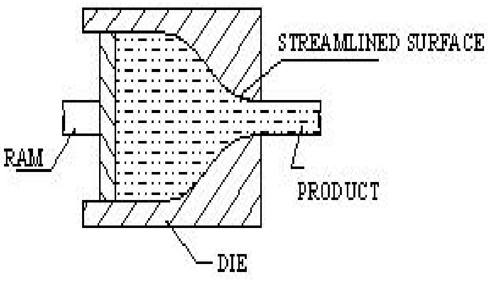


**Fig .1: Streamlined Die**

## VELOCITY

The following assumptions are required to construct the velocity field [2] for the extrusion of regular hexagonal section from cylindrical billets. The material of the billet passing through sector OAB Fig. (2) at the die entry goes through triangular PQR at the die exit, preserving the extrusion.

Stream surface OAPQ consists of a number of curved streamlines, which start from a point A’ at the entry and end at a corresponding point Q’ at the exit maintaining the proportionality of the position.

Any coordinate along streamline A’Q’ in Fig.2 is formulated in a Cartesian coordinate system as follows.

$$X = f_1(z)\ b_1z^5 + b_2z^4 + b_3z^3 + b_4z^2 + b_5z + b_6$$
$$Y = f_2(z) = c_1z^5 + c_2z^4 + c_3z^3 + c_4z^2 + c_5z + c_6$$
$$z = z \qquad \text{……… (1)}$$

Where $b_i$ and $c_i$ (i = 1,2,3,4,5 and 6) are constants, determined by the boundary conditions. Consider that this streamline does not produce any abrupt change of flow direction along the extrusion axis at the entry and the exit of die.

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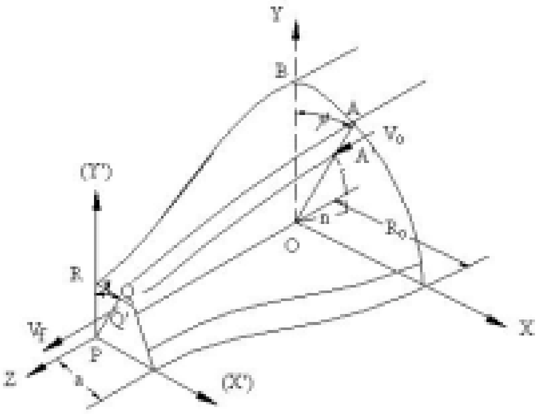



**Fig.2 : Deformation zone for Streamlined extrusion die (Round billet to Hexagonal shape)**

The boundary conditions are given for equation (1) as

$X = n \sin \phi,\ \partial x / \partial z = 0,\ \partial^2 x / \partial z^2 = 0$

$y = n \cos \phi,\ \partial y / \partial z = 0,\ \partial^2 y / \partial z^2 = 0$

at $z = 0$

$x = n / Ro\ a \tan \psi,\ \partial x / \partial z = 0,\ \partial^2 x / \partial z^2 = 0$

$y = n / Ro\ a,\ \partial y / \partial z = 0,\ \partial^2 y / \partial z^2 = 0$

at $z = L$

………(2)

Where

$\tan \psi = 6 / \pi (\pi / 6) . \phi$

$= c\phi$

Where Ro is the radius of billet, 'a' is the half-side length of product cross-section, N is the number of sides in regular polygon, L is the length of die, n is the distance from the axis to an arbitrary point E' at the die entry, and $\phi$ and $\psi$ are the angles between the plane of symmetry and the stream surface at entry and exit of the die respectively. Substitution of these boundary conditions into equation (1) gives.

$x = n \sin \phi + n (a / Ro\ c\phi - \sin \phi)$
$[\, 6 Z^5 / L^5 – 15 Z^4 / L^4 + 10 Z^3 / L^3 \,]$

$y = y = n \cos \phi + n (a / Ro – \cos \phi)$
$[\, 6 Z^5 / L^5 – 15 Z^4 / L^4 + 10 Z^3 / L^3 \,]$

$z = z$

……… (3)

Assuming that the plastically deforming zone is bounded by shear planes at the entry and the exit of die, and utilizing the determinant of the Jacobian of equation (4), the velocity components for incompressible material are determined as

$Vx = n (a / Ro\ c\ \phi - \sin \phi) f'(z) / g (\phi, z) . Vo$

$Vy = n (a / Ro - \cos \phi) f'(z) / g (\phi, z) . Vo$

$Vy = 1 / g (\phi, z) . Vo$

……… (4)

Where

$g (\phi, z) = [\, (1 – f)^2 + c (a / Ro\ f)^2 \,]$

$+ [\, (1 + c) (1 – f) a / Ro\ f \,] \cos \phi$

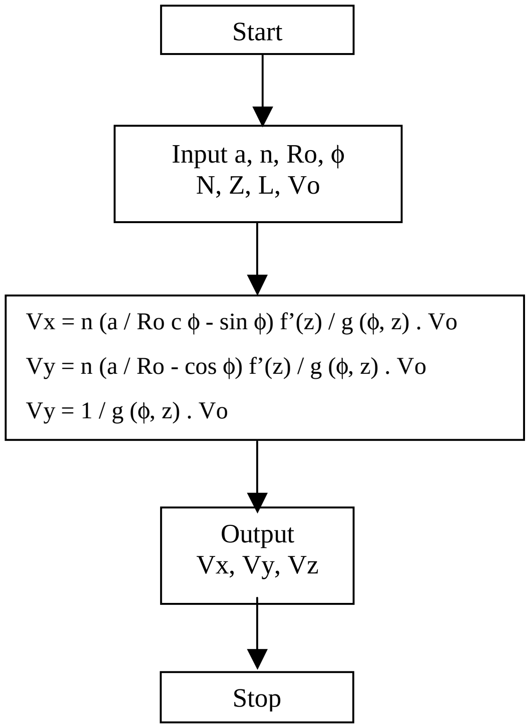
$+ [c (1-f) a / Ro\ f \,] \phi \sin \phi$

**COMPUTER PROGRAM FOR THE CALCULATION OF VELOCITY COMPONENTS**

Computer program is developed for the calculation of velocity components values (Vx, Vy, Vz) for various reduction ratios by changing the following parameter.

(i) Reduction ratio
(ii) Position along the die length
(iii) arbitrary radius at the inlet of the bullet and
(iv) sweep angle.

The flow chart for the program is given below.




**RESULTS AND DISCUSSION**

Metal flow analysis using velocity field has been done for the reduction ratios of 60% and 70% for extruding ircular rod into a hexagonal shape. The following inferences can be made.

When the reduction ratio is 70%, Vx and Vy components remains zero along the length of the die when the sweep angle is zero as shown in Fig.(3). The Vz component steeply increases for all the reduction ratios. Vx remains zero along the length of the die as shown in Fig. (4). Vy value decreases to the negative ordinate and then attains zero at the die exit. Vz component gradually increases and attain of maximum value at the die exit. In general, when the sweep angle remains zero, the velocity component along the x direction for all the values of the radius of the billet is zero. However, velocity component along the Y direction initially attains negative value and then becomes zero at the die exit. While the Vz component gradually increases and then attains its peak at the die exit. When the reduction ratio decreases to 60% as shown in Fig.(5,6), it is observed that the velocity components Vx, Vy and Vy respond in the same way; but the peak value of Vz is lower when compared to larger reduction ratio. When the sweep angle value is changed to 15$^o$, it is observed that both Vx and Vy component gradually increases and attains peak at the die exit. When the sweep angle is change to 30$^o$, it is observed that Vx, Vy and Vz components respond in the same way as mentioned in the case of sweep angle of 15$^o$, but the negative peek value of Vx increases. However, the negative peek of Vy decreases. There is no change in the value of Vz component for both the values of sweep angle. When the reduction ratio decreases to 60%, it is observed that the velocity components Vx, Vy and Vz respond in the same way; but the peak value of Vz is lower when compared to larger reduction ratio. When the sweep is increases to 45$^o$, the Vx and Vy components take equal negative values along the length of the die and attain zero at the die exit. Vz gradually increases and takes maximum value at the exit.

## CONCLUSIONS

It is concluded that the Vx and Vy components attain negative value and then goes to zero at the die exit when the metal is getting extruded through the die. But the Vz component always increases with the die length. The rate of increase of Vz is more for larger reduction ratios.

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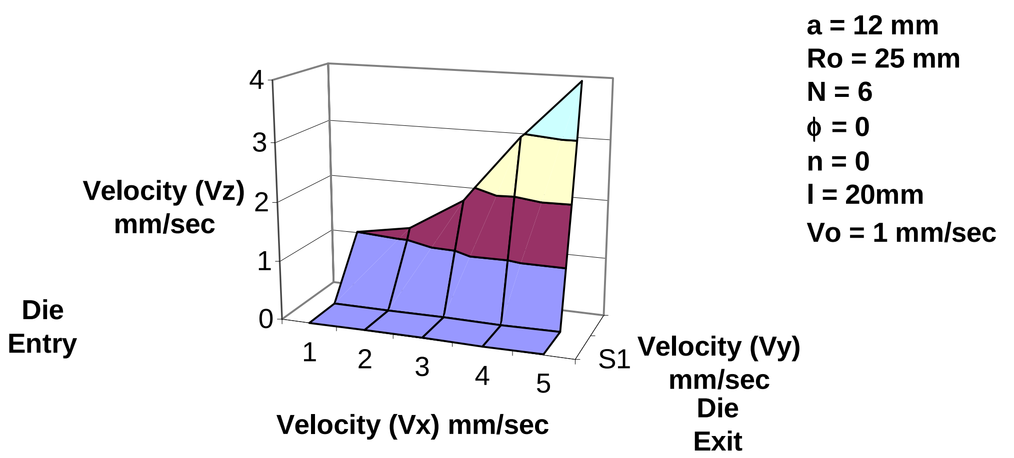


**Fig.3 Variation of velocity components with respect to the Die Length**

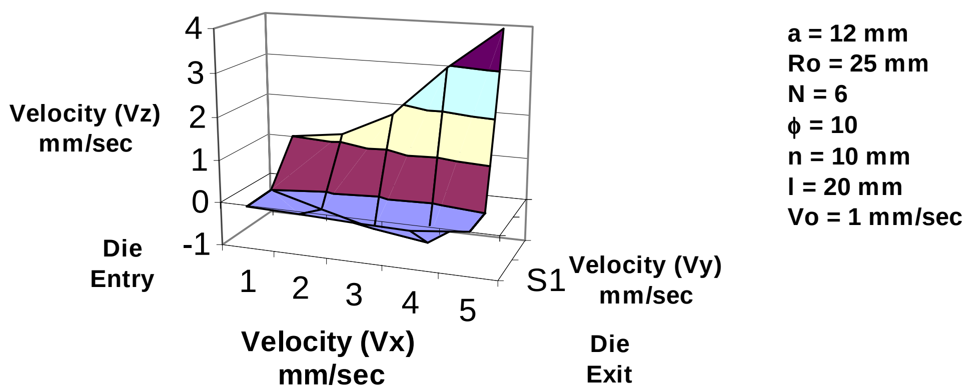


**Fig. 4 Variation of Velocity components with respect to the Die length**

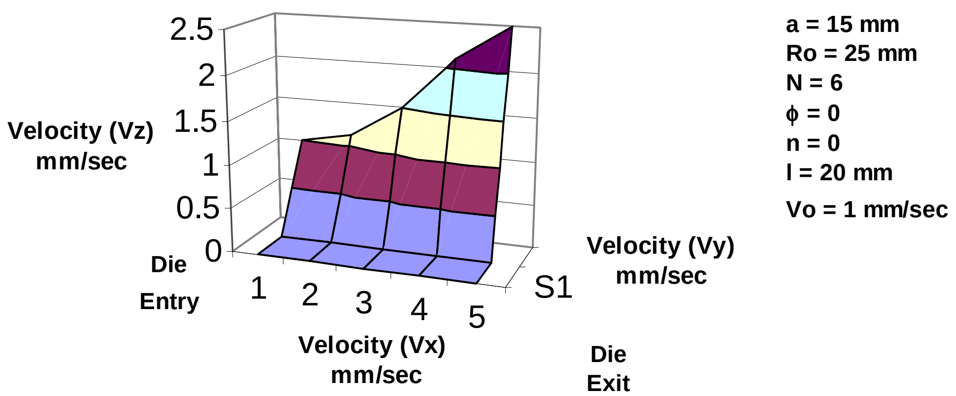


**Fig. 5 Variation of velocity components with respect to the Die length**

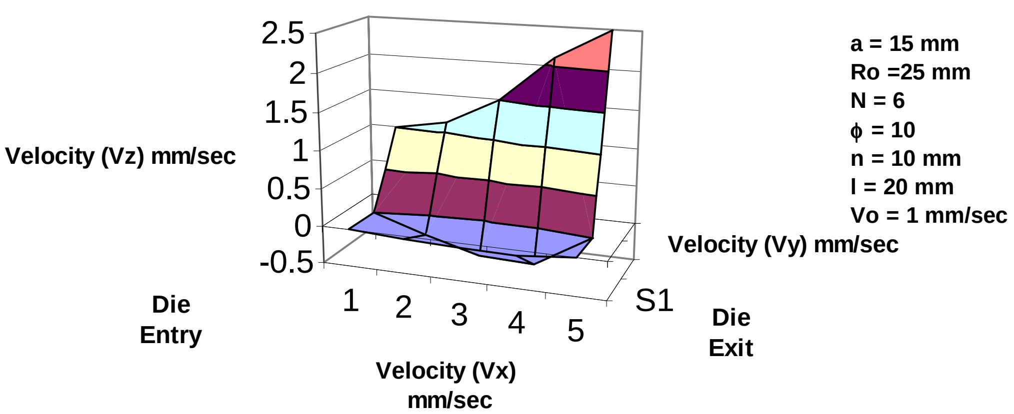


**Fig.6 Variation of velocity components with respect to the Die length**