A NUMERICAL ANALYSIS OF EXTRUSION OF SQUARE SECTION FROM ROUND BILLET THROUGH MATHEMATICALLY CONTOURED DIE WITH DESIGN OF DIE PROFILE

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ABSTRACT

The die profile plays a significant role in smooth flow of material and evolution of uniform micro-structure. It is observed that the quality of extruded product is better in converging die in comparison to flat-faced square die in general. The non-linear converging dies have some advantages over linear converging dies in terms of reduction in extrusion load, improvement in flow characteristics and evolution of uniform microstructure. The cosine die profile is observed to be the most ideal die profile with zero velocity discontinuity at the exit and entry plane. In the present investigation a die profile is designed for extrusion of square section from round billet with a cosine die profile. It is proposed to carry out FEM modeling using DEFORM-3D software for lead and aluminum.
***Keywords**: Cosine Die, Square Section, DEFORM-3D, Extrusion, Die-Design*

1. INTRODUCTION

The die profile plays a significant role in the reduction of extrusion load, gradual flow of material and evolution of uniform microstructure for linear and non-linear converging dies. On the other hand there is severe and drastic deformation in the material in flat-faced or square dies resulting in product with poor quality and surface integrity. The motivation of research has got some priority to investigate the metal flow and other process parameters of extrusion of different sections using converging die-profiles. Ponalagusamy et al. (2005) designed die profile for streamlined extrusion die with Bezier curve approach. Maity et al. (1996) developed a class of upper bound solutions for

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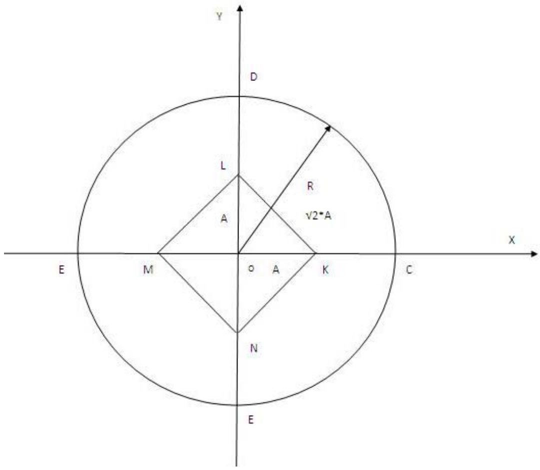
extrusion of square sections from square billet using a cosine, elliptic, parabolic, hyperbolic and circular die. The dual stream function method is used based on the continuous velocity field. It is observed that the performance of cosine die profile is superior to other die profiles. Narayanasamy et al. (2006) have modeled the extrusion of circular section from circular billet through cosine die profile. It was evident from their analysis that the performance of cosine die profile is superior to the conventional shear dies and the straightly converging dies. Narayanasamy et al. (2003) also developed a streamlined die using computer aided design for smooth flow of material. Frisch et al. (1978, 1977) have investigated the upper bound solutions with experimental flow studies using axi-symmetric curved dies with different analytic geometries. But three dimensional extrusions through mathematically contoured dies were not reported. Ajiboye et al. (2006) investigated the effect of die land length on the cold extrusion of some selected geometry using upper bound analysis. For a particular die length the normalized extrusion pressure increases with increase of percentage reduction in area, Gordon et al.(2007) used adaptable die design to determine the die profile which produce minimal distortion in the product. Jonsion carried out extrusion of pure lead and tellurium lead for circular, square, rectangular, triangular and I-section. It is shown that for particular reduction in area, the load is independent of the section shape. Rout and Maity [7] investigated extrusion of square section from square billet through a polynomial shaped curved die. It is observed that the performance of the polynomial shaped converging die is superior in comparison to elliptic, circular, hyperbolic and parabolic. But under some boundary conditions the cosine die profile yields the minimum pressure in comparison to that of polynomial shaped die resulting in saving of energy. Maity and Rout [8] investigated extrusion of square section from square billet using Bezier shaped die based on dual stream function method. It is observed that the performance of the polynomial shaped die is almost identical to the Bezier shaped die. Sahoo et al. (1999) have modeled the extrusion of section having re-entrant corners using the spatial elementary rigid region technique linear converging die. It seems that not adequate investigations have been reported for extrusions through non-linear converging dies, though the performance of non-linear converging die is superior to the linear converging die in terms of reduction in extrusion load, evolution of uniform micro-structure and smooth flow of material. It is also clear that cosine die profile is the most ideal profile.

In the present investigation a non-linear converging die profile has been designed for extrusion of square section from round billet with cosine die profile function. The die profile function satisfies the geometrical boundary conditions at the entry and exit planes. The main advantage of cosine die profile is that the flow of material is tangential at the exit and entry plane with no velocity discontinuity resulting in reduction of extrusion load with smooth flow of material. The nature of solution is general in nature which can be extended to other sections such as triangle, hexagon and others. An attempt is taken to carry out FEM modeling using DEFORM-3D software using aluminum as work material. The extrusion pressure, the effective stress, strain, strain rate and velocity of material flow will be investigated for different reductions and boundary conditions.

2. DIE PROFILE DESIGN

A non-linear converging cosine die-profile is designed for extrusion of square section from round billet as shown in Fig. 1(a). The longitudinal section of the die profile is shown in Fig. 1(b) where R is the billet radius, L is the die length and A is the half of the diagonal length of the billet at exit of the die. Fig. 1(b) Gives the resultant velocity at the entry and exit plane tangential to die profile.



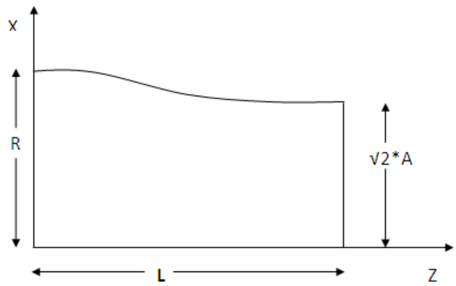


Fig. 1 - *Schematic diagram of billet and product section (a), Longitudinal section (b)*

Since the cross-section is changing from round to square along the axial length, the cross-section at any arbitrary position in between will be a different shape. Referring to fig.1 the general equations for determining x and y co-ordinates in the die profile for particular value of z are as follow:

$$x = \left[\frac{R \cdot \sqrt{1 - \frac{P}{N}} + A \cdot \left(1 - \frac{P}{N}\right)}{2} \right] + \left[\frac{R \cdot \sqrt{1 - \frac{P}{N}} - A \cdot \left(1 - \frac{P}{N}\right)}{2} \right] \cos\left(\frac{\pi \cdot z}{L}\right) \quad (1)$$

$$y = \left[\frac{R \cdot \sqrt{\frac{P}{N}} + A \cdot \left(\frac{P}{N}\right)}{2} \right] + \left[\frac{R \cdot \sqrt{\frac{P}{N}} - A \cdot \left(\frac{P}{N}\right)}{2} \right] \cos\left(\frac{\pi \cdot z}{L}\right) \quad (2)$$

where P = 0, 1, 2, 3, 4….N.

The cross-section of the deformed material at any axial position is divided into N number of points. Where p is any point on the profile and N is maximum no. of point taken. The co-ordinates have been determined in those points.
Now percentage fraction of reduction is taken as (1-Q). It is determined as follows:

$$\frac{\pi \cdot R^2 - 2 \cdot A^2}{\pi \cdot R^2} = 1 - Q \quad (3)$$

From equation (3) the values of A and Q are determined as follows:

$$Q = \frac{2 \cdot A^2}{\pi \cdot R^2}$$

$$A = R \cdot \sqrt{\frac{\pi \cdot Q}{2}}$$

Case 1:
At Z=0, i.e. at the plane of entrance we get from equations (1) and (2)

$$X = R \cdot \sqrt{1 - \frac{P}{N}} \tag{4}$$

$$Y = A\left(1 - \frac{P}{N}\right) \tag{5}$$

and cross-section will be circular which is shown in the **Fig. 3**

Case 2:
At Z=L, i.e. at the exit plane again from equations (1) and (2)

$$X = R \cdot \sqrt{\frac{P}{N}} \tag{6}$$

$$Y = A \cdot \frac{P}{N} \tag{7}$$

Case 3:
At Z=L/2, i.e. at the plane of mid axial position, similarly from equation (1) and (2)

$$X = A\left(1 - \frac{P}{N}\right) \tag{8}$$

$$Y = A\left(\frac{P}{N}\right) \tag{9}$$

3. AUTOCAD MODEL

Using equation (1) and (2) solid model of cosine die is generated in AutoCAD software. Taking R=15 mm, A=13.39mm, N=50 no of points has been generated using MATLAB software. Generated points are used in AutoCAD software to generate the solid model of the cosine die as shown in the Fig. 2(a) and top view of the die is shown in Fig. 2(b)

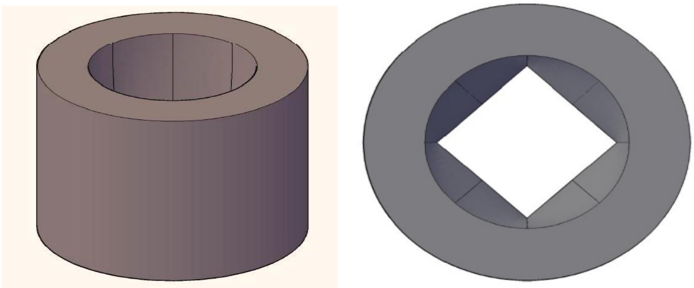


Fig.2 - *Solid model (a) and top view of die (b)*

4. RESULTS AND DISCUSSION

The die profile has been made for extrusion of square section from round billet. The die profile has been modeled at different axial positions. Due to symmetry of the section only one quadrant of the die profile has been plotted. The cross-section of the die profile at the entrance plane is shown in Fig. 3 which is a circle with radius equal to 15mm.

The cross-section of the die-profile section at the exit plane is shown in Fig. 4. This is a square with semi diagonal length equal to around 13.93mm corresponding to 50% reduction. The axial die length is equal to 50mm. The cross-section at mid axial position is shown in Fig.5 which is neither a circle nor a square. This indicates that the cross-section gradually changes from circle to square. The similar cross-sections are given Fig.6 and Fig 7 for Z=0.2L and Z=0.7L corresponding to 50% reductions. It is evident that the resultant velocity at the exit and entry planes is tangential to the die-profile. So there is no velocity discontinuity at the exit and entry planes with no redundant work. A solid model has been developed for 50% reduction using Auto-CAD 2008. The corresponding STL file has also been developed in order to do FEM modeling using DEFORM-3D commercial software using aluminum as work-materials.

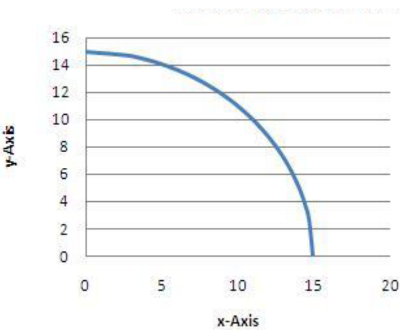


Fig. 3 - *Cross-section of die-profile at the entrance plane (Z=0)*

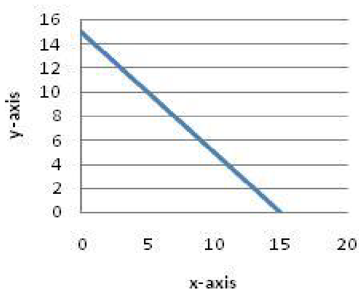


Fig. 4 - *Cross-section of die profile at the exit plane (Z=L).*

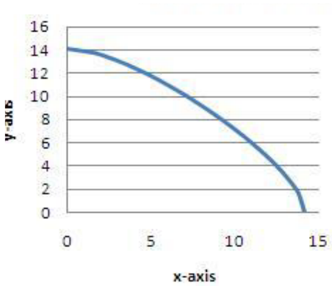


Fig. 5 - *Cross-section of the die profile at mid axial position (Z = 0.5L)*

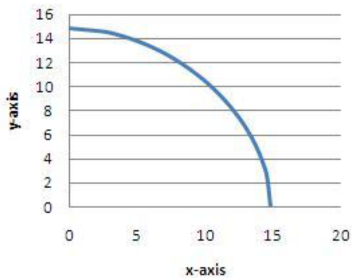


Fig. 6 - *Cross-section of the die profile at Z = 0.2 L*

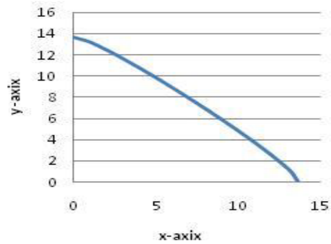


Fig. 7 - *Cross-section of die profile at Z=0.7L*

The STL file generated in AutoCAD is used in DEFORM-3D software for simulation of extrusion process for cosine die as well as taper die using Aluminium-1100 as work material. It is found that maximum load in case of cosine die is less than that of taper die as shown in Fig. 11, It is also observed that increase in load is gradual in case of cosine die. Effective stress distribution is given in fig.8. The distribution of maximum principal stress is given in Fig. 9. The distribution of velocity is given in Fig. 10

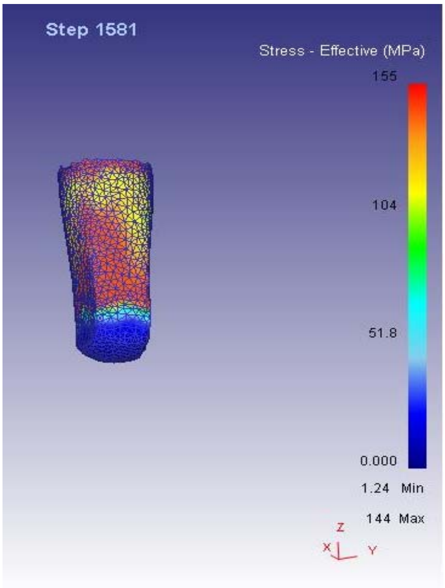


Fig.8 - *Effective stress distribution in the material during the process in deformation zone*

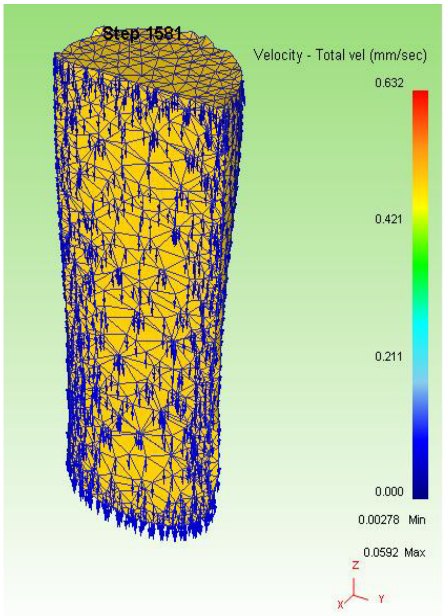


Fig. - 9 *Max. Principal stress distribution in the material during the process in deformation zone*

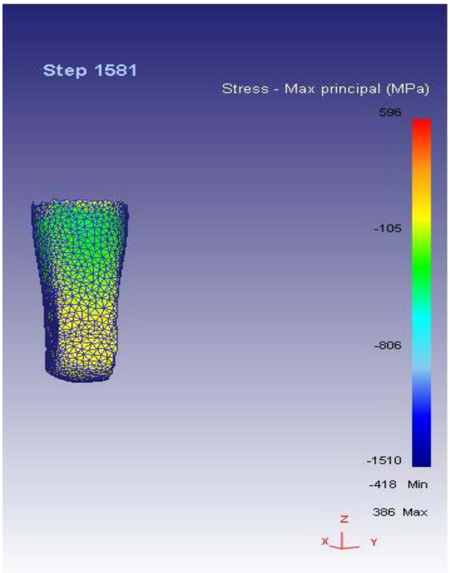


Fig. 10 - *Max. Principal stress distribution in the material during the process in deformation zone*

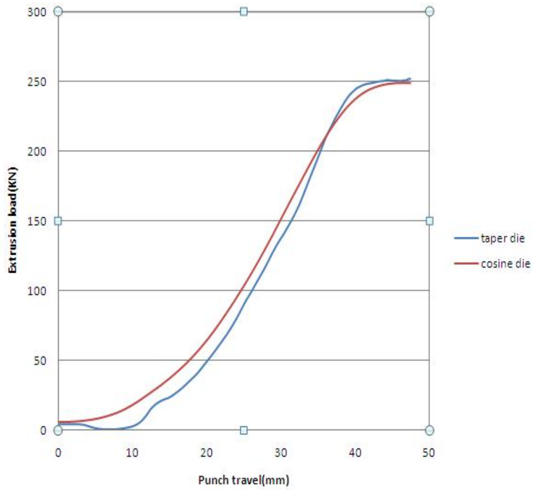


Fig. 11 - *Graph between punch travel and extrusion load for cosine die and taper die*

5. CONCLUSION

- A die profile has been designed for extrusion of square cross-section from round billet a solid model has been developed.
- FEM modeling has been carried out for extrusion through cosine die using Aluminium-1100 as work material
- It is observed that there is reduction in extrusion load in cosine die and increase in load is more gradual in case of cosine die compare to taper die.

REFERENCES

[1] Ajiboye, M.B. Adeyemi , Upper bound analysis of die land length in cold extrusion, Journal of Materials Processing Technology 177 (2006), pp. 608–611.

[2] Frisch, J. and Mata-Pietric, E., Experiments and the Upper Bound solution in Axisymmetric extrusions, In: Proceedings of the 18th International Machined Tool Design Research Conference, London, Macmillan, 1978, p.55.

[3] Frisch, J. and Mata-Pietric E., Metal flow through various mathematically contoured extrusion dies. In: Proceedings of the North America Metal-working Research Conference, North America, 5, 1977.

[4] Gordon, C.J. Van Tyne, Y.H. Moon, Overview of adaptable die design for extrusions, Journal of Materials Processing Technology 187–188 (2007), pp. 662–667

[5] Johnson, Experiments in the cold extrusion of rods of non-circular sections, Journal of Mechanics and Physics of Solids 7 (1958), pp.37-44.

[6] Maity, K P, Kar, P K., and Das, N S, A class of upper bound solutions for the extrusion of square shapes from square billets through curved dies, International Journal of Materials Processing Technology, 62 (1-3), 1996, pp.185-190.

[7] Maity, K. P. and Rout A. K., An Upper Bound solution to Three-dimensionla extrusion through a Bezier shaped curved die, International Journal of Manufacturing Technology and Research,5, 2009, pp.1-2.

[8] Narayanasamy, R, Ponalagusamy, R, Venkataresan, R, and Srinivasan, P, An upper bound solution to extrusion of circular billet to circular shape through cosine dies, International Journal of Materials and Design, 27(5), 2006, pp. 411-415.

[9] Narayansamy R, Srinivasn P and Vekatesan R., Computer aided design and manufacture of streamlined extrusion dies, International Journal of Materials Processing Technology, 138, 2003, pp.262-264.

[10] Ponalagusamy, R., Narayansamy, R and Srinivasan, P, Design & Development of streamlined extrusion dies a Bezier curve approach, International Journal of Materials Processing Technology, 161, 2005, pp.375-380.

[11] Rout A K and Maity K P, Numerical and Experimental study on the three-dimensional extrusion of square section from square billet through a polynomial shaped curved die, Int. J. of Advanced Manufacturing Technology, Springer Publication, In Press.

[12] Sahoo, S. K., Kar, P. K. and Singh K. C., A numerical application of the Upper Bound technique for round-to-hexagon extrusion through linearly converging dies, International Journal of Materials Processing Technology, 91,1999, pp.105-110.

NUMERIČKA ANALIZA ISTISKIVANJA KVADRATNIH PROFILA IZ CILINDRIČNIH UZORAKA SA DIZAJNIM PROFILA ALATA

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REZIME

Profil alata igra značajnu ulogu za nesmetano tečenje materijala i ostvarivanje ujednačene mikrostrukture kod istiskivanja. Pokazano je da je kvalitet obradaka dobijenih istiskivanjem bolji pri primeni konvergentnih alata nego u slučaju primene ravnih kvadratnih alata. Nelinearni konvergentni alati imaju određene prednosti u odnosu na linearne konvergentne alate u smislu redukcije sile koja se javlja u procesu, poboljšanja uslova tečenja materijala i obezbeđivanja ujednačenije mikrostrukture. Alati sa kosinusnim profilom se smatraju idealnim zbog toga što ne postoji diskontinuitet u brzini tečenja na ulaznoj i izlaznoj ravni alata. Za istraživanja prikazana u ovom radu konstruisan je alat za istiskivanje četvrtastog poprečnog preseka iz cilindričnih uzoraka. Predloženo je korišćenje MKE primenom DEFORM-3D programa.

***Ključne reči**: Kosinusni alat, kvadratni poprečni presek, DEFORM-3D, istiskivanje, dizajn alata*