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Virtual Design And Fabrication Of A Continuous Extrusion Setup With Process Analysis

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ABSTRACT

The production of complicated metallic profiles with high degree of dimensional accuracy and control with very thin walls has been the major problem encountered with conventional extrusion process. In this paper a design and fabrication of a continuous extrusion process for extruding complicated endless profiles has been presented virtually using computer aided design and manufacturing concepts. The iterative process of CAD has been used to arrive at the final design of various components and has been fabricated virtually by Auto CAD 2002. The setup has been evaluated using plastic deformation concept to calculate the total power and pressure required for aluminum coil of ¼ inch diameter. The analysis of the design therefore includes hot extrusion die design analysis and the continuous extrusion process analysis using Upper Bound Method and Finite Element Method.

Key words: Continuous Extrusion, FEM, Upper Bound Method

1. Introduction:

Extrusion process is chip less manufacturing process of forcing the work material to flow through a die opening of desired shape. In conventional or direct extrusion finds application in the manufacture of solid rods, bars, hollow tubes, and hollow and solid sections according to the design and shape of the die. But in the modern era of science and technology there is a requirement of such a process in which continuous long profiles can be formed without any interruption i.e. a continuous extrusion process.

The basic principle of continuous extrusion process involves a wire/rod which is inserted in the groove of wheel is drawn by friction against the wheel and the groove closed by a close fitting shoe as shown in Fig. 1.a and 1.b. The material is prevented to continue its passage around the wheel by means of an abutment. As a result, high temperatures and pressures are developed in the material, which becomes plastic and subsequently emerges from the machine through an extrusion die. The product can take a variety of forms including tubes, solids and complex profiles. A critical part of the process is the extrusion shoe, which houses the extrusion die, the separate tooling segments and the abutment. Since the material generates frictional heat and modification heat, temperatures up to 500 degree Celsius or more can be achieved, without using heater for the copper wire. The material is in the high plastic flow state due to the modification to the shear direction at the abutment and the high temperature .thus near net shapes of irregular sections become possible. in addition ,since the extruded material is completely recrystallized, it is in a tempered state, since the form of supplied material is a wire rod ,it possible to extrude continuously , without having to stop the machine in order to join pieces of material together . This is advantageous because large coils of products can be formed.

The continuous extrusion forming process use frictional force between a circular driving wheel and material, as shown in Fig. 1, can produce significantly long continuous products of a variety of sectional shapes which are hard in the classical forming processes owing to their methodological limitation [1]. Because of its superiority and impact on the current forming technology are evident, demand from industry has been growing rapidly. Basic experimental and analytical studies have been underway continuously since the late 1980s. However, theoretical and numerical studies are still insufficient to analyze accurately the complicated process characteristics. Furthermore, study on the effects of major process parameters such as wheel velocity, relative die opening width, and flash gap size is essential for the optimal design of Continuous

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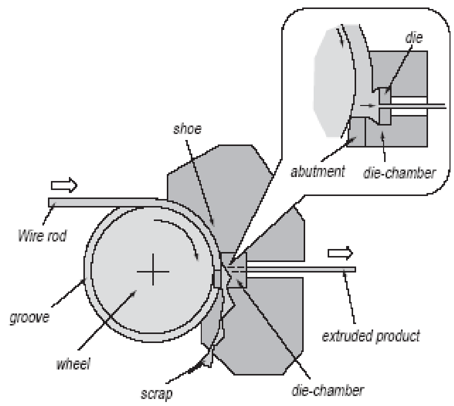


Figure.1a. Details of Continuous Extrusion process

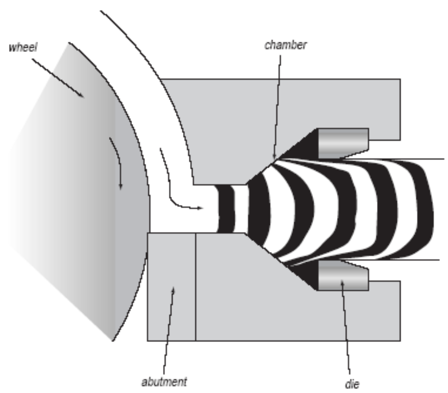


Figure.1.b. Metal flow from abutment passage to die entry

2. Literature Review: Lu et al. (1998) [5] developed a mathematical model for the continuous extrusion process. The model enables the prediction of the temperature, stress, strain and strain – rate fields in the work piece into machine and machine components. Cho et al. (2000) [6] proposed to calculate the powers required in steady state CONFORM process. In addition, comparison with respect to the extrusion ratio was made, from which it was observed that the powers decrease as the extrusion ratio increases. Aluminum (Al -1100) of yield stress 60 MPa was used as that material. Manninen et al. (2010) [7] investigated the FEM modeling of conform extrusion. The material model was visco plastic and thermally coupled. The abacus/explicit and DEFORM-3D codes were used for the simulation. Tonogi et al. (2002) [8] describes the technology of conform extrusion developed for irregular section copper and examples of products to which it can be applied. Die strength, metal flow and internal defects of copper irregular sectional extrusion was examined. Manninen et al. (2006) [9] explain the mechanics of flash formation during steady state continuous extrusion. They developed an analytical model for estimating the flash shape and the amount of scrap produced. Katajarinne et al. (2006) [10] carried out realistic 3D finite element simulations to study the formation of flash in continuous extrusion of copper under different frictional condition. Kim et al. (1998) [11] investigated the effects of several significant process parameters on the process characteristics in the CONFORM process, such as material flow, defect occurrence, temperature and effective strain distributions using DEFORM commercial FEM Code.

Khawaja et al. (2001) [12] investigated an active gap sensing and control system for improving conform extrusion product quality. The gap is measured using an air gauge system and controlled using a hydraulic actuation system. Khawaja et al. (2004) [13] investigated, and designed a high temperature capacitive gap sensing system and implemented on a copper extrusion machine in a production plant. It was shown that machine set-up time was reduced from 35-40 minutes to 5 minutes with active gap sensing. It was also shown that there is a linear reduction of waste levels from 20% to 2% when gap size is reduced from 1mm to 0.15mm. Clode et al. (2005) [14] investigated and implemented high temperature capacitive gap sensing system on a copper conform extrusion machine in a production plant. They proved that the sensors can be used for on-line direct gap measurement and control and for the first time, provide a detailed view of extrusion zone gap behavior during a full production cycle. Form the experimental results, three different stages of a conform extrusion cycle, start, slugs feed, and steady state extrusion can be clearly identified. The gap sensor is used to evaluate the relationship between gap size, and waste levels. It is shown that there is a linear reduction of waste levels from 20% to 2% when the gap size is reduced from 1 to 0.15.mm.

Cho et al. (2000) [1] address a parametric investigation on the occurrence of the surface defect in this process. Here, the wheel velocity, the extrusion ratio, the abutment height, the friction coefficient and the flash gap size are taken as parameters and numerous parametric numerical experiments are carried out in order to analyze their effects on the surface defect occurrence. They used DEFORM-3D for the simulation. Cho. et al .(2001)[15] addresses the three dimensional finite element analysis of the process aimed at the parametric investigation of the curling phenomenon and the understanding of the process characteristics closer to the real process .For this goal, they first made the flow dynamic analysis on the phenomenon as well as three dimensional finite element analysis of CONFORM process. Cho et al. (2003) [16] numerically examined the effects of wheel diameter on the surface separation and curling phenomenon as well as after significant process characteristics, through the two-dimensional finite element analysis of CONFORM process for solid section aluminum products.

Peng- yue et al.(2007)[17] carried out study on CONFORM process for producing concave bus bar under different extrusion wheel angular velocities by three- dimensional finite element technology based on software DEFORM-3D .The distributions of velocity field, stress field, strain field, temperature field and damage field were investigated under different extrusion wheel angular velocities.

Zhu et al. (2004) [18] investigated a new severe plastic deformation (SPD) technique which combines equal channel angular pressing (ECAP) with conform to process ultrafine grained (UFG) materials in a continuous extrusion manner. In this invention principle used to generate frictional force to push a work piece through an ECAP die is similar to the conform process, while a modified ECAP die design is used so that the work piece can be repetitively processed to produce UFG structures. Wei et al .(2009)[19] analyzed the deformation behavior of the pure copper rod in the continuous ECAP process using DEFORM-2D.The effect of die angle φ and the friction between the die channels and the specimen on the stress strain distributions, strain homogeneity, the feature of shear deformation and the torque was investigated. In the continuous ECAP, shear deformation exists in the die angle ranged from 900 to 1200; however the pattern and extent of shear deformation are different to that in Conform and ECAP.The effective strain is uniform in most parts of the work piece. As ϕ increases, the corner gap becomes smaller and the strain distributions are less homogeneous. The extent of shear deformation, homogeneity of stress strain can be improved by the friction on the interface of the die and work piece but the maximum torque value increases. The assumed shear deformation was further divided into three stages, which was well explained by torque-time curves and the effective stress fields. The results indicate that the continuous ECAP process is a promising approach for producing ultra-fine sheet, bar, rod and wire. Langdon et al. (2010) [20] made investigation to critically evaluate the ECAP-Conform process with a special emphasis on the two areas where no information is at present available. First, detailed hardness measurements were undertaken to evaluate the extent of homogeneity within the microstructure after processing by ECAP-Conform with separate measurements taken to determine both the homogeneity within the cross-sectional planes of processed rods and the variations in the micro structural homogeneity along the lengths of the processed rods. Secondly, mechanical testing was undertaken to determine the extent of any plastic anisotropy at may be present within the rods after processing by ECAP –Conform. The experiments were conducted using a commercial Al-6061 alloy.

Kumar et al.(1999) [21] developed a feature recognition methodology based on wire frame solid modeler to recognize hollow/solid extrudable components using single and multiple hole die for designing extrusion dies.

3. Virtual Design &Fabrication of the Continuous Extrusion Setup:

Based on the previous discussion a three dimensional working model for a continuous extrusion setup for ¼ inch aluminum feedstock has been designed. The CAD software Auto CAD 2002 has been used for the purpose. The designed setup is outcome of the iterative process of the CAD and it is working as well as feasible setup. In the designed Fig ( ), a wheel is shown on which trapezoidal groove has been cut. The shaft of the wheel is coupled with the shaft of the motor that rotates through gearing arrangement. The feedstock through the dragger moves and is fed to the groove cut on the wheel. As the wheel rotate, feedstock is carried away along with the wheel up to the one fourth portion of the wheel where a detachable abutment is placed which restricts with friction the feedstock to its further movement along with the wheel. As a result, the feed stock is heated to a high temperature initially due to friction and then after restriction with the abutment. Due to pressure the feedstock becomes soft plastic alloy while reaching to the die set. At the end of the abutment a die is placed. The entry of the die set is specially contoured to provide the easy entry of the feedstock in it. As the material gets soften, the material easily passes through die to get extruded to a desired shape and size. The output product through the die is coiled away to a coiler attached with another motor. The whole arrangement is mounted on foundation. The end coiler's speed can be adjusted with the desired speed of product.

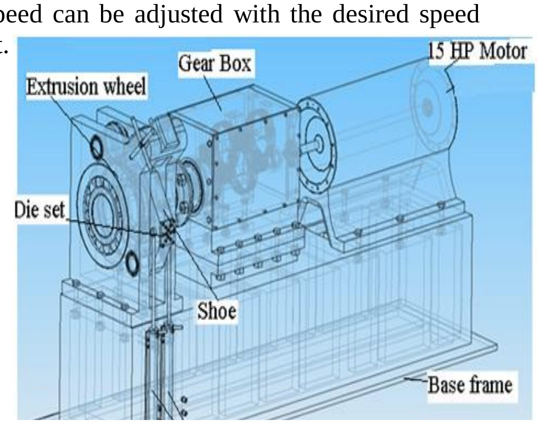


Figure.2. Set-up of Extrusion

4. Design and deformation analysis of continuous extrusion process

To make the process continuous a continuous grooved section pressure container is required. And this is most simply provided by having a rotating grooved wheel. The stationary side shoe which fits around part of the wheel circumference and is of sufficient length for the process. The product may be extruded in either a radial or tangential direction, or indeed in both.

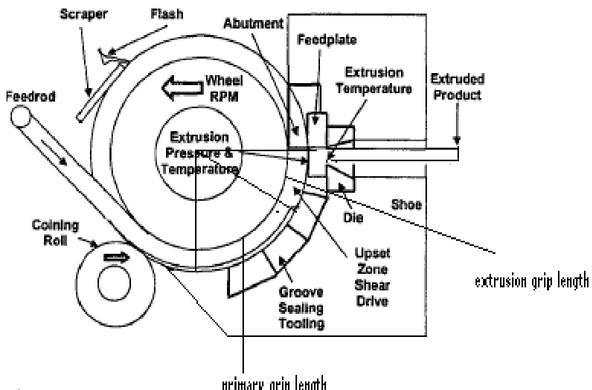


Figure.3. Diagrammatic arrangement of continuous extruder

It is possible to predict the grip lengths necessary to ensure that extrusion will occur from knowledge of the geometry, feedstock property, coefficient of friction and the extrusion ratio.

l_2=extrusion grip length
l_1=primary grip length

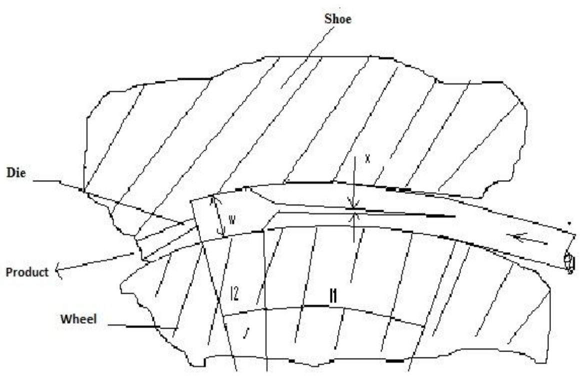


Figure.4. detail showing grip length

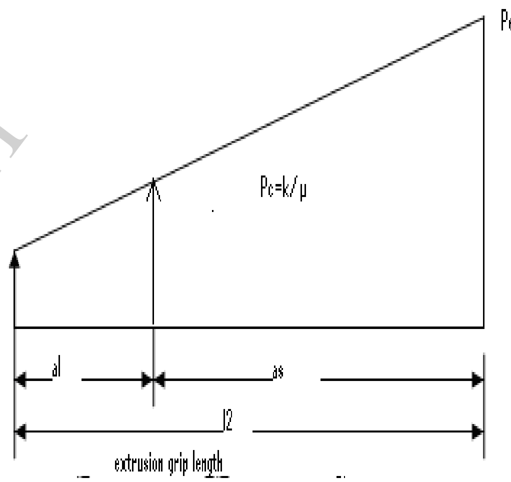
The coining of the feedstock into the groove compresses the material setting up yield stress in the outer fibers containing the sided of the container. The primary grip length friction force must set up axial yield in the metal, and only two sides of the groove are effective, the other two sides canceling each other. Then

Primary driving force $=2\,Y\mu x l1$
This must generate axial yield$=YA$
Where, Y=compressive yield strength of feedstock
X=contact width
$l1$=primary grip length
A=cross sectional area of feedstock =cross sectional area of groove
Now if groove depth =groove width =w, then-

$$A=w^2$$

And if, $X=w/4$ then,
$l1=2w/\mu$

<u>Extrusion grip length</u>: - there is increase in contact stress between the feedstock and container wall from the point at which yielding occurs up the point at which shearing of the feedstock can occur. The contact stress for this discontinuity between skidding and shearing is given by:
$Pc=k/\mu$



Figurwe.5. variation of pressure along extrusion grip length

$$l2=a_l+a_s$$

Then,
$P_eA'=2w\,[a_l/4+a_s]$
Where;
a_l=length over which sliding can occur
a_s=length over which shearing can occur
w=depth and width of groove
k=shear strength of feedstock
μ=coefficient of friction
P_e=extrusion pressure
Pc=contact pressure
A'=cross sectional area of groove ($w^{2)}$
In the extrusion of metals with low shear strength, $a_l << a_s$
Then,
$l2= a_s$
The extrusion grip, $l2=[\,P_ew/2k]= [P_e/Y]$

Now the total power requirements for extrusion of feed rod have the following components…

a. Die power (P_D):- this correspond to the total power consumed inside the die for the deformation of the material .it is found based on the theory of upper bound model.

b. Container power (P_c):- this corresponds to the power consumed inside the container portion of the die set. So the expression of the power consumed inside the container is…

$$Pc=2\pi\ \mu\ (\sigma_0/\sqrt{3})\ L_{opt}\ R_0\ V_0\ \text{watts}$$

Where, L_{opt}=optimum die length
R_0=radius of feedstock
V_0=peripheral velocity of wheel
σ_0=yield shear stress of feedstock material

c. **Bearing power (P_B):** - this corresponds to the power consumed inside the bearing portion of the die set. So the expression of power consumed inside the bearing portion is…

$$P_B = \mu\ (\sigma'/\sqrt{3})\ L_1 P_1 V_{end2}\ \text{watts}$$

L_1=bearing length of feedstock
P_1=perimeter of product
V_{end2}=velocity of product
σ'=flow stress of the feedstock material

d. **Biting power (P_b)**:- this corresponds to the power consumed while the feed stock make entry into the shoe portion and grooved wheel. Due to very high friction the temperature of feed stock rises. So the expression of biting power is given as…

$$P_b=Y\ \mu x l1 * V_0\quad \text{watts}$$

e. **Deformation power or shear power at the shoe face(P_f)**:- at the shoe face the material gets softened and tends to make the way into the die region .before stepping into the die, the material gets deformation at the shoe face and become soft . Therefore some power is consumed in deformation at the shoe face.

Shear power=shear force*deformation velocity
=wl2K*(peripheral velocity of wheel)

f. When the feed stock strikes the abutment, the feedstock finds only the way into the container surface after reflecting from the abutment .there are feedstock attains the plastic stage and turns into the grooved surface of container .so, the expression for consumed is…

$$P_{turning}= \sigma'/\sqrt{3} * \mu * L_1 * P_1 * V_0 * Cos\Theta$$

Where, Θ=angle between horizontal container surface and feedstock while turning

So, the total power required for extrusion of feedstock is given by…

$$Pe= (P_D) + (P_c) + (P_B) + (P_b) + (P_f) + P_{turning}$$

Total average pressure required for extrusion of feed stock

$$= [(\text{total power})/ \pi R_0^2 V\ (\text{peripheral})]$$

Also the total torque can be estimated in the fallowing way…

$$\text{Total power } (P)=[(2\ \pi\ N\ T)/60\}$$
$$Or,\ T= [(P*60)/2\ \pi\ N]$$

Design of slot (Wheel groove) :- the trapezoidal groove is cut on the periphery of the wheel. Feedstock when passed through this groove very high frictional force is developed .this frictional force play vital in raising the temperature .so, the design of slot should be as such to attain the extrusion temperature .so; the design of slot should be as such to provide thigh friction to feedstock while making entry into the groove.

5. Estimation of temperature:-

estimation of temperature rise due to the friction when feed stock enters into the groove ,the fallowing expression indicates the temperature rise.

$$\Delta T= (P_f*t_c)/ (\rho V_s*C_p)$$

Where,
t_c =constant time of feed stock with the groove
ρ= density of feed stock material
C_p=specific heat of feedstock material
V_s =volume of feedstock material

Design of gearing system: - To rotate the wheel at optimum rpm the worm gearing arrangement is designed.

Design of wheel shaft: - The shaft on which wheel is mounted is designed on the basis of torque.
Torque in shaft is given by T= $2\pi N/60$
Where T is Torque and N is rpm of the shaft

6. Results and Discussion

:The average pressure, total extrusion power and total torque has been determined using upper bound technique for Al-6061 aluminum alloy of ¼ inch diameter for extrusion ratio of 1.25. The average extrusion pressure, total extrusion power and total torque are found to be 1106 MPa, 5.5 KW, and 5.25 KNm respectively.

7. Conclusion

: A continuous extrusion setup has been designed for extrusion of complicated endless profiles using iterative process of the CAD and has been fabricated virtually by Auto CAD 2002. With the aid of designed continuous extrusion setup, analysis of average extrusion pressure, total extrusion power and total torque for extrusion of ¼ inch diameter of Al-6061 alloy has been made using upper bound technique. It has been observed that the results obtained are found to be accurate and satisfactory for the designed extrusion setup.

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