CHAPTER 1

INTRODUCTION

1.1 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.

The continuous extrusion forming process uses the frictional force available between a circular driving wheel and the feedstock material, as shown in Figure 1.The process can produce significantly long continuous products of a variety of sectional shapes which are hard to produce through the classical extrusion processes owing to their methodological limitation [Green et al., (1972)]. Because of the superiority of Continuous Extrusion and impact on the current forming technology are evident, demand from industry has been growing rapidly. Basic experimental and analytical studies on Continuous Extrusion have been underway continuously since the late 1980s. However, theoretical and numerical studies are still insufficient to analyze accurately the complicated process characteristics. Furthermore, studies on the effects of major process parameters such as wheel velocity, relative die opening width, and flash gap size is still essential for the optimal design of Continuous Extrusion process [Etherington et al., (1974)].

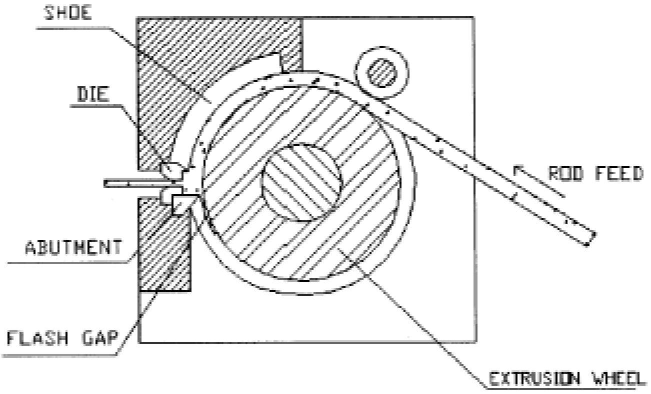
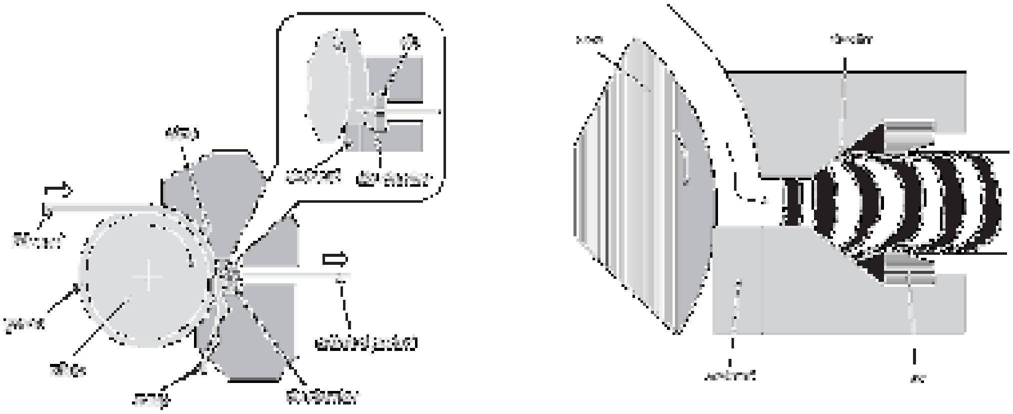


Figure 1.1: Schematic diagram of Continuous Extrusion process [Green et al. (1974)]

1.2 Principle of Continuous Extrusion process: - The principle of Continuous Extrusion process involve a feedstock inserted in the groove of wheel is drawn by friction against the wheel and the groove being closed by a close fitting shoe [Fig 1.2 a] & [Fig 1.2 b]. The material is prevented from continuing 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 out of the machine through an extrusion die. The product out 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 temperatures up to 500 degree Celsius or more can be achieved, without using any heater. The material undergoes a high plastic flow state due to the modification in the shear direction at the abutment and a 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 stock material is a wire rod, it is possible to extrude continuously, without having to stop the machine in order to join pieces of material together. This is the main advantageous because large coils of products can be formed [Boyer et al., (1985)].



(a) Continuous Extrusion machine

(b) Metal flow from die

Figure 1.2: Principle of Continuous Extrusion process [Bridewater and Maddock, (1992)]

Table 1.1: Comparison between Conventional Extruder and Continuous Extruder [Agrawal et al. (2002)]

Points	**Conventional Extruder**	**Continuous Extruder**
Feed	Billet	• Coiled rod • Molten metal • powder material
Process	• billet homogenizing needed • discard in the process preheating needed for billet • intermittent • tooling are big and need preheating • man power at least 6	• not needed • not discard • continuous • tooling are big and do needed preheating • manpower only 4
Cost	• tooling cost high • power 1000 Kwh/T • maintenance cost is high • productivity higher • product range higher • tolerance wider	• low • 600 Kwh/T • Low • Lower • Lower • Tolerance closer
Product	• Possible in cut length • Product such as ref. tubes & very thin tubes not possible • Recovery 75%	• In cut length and continuous coils • Possible • 85%
Metallurgical properties	• Strength good in all alloys • Elongation is good • Surface quality good	• perfect for 6063 • good • good

1.3 Important Metallurgical Considerations in Continuous Operation

The continuous extrusion process involves a severe thermo-mechanical deformation of the material & during the process extrusion is not homogeneous unless stabilized.

The following observations regarding materials flow are noticed:

1. Materials flow from the wheel into the expansion chamber in semi-spherical wave pattern, this results in material flow along the centre and other edges of the

expansion chamber, feeder block and the die. Areas of dead metal zones are also created along the corners of the expansion chamber and the feeder block.

2. There is a central layer that appears deformed, and the grains appear larger compared to the grains in the peripheral regions.
3. The material along the peripheral regions surrounding the central regions appears to have undergone several deformations.
4. The surface layer of the feed rod appears to end up at the surface of the product.

Several experiments have been carried out using input rods, which have been scalped or chemically treated to remove any surface oxides. The die shaving and the chemical etching of the surface produce a slight reduction in the overall oxide within the material. However, the contribution of surface oxides to the swirls appears to be very small compared with the contribution of the carry-over aluminum sticking to products, which cannot be produced normally on the conventional extruders.

1.4 Main Element features of the Continuous Extrusion Setup

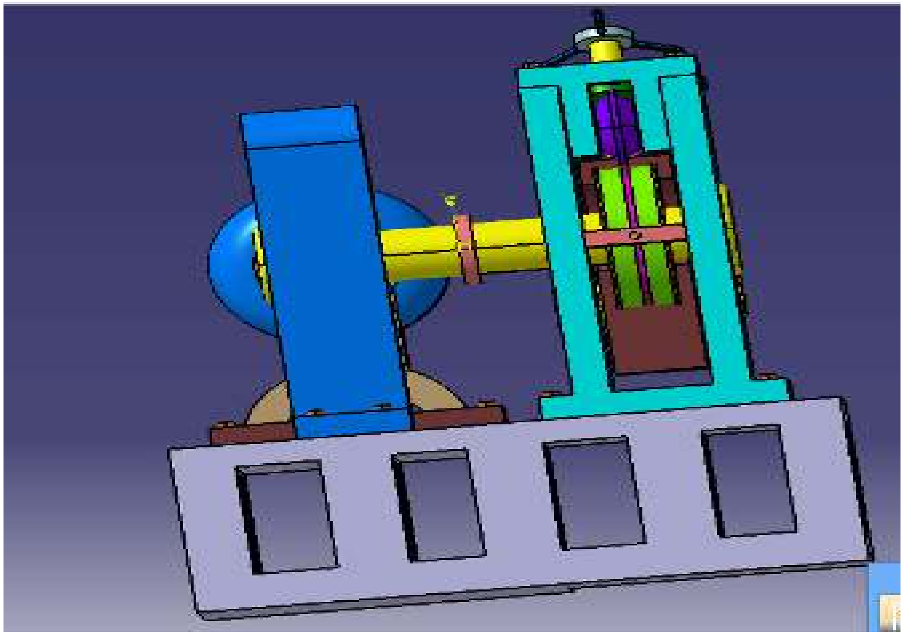


Figure 1.3: Schematic Diagram of Design Developed and Fabricated Continuous Extrusion Setup for 9.5 mm Aluminum feedstock material

Continuous Extrusion Press

The basic principle and process of extrusion as employed in a conventional extrusion and the continuous unit are same. However it is necessary to pre heat the metal to a temperature of 440 to 460^0C and then to exert a unidirectional substantial force to cause the metal flow through a die mounted in a rigid position.

The Extrusion Wheel

In a continuous extrusion press a 300 mm grooved wheel has been mounted on a shaft. The shaft is powered to rotate though a train of gears by a powerful D.C. Motor to impart a anti clockwise variable rpm of 0 to 30. The extrusion wheel is machined out of AISI HII Steel and heat-treated and tempered to a handiness of RC 48 to 50. The extrusion wheel acts as a carrier of the metal and ensures positive flow of metal to the die chamber.

The Extrusion Shoe

The Extrusion Shoe is an L shaped device made of H_{11} steel. The shoe is mounted on a hydraulically movable bed-plate. The L shaped shoe in machined in such a way that when the shoe is brought close to the wheel it embraces the moving wheel leaving a constricted gap for the feed rod to pass between the wheel and the plates arranged one over the other. These are called as entry plate friction plate and the feeder plate. These plates are fixed up on the extrusion shoe in such in such a way that the entry gap between the wheel and the entry plate is 0.9 mm and at the exit is 1.2 mm max. The Extrusion shoe is also provided with an abutment bridge, where is ABUTMENT fixed. This abutment sits just above the die-chamber in the grooved wheel and stops the feed rod to rotate along the wheel beyond this point, just below the abutment bridge there is Die chamber in the shoe. The Die along with its support tooling is housed in this chamber.

Hydraulic Intensifiers

There are two hydraulic intensifiers, which exert locking pressure of about 7000 PSI from the top and Rear, of the shoe and are called the top and Rear clamps. These clamps are operated to hold the shoe firmly in position and I turn the die assembly to withstand the Extrusion force caused by the constant input of metal by the positive rotation of the wheel pushing the metal.

The Feedstock

The metal feed to the continuous extruder is 6.35-mm properzi rod of aluminum. The production of feed rod though out the scope of this paper, is described here in the sketch. He feed rod in coil from, weighing 1 to 2 M.T. is mounted on the pay off wheel. One end of rod is pulled and passed though a cleaning system. The chemical cleaning system is essential to ensure quality. The feed flows thoroughly cleaning to free it from dirt, oil and grease etc. some conform units even deploy brushing rolls to remove the outer skin, so as to remove all adhering dirt, nicks and scores from the rod to provided a smooth surface to the rod.

The process of continuous Extruder is comparatively simpler, as compared to a conventional Hydraulic Extruder. The continuous process uses rod in coil form produced on properzi machine as stock.

1.5 Types of Continuous Extrusion Processes

Radial extrusion

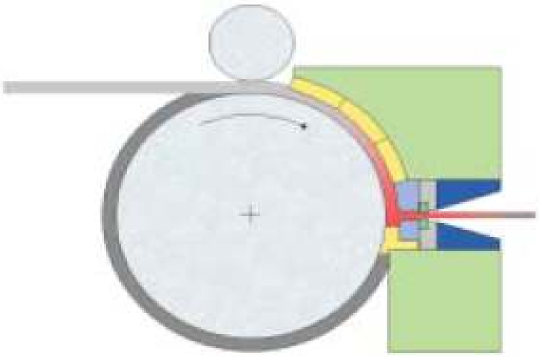
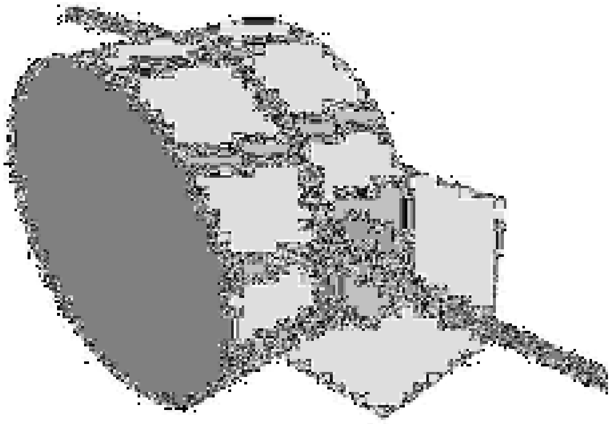


Figure 1.4: Radial extrusion [IR 1, (BWE Ltd, UK)]



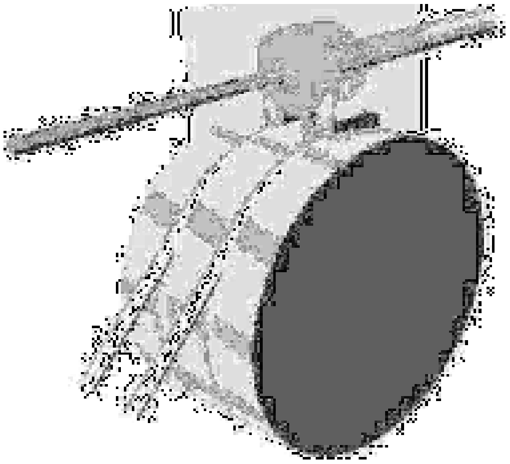


Figure 1.4(a): Single groove radial [IR 1, (BWE Ltd, UK)]   Figure 1.4(b): Twin groove radial

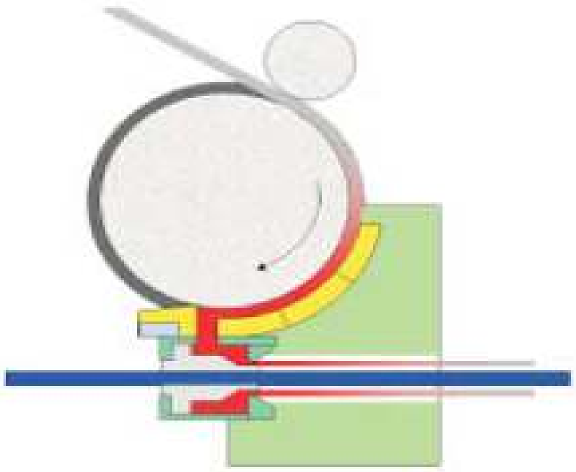


Figure 1.5: Tangential Extrusion process [IR 1, (BWE Ltd, UK)]

The flow of direction of extruded material is along radial direction to the extrusion wheel in case of radial continuous extrusion process as shown in Fig. 1.4 above. In single groove radial only one feedstock can be feed in the groove of extrusion wheel whereas in twin groove radial, two feedstock can be feed at a time in the groove of extrusion wheel as shown in Fig.1.4 (a) and Fig.1.4 (b) respectively. The flow of direction of extruded material is along tangential direction to the extrusion wheel as shown above in Fig. 1.5.

1.6 Deformation Characteristics of metal during the process

The metal flow pattern in extrusion, as in other forming processes is important because of its influence on the quality and mechanical properties of the final product. The material flows longitudinally, much like incompressible fluid flow in a channel, thus extruded products have an elongated grain structure.

A common technique for investigating the flow pattern is to section a round billet in half lengthwise and then mark one face with a square grid pattern. The two halves are placed in the chamber together and extruded. The products are then taken apart and studied. Typically, three different metal flow patterns have been observed during the process of extrusion depending upon the prevailing conditions. The conditions under which the different flow patterns are obtained are shown in Figure 1.5 and described below.

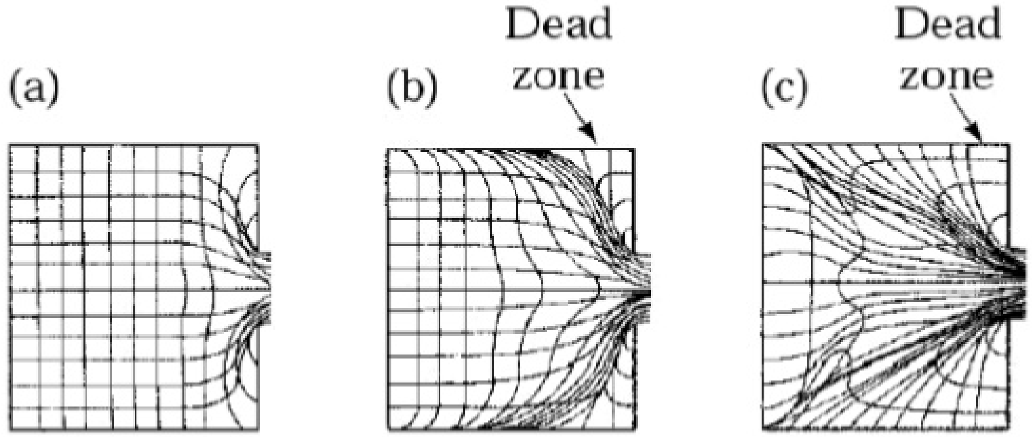


Figure 1.6: Pattern of Material flow in process of Extrusion [Lau and Stranger, 1981]

a. The most homogeneous flow pattern is obtained when there is low friction at the billet –container- die interfaces. This type of flow occurs in direct extrusion or when the lubricant is very effective in direct extrusion. Figure 1.6 (a).

b. The type of flow shown in Figure 1.6 (b) occurs when the friction at the billet – chamber interface is high. A dead-metal zone develops here. As a result a high shear area appears as the material flows into the die exit, somewhat like a funnel. This configuration may indicate that the billet surfaces could enter the high shear zone and be extruded, causing defects in the extruded product.

c. Figure 1.6 (c) shows pattern obtained at high friction or with cooling of outer regions of the billet in the chamber. This type of pattern observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe, or extrusion defect.

Thus the two factors that greatly influence metal flow in extrusion are the frictional conditions at the billet-container –die interfaces and thermal gradients in the billet.

1.7 Types of defects occurring during extrusion

Depending on the material condition and on process variables, extruded products can develop several types of defects that can significantly affect their strength and product quality. There are three principle extrusion defects; internal cracking, pipe and surface cracking as described below. Figure 1.6 (c) shows pattern obtained at high friction or cooling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whose strength increases rapidly with decreasing temperature, leads to a defect known as pipe, or extrusion defect.

Thus the two factors that greatly influence metal flow in extrusion are the frictional conditions at the billet-container-die interfaces and thermal gradients in the billet.

(i) Internal Cracking:

The center of an extruded product can develop cracks variously called as center cracking. Center burst. Arrowhead fracture or chevron cracking these cracks are attributed to a state of hydrostatic tensile stress at the centerline in the deformation zone in the die. This situation is similar to the necked region in a tensile test specimen.

The tendency for center cracking:

a. Increases with increasing die angle:

b. Increases with increasing amount of impurities; and
c. Decreases with increasing extrusion ratio and friction

These cracks have also been observed in tube extrusion and in tube spinning. They appear on the inside surfaces of tubes and for the same reasons. The major variables influencing this are the die angle, extrusion ratio and friction. Experimentally, it was observed that for the same reduction, as the die angle becomes larger, the deformation across the part becomes more inhomogeneous. Also smaller the die, the longer is the contact length. The size and depth of the deformation zone increases with increasing contact length. The internal cracking is shown in Fig. 1.7 (a)

(ii) Pipe

The type of metal flow pattern shown in Fig. 1.6 (c) tends to draw surface oxides and impurities toward the center of the center of the billet, much like a funnel. This defect is known as pipe defect, also tailpipe or fishtailing. As much as one third of the length of the extruded product may contain this type of defect and have to be cut off as scrap.

Piping can be minimized by modifying the flow pattern to a more uniform one: for example, by controlling friction and minimizing temperature gradients. Another method is to machine the billet’s surface prior to extrusion. So the scale and surface impurities are removed. These impurities can also be removed by chemical etching of the surface oxides prior to extrusion. The pipe defect is shown in Fig. 1. 7 (b)

(iii) Surface Cracking

If the extrusion temperature, friction, or extrusion speeds are to high, surface temperatures rise significantly and can lead to surface cracking and tearing (fir – tree cracking or speed cracking). These cracks are inter – granular and are a result of hot shortness. These defects occur especially in aluminum, magnesium, and zinc alloys, although they may also occur in high temperature alloys. This situation can be avoided by lowering the billet temperature and the extrusion speeds.

Surface cracking may also occur at lower temperatures, where it has been attributed to periodic sticking of the extruded product along the die land. When the product being extruded sticks to the die land, the extrusion pressure increases rapidly. Shortly thereafter, the cycle is then repeated continuously, producing periodic circumferential cracks on the surface Because of the similarity in appearance to the surface of the bamboo stem which it causes, it is known as bamboo defect. The surface cracking is shown in Fig. 1. 7 (c).

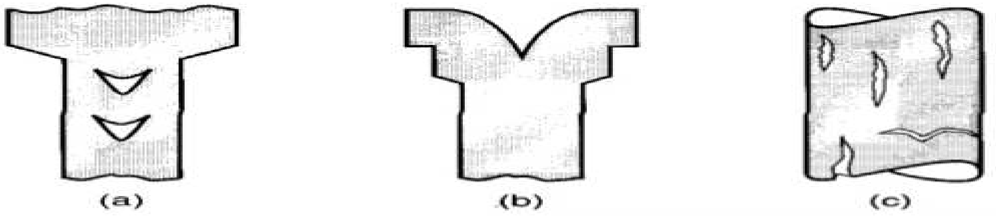


Figure 1.7: Extrusion defects (a) Internal cracking [Cocks and Ashby, 1980], (b) Piping [Tang et al., (1994)], (c) Surface cracking [Lee et al., (1973)]

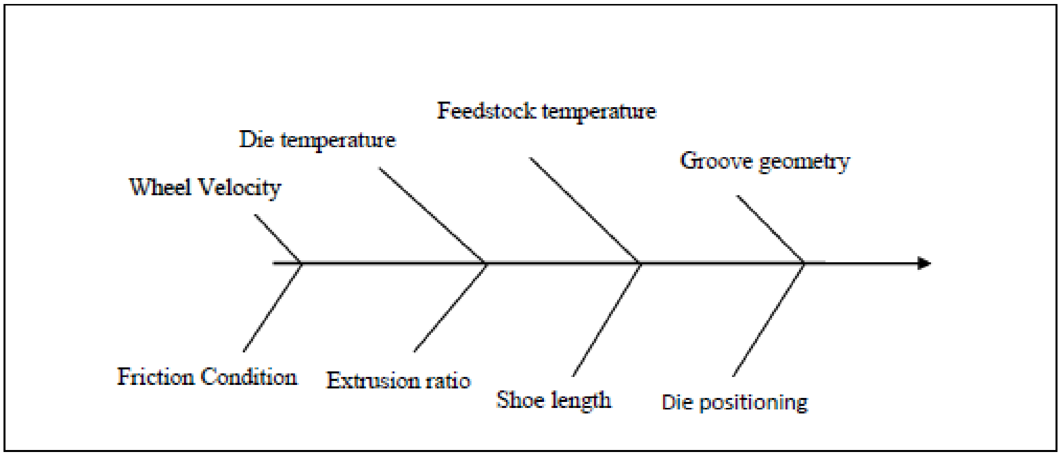


Figure 1.8: Process variables in Continuous Extrusion process

1.8 Analysis of the extrusion process

It is very essential to know the load or range of load required for the plastic deformation of material to be carried out. In extrusion process, we ought to know the load (extrusion load) and pressure (extrusion pressure) at which the extrusion will occur through the die orifice. Therefore, analysis of extrusion process is an important issue which should be carried out in order to explore the process completely.

There are several methods to analyze the extrusion process available from literature.

a. Slab method
b. Uniform – deformation energy method
c. Slip – line field theory
d. Upper bound solutions
e. Finite element method
f. Physical modeling technique (PMT)

These methods can be briefly described below.

Slab method:

The slab was the earliest approach developed in the 1920s by von Karman, Hencky, and Siebel and later by Sachs (1953). The method makes use of an assumption that the metal deforms uniformly in the deformation zone. This approach is generally used in strength of materials.

The expression for axial stress at the die exit needed to cause deformation considering frictionless condition is given by

$$\sigma_{xa} = \frac{2}{\sqrt{3}} \sigma_0 In \frac{1}{1-r} \qquad \ldots\ldots\ldots\ldots (1.1)$$

Where, σ_{xa} is the axial stress, σ_0 is the yield stress and r is the fractional reduction in the cross sectional area.

Uniform – deformation energy method

The results that are obtained by the method can be obtained much more simply by means of the uniform – deformation energy method.

$$\sigma_{xa} = \sigma_0 \, In \frac{1}{1-r} \qquad \ldots\ldots (1.2)$$

Where, $\bar{\sigma}_0$ is the average yield stress. The above expression neglects the influence of transverse stresses (plastic constraint). It also differs from Eq. (1.1) by the magnitude of the average yield – stress term.

Slip – line field theory

Many researchers have analyzed extrusion process by the slip-lined field method. [Hill et al., (1948)] proposed a slip-line field for sheet extrusion through a wedge shaped die. [Johnson et al., (1962)], [Johnson et al., (1973)] used slip-line method to analyze various plane strain extrusion processes such as symmetric extrusion, extrusion through unsymmetrically placed single hole die, dies with oblique faces, stepped dies, multi-hole dies etc. It was the first approach to analyze metal working processes that did not assume homogeneous uniform deformation. The slip line field's account for inhomogeneous deformation in the calculation of the over all forming loads. The average draw stress for the strip according to this theory is given by the expression.

$$\sigma_{xa} = \frac{2}{\sqrt{3}} \sigma_0 \left[\frac{2(1+\alpha)\sin\alpha}{1+2\sin\alpha}\right] \qquad \ldots\ldots\ldots..(1.3)$$

Upper bound solutions

For many metal working processes there is no slip – line fields to allow prediction of stresses. Moreover, slip – line field's techniques have been developed that have general applicability. An upper – bound solution provides an over estimation of the required deformation force while a lower – bound solution provides an under estimate of the force. The degree of agreement between the upper – and lower – bound predictions is an indication of how close the prediction is to the exact value. A lower – bound analysis requires that a statically admissible stress field be found throughout the entire material without making an attempt to ensure that the velocity conditions are satisfied at every point in the material. The term statically admissible stress field means that the assumed stress field satisfies the equilibrium equations and the stress boundary conditions and that its does not violate the yield criterion. From the practical point of view the upper – bound technique is more important the lower – bound since calculations based on upper bound will always result in an over estimate of the load that the press or machine will be called upon to deliver. The upper – bound technique has been used widely by civil engineers for the plastic design of the steel structures (theory of limit design). In the upper – bound analysis a kinematically admissible velocity field is constructed and the loads are calculated to cause the velocity field to operate. No attempt is made to satisfy the stress equilibrium conditions at any point in the field. An extensive literature exists on upper bound analysis of metal forming processes and have been reviewed many researchers [Avitzur et al., (1989)], [Avitzur et al., (1983)], [Avitzur et al., (1980)], [Yang et al., (1989)], [Yang et al., (1987)], [Yang et al., (1985)], [Yang et al., (1978)] [Johnson et al., (1960)], [Hartley, 1973], [Bramley et al., (1992)], [Reddy et al.,(1995)], [Furlong et al., (2001)] and many more.

Finite element method

The FEM is a method used to solve engineering problems through numerical analysis. The process relies on the use of fundamental equations related to material behavior and established mathematical approaches to iteratively solve the equations to determine state variables such as stress, strain, strain rate and temperature related to a given deformation problem. Decreasing costs associated with computer hardware and the increased availability of software and increasing costs associated with "in-house" experimentation are driving forces for use of FEM in industrial practice Proper use of FEM can result in lower turn around times from design to product [Altan et al., (1986)].

Commercial and in-house/self-programmed versions of FEM code are used to solve a large number of engineering related problems. Each version has its own advantages and disadvantages which must be understood before applying the solutions. With the increasingly important role of FEM in the manufacturing process for both design and process and product optimization, it is important to understand how to approach the engineering or scientific problem using this technique and how to interpret the results.

Additionally, the drawbacks must be identified and methods to rectify them should e determined.

Currently, there are several pieces of information that are not predicated by commercial FEM packages and therefore additional experimental and characterization resources are still needed. The ability of FEM code to simulate complex micro structural reactions and chemical changes is still limited. Microstructure development and the resultant mechanical properties cannot easily if at all be modeled today and normally only average or general mechanical properties are given for a deformed work piece. By utilizing FEM software to determine processing variables stress. Temperature, strain, and strain, rate, virtual simulations etc can be performed without using actual extrusions.

Physical modeling technique (PMT)

The Physical Modeling Technique is an alternative analysis method for providing information on the plastic flow of metals, load predictions. Formation of voids or flaws, and fields to investigate plane strain slip line field solutions. The main advantage of the physical modeling approach over analytical and numerical methods is its relative simplicity and ease of implementation. Since the load required to deform a model material is lower than that required to deform the actual material, less expensive equipment can be used to perform the analysis. Successful implementation of the physical modeling technique is based on the simulation implementation of the physical modeling technique is based on the simulation of an actual metal forming process utilizing a model material and tools under conditions similar to the actual process. Typical modeling materials used in the physical modeling technique are Plasticine, lead, and was, while typical model dies are frequently made of steel, aluminum, or plexiglass, Modeling materials can be classified into two groups metallic and non-metallic Since the use of nonmetallic modeling material is more common than metallic materials, several researchers have attempted to determine various characteristics of modeling materials such as wax and Plasticine, for use in the simulation of cold and hot metal forming processes. The most widely used modeling material in deformation studies is Plasticine, a registered trade name by Harbutt, UK which has been acquired by Peter Pan. For the past

50-60 years, Plasticine has been successfully used as a convenient model material to simulate the plastic deformation of metals as observed in forging, rolling and extrusion processes. Hasan sofuoglu, Jahan Rasty (1999). Hasan Sofuoglu, Jahan Rasty (2000) and Hasan Sofuoglu (2003) have attempted physical modeling technique to study the extrusion process.

1.9 Role of computer simulation in analyzing extrusion process:

The analytical approaches of extrusion die profile design involve large numbers of assumptions whereas experimental approaches require large numbers of experimental try outs. Due to these reasons, process design period is excessively elongated. In modern scenario there is stiff competition amongst industries to produce quality products at reduced cost and time span.

To meet these challenges, computer simulation based design development of manufacturing processes are getting wide popularity. These software work in virtual environment and are close to reality as very less assumptions are involved. The falling costs of hardware and software have made the computer simulation within the reach of even medium to small scale industries.

Computer simulation using mathematical modeling including finite element method has now emerged as a very powerful tool for the numerical solution of a wide range of engineering problems. It is used successfully in the deformation and stress analysis of aircrafts, automobiles, bridge structures and buildings, field analysis of heat flux, magnetic flux, fluid flow, seepage, and other flow problems. It is found that with the advances in computer technology & mathematical modeling along with CAD system graphics, complex problems can be modeled easily.

Simulation gives a clear visualization of how the stress is generated in the billet during the extrusion process. The stress values for various materials and for variation of applied forces can be obtained by merely changing the input values and the forces. By simulating manufacturing processes on a computer, this advanced tool allows designers and engineers to:

1. Reduce the need for costly shop floor trials and redesign of tooling and processes.
2. Improve tool and die design to reduce production and material costs.
3. Shorten lead time in bringing a new product to market.

1.10 Motivation behind the study

During the literature survey on continuous extrusion process, it was observed that most of the researchers have emphasized on the manufacturing aspects such as the design of die angle, die profile design, optimization of ram force, and the like. Some literature was found [Zhao et al., (2013)] considering mainly the metallurgical aspects. It was rare to find literature which takes into account numerical, analytical, fabrication, metallurgical, manufacturing and optimization aspects together. This motivated to work & incorporate all these aspects together.

1.11 Objectives of the thesis work

The major objectives of this study are as follows:

a. To design develop and fabricate a continuous extrusion machine set up for extrusion of non ferrous metals and alloys such as Aluminum and Copper.
b. Experimental validation on the designed developed and fabricated set up to study continuous extrusion process in detail.
c. To study the effects of extrusion wheel velocity and extrusion ratio on the process characteristics and material characteristics before and after deformation of the material.
d. To study the continuous extrusion process in detail and effects of various process parameters (such as wheel velocity, extrusion ratio) on process characteristics with the help of 3D finite element simulations techniques.
e. To apply soft computing methods such as Design of Experiment, Artificial neural network and Genetic Algorithms for optimization of continuous extrusion process parameters & predicting the unseen behavior of Continuous Extrusion process.

1.12 Organization of the research work

The chapters of thesis is organized in the following manner:

First chapter is on the introduction to the continuous extrusion process, classification of the continuous extrusion process based on application of direction of flow of extruded product, deformation of metal during extrusion, types of defects occurring during extrusion process, methods of analysis of extrusion, motivation behind the study and objectives.

Second chapter is that of literature survey. The literature survey has been divided into seven sections with emphasis on the section of the finite element method (FEM).The different issues reported in the literature survey are, investigation made in the optimal design for conform process, investigation made in the flash formation analysis, investigation made in the modeling and analysis of the process, investigation made in the wheel tool gap sensing, investigation made in the surface defect and curling phenomenon and some miscellaneous investigations.

In third chapter the analysis, modeling and simulation of the continuous extrusion process is proposed. Upper bound analysis of total extrusion power for Aluminum and Copper feedstock material has been done in third chapter. This chapter is concerned with the analysis of the continuous extrusion process for Aluminum and copper feedstocks's of different diameter at different extrusion wheel speed and for different die arrangement in abutment die chamber using upper bound method. The chapter deals with the analysis of forces required starting from entry of feedstock in the groove of extrusion wheel up to its final extrusion through the die orifice. Therefore complete estimation of each element of total extrusion power has been made in this chapter using upper bound technology. A brief discussion about the contact pressure, primary grip zone and secondary grip zone has been done. Chapter also deals with the estimation of all power terms in continuous extrusion process. Few examples are also taken to illustrate the analysis of continuous extrusion process completely.

In third chapter modeling and simulation of continuous extrusion process for different metals and alloys such as pure Aluminum and pure Copper has also been carried out. Modeling and simulation of continuous extrusion process for non-ferrous metals and alloys is presented including connecting CAE processes and FEM. A simulation package (DEFORM 3D) is used to analyze the forming of Pure Aluminum feedstock (AA 1100) and Pure Copper(C 101) feedstock for continuous extrusion process. Simulation results are used to suggest design modifications in the geometry and tooling required to get the optimum result. The Simulation results are compared with the analytical results to generate knowledge as well as validating result. Study of several field such as load distribution, torque distribution, effective stress field, effective strain field, damage field, temperature field and velocity field has been done. All the Simulations have been carried out for different feedstock sizes as well as for different extrusion wheel velocities and wheel groove friction conditions. Simulations also have been carried out for warm condition of feedstock. Parametric study of different simulation parameters such as extrusion wheel speed, extrusion ratio, wheel groove friction etc. and their influence on total forming load have been carried out.

In the fourth chapter, Design Development and Fabrication of Continuous Extrusion machine setup using the results of simulation is presented. How the chronological development of Continuous Extrusion machine took place at IIT (BHU) has also been discussed in brief. An attempt was made to modify the existing Continuous Extrusion setup but due to several limitations associated with the existing setup, material was not coming out of the extrusion die successfully. Therefore decisions were made to carry out simulations by making several design changes in the geometry of Continuous Extrusion tooling's like Extrusion wheel, Coining wheel, Extrusion shoe and some additional components were also incorporated. After the successful running of simulations by making several design changes, it was thought to refabricate the Continuous Extrusion machine setup for 9.5 mm feedstock material. So, finally a Continuous Extrusion machine setup for 9.5 mm feedstock material has been designed developed and fabricated for producing defect free rods of infinite length of several diameters depending on the size of extrusion die. In this chapter Continuous Extrusion process has been investigated in detail for nonferrous metals and alloys.

In the fifth chapter experimental studies have been performed on different metals and alloys like Aluminum and Copper. The fabricated and commercial setup has been used for the extrusion of circular rod and results (products) has been found satisfactory. A validation has been performed for Aluminum and Copper rod and result have been compared with simulation. Therefore, the good agreement has been achieved between simulation and experimental study and prediction process is possible. The effect of different parameters on total extrusion power has been presented. Characterization of continuous extrusion process like microstructure analysis and parametric study including comparison between simulation and experimental results are also performed in this chapter. Microstructure analysis of the extruded products of Aluminum and copper before and after deformation has been carried out. Material properties of Aluminum and copper have been found using tensile and hardness test. A brief parametric study of continuous extrusion process by comparing simulation and experimental results has also been carried out.

Sixth chapter is about Optimization of continuous extrusion process parameters using soft computing methods such as Response Surface Methodology, Artificial Neural Network and Genetic Algorithms has been carried out in seventh chapter. The optimization of continuous extrusion process parameters such as total load, torque, effective stresses and damage value etc. during continuous extrusion of feedstock material for several values of extrusion wheel velocities, product diameters, frictional conditions, feedstock temperatures, die temperatures has been done in this chapter using statistical software Minitab version 15.1.0.0, USA, Artificial neural network and Genetic algorithms. The continuous extrusion process variables such as extrusion wheel velocities, product diameters, frictional conditions, feedstock temperatures, die temperatures having impact on process parameters or response variables of continuous extrusion process such as total load, torque, effective stress, damage value, product temperatures, hardness, ultimate tensile strength, yield strength etc. has been screened using Plackett-Burman design (PBD) and optimum level of the screened components has been determined using central composite design (CCD) method. A brief comparison of results of optimization obtained through Response surface methodology, artificial neural network and Genetic algorithms has also been made.

Seventh chapter is on conclusion and scope of further studies. Brief summary of the thesis and salient findings of this study are given. Areas of further scope of studies are recommended.