ABSTRACT

The Continuous Extrusion (CE) forming process uses natural frictional force between a circular driving wheel and material to produce sufficiently long continuous products. Variety of sectional shapes which is hard to produce by classical forming processes is produced by Continuous Extrusion. There exists variety of versions of CE process. The Continuous Extrusion process is better than the conventional extrusion process in many ways such as: (i) The input material can be used in varied forms such as coiled rod, molten metal and powder material. (ii) Tooling's preheating and homogenizing are not needed. (iii) Manpower requirement for running CE is low. (iv) Tooling cost and their maintenance cost is also low. (v) Products can be obtained in cut lengths and in continuous coil form. (vi) Products such as refrigeration tubes and very thin tubes are well produced. (vii) Scrap rate is reduced.

Because of its superiority and impact on the current forming technology, demand of products produced by CE from industry has been growing rapidly. Better surface quality, reduced effective stresses are some of the benefits of Continuous Extrusion process in comparison to conventional extrusion process. The analysis and performance of the Continuous Extrusion process depends on various factors such as peripheral speed of extrusion wheel, extrusion ratio and size of flash gap, wheel groove and shoe surface conditions etc.

The study area of continuous extrusion can be categorized into four main branches as: (i) conceptual design, development steps, (ii) concepts of Continuous Extrusion process, (iii) experimental study on different metals and alloys especially for Aluminum Al 1100, (iv) industrial applications. Conceptual design is the key activity in early product design and development (PDD). PDD determines the product functions, forms and the basic structure. Major manufacturing cost is committed in early conceptual design process. The steps of conceptual product development process may be mentioned as: (i) preliminary idea and sketching the concept idea, (ii) preliminary design and alternatives, (iii) feasibility study, (iv) feasibility alternatives, (v) detailed design, (vi) component generation and (vii)

functional study. In recent time this is facilitated by CAE modeling and analysis and subsequently final freeze design and manufacturing. A better way to study the behavior of Continuous Extrusion process for non-ferrous materials such as Aluminum, Copper and Brass is by means of Computer Aided Engineering based procedure. The technology of product manufacturing by Continuous Extrusion process is developing very fast to shape complex profiles of products.

There have been a lot of investigations about Continuous Extrusion process. Most of them involve finite element simulations using finite element method and CAE activities (Computer Aided Engineering) corresponding to rod and tube extrusions. Only few investigations in the field of Continuous extrusion process relates to surface separation and curling phenomenon, analysis of flash formation and measurement of flash gap size. Very few experimental studies have been carried out related to continuous extrusion of Aluminum alloy with the deformation behavior and material characterization. Different areas of research in Continuous Extrusion have been identified and detailed literature survey has been categorically presented

It is observed from the literature that there is no investigation carried out related to metallurgical, manufacturing and optimization aspects together on Continuous Extrusion process.

In this thesis most of the work is being introduced and scope of the present work has been highlighted.

There have been several challenges such as optimization of process parameters in Continuous Extrusion process of nonferrous materials such as Aluminum and Copper feedstock materials and its experimental study. Microstructure analysis of extruded product in Continuous Extrusion process is an area, still to be explored in the field of Continuous Extrusion process.

The work proposed in this thesis is an attempt to study Continuous Extrusion of Aluminum and Copper feedstock material so as to generate enough knowledge and make it avail of the technology for industry applications.

As the summary, the following topics of interest are presented:

a) Literature review of Continuous Extrusion process, FEM simulation and Optimization.
b) Modeling, CAE simulation, parametric study and analysis of Continuous Extrusion process for Aluminum and Copper feedstock materials using different sizes of die and friction conditions.
c) Design modification and Optimization of Continuous Extrusion process.
d) Design, Development and Fabrication of a Continuous Extrusion machine setup for 9.5 mm feedstock material.
e) Experiments and testing on the machine setup: for Aluminum feedstock material (9.5 mm diameter) under different combinations of extrusion wheel speed and extrusion ratio and some parametric study (Total Load vs Wheel speed, Total Load vs Extrusion ratio).
f) Validation & comparison of simulation and experimental results for Aluminum and Copper feedstock materials.
g) Investigation on microstructural analysis: before and after extrusion using Light Optical Microscopy (LOM).
h) Investigation on strength of Extruded products: tensile and hardness test of feedstock material before and after extrusion.
i) The optimization of CE process parameters

The above work has been organized in seven chapters. A brief description of each chapter is presented in the following sections:

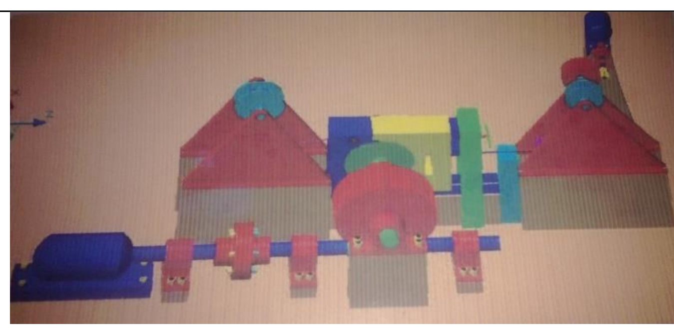
An introduction to Continuous Extrusion process has been presented in C**hapter 1**.

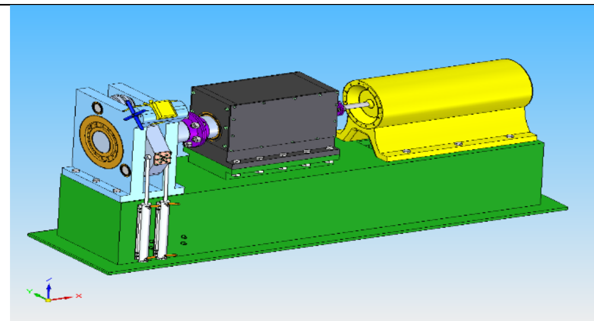
Chapter 2 has been devoted to literature survey related to the area of Continuous Extrusion process. The main aim of this chapter is to introduce various research works already been carried out by different researchers in the area of Continuous Extrusion process.

In **Chapter 3** analysis, modeling and simulation of the continuous extrusion process is proposed. An Upper bound analysis of total extrusion power for Aluminum and Copper feedstock material has been given in third chapter for Aluminum and copper feedstock having different diameter at different extrusion wheel speed and having different die arrangement in abutment die chamber. 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 CAE processes. A simulation package (DEFORM 3D) is used to analyze the forming of Pure Aluminum feedstock (AA 1100) and Pure Copper(C 101) feedstock. Simulation results are used to suggest design modifications in the geometry and tooling required to get the optimum result.

In **chapter 4**, Design Development and Fabrication of a Continuous Extrusion machine setup is presented based on the simulation results as presented in chapter 3. The chronological development of Continuous Extrusion machine at IIT (BHU) is presented briefly in Table 1. 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 depending on the size of extrusion die and feedstock. In this chapter Extrusion of nonferrous metals and alloys has been investigated.

Table 1: Chronological Development of Continuous Extrusion Setup

Year	Title of Work	Figure of Developed Setup
2003	Virtual Design, Fabrication and Analysis of the Continuous Extrusion process was done as a M. Tech thesis.	

2007	CAE Simulation of the Continuous Extrusion process was done as a M. Tech thesis.	
2008	Continuous Extrusion machine setup was fabricated under a DST project for extrusion of thin rods, wires, sheets and strips for 8 mm Aluminum feedstock material.	
2012	Modification of Continuous Extrusion machine setup was done for extrusion of thin rods, wires, sheets and strips for 8 mm Aluminum feedstock material.	

2015	Design Developed and Fabricated Continuous Extrusion setup for 9.5 mm Aluminum feedstock material.	

In **chapter 5,** experimental studies have been performed on different metals and alloys (Aluminum and Copper) on the setup developed for the extrusion of circular rod. Validation of the result for Aluminum and Copper rod have been carried out with simulation results as shown in Table 2. The result shows a good agreement between simulation and experimental study. The effect of different process parameters on total extrusion power has also been presented and Characterization & microstructural analysis of extrusion process (microstructure analysis and parametric study) is performed on the extruded products (Aluminum and copper) before and after the deformation. Material properties of extruded Aluminum and Copper products have been found using tensile and hardness test.

Table 2: Result Validation for Aluminum (AA 1100) and Copper Feedstock Material (C 101)

Material	Feedstock Diameter (mm)	Wheel Velocity (RPM)	Extrusion Ratio	Simulation Power (kW)	Experimental Power (kW)	% Error
Aluminum AA 1100	9.5	8	2.5	16.53	17.6	6.47
			1.84	16.79	16.72	0.42
			1.41	14.9	16.2	8.72

Copper C 101	12.5	8	4.34	58	58.2	0.4
			3.18	55	55.4	0.8

Chapter 6, is devoted to Optimization of the continuous extrusion process. Soft computing methods such as Response Surface Methodology, Artificial Neural Network and Genetic Algorithms has been introduced for prediction of Continuous Extrusion process. The optimization of CE process parameters (i.e. total load, torque, effective stresses and damage value etc.) during extrusion of feedstock material for different process variables (extrusion wheel velocities, product diameters, frictional conditions, feedstock temperatures, die temperatures) has been carried out in this chapter using statistical tool Minitab version 15.1.0.0, USA, Artificial neural network and Genetic algorithms.

Conclusion and Scope for the future work is presented in **chapter 7**.