# Optimal Process Control Parameters Estimation in Aluminium Extrusion for Given Product Characteristics

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*Abstract*—**This paper investigates a technique to find an optimal set of conditions for an isothermal process to extrude a product for a given shape and material properties with minimal defects. The inputs to this model are: the product geometry and its material data such as flow curve and microstructure during dynamic recrystallization. This is an inverse problem and the model is formulated as a non-linear least-squares minimization problem coupled with a finite element model for the extrusion process. It is done by constructing an iterative procedure using an optimisation routine such as *MATLAB*'s *lsqnonlin* and at each iteration, the extrusion flow is solved using *ABAQUS*. First all control points of a Bezier-curve for the die surface that minimizes the redundant strain inside the deformation zone are found. Then the initial billet temperature, die temperature and the ram speed that closely match with the strain rates and temperatures for the desired microstructure (grain size) are obtained.**

***Keywords: Extrusion; Inverse problem; Parameter estimation; Optimization.***

## 1 Introduction

The metal flow during extrusion through a die is complex and not uniform, which causes a cross-cracking, bending, distorting and twisting of the extruded product. To improve the quality of the workpiece, the die cross-section layout and operating conditions must be taken into account in the design of a new product.

Computer simulation of extrusion using the finite element method is a popular option to replace the traditional trial and error method during process design. A finite element model, which is capable of describing the behavior of metal flow during extrusion, requires several input data such as die geometry, material behavior laws, friction laws and operating conditions.

In reality, material data can be obtained using available experimental data, but optimal values of die geometry and operating conditions are often not accurately known and therefore guessed. Methods to determine die geometry and operation conditions are an important part of designing an extrusion process.

Several articles have been published in this area. Wifi *et al*[6], used the incremental slab technique and Bezier-curve technique to find the optimum curved die profile that minimizes the extrusion load for a hot extrusion process. Lee *et al*[1] used the finite element method and flexible polyhedron search method to produce a uniform microstructure. They used Bezier-curves to generate all possible die profiles and used plain carbon steel for the billet.

The novel concept of this research is to determine the optimal conditions of isothermal extrusion with regards to billet temperature, container temperature, extrusion speed and microstructure for a non-adiabatic die profile basing it on techniques available in the literature.

## 2 Forward Problem

Extrusion is a thermo-mechanical deformation process in which a block of metal (billet) is forced through the die opening of a smaller cross sectional area than that of the original billet. In this process, the large deformations are mainly plastic or viscoplastic, allowing the elastic part to be neglected. Strain is a measure of deformation and at high strain rates metal flow is analogous to fluid flow. Therefore the material behavior can be described as that of fluid flow.

(i) Conservation of mass

$$\frac{D\rho}{Dt} + \rho\nabla \cdot \mathbf{V} = 0 \tag{1}$$

where $\rho$ is the density of the material and $\mathbf{V}$ is the velocity vector. If the material is incompressible, density is unchanged and the Equation (1) is simplified to

$$\nabla \cdot \mathbf{V} = 0 \tag{2}$$

(ii) Conservation of momentum

$$\rho\frac{D\mathbf{V}}{Dt} = \rho\mathbf{f} + \nabla \cdot \sigma \tag{3}$$

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