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Design Optimization of Die Extrusion Parameters for different shapes of Die- A Review Study

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Abstract:

Forming is a mechanical process used in manufacturing industries wherein materials (mostly metals) undergo plastic deformations and acquire required shapes and sizes by application of suitable stresses such as compression, shear and tension. Current research reviews the state of the art in case of Die extrusion process. On the basis of review of the previous literature several conclusions can be drawn for example- Die extrusion has been one of the most prominently employed metal forming process all across the globe and is having its distinguished advantages over other type of metal forming processes, Because of its advantages & importance, numerous researchers have analysed the process of die extrusion in order to enhance the overall performance of die extrusion, For performance enhancement several process parameters have been marked to be important for example ramming speed, die angle, die cross section, flow velocity etc., All the process parameters have their impact on the performance of the die extrusion, Die angle is the most important process parameter of them all when performance optimization of die extrusion is concerned.

Keywords: Forming, die extrusion, ramming speed, die angle, die cross section, flow velocity, performance optimization.

Introduction

Forming is a mechanical process used in manufacturing industries wherein materials (mostly metals) undergo plastic deformations and acquire required shapes and sizes by application of suitable stresses such as compression, shear and tension. In the forming process, no material is removed; it is completely displaced and deformed into the required shape. Some of the commonly used forming processes in the manufacturing industry are:

- Forging
- Rolling
- Extrusion
- Thread rolling
- Rotary swaging
- Explosive forming
- Electromagnetic forming

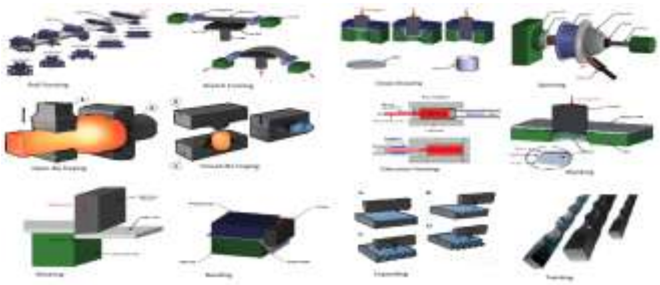

Fig. 1 Various Types of Forming Processes

Extrusion is a process used to create objects of a fixed cross-sectional profile by pushing material through a die of the desired cross-section. Its two main advantages over other manufacturing processes are its ability to create very complex cross-sections; and to work materials that are brittle, because the material encounters only compressive and shear stresses. It also creates excellent surface finish and gives considerable freedom of form in the design process.

Also referred to as "hole flanging", hollow cavities within extruded material cannot be produced using a simple flat extrusion die, because there would be no way to support the centre barrier of the die. Instead, the die assumes the shape of a block with depth, beginning first with a shape profile that supports the centre section. The die shape then internally changes along its length into the final shape, with the suspended centre pieces supported from the back of the die. The material flows around the supports and fuses to create the desired closed shape. The extrusion of metals can also increase their strength.

Extrusion dies are metal channels that impart a specific cross-sectional shape to a polymer stream. The design difficulty centers on achieving the desired shape within set limits of dimensional uniformity at the highest production rate possible.

Extrusion dies are essentially thick, circular steel disks containing one or more openings to create the desired profile. They are normally constructed from H-13 die steel and heat-treated to withstand the pressure and heat of hot aluminium as it is pushed through the die.

While it may appear that aluminium is a very soft metal, the reality is it takes a tremendous amount of pressure to push a solid log (billet) of aluminium through a thin, multi-holed die to create the desired shape. In fact, it takes 100,000-125,000 psi of force to push a billet through an 8” inch press.

Literature Review

Evangelos Giarmas et al. (2022) This paper presents an overview of the recent advances in optimization of die design through finite element analysis for aluminium alloys of 6xxx series. The die design and optimization play a crucial role in the production of 6xxx series alloys, in order to attain high quality's final products. Before the use of finite element analysis (FEA) in aluminium extrusion industry, many experiments and modifications are needed until an acceptable product becomes available. The use of finite element analysis acquires a key role in the direction of eliminating trials and defective extrudates and use is gaining more and more ground through most of the manufacturers. This review will show how various studies try to enhance the performance of the extrusion dies through simulations and how the majority of the most common defects could be prevented if the use of the suitable software and techniques are implemented. The main covered areas from the current review are material flow optimization, flow balance in extrusion of complex aluminium profiles, spread extrusion die design, optimization of porthole extrusion dies, front end and back-end defects, die bearing geometry and surface defects, automatic die design optimization and liquid nitrogen die cooling.

Prof. Dipali Bhoyar et al. (2022) The process of extrusion plays a vital role in the production process of different parts in various environments. the extrusion temperature and load have significant on quality and cost of the extruded parts respectively. Hence, development of economical process conditions is found as vital. Forward extrusion model is developed to analyze the process responses temperature, extrusion load, extrusion ratio and blank velocity for different process designs. there is lot of variations in the production of parts during extrusion with conventional processes to the latest automation in the manufacturing. There is a need to develop different die designs by varying input processes variables for the extrusion process in an optimum manner. The purpose of the present paper is to determine the optimization of extrusion process variables at minimum extrusion force. The present work deals with the FEM approaches, in order to determine optimal values of logarithmic strain, die angle and friction coefficient with a purpose to find minimum Extrusion force and the obtained results are compared with those in existing literature. The obtained results lead to the lower energy consumption, better tool life, better formability of the work material, and the better quality of the finished extruded part. With the optimal values obtained in the technique, a three-dimensional model is developed and analysis is carried out on ANSYS platform. Based on the ANSYS results optimal values or the extrusion process variables are determined.

Mulualem Hailu Besha et al. (2022) There is a huge application and demand for titanium alloys with excellent upgraded mechanical, metallurgical, and material properties in modern industries. To fulfil the demand of modern industries metal forming process is highly desirable. Among all metal forming processes, a special type of cold forming called the continuous extrusion process has been highly appropriate to fulfil the demands. The theoretical analysis has been carried out through Upper Bound Method. The numerical simulation has been carried out through the three-dimensional finite element tool DEFORM3D. The experimental plan and design have been carried out using Taguchi (2^3) array methods on the MINITAB platform by considering extrusion wheel velocity and feedstock temperature as chief extrusion parameters. The experimental validation process was executed on 12.5 mm CP- Titanium grade 2 feedstock materials using a TBJ350 CONFORM machine setup. The optimization process of parameters for the optimum value of the response variable was carried out through Grey Relational Analysis.

Tariku Desta et al. (2021) The product of high complex profile, high strength, high productivity and excellent material properties with infinite length can be produced by Continuous Extrusion (CE) process. The numerical simulation of Aluminium (AA 1100) feedstock material at different wheel velocities, product diameter, feedstock temperature, die temperature and friction condition has been carried out using 3D simulation tool Design Environment for Forming (DEFORM-3D) in this paper. The development of mathematical model is carried out to investigate the influence of wheel velocity, extrusion ratio, feedstock temperature, die temperature and friction conditions on total load required for the deformation and extrusion of feedstock material through Response Surface Methodology (RSM). The statistical significance of mathematical model is verified through analysis of variance (ANOVA). The most optimum value of extrusion load has been found to be 136.4kN through iterative process of Genetic Algorithm (GA) using Artificial Neural Network (ANN). The optimized value of input process variables for minimum value of extrusion load obtained has been found to be 13 Revolutions per Minute (RPM) as wheel velocity, 5mm as product diameter, 0.95 as friction condition, 650∘∘C as feedstock temperature and 550∘∘C as die temperature. This paper with proposed methodology will be helpful for industries working in the area of CE in terms of minimizing energy consumption during production process of bus bars, tubes, wires, cables, sheets, plates, strips, etc.

Anupama Francy Kothasiri et al. (2021) Extrusion is a simple metal forming process in which a block of metal is forced through a die orifice with a certain shape under high pressure. This extrusion process is influenced by many process parameters such as die angle (DA), ram speed (RS), coefficient of friction (COF), Extrusion ratio, Die land height, work piece diameter and length, material properties etc. In extrusion process, extrusion force is crucial parameter, the flow of metal and hence the extrusion force is significantly influenced by the above parameters which results in quality of the product. The present study numerically investigates the influence of major process parameters such as die angle, ram speed, coefficient of friction on the extrusion process. The AA2024 material is chosen as work piece material and the extrusion force and damage is considered as the output responses. The input process parameters are varied in three levels (Level - 1: 10° DA, 1.6mm/min RS, 0.06 COF; Level - 2: 20° DA, 3.2mm/min RS, 0.08 COF; Level - 3: 30° DA, 4.8mm/min RS, 0.01 COF). Numerical simulations are performed by using DEFORM 3D software. The simulations are conducted as per L27 orthogonal array. From the results it is observed that Increase of die angle, ram speed and coefficient of friction increases the extrusion force. The die angle has highest (86.45%) influence on the extrusion force, then after ram speed (6.60%). The coefficient of friction has insignificant influence (0.55%). It is also noticed that the damage is considerable after the 20 die angle. A multi parameter optimization is also done by using the grey relation analysis by considering the equal weightage of extrusion force and damage. The optimum levels of input process parameters for the minimum extrusion force and damage are DA level 1, RS level 1, and COF level 3.

Wael Shaheen et al. (2019) This article investigates different types of compound die piercing punches and double cutting operation parameters in terms of optimization using finite element technique, Taguchi method, regression analysis, and analysis of variance. The article overcomes the current knowledge gap in studying various cutting edges of piercing punches such as flat, chamfered, flat edge with concave hemisphere, and convex shaped when using the compound dies in stamping operations. The analysis of the compound die is carried out using ANSYS software. The main focus is to determine the contribution of key parameters for obtaining optimum cutting tool design. The best piercing punch is selected based on minimum burr height of the product. The values of cutting process parameters and burr heights have been analyzed using Minitab software. The results obtained indicate that the burr heights of the final product are at a minimum when the sheet metals are thicker and larger when the sheets are thinner. The chamfered and convex punches provided minimum burr heights which are as low as 0.034 mm for a typical sheet metal. This study provides a better outcome compared to the available experimental data in the literature. The investigation also designed efficient compound dies resulting in improved product quality.

B. Bhavani et al. (2019) The study at considers Technical and monetary viability of an extrusion plant depends on the minimization of defects that result in product rejection. Attempts at improvement of extrusion satisfactory and productivity as a consequence translates straightaway into an evaluation of product defects Aluminium extrusion are maximum extensively and leading steel forming system finished in industries. There also trouble of various type of defects generated at some stage in extrusion. Every time realistic trial and errors experiments are time consuming, high-priced and no longer proven to discover effects of changing diverse parameters to growth productivity and reduce defects the extrusion load and pressure throughout the recent extrusion technique of 6061 Aluminium Alloy by using Deform3D simulation. The impact of extrusion system parameters particularly, extrusion ratio, ram velocity, initial temperature of billet and cross segment of die on the responses extrusion load and strain were investigated. Some of the maximum substantial layout parameters such as coefficient of friction and heat transfer coefficient are taken into consideration. The geometries of the die, box, ram and billet were generated in CATIA and for analysis Deform-3D is used that's a FEM based simulation procedure. Layout is employed to simulate the experiments for every set of chosen extrusion variables via Finite Element Analysis solver.

Engelhardt, Marcus et al. (2019) The use of finite element analysis (FEA) to predict material flow and die deflection is well implemented in the scientific community but it is still new in the extrusion industry or for die makers. This paper deals with the advantages and limitations of FE-analysis to predict material flow and to optimize die design from an industrial point of view. For this study two software packages, HyperXtrude and PF-Extrude, have been used to predict the material flow in two applications, the optimization of a heat sink profile and the filling process of a porthole die.

Sarojini Jajimoggala et al. (2019) Significance of improving the material processing techniques for Al alloy has been felt due to its enormous application in various key industries. The process of Al alloy extrusion has gained great popularity in recent years due of its simplicity and low cost. Since improper selection of process parameters leads to poor quality and yield, in the present work, an attempt was made to simulate hot direct extrusion of AA6061alloy using Deform-3D, and the results were analysed using ANOVA to check the significance of process parameters. The results showed that the order of significance was cone half angle, ram speed and coefficient of friction. The optimal process parameters were selected through Taguchi-based grey relational analysis with multiresponse optimization technique.

Prasad Satish Divekar et al. (2019) The present work proposes an integrated FEA based approach to evaluate the extrusion process conditions numerically and to find the optimal process variables for the forward extrusion of Al 6061 alloy. The simulations are carried out for different ram velocities, coefficient of frictions and die angles. The simulation results of temperature, extrusion load, extrusion ratio and blank velocity are presented. Consequently, optimization has been carried out for to minimize the temperature and to minimize extrusion load using Taguchi's technique. The present work deals with the different approaches; one is a statistical method, i.e., Taguchi orthogonal array and the one is an evolutionary algorithm, i.e., Particle Swarm Optimization in order to determine optimal values of logarithmic strain, die angle and friction coefficient with a purpose to find minimum Extrusion force. With the optimal values obtained in both the techniques, a three-dimensional model is developed and analysis is carried out on ANSYS platform. Based on the ANSYS results optimal values or the extrusion process variables are determined.

Nimesh Kapadia et al. (2015) This study considers Technical and economic viability of an extrusion plant depends on the minimization of defects that lead to product rejection. Attempts at improvement of extrusion quality and productivity thus translate straightaway into an analysis of product defects. Aluminium extrusion is most widely and preferable metal forming process done in industries. There also problem of different kind of defects generated during extrusion. Every time practical trial and error experiments are time consuming, costly and not validated to find effects of changing various parameters to increase productivity and reduce defects. In this research work simulation of direct extrusion of Aluminium alloy (6063) in the form of round circular billet to round circular solid profile is done. Analysis was based on Taguchi's L9 orthogonal array. The simulation software HyperXtrude, which is customized software for various extrusion analyses, is used for analysis. Also, analytical calculation is generated to compare both analytical and simulation results. Both results are closely matched.

F. Ghaemi et al. (2013) One of the most important design parameters in extrusion process is the shape of die profile. In the present research work, an optimum extrusion die profile has been obtained through implementation of slab analysis in a computational algorithm. Moreover, extrusion process through both optimum conical and curved die has been performed experimentally and also by finite element method. It has been demonstrated that material work hardening characteristics and friction condition have remarkable effects on the optimum streamlined die profile. Also, results prove that the streamlined die profile designed based on the developed approach, is superior to the conventional conical dies from both metallurgical and manufacturing perspectives. Consequently, the proposed method can be regarded as an efficient and reliable tool for designing streamlined die profiles. Hence, this technique can be used to produce desirable conditions in both process and product quality in terms of extrusion force, deformation homogeneity and die wear.

K. K. Pathak et al. (2010) In this study, experimental verification of a proposed extrusion die profile design approach, which aims to satisfy microstructural criteria at maximum production speed and minimum left out material in the die cavity, is presented. The design problem is formulated as a nonlinear programming problem, which is solved using genetic algorithm (GA). Selection of the processing parameters is carried out using dynamic material modeling (DMM). Microstructural study reveals considerable grain refinement in the extruded tube.

Nadhir Lebaal et al. (2009) Balancing the distribution of flow through a die to achieve a uniform velocity distribution is the primary objective and one of the most difficult tasks of extrusion die design. If the manifold in a Coat-hanger die is not properly designed, the exit velocity distribution may be not uniform; this can affect the thickness across the width of the die. Yet, no procedure is known to optimize the coat hanger die with respect to an even velocity profile at the exit. While optimizing the exit velocity distribution, the constraint optimization algorithm used in this work enforced a limit on the maximum allowable pressure drop in the die; according to this constraint we can control the pressure in the die. The computational approach incorporates three-dimensional finite element simulations software Rem3D and includes an optimization algorithm based on the global response surfaces with the Kriging interpolation and SQP algorithm within an adaptive strategy of the search space to allow the location of the global optimum with a fast convergence. The optimization results which represent the best die design are presented according to the imposed constraint on the pressure.

Durmus Karayel (2008) This study aims the modeling and simulation of the direct extrusion process and determination of optimal process parameters using Finite Element Method (FEM) and Artificial Neural Network (ANN) cooperatively. First, the die set has been designed for direct extrusion of an aluminium rod and its numerical simulation has been prepared by mean of ABAQUS/EXPLITIC finite element code. So, both the values of the process parameters according to extrusion load and the critical stress values have been determined. After, the ANN model of the process has been developed under MATLAB and has been trained with the results of finite element simulations. Also, the optimization software which can run together the ANN model has been developed and has been used to determine the optimum process parameters.

P. Kathirgamanathan et al. (2008) 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.

Wu Xianghong et al. (2006) Uniform material flow in the cross section of the bearing exit in an aluminium extrusion process is extremely important for getting high quality products. In general, several measures are taken to eliminate non-uniform material flow, such as adjustment of the size, shape and location of portholes and welding chamber, modifications of local bearing lengths, etc. In the present work, an aluminium profile porthole die extrusion process is simulated using the finite volume method based numerical analysis software Msc/SuperForge. The simulation results show that with the originally designed die the material flow velocities in the profile cross-section of the bearing exit are non-uniform. Aiming at solving this problem, three die structure modification schemes are proposed and their extrusion processes are simulated, respectively. The optimal die design scheme is determined by comparing the simulation results. For comparison, the same process is simulated with finite element based DEFORM 3D, and the results are similar with those obtained with SuperForge, but the accuracy is lower and much more computation time is needed due to frequent mesh regeneration.

W. Michaeli et al. (2004) The primary aim of the rheological design of extrusion dies in polymer processing is to obtain an even velocity distribution at the outlet of the die. For a given complex cross-section of a profile, no procedure has yet been found to predict the die geometry with respect to obtaining an even velocity profile at the outlet. Hence the optimization of the geometry has to be done by "trial and error". In this paper a new calculation method is presented which uses a combination of the finite-element-analysis (FEA) and a flow analysis network (FAN). With the aid of this method, it is possible to accelerate the iterative optimization process for the design of profile extrusion dies. Furthermore, this method is combined with an optimization scheme based on the evolution strategy. The result is an algorithm to optimize the flow channels in extrusion dies automatically.

Zou Lin et al. (2003) An improved method to obtain the optimal die profile which yields more uniform surface-load distribution on die profile surface via integrating finite element analysis is applied to the hot extrusion process. The die profile of the hot extrusion is represented by a cubic–spline curve. Updated sequential quadratic programming (SQP) method is adopted to accomplish the optimum calculation for unsteady metal forming based on the rigid–viscoplastic finite element method (FEM). The analysis for unsteady metal forming has been performed to simulate the process on the die curve acquired from optimum calculation. The above approach can improve the die life in hot extrusion processes.

Mahender P. Reddy et al. (1998) Extrusion die design is still an art and depends heavily on previous experience and several in-plant trial and error processes to manufacture a single die, of particular importance is the shape of the die passages. In this paper we present an algorithm for optimal design of extrusion dies using an hp-adaptive finite element model and shape optimization based on an efficient response surface methodology, hp-adaptive finite element analysis is used to obtain accurate flow solutions. Starting with an initial guess for the die geometry, we iteratively solve the fluid flow and optimization problems to produce a die design that satisfies the objective function and constraints. Results for a two- and three-dimensional extrusion problem are presented to show the robustness of the approach and its effectiveness in simplifying the method of die design. The advantage of this approach is that, in addition to removing the guesswork from mesh generation, it eliminates the time-consuming trial and error experiments in extrusion die design. The present research also highlights another use of the response surface methodology in multidisciplinary design optimization.

Conclusions

Current research study is focused on reviewing the Optimization process for the die extrusion parameters. For the purpose several previous researches have been studied, investigated and analysed. On the basis of review of the previous literature following conclusions can be drawn-

- Die extrusion has been one of the most prominently employed metal forming process all across the globe and is having its distinguished advantages over other type of metal forming processes.
- Because of its advantages & importance, numerous researchers have analysed the process of die extrusion in order to enhance the overall performance of die extrusion.
- For performance enhancement several process parameters have been marked to be important for example ramming speed, die angle, die cross section, flow velocity etc.
- All the process parameters have their impact on the performance of the die extrusion.
- Die angle is the most important process parameter of them all when performance optimization of die extrusion is concerned.

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