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A study on metal extrusion process

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Abstract

Extrusion is a manufacturing process used to create objects of a fixed cross-sectional profile. A material is pushed through a die of the desired cross-section. A brief and concise review of the contributions made by the previous researchers in the area of extrusion process has been presented. Steel material and aluminium alloys are mostly used by researchers as die and billet material in extrusion process. FEM modeling of extrusion process is carried out by employing axisymmetric conditions in most cases. Meshing of the work piece is generally done by using axisymmetric quadrilateral elements. Experimental set-up and tools utilized in formation of extrusion process are presented and discussed. FEM results are presented in terms of variation of punch stroke, punch force.

Keywords

Tube extrusion process, Finite element simulation, Mesh adaptivity, Thermo mechanical coupled extrusion.

1.Introduction

Extrusion is metal forming process which is widely used in industry and daily life equipment . It is another kind of manufacturing process which involves shearing and compression. Practical application of extrusion includes railing for sliding doors, tubing having various cross sections, structural and architectural shapes, and door and window frames. Extruded products can be cut into desired lengths, which then become discrete parts such as brackets, gears and coat hangers. It is a process in which required product can be formed are formed by using round die or it may various shapes. A round billet is placed in a chamber and force through a die opening by hydraulically driven ram or pressing or pressing stem. This process usually comprises of axisymmetric die.

The die angle, reduction in cross-section, Extrusion speed, billet temperature and lubrication all affect the extrusion pressure. Extrusion is generally classified into four types. They are: Direct extrusion, indirect extrusion, impact extrusionand hydrostatic extrusion.
In direct extrusion a solid ram drives the entire billet to and through a stationary die and must provided additional power to overcome the frictional power to overcome the frictional resistance between the surface of the moving billet and confining chamber.

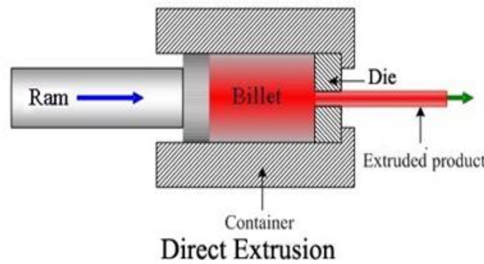


Figure 1 Direct extrusion [29]

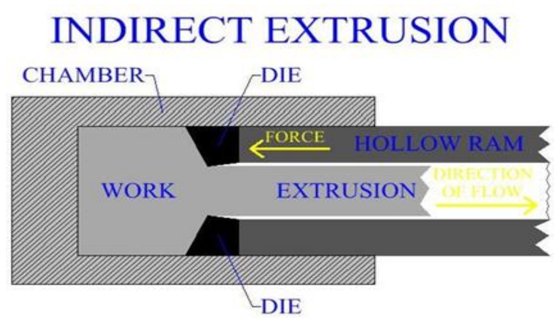


Figure 2 Indirect extrusion [29]

In indirect extrusion process a hollow ram drives the die back through a stationary, confined billet. Since no relative motion, friction between the billet and chamber is eliminated and the required force is lower. In impact extrusion process the extruded part are stripped by the use of stripper plate, because they tend to sticks to the punch.

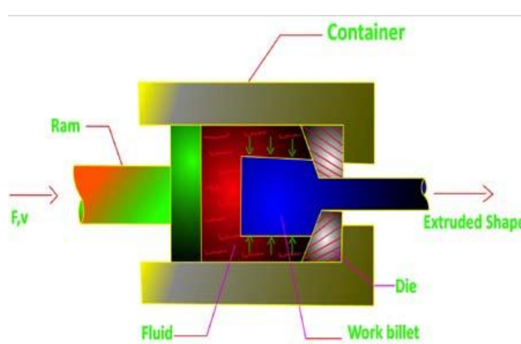


Figure 3 Hydrostatics Extrusion [30]

In hydrostatics extrusion high pressure fluid applies the force to the workpiece through a die. Billet-chamber friction is eliminated, and the pressurised fluid acts as a lubricant between the billet and the die. In extrusion mesh distortion is the major problem of FE simulation. In this study we focused on the area of mesh adaptivity and thermo mechanical modelling of the forming process. In past, various researchers contributed in the area of metal extrusion process. Subramanian and, Palaniradja [1] investigated by simulating tension and compression by using different extrusion textures, they found the differences of mechanical properties between center and side areas of the extruded bar. Hojda et al. [2] used Abaqus/Standard for a 3D Finite Element Method is presented that is capable of simulating the highly nonlinear hybrid forward extrusion process (thermomechanical and electric field) incorporating a remeshing routine, this model is extended to couple a strain based damage with electrical resistivity Ab Rahim et al. [3] investigated the trends and the concept of emerging to identify the recyclability contents of the product for recycling aluminum chips by the hot extrusion process. Zhou et al. [4] used an analytical model for predicting the shapes of rectangular bars with variable curvatures along their lengths through a novel forming method, differential velocity sideways extrusion (DVSE) has been developed on the basis of the upper bound method. Joun et al. [5] used dynamic material modeling (DMM) for selection the processing parameter. Akhgar et al. [6] investigated hot extrusion of AA6061–5% SiCp composite to determine the composite thermo-mechanical behavior during deformation and the mechanical proper- ties of extruded composite. Pourbahari et al. [7] investigated on the grain refinement by the dynamic recrystallisation (DRX). Tahmasbi et al. [8] used Friction stir extrusion (FSE) process in which a sample is produced through the heat generated by the friction between die and materials, and the extrusion pressure.Yu and Zhao [9] investigated on the Fine nano structures of bonding interfaces of weld seams formed by porthole die extrusion in the absence/ presence of a gas-pocket behind the bridge of the extrusion die to understand the underlying interfacial bonding mechanisms. Sahu et al. [10] investigates the multi-hole extrusion process. Forward, backward and forward-backward multi-hole extrusions have been carried out to determine the extrusion load and variation of extruded product lengths. Wang and Feng. [11] they were carried out experimental and numerical simulation to demonstrate that extrusion-forging process can be used to create such micro scale surface features. Chen et al. [12] hot extrusion experiments of AZ91 alloy were carried out at various ram velocities of 0.1, 0.5 and 1.0 mm/ s. They investigated the dead metal zone, shearing zone, inflowing zone and slight deformation zone of the part remaining from extrusion exhibited varied microstructure characteristics. Rattanochaikul et al. [13] reports a preliminary research and development work of a new rheo-extrusion process using the Gas Induced Semi-Solid (GISS) technique. The effects of the plunger speeds and solid fractions on the extrudability of an aluminum 356 alloy were investigated. Pathak et al. [14] investigated a finite element simulation of tube extrusion process by different mesh adaptivity schemes. A comparison of these schemes has been made based on stress, strain distribution, and load-stroke curves. Khosravifard et al. [15] a finite element analyses of rod extrusion process are carried out considering various processing parameters. They investigated the effect of these parameters on mechanical performance. Pathak et al. [16] used genetic algorithm (GA) and dynamic material modeling (DMM) for experimental verification of a proposed extrusion die profile design approach, which aims to satisfy micro structural criteria at maximum production speed and minimum left out material in the die cavity. Bovas et al. [17] they investigated the effect of melt temperature on the surface roughness and wettability of the catheter surfaces were analyzed through ANOVA. Matli et al. [18] a nano-sized Si_3N_4 (0, 0.5, 1.0 and 1.5 vol%)/Al composites were fabricated using a powder metallurgy method involving microwave sintering technique followed by hot extrusion. The influence of Si_3N_4 content on the structural, mechanical and thermal behaviour of Al–Si_3N_4 nanocomposites was systematically investigated. Chen et al. [19] the isothermal hot compression tests of homogenized 7005 aluminium alloy at the deformation temperatures ranging from 623 K to 823 K and with the strain rates ranging from 0.001 s 1 to 10 s 1 were conducted for constitutive analysis. Dong et al. [20] a deep understanding of hot deformation behaviour of a material plays a crucial role in determining process parameters and designing extrusion dies during the extrusion process of the aluminium alloy profiles. Ebrahimi et al. [21] equal channel forward extrusion process as a severe plastic deformation method has been experimentally and numerically investigated on the 6082 aluminium alloy. Gagliardi et al.[22] investigated the porthole die profile used to produce hollow complex cross-section profiles. 12 geometric variables of a standard porthole die, used to extrude profiles with circular section, were identified and varied on three levels. 23. Parvizian et al. [23] they modeled and simulate hot metal forming processes in which material undergoes large deformations with help of the Finite Element (FE) software ABAQUS using Lagrangian formulation. Hosseini et al. [24] a modified novel backward extrusion process implementing severe plastic deformation is presented for processing of ultrafine-grained materials. The process was applied to commercially pure aluminium, and microstructure and micro hardness measurements were investigated. Ramezani and Neitzert [25] developed FE model can be used for investigating direct extrusion and selecting appropriate die design parameters for the process. Reddy et al. [26] investigated pure aluminium for Equal Channel Angular Extrusion (ECAE) processing. Kapadia and Desai [27] investigated both analytical and simulation result. Simulation of direct extrusion of Aluminum alloy (6063) in the form of round circular billet to round circular solid profile is done. Ghaemi et al. (2013) [28] investigated on the shape of die profile. Extrusion process through both optimum conical and curved die has been performed experimentally and also by finite element method.

2.Overview of extrusion process

2.1Material utilised in extrusion process

Metals that are commonly extruded include Aluminium, Brass, Copper, Lead and tin, Magnesium, Zinc, steel, Titanium. Aluminium is most commonly extruded material. Aluminium can be hot or cold extruded, If it is hot extruded it is heated to (300 to 6000C). Magnesium and Aluminium alloys have a 0.75 micrometer RMS or better surface finish. Titanium and steel can achieve a 3 micrometers RMS. *Table 1* shows the description of the author who have used variety of material as a extruded material for manufacturing by extrusion process. It is clear from table that in majority of the researchers have used Al materials. Some cases they have also used different Magnesium alloy for extrusion process.

Table 1 Metal used work piece by previous researchers

Author	**Year**	**Material**
Subramanian and, Palaniradja [1]	2018	Magnesium alloy
Akhgar et al. [6]	2011	AA6061-5% Sicp
Pourbahari et al. [7]	2018	MG-Gd-Al-Zn magnesium alloy
Tahmasbi et al. [8]	2018	Aluminium alloy AA7022
Chen et al. [12]	2018	Az 91 alloy
Rattanochaikul et al. [13]	2017	Aluminium 356 alloy
Matli et al. [18]	2017	Al-Si3N4 nano compoites
Chen et al. [19]	2015	7005 Aluminium alloy
Dong et al. [20]	2016	AA6N01
Ebrahimi et al. [21]	2016	6082 Aluminium alloy
Ramezani and neitzert et al.[25]	2016	Ti-6Al-4v powder alloy
Kobayashi et al.[27]	1989	Al alloy (6063)

2.2FEM modelling of extrusion process

Finite element simulation is considered as a powerful and efficient methodology for obtaining defect free products in extrusion process, as various researchers applied this method in the past. Jain et al. [14] conducted FEM simulation of tube extrusion process using aluminum as billet material and steel as die-material. Figure 4 shows the schematic illustration of tube extrusion process and Figure 5 shows FEM model of axisymmetrical tube extrusion. Table 2 shows the material properties of the billet and die.

Materials for die and tube are die steel and aluminium, respectively

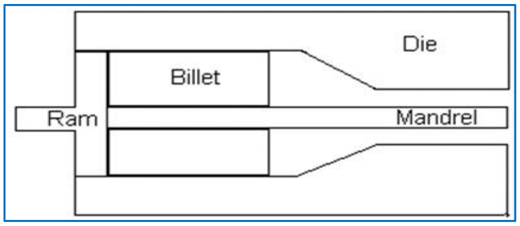


Figure 4 Tube extrusion setup [14]

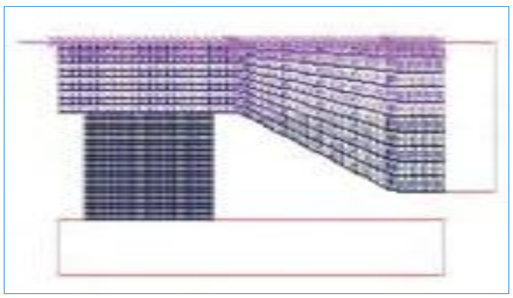


Figure 5 FEM Simulation [14]

Table 2 Material properties of billet and die materials

Material Properties	**Billet**	**Die**
Young's Modulus (Mpa)	70000	220000
Yield Strength (Mpa)	80	1200
Poisson ratio	0.3	0.3
Hardening Component	0	0

Hirt et al. (2017) utilized commercial software package ABAQUS for three-dimensional FEM simulation of hybrid forward extrusion process. They performed a thermo- mechanical and electrical analysis of forward extrusion process. Figure 6 (a) shows the solid forward extrusion process with resistive heating, Figure 6 (b) shape of the formed part and computer tomographic image of cold and warm formed part in the region of extrusion shoulder three. Figure 6 (c) shows geometry of extrusion die .Figure 6 (d) shows the flow curves for different temperatures at at a constant strain rate of 1 s^{-1}.

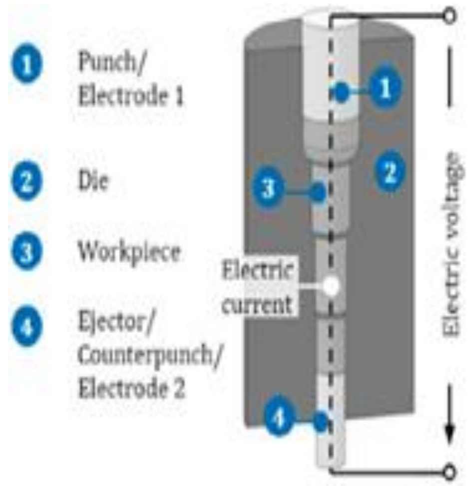


Figure 6 (a) Solid forward extrusion process with resistive heating

Figure 6 (b) Shape of the formed part and computer tomographic image of cold and warm formed

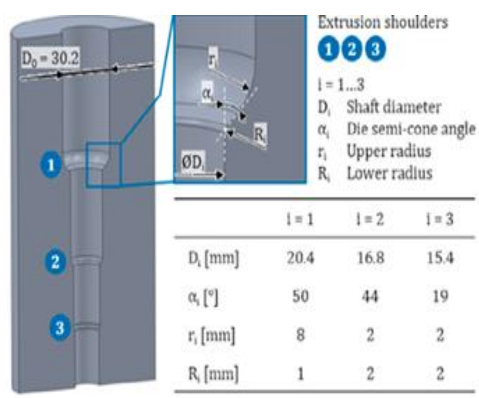


Figure 6 (c) Shows geometry of extrusion die

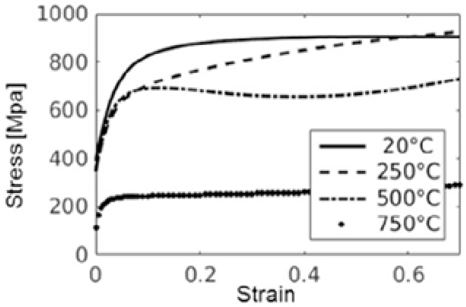


Figure 6 (d) Shows the flow curves for different temperatures at constant strain rate of 1 s^{-1}

Figure 6 a)solid forward extrusion process extended with resistive heating b) shape of the formed part and computer tomographic image of cold and warm formed part in the region of extrusion shoulder three c) geometry of the extrusion die d) flow curves for different temperatures at a constant strain rate of 1 s^{-1}. [2] Mahnken et al. (2010) (23) they modelled and simulate hot metal forming processes in which material undergoes large deformations with help of the Finite Element (FE) software ABAQUS using Lagrangian formulation. The microstructure evolution is modelled effectively with the help of internal state variables. Element distortion and contact during the re meshing simulation of large deformation processes is controlled with the help of a custom adaptive remeshing system based on Python scripting and utilisable in commercial programs such as ABAQUS. Element distortion of material can be by using an adaptive remeshing scheme. They improved the quality of the mesh of number of elements during the simulation. Figure 6 is done by using the adaptive refinement. After each small time step, the distorted elements will be identified in a post processing step. Then the distorted elements divided into smaller elements. The number of elements started from around 2000 at beginning of the simulation and increases up around8000 at the end of the simulation.

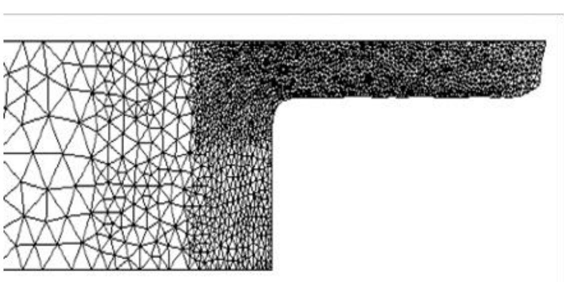


Figure 6 Simulation of extrusion process using adaptive mesh refinement

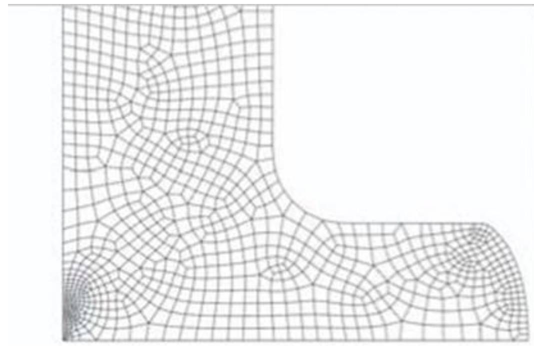
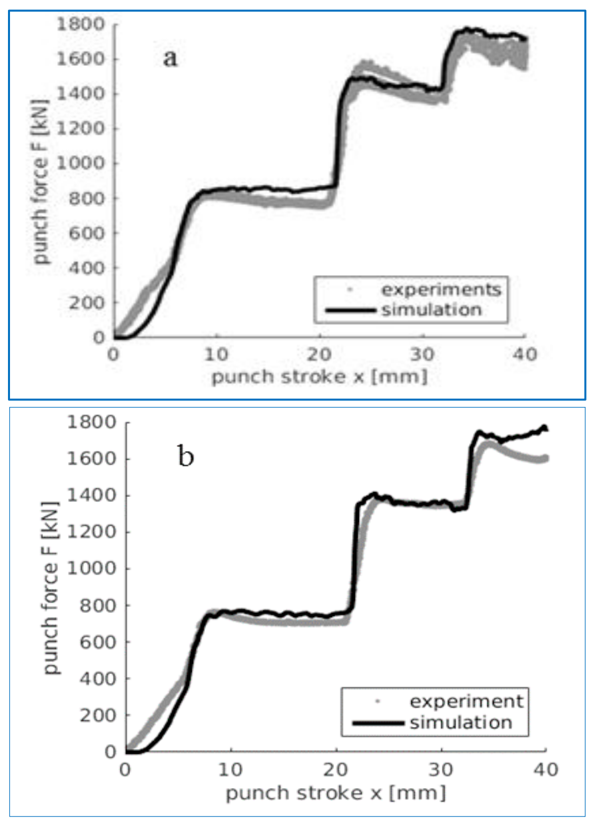


Figure 7 Mesh topology in simulation of forging process using remeshing scheme

3.Result and discussion

The FE model presented different types of result there are force predicted by the FE simulation, the forces are shown together with the corresponding measured force from experimental for three condition cold, preheated and hybrid condition in Figure 3. As a good match of the rising force at each projection at nearly the same punch stroke in experiment and simulation is an indication of the properly implemented re meshing procedure and volume loss is negligible.



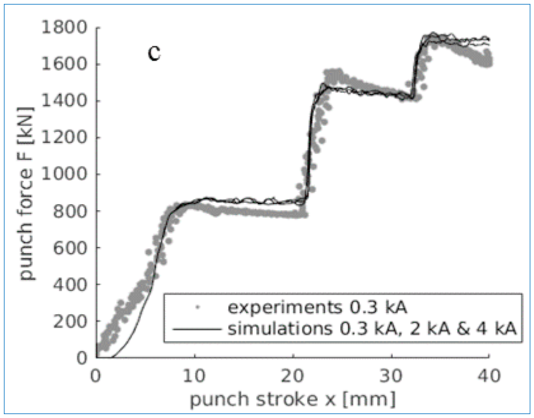


Figure 8 Comparison of measured and simulated punch forces for (a) cold (b) pre-heated to 450°C and (c) hybrid condition.[2]

The thermo mechanically coupled extrusion process of aluminium alloys and forging of steels, both are implemented as user material subroutines (UMAT) in FE software ABAQUS. The CAX4TR element which is quadrilateral axisymmetric element are applied with temperature as a degree of freedom in a coupled temperature-displacement simulation. ABAQUS gives to the output database of the simulation results by using the Python programming language. The system enables us to check the mesh quality or any other remeshing criteria in a post processing step.

4.Conclusion and future work

In the body of work presented in this paper, extrusion process is studied by considering various aspects of extrusion process. A brief and concise review of the contributions made by the previous researchers in the area of extrusion process is also presented. It is found that researchers have utilized aluminium material for extrusion as workpiece material in majority of cases, however in the recent past, the usage of steel alloy has also been started. It has also been found that researchers carried out FEM modelling of extrusion process by employing axisymmetric conditions and modelled problem with half and quarter geometry. Meshing of the die is done by using axisymmetric quadrilateral elements. FEM simulation is found be powerful and efficient methodology in analysis of metal extrusion process.

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