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A new design for Equal Channel Angular Extrusion

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Abstract

A new die design has been proposed for processing of materials using Equal Channel Angular Extrusion (ECAE). The proposed design is an improvement over the existing ones and has an additional attribute to process materials at high temperatures (up to 500 °C). The design has been tested for different materials at different temperatures and it has shown the benefit of reducing the load requirement during pressing. This benefit is attributed to the reduction of friction and appropriate tooling.

Keywords : Equal channel angular extrusion, die design

1. Introduction

Equal channel angular extrusion (ECAE) is at present one of the most promising technique to produce bulk nanostructured or ultrafine-grained materials (grain size in the range 100 – 1000 nm) for structural applications [1-3]. The process has received considerable attention in the last few years due to the advent of nanotechnology, and it continues to receive the attention of the scientific community due to its future industrial potential.

During the process a metal billet is pressed through a die consisting of two channels, equal in cross-section and intersecting at an angle ϕ (generally, 90° or 120°). The billet undergoes essentially simple shear deformation but retains the same cross-sectional geometry, so that it is possible to repeat the pressings for a number of passes, each one refining the grain till the extent which is determined by the material characteristics. By multiple passing, very large effective

deformation can be developed in bulk products. The process also leads to the formation of strong crystallographic texture in the material [1, 2, 4, 5]. In ECAE, it is possible to rotate the billet around its longitudinal axis between each adjacent two passes, creating different routes [6].

Ever since this kind of processing has become the focus of attention to produce ultra-fine grain materials, different design variations of the die have been proposed. However, it is uniquely agreed, based on the calculations of the Von Mises strain per pass imparted to the material [7], that a die with 90° intersection angle and without rounding of its corner region is the most effective in terms of producing maximum grain refinement.

However, even with these considerations, the conventional ECAE die reported in literature and widely used in most of the ECAE experiments, imposes some problems. This includes the presence of excessive friction during the relative motion of the work

piece with the die walls. This becomes particularly significant when the strength of the material to be extruded is comparable to the capacity of the press or the extrusion experiments have to be carried out at elevated temperatures. In the present work, it was therefore proposed to design a new ECAE die incorporating necessary modifications in its features, so that the friction effect can be reduced to a minimum possible extent, as this would benefit the experimenter to extrude relatively stronger/longer material with same capacity of the press.

The important points to be considered in this regard include: (i) the optimization of a design which reduces the friction up to the best

possible extent, (ii) the choice of die material, which should be appropriate from the strength point of view, as well as chemically inert with regard to their interaction with the work piece and the atmosphere at the temperature of ECAE processing.

The other design problems are associated with the different parts of conventional dies, particularly with regard to the problem of dimensional stability under the pressure applied during extrusion. It is generally essential for such devices to have minimum joints, so that under the conditions of high pressure the material should not flow in-between the die elements. This phenomenon is supposed to be even more critical at high temperatures.

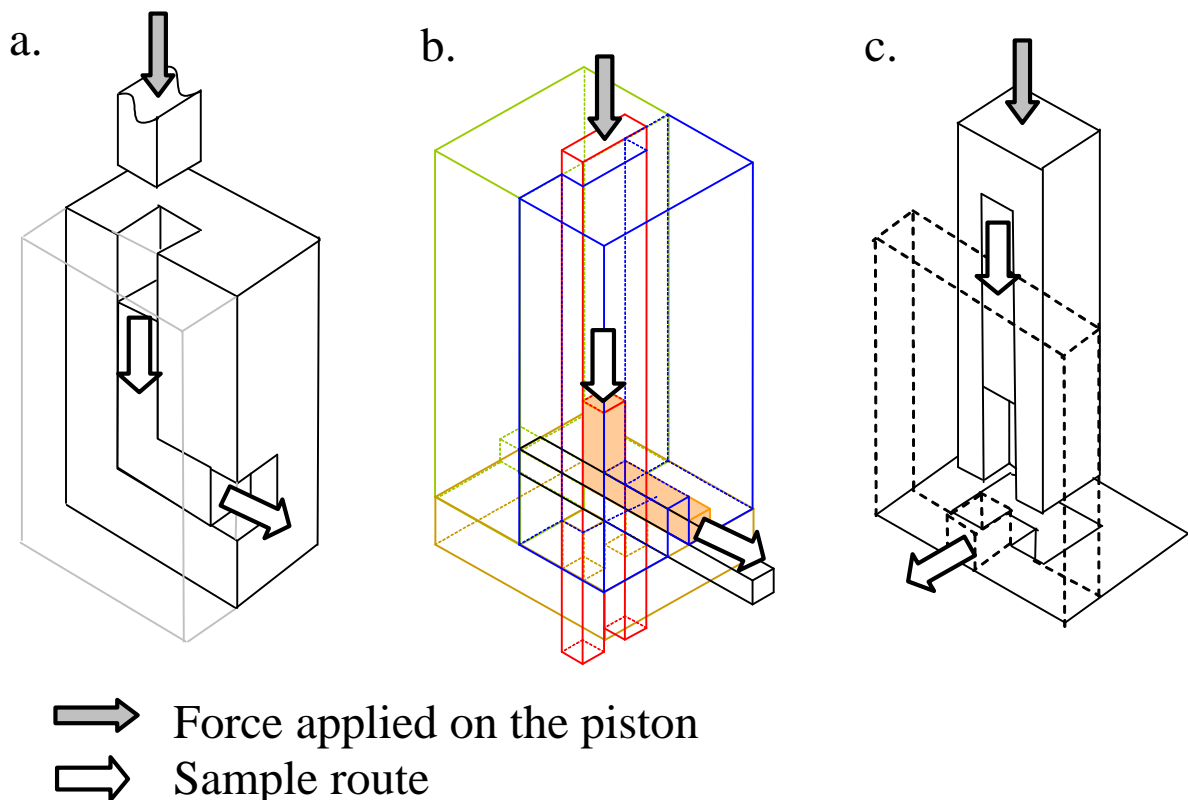


Fig. 1: The schematics of three proposed designs: (a) the conventional one [3], (b) the modified one [8], and (c) the newly proposed one (this work)

2. Specific design considerations

A few preliminary considerations for designing a new ECAE die - based on the discussion given above and also according to certain specific requirements - were as follows: (a) $\Phi = 90^\circ$ and $\psi = 0^\circ$ (the latter is the rounding angle of the corner), to maximize the deformation; and (b) samples with a square cross section of 10 mm^2 and a maximal length of 100 mm could be extruded. The other technological considerations were: (i) The die should be adaptable to normal laboratory materials testing machines, (ii) it should be completely separable, (iii) it should be able to work up to 500°C with a complete thermal insulation from its environment.

The piston shape:

The conventionally available [3], a recently modified [8] and the newly proposed shapes of the piston are shown in Fig. 1. The first one (a) is the classical design where the shape of the piston is the same as the sample. In the second one (b), *two* lateral sides of the

sample are surrounded by the piston and the bottom side of the channel is free to move in order to reduce the friction. In our newly proposed design (c in Fig. 1), the piston surrounds *three* lateral sides of the sample but it doesn't have a bottom gliding part. The last proposed design was based on the facts that it reduces the friction as well as prevents the piston from bending.

An elastic simulation was carried out in order to examine the state of the die during ECAE process, with a sample introduced in a die composed of a single piece. This was also needed to provide a feedback on possible splitting of the die into subsections, before the design part of the work. For simulation purpose, both the sample and the die materials were considered elastic. The sample dimension was kept $100 \text{ mm} \times 10 \text{ mm} \times 10 \text{ mm}$. The results of the FEM calculation are shown in Fig. 2. In the figure the von Mises equivalent stress is plotted (the grey-scale goes from 0 (white) to 2500 MPa (black)). The highest value reached is 2450 MPa .

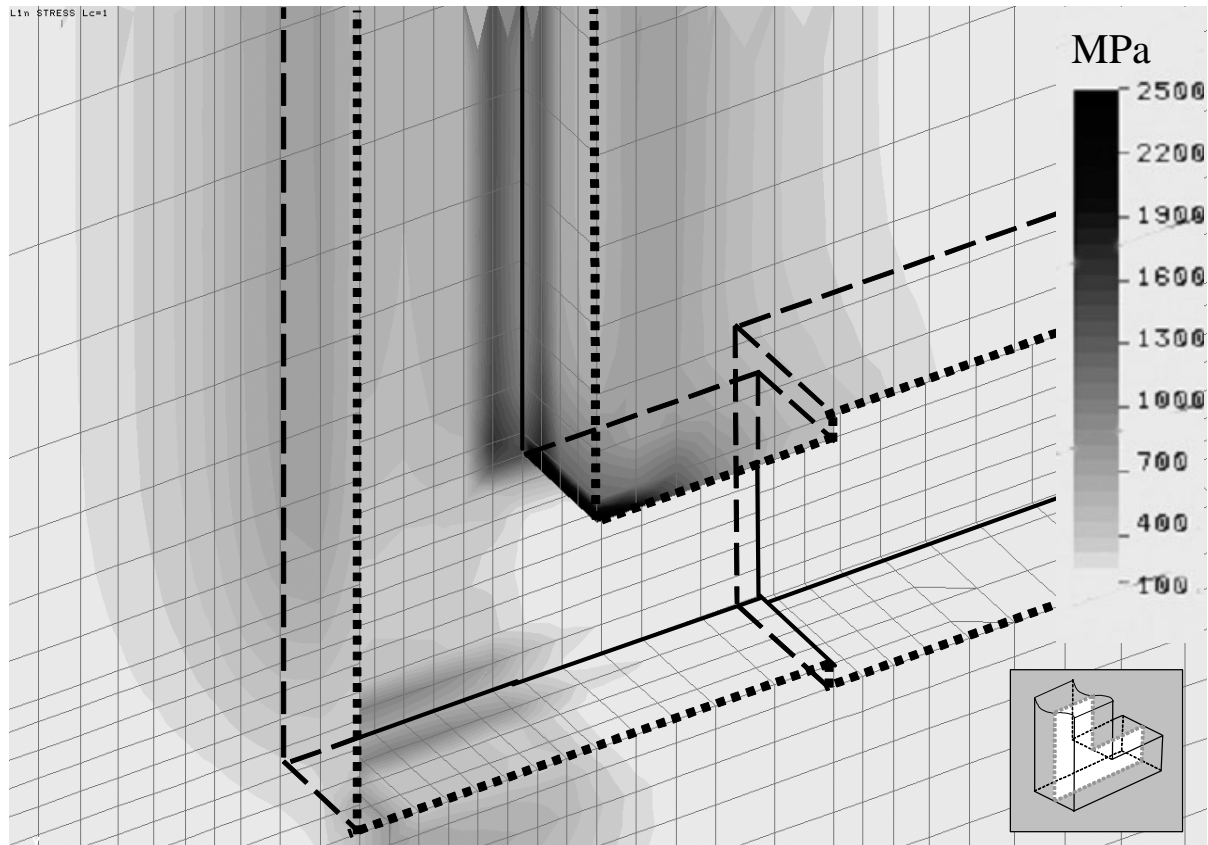


Fig.2: Variation of Von Mises equivalent stress in the die on the basis of elastic calculations. (The section of the sample is 1 cm², its length 8 cm and the extrusion force is 16 kN.)

As can be seen in Fig. 2, the chosen geometry presents some problems of stress concentrations, because the lateral forces induced by the pressure in the channel result in high stress concentrations in the corners of the rectangular hole where the piston glides. Our design optimisation indicated that a new elliptical section for the piston (and the hole where it glides) reduces the stress concentration to its minimum, as illustrated in Fig. 3. It is worth noting that this shape also allows better lubrication between the gliding parts.

The die:

The design of the die has to take into account the necessity to have separated parts that permit (after dismantling the die) accessing the channel for maintenance if it is needed. These different parts were chosen so as to minimise the number of joints in the channel (fractioning) and to maximise the possibility of access to the channel. It was proposed to separate the channel at its lower part of the outlet channel. Thus, the die made up of three parts: piston, die body, and the drawer.

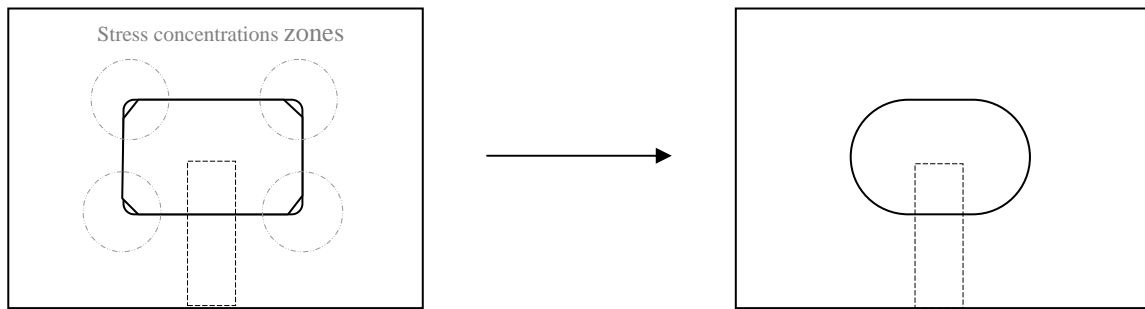


Fig.3: Change of the piston cross section in order to reduce stress concentration during loading

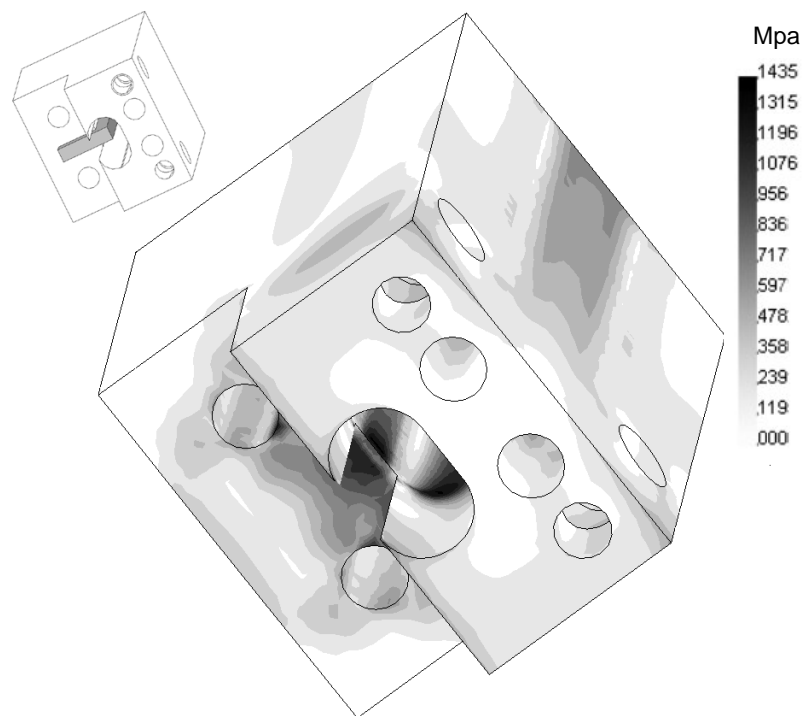


Fig. 4: The distribution of the von Mises equivalent stress obtained by FEM calculations. The gray scale goes from 0 (white) to 1435 (black) MPa. The highest value reached is 1435 MPa.

The new design was then tested using FEM elastic calculations to check whether it would be safe during extrusion. In Fig. 4, one can see the distribution of the equivalent stresses within the body at the beginning of extrusion. The stress levels are much lower in comparison with those calculated in preliminary design calculations (compare to Fig. 2).

Materials for the components:

For fabrication of the die, Inconel 718 seemed to be a good compromise between machinability and strength due to its relative ease in machining and dimensional stability after thermal treatments like solutionising and ageing, as well as quality of surfaces after such treatments. In order to protect the material testing machine (MTS) from thermal effects (thermal

sensitivity of the load cell), the following precautions were taken: (i) the choice of a *stainless steel* for interface part as a first step towards insulation, because of its low thermal conductivity (ii) the *thermal insulation from the environment* using ceramic foam for the reasons of its good insulation properties as well as its easy manufacturing in order to build the insulation box. The insulation layers of the charge cell and of the traction machine plate must be able to transmit the force of the piston (until 160 kN). For this purpose, a composite material made of mica (mineral) layers and a silicon resin was chosen. Heating was done using a PID regulator and a thermocouple of the K type. The die with its complete set up (without insulation box) can be seen in Fig. 5.

3. Experiments with the new ECAE system vis-a-vis to the conventional one

For the first set of experiments, the machine was tested at room temperature with commercially pure Al and Cu. Specimens with 10 mm x 10 mm square cross section and 100 mm length were machined from these annealed bars. The ECAE experiments were carried out at a cross head speed of 1 mm s⁻¹ at room temperature. A lubricant based on molybdenum disulfide (MoSi₂) was used.

In the second set of experiments, copper and titanium with commercial purity were extruded at higher temperatures. The copper was extruded at 100, 200 and 300° C, while titanium was extruded at 350, 400 and 450° C. These materials were also received in the form of an extruded bar and specimens with dimension 100 mm x 10 mm x 10 mm were machined from the same.

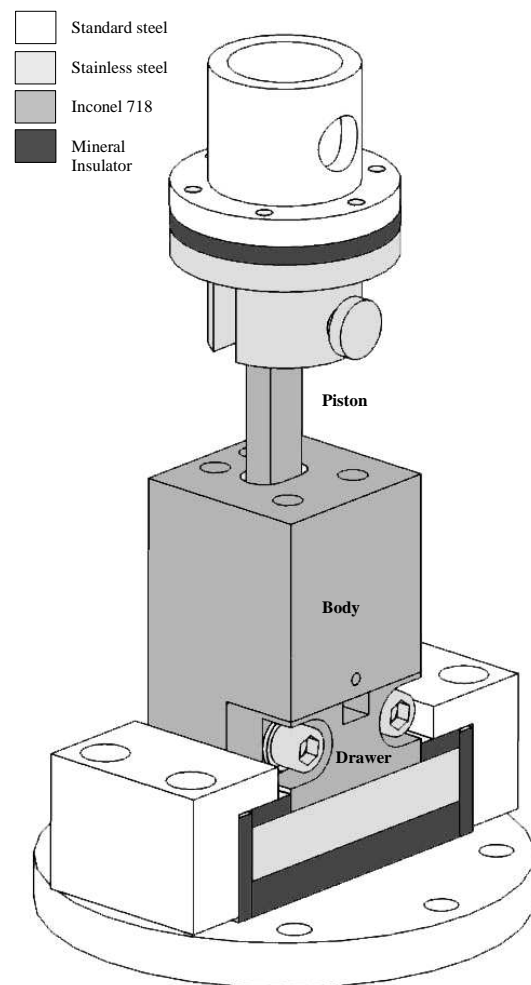


Fig. 5: Final Design.

A representative photograph showing the materials extruded under different conditions is presented in Fig. 6. The corresponding load-displacement curves (for extrusion at room temperature) for both the type of die are displayed in Fig. 7. It can be clearly seen that there is a net reduction in load requirement by about 25 kN with the newly designed die, which is quite significant, particularly when the load requirements are close to the maximum limit of the load cell.

4. Conclusion

An improved design of experimental set up has been proposed for performing equal channel angular extrusion at laboratory scale. The additional benefit of this design is

realised in terms of its capability to perform ECAE up to 500° C, and a very accurate control of temperature at the critical location, that is, close to the shear plane of the die. This is to be mentioned here that previous reports about the ECAE of commercially pure titanium mention the adequate ECAE temperature as 400° C (single pass), while with the newly designed die it was possible to extrude the same at 350° C, without any flaws at the surface and well within the limits of our load cell (which was 200 kN).

Multiple pass experiments could also be carried out without any problem up to at least 4 passes using three different routes (A, Bc and C) of ECAE.

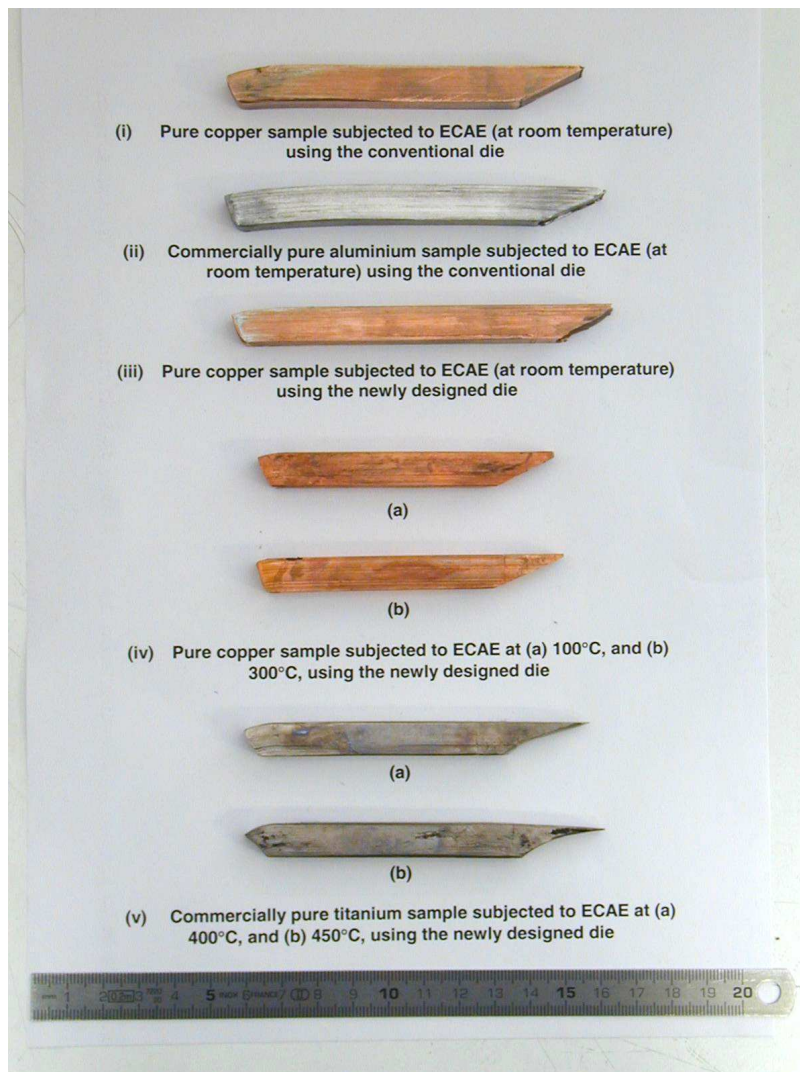


Fig. 6: Different materials subjected to ECAE using a conventional die and the newly designed die.

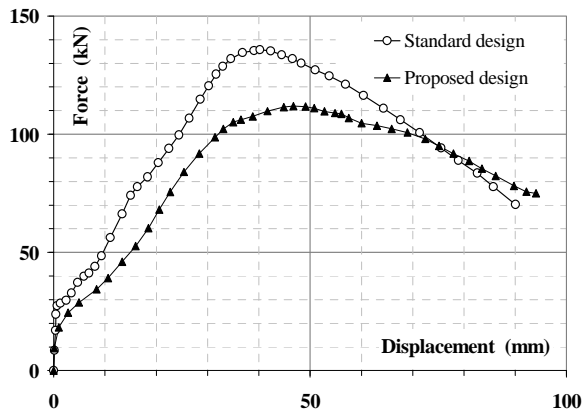


Fig. 7: The load displacement curves for the samples (i) and (iii) of Fig. 6.

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