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COMPUTATIONAL AND MICROSTRUCTURAL ANALYSIS OF EQUAL-CHANNEL ANGULAR PRESSING (ECAP) PROCESS THROUGH DIFFERENT CHANNEL ANGLES

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ABSTRACT

Severe Plastic Deformation (SPD) is an innovative process capable of producing uniform plastic deformation in a variety of materials, without causing significant change in geometric shape or cross section. SPD involves simple shear deformation that is achieved by passing the work piece through a die containing two channels of equal cross section that meet at a predetermined angle usually between 90° to 135°. Equal-Channel Angular Pressing (ECAP), a typical SPD process, has emerged as a widely known procedure for the fabrication of ultrafine-grained metals and alloys. The present work attempts to design, model and analyze ECAP dies with different channel angles viz. 90^0, 120^0 and 135^0. The designed dies are modeled in SolidWorks and analyzed in COSMOS. Computational results indicate that the SPD properties are decided based on the die angle as the strain rates produced depends on the die angles. Best strain rates and mechanical properties are achievable with increase in acuteness of the die angle accompanied by the application of high pressure. Metallurgical test results obtained from specimen processed through the fabricated dies indicate enhanced mechanical properties are feasible in ECAP processed components as compared to conventional extrusion. Based on the product requirements superior mechanical properties can be produced in ECAP process in different dies.

***Keywords**: ECAP, Die Design, Die Angles, Computational analysis, Microstructures*

1. Introduction

The mechanical and physical properties of materials play a very important role in any field of materials usage. Nanotechnology has taken the modification of these properties to altogether different levels over the past few years of research. The basis of nanotechnology is centered about two major approaches of manufacture and research. These are - the Bottom up and the Top Down approaches. The Bottom Up approach concentrates on building the macrostructure from the nanoscale, while the Top Down approach involves reaching the nanoscale by breaking down macroscale units. Both of these routes have been getting their deserved attention by various experts in many fields. While the Bottom Up approach promises to deliver advanced technologies like Molecular self-assembly and DNA coded technologies, the Top Down offers interesting prospects in Micro-electromechanical systems (MEMS) and Nano-electromechanical systems (NEMS). In present day science, out of the two popular approaches mentioned above, the Top Down approach has had greater popularity in industry and application oriented research due to its more immediate applicability compared to the former. This approach has been widely researched and observed in many routes, including the class of processes known as SPD (Severe Plastic Deformation) processes. Equal Channel Angular Pressing (ECAP) was invented in the former Soviet Union by Vladimir Segal in 1977, for which he obtained an Invention Certificate of the USSR, similar to a patent. For deforming alloys to severe plastic strains, constant billet geometry gives a big advantage over conventional metal working processes such as rolling and extrusion, where the work piece is always being reduced in one dimension. In the equal channel angular pressing (ECAP), there is no geometric restriction to the maximum strain that can be reached and alloys have been processed to strains greater than 10 using this method. With this unique feature, the applicability of ECAP has been currently expanded for various kinds of materials. It has been shown that a material with a coarse grain size can be refined to have a fine grain size through intense plastic deformation. With the large accumulative strain while keeping the shape of a material, the ECAP is very effective in producing ultra-

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fine grain size even in a bulk form. The introduction of an ultra-fine grain size may lead to significant change in the mechanical properties of the material. Most of the works to date have been trying to understand the development of fine grain size with high miss orientation angles by employing different processing routes and cyclic pressings.

They have revealed that sub grains form in the early stage of cyclic pressings and these sub grains subsequently evolve with further pressings into an array of grains separated by high angle grain boundaries with further pressings. In spite of the effective shearing deformation, there seems to be a limit in the reduction of grain size with increasing number of ECA pressings. The present work using dies with channel angles of 900, 1200 and 1350 has made the suggestion that two to four passes followed by the low-temperature annealing can be useful to break down an initial coarse structure, refine the grain size and increase the strength of the material.

As a new materials processing technology, severe plastic deformation (SPD) was introduced by V.M.Segal with coworkers in the beginning of the 1970s at the Physical Technical Institute in Minsk, Russia.

1.1 Principle of ECAP

The two channels of equal cross section intersect at an angle 2θ and ψ, where ψ is the angle subtended by the arc of curvature at the point of intersection.

A well lubricated billet which has the same cross section is placed into one of the channels. In contrast to traditional forming operations with relative moderate strains, SPD detects a strong effect of processing mechanics on structure evolution. Therefore, the process optimization presents significant practical interest and sometimes, is the key factor for successful commercialization. For ECAP, deformation mode together with accumulated strains and loading history play an important role in structure evolution. In particular, optimal processing should provide simple shear deformation mode and cross loading along three mutually perpendicular directions with sufficiently high strains.

These characteristics are provided by corresponding boundary conditions at each pass and the special systems of billet orientations during multi-pass deformation when the material hardening ability disappears.

1.2 Design of ECAP die

Table: 1 Material for processing: AA6351

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
.07- 1.3	0.5	0.1	0.4 - 0.8	0.4 - 0.8	0.2	0.2	Remaining

Table:2 Die Material: AISI H13

C	Mn	Si	Cr	Mo	V	Fe
0.4	0.35	0.96	4.95	1.45	0.95	Remaining

1.3 Solid die

During pressing the axial stress on the sample is being translated to pressure exerted on the inner surface of the inlet channel .The maximum pressing load is taken to be around 700 tons. σ = F/A, where A is the sample cross section area, F is the force applied due to the application of pressing load of plunger. 1 ton force = 9.96 kN.

$$\sigma = \frac{F}{A} = \frac{6974*1000}{s^2} \text{ N/mm2}$$

$$=111.584 \text{ N/mm2}$$

The tensile strength (yield) of the die material H13 is 1650 MPa. The stress developed on the upper surface of the die is calculated to be around 109.76 N/mm2, hence the die is considered to be safe. The shear strength of the die material H13 is 81000MPa.

1.4 Split die

For holding of two split dies together, we use 5 bolts and nuts. The total load exerted on the 5 bolts and nuts is 6860 kN. Hence the total load on each single bolt is 6860/5=1372 kN

The shear stress on the bolt is giveb by = σ = $F/A = \frac{1372*1000}{\frac{\pi}{4}*d^2} = \frac{1372*1000}{\frac{\pi}{4}*25^2}$ = 2796 N/mm2

2. Analysis in COSMOS

The modeled die is analyzed in COSMOS for the stress distribution. The strain rate distribution in the work piece material is simulated as the material passes through the channel angle. The strain rate distribution for 90^0, 120^0 and 135^0 in the work material is shown in Figure.1, 2 and 3 respectively. The effective strain was found increase with decrease in channel angle. The maximum strain is observed near the exit of the channel inner edges.

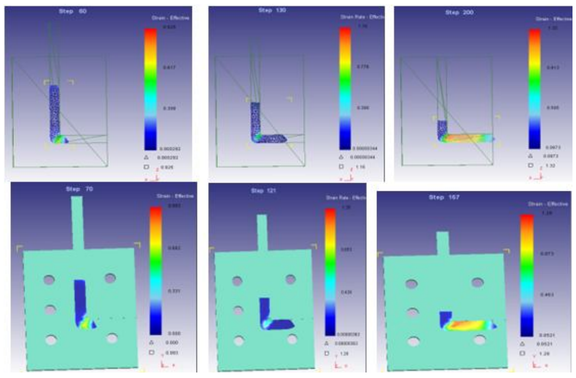

Fig.1 Effective strain in the workpiece – wire frame and solid model (90^0 Channel angle)

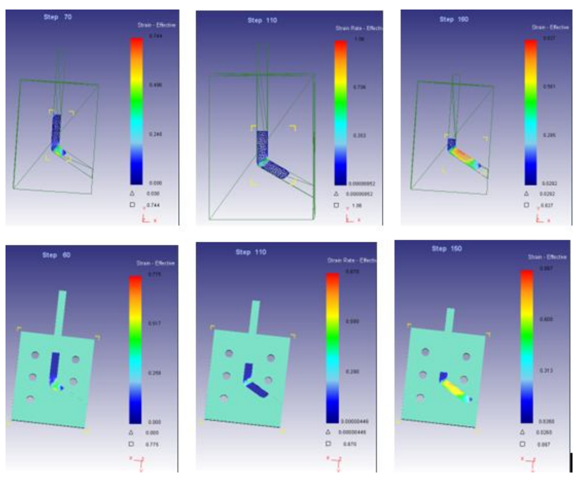

Fig.2 Effective strain in the workpiece – wire frame and solid model (120^0 Channel angle)

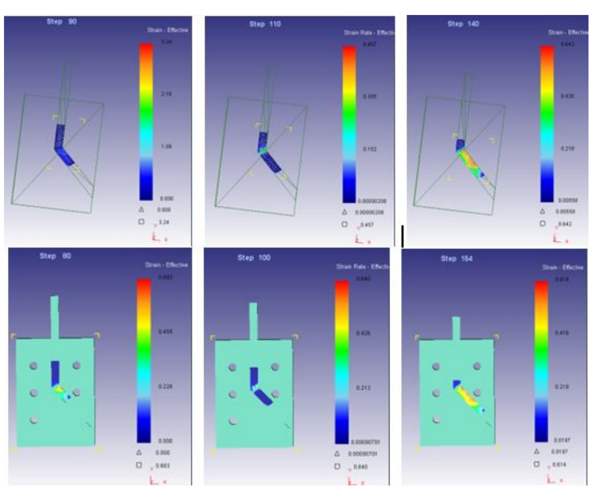

Fig.3 Effective strain in the workpiece – wire frame and solid model (135^0 Channel angle)

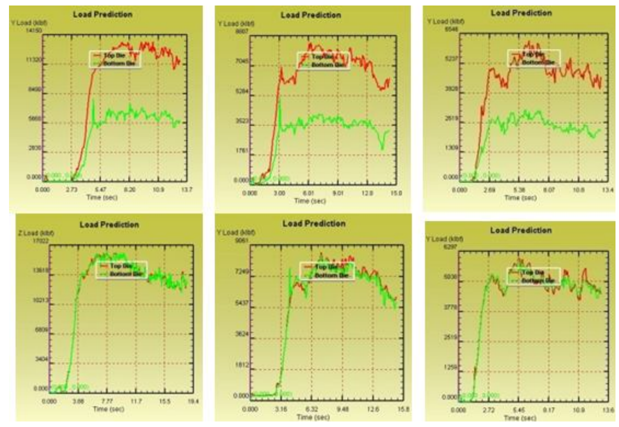

Fig.4 Load Prediction for the the workpiece (90^0, 120^0 and 135^0 Channel angle)

3. Experimentation and Microstructures

The designed and modeled dies are manufactured and the material is processed in 40 tonnes hydraulic press. The obtained samples are tested for microstructures in optical microscopes. The obtained microstructures indicates equiv axed elongated grains and superior microstructural behaviour as shown in Figure.6. The microstructure shows superior grains with decrease in channel angles

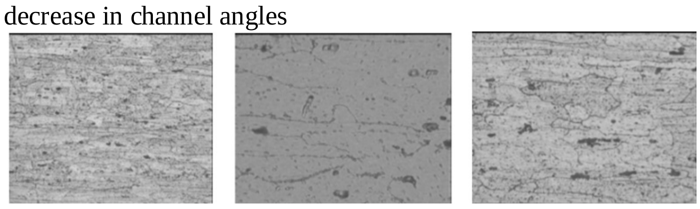

Fig. 6ECAP processed microstruture in 90^0, 120^0 and 135^0

4. Conclusions

The aim of the paper is to design, analyze and manufacture an ECAP dies with channel angles 90^0, 120^0 and 135^0 is successfully achieved.

The effective strain rate distribution in the processed material is found to increase with decrease in channel angle. This maximum strain occurs near the inner edge of the channel at the exit end.

The stress limits developed in the die are found to be within the safe limits of the design.

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