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Novel molding technique for ECAP process and effects on hardness of AA7075

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1. Introduction

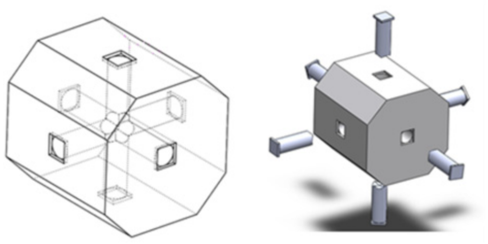
In past two decades equal channel angular pressing (ECAP) method has been widely used as a technique of producing microstructures and nanometer range in bulk materials introducing extremely large plastic deformation processing. In this process, internal stress, strain and strain rate distributions on the sample are fundamental to the determination of the optimum process conditions for a given material. Fine-grain structured metallic materials, which produced by ECAP methods, have higher strength, super plasticity, ductility and toughness than coarse-grained materials produced by using one of the conventional methods [1]. In the ECAP technique billet forms keep their shape and sizes, also causes to great stress segregations and improve to microstructures in materials [2-4]. ECAP technique is plastic deformation process that realized by pressing the work-piece from a channel to other one which has different direction. The major advantage of the ECAP process is maintaining the billet shape without change. Moreover, ECAP' ed samples are free from porosity thus the process can be used for manufacturing the large bulk samples for a wide range of industrial applications [5-10]. Each successive passes changes the sample's characteristic. This variation makes the microstructure and the grain locations uniform and unidirectional respectively. ECAP process depends on the die's channels shape and number. Conventional ECAP dies have two or four channels. Samples can be replaced into the channel on the top of the die. If the deformation direction of the samples were changed it is called as "routes" in literature [11-17]. Before replacing the sample into die for the second pass, the sample can be rotated 90° and 180° around its longitudinal axis. In practice, 4 different processing routes have been identified: In route A, sample is pressed without any rotation. In route BA the sample should be rotated 90° CW and then CCW continuously for the each pass. In route BC, the sample is rotated 90° in the same way for each pass. In route C, sample is rotated 180° in the same way for each pass [18-23]. Although many researchers choose the square form samples because of easy replacing on the route, there are some cylindrical form have been studied also such as for producing rivets or bolts. But cylindrical form has a few disadvantages, one of which is precision of route because of manual guiding [1, 24-27].

This study includes a novel ECAP die design which named "Hexa Die" and it has six channels. Hexa die method has been provided shorter process duration and higher precision for angular rotation than the traditional die methods. Hexa die can keep closed during the all ECAP process steps. Sample can be passed many times and many different routes without removing or disassembly of the die. Hardness measurements of the reference and ECAP' ed samples have been done after they passed in route C for 1, 2, 3 and 4 times. Finally it has been seen that ECAP process time has reduced dramatically and alignment problem of the cylindrical sample eliminated by using Hexa die.

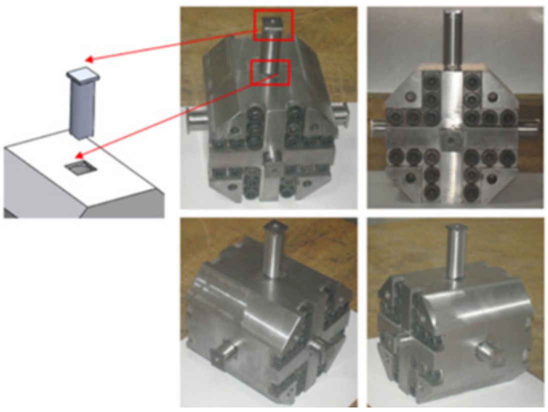
2. Material and method

2.1 Design and manufacturing of die

In this study, a die was design and manufacturing was carried out treating to ECAP process for cylindrical shape materials. When studies in relation to ECAP are examined, it was seen that materials have generally whether square or rectangular geometry. An approximate rotation could be achieved between successive passes during the processes for cylindrical shape material. Furthermore process speed can take quite a long duration. A die was designed and manufactured to eliminate this sort of problems. As the die has six channels, each of it is used in ECAP, is called as hexa die. 3D schematic image is shown (Fig. 1, a). The design of the used in ECAP process has a significant importance as it lets apply variables of process. The study was conducted using impax supreme material in ECAP die. The die was designed to eliminate the contamination, to control the interior surface and any problem could arise during and after the ECAP process. Sharp chamfers are made as regarding the ease of rotation of die during the rotation process and ease of making required movement. With a diameter of 20 mm, holes are drilled on 6 sides of die to provide all rotations. Regarding the direction of rotation, holes are replaced by pins with appropriate tolerance to finalize the system. Two-piece die is assembled using 4 guide pins, 20 steel 12, 9 screw and nuts. Canals which are suitable for pin caps that are 2 mm each square shape and at the center of the surfaces where the holes on were created to obstruct rotation of die pins during process and provide to be arrangable at desired angle at the die faces where the pin holes on. After manufacturing process 64HR$_C$ hardness is obtained by applying hardening heat treatment. Designed and manufactured of new design die pictures taken from various aspects are presented (Fig. 1, b). A die with two parts, specially designed pin shapes and die holder are the three main sections of ECAP system. Using the Deform 3D software program before manufacturing of designed die, an analysis was done, by means of the values of the study to be carried out.



a

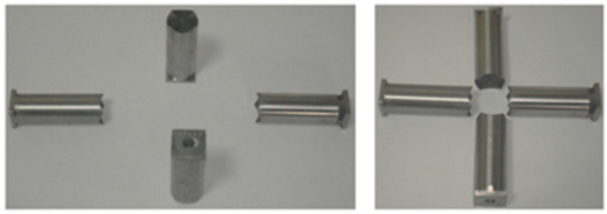


b

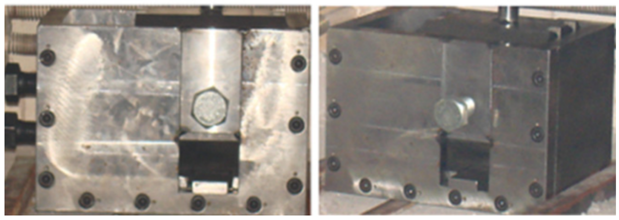
Fig. 1 Designed and manufactured new ECAP die: a) designed 3D schematic illustrations of new ECAP die; b) manufactured ECAP die

2.2. The die pins and the die holder

Die pins are designed specially to provide cylindrical materials can move easily depending on rotations and able to apply severe plastic deformation process in each direction during ECAP process. While one end of the pins is processed two-way crescent shape the other end is processed square shape to prevent rotation of them. During processes, AISI H13 hotwork tool steel was used to prevent any deformation at pin materials and then the pins were hardened. Die pins are facilitate to remove from die of to screw-cutting on caps to diameter of 3 mm. Designed and manufactured pin shapes of ECAP are presented in Fig. 2, a. It is important to keep the die constant and in accurate axis with press stroke during ECAP process. At the same time when the continuing with consecutive pressing processes is considered, it is remarked that die holder's design is also important. Therefore die holder is designed as obstruct to move of the die during process, easily remove the die after process, allow to be demountable pressed material and die pins. Die holder that was seen in Fig. 2, b was designed to balance thermal expansions and stretch after lateral loads that are made from pins while pressing.



a



b

Fig. 2 Die pins and die holder: a) designed and manufactured ECAP die pins; b) die holder

2.3. ECAP system

High capacity hydraulic press (1200 kN) is used for ECAP process. Private manufactured heat treatment furnace is placed on the hydraulic press in order to prevent to heat loss and able to provide of temperature control. ECAP process is performed at temperature of 210°C and strock speed of 1.5 mm/s. The equipment of this process is given (Fig. 3).

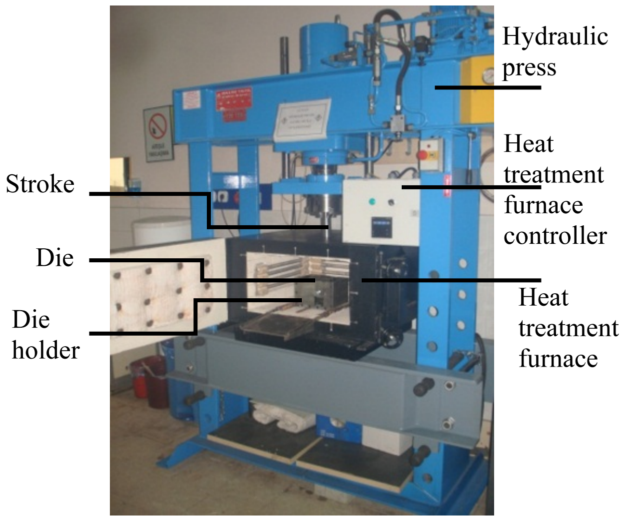


Fig. 3 ECAP process

At this study, commercial purity AA7075 rods in diameter of 20 mm and length of 55 mm are used as the samples. The AA 7075 with the chemical composition of 5.60 Zn, 2.53 Mg, 1.59 Cu, 0.22 Fe, 0.21 Cr, 0.14 Si, 0.11 Mn and Al balance in the form of extruded ingot used in the present work. After those samples were ECAP' ed in various pass and "C" route. ECAP process is realized successfully for each surfaces respectively 1 pass, 2 pass, 3 pass and 4 pass at various rotation. Reference sample and next situations of this sample after ECAP process at temperature of 210°C are presented (Fig. 4).

Experimental results are compared with analysis results that are obtained by Deform 3D program. Experimental data's are similar value with simulation data's and this data's are given in Fig. 5. The sample that is obtained after certain rotation and desired pass numbers in ECAP process is given in Fig. 5, b. Two section of die is given in Fig. 6 to show the forms of the sample.

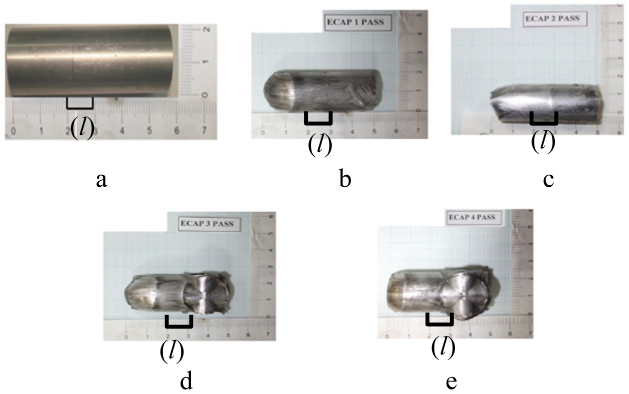


Fig. 4 Reference sample and ECAP' ed samples: a) Reference sample; b) 1 Pass; c) 2 Pass; d) 3 Pass; e) 4 Pass

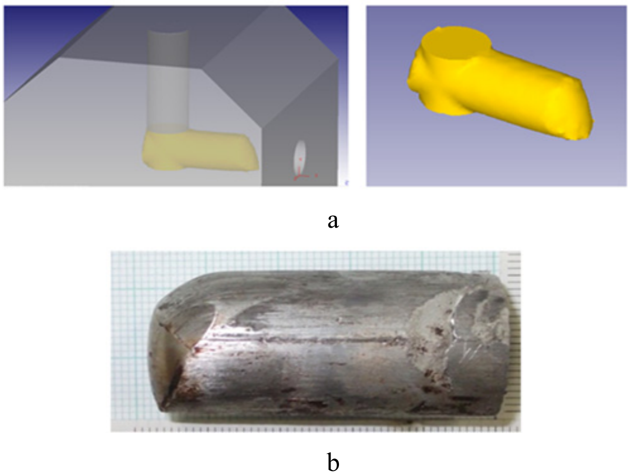


Fig. 5 Matches pictures of experimental data with teoric data: a) Analyzed sample with Deform 3D program; b) ECAP' ed sample

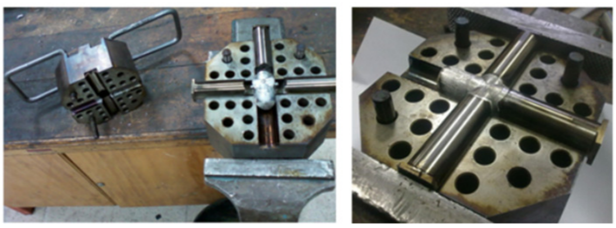


Fig. 6 Opened die pictures of ECAP' ed sample

ECAP process was performed with hydraulic press at stroke speed of 1.5 mm/s and force of 300 kN. During pressing, highly purified MoS_2 in liquid form was used as lubricant. A and B_C rotations were used at various passes in ECAP process. As a result of processes any deformation was not seen at die or die pins. Thus designed versatile pattern of ECAP die can be use easily at future studies. Hardness measurements of reference and ECAP' ed samples were examined. Obtained measurements are displayed in Fig. 7. Hardness measurements are taken in an average of five hardness measurements in the middle of the samples and measurement length has been defined in Fig. 4 as (*l*). These results are compatible with the other researcher's results in [28, 29].

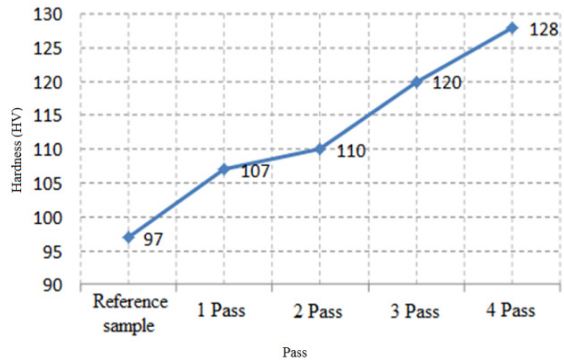


Fig. 7 Hardness measurements of reference and ECAP' ed samples

After the acquisition results, it is seen that there is an increase at hardness values of ECAP' ed samples according to reference sample. Photographs of the materials that are pressed in different rotations and same conditions are displayed in Fig. 4.

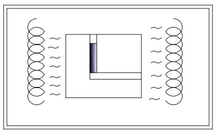
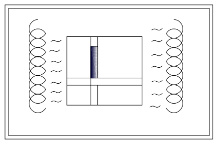
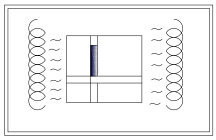
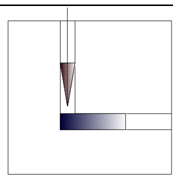
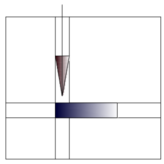
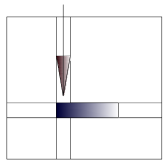
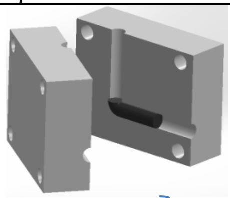
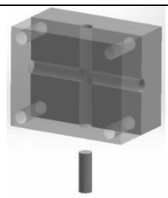
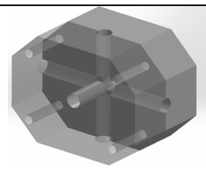
The corresponding load and number of pass values at process temperature 210°C. It can be clearly understand that there is a net increase in load requirement because of the increase at the number of pass. During the ECAP processes applied forces to 210 kN for 1 pass, 240 kN for 2 pass, 260 kN for 3 pass and finally 300kN for 4 pass. Process duration for 55 mm length material was completed in 37 s while using 1.5 mm/s stroke velocity. A and B_C routes were required 25 s. for rotations of die. The process step times of the two, four and novel hexa die methods have been compared theoretically in Table.

3. Conclusions

This study made a major contribution to ECAP Studies. A new design die named as Hexa die was manufactured. Hexa die has been used in ECAP process for cylindrical materials which were subjected to pressing process at desired routes. ECAP process has been performed at temperature of 210°C and stroke velocity of 1.5 mm/s. During the ECAP process of cylindrical materials, the manual rotation problems while crossing between passes are eliminated with hexa die. By increasing ECAP process velocity, it was ensured shortening of process duration. During the process, the samples have been able to rotate through desired routes without removing from inside of the die so that ECAP process takes a shortener processing time. Hexa die can be use easily in ECAP process for much kind of materials. When the samples which obtained from experimental studies, were compared with computer aided simulation studies it was seen that same sample forms have been acquired. Moreover Hexa die is not only for passing the cylindrical shape materials but also different geometric forms can be used. After from studies it was seen that there was no deformation at the die. Different routes (A, B_A, B_C and C) can be applied at multiple pass (4 pass) without any problem.

Table

Two pass processing time table for different ECAP dies

Step No	Process	Die type		
		Two channel die	Four channel die	Hexa die
1	Sample placement and die heating			
2	First pass	 One pass : 37 s	 One pass : 37 s	 One pass : 37 s
3	Rotating the sample to different route	 Die cooling Die disassembly Sample removing } 3600 s Die re-assembly Sample placement Sample re-heating } 2400 s	 Die rotation to remove the sample: 25 Sample removing pass: 37 Die rotation to placement of the die pin: 25 Sample replacement: 20 Sample re-heating: 600 } 707 s	 Die rotation: 25 s
4	Second Pass	One pass : 37 s	One pass : 37 s	One pass : 37 s
Total Duration		6074 s	781 s	99 s

Acknowledgements

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ORIGINALUS FORMAVIMO METODAS TAIKOMAS VIENODO SKERSMENS KAMPINIŲ KANALŲ PRESAVIMUI IR JO ĮTAKA AA7075 KIETUMUI

R e z i u m ė

Šiame straipsnyje pateikiama originali vienodo skersmens kampinių kanalų presavimo technologija antgaliu, pavadintu „Hexa die“ suprojektuotu ir pagamintu tam, kad sumažinti proceso trukmę bei išvengti problemų atsirandančių bandinį presuojant rankiniu būdu. Preso formos paviršiai buvo apdirbti taip, kad iš suformuotų cilindrinių kanalų būtų galima ištraukti ECAP bandinius. Šie kanalai 100% užtikrina cilindrinių bandinių praeinamumą. Eksperimentiniai tyrimai buvo atliekami su bandiniais pagamintais iš tų pačių medžiagų (AA7075), esant 210ºC pastoviai temperatūrai ir “C” sukimui. Tyrimo metu tradicinės ir naujos technologijos procesų trukmės rezultatai buvo palyginti su teoriniu grafiku. Nustatyta, kad originali „Hexa die“ technologija našesnė ir efektyvesnė dėl to, kad proce-

sas vyksta trumpiau, greičiau ardomos ir pakartotinai surenkamos formos ir daugelio kitų faktorių.

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NOVEL MOLDING TECHNIQUE FOR ECAP PROCESS AND EFFECTS ON HARDNESS OF AA7075

S u m m a r y

In this study, a novel Equal channel angular pressing (ECAP) die which named "Hexa die", designed and manufactured in order to reduce process duration and eliminate manual sample rotation problems. For this reason, the surfaces of die was machined to get the cylindrical channels be able to extract out of ECAP samples. These channels provide 100% accuracy for angular routes for cylindrical samples. Experiments are carried out with the same sample materials (AA7075) at a constant temperature (210°C) and "C" rotation. In the study, process time scenarios for traditional and novel Hexa die techniques have been compared in a theoretical time table. It has been shown that Hexa die has crucial time advantages in order to eliminating the old die process steps such as cooling and reheating time, disassembly and re-assembly of the dies, manually rotation of samples and many of others. And finally ECAP'ed samples hardness have been measured.

Keywords: molding, ECAP, deformation, Hexa die, aluminum, hardness.

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