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Effect of Strain in Cold ECAP by Rota C in Mechanical Behavior and Homogeneity of AA1070 AL Alloy

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Abstract: The aim of this study is evaluate the mechanical behavior of an Al AA1070 aluminum alloy produced from rolling hot process, by equal channel angular pressing (ECAP). The process is cold via route C with 5 consecutive passes and accumulated a total strain of $\varepsilon 5 = 5.95$. The as received material has a coarse grain micro structure with grain size of 15.7 ± 17.5 µm and micro hardness Vickers 31.1 ± 2.5. The mechanical behavior and micro hardness Vickers of the samples were evaluated by tests of Vickers hardness, creation of hardness maps and force-deformation graph during the ECAP process. It was observed that the mechanical properties of the material changed with an increase of hardness approximately 50% from 31.1HVto 46.6 HV and increased strength of the material in view of the force required for the passage of the billet through the die was 40% higher in the later passes to the first. The hardness maps presented heterogeneously and became more uniform over the processing passes fact in agreement with the observed standard deviations. The ECAP process was effective only until the second pass processing.

Keywords: Pressing by equiangular channels (ECAP); Aluminum alloy; Severe plastic deformation; mechanical behavior; micro hardness Vickers.

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I. INTRODUCTION

The Equal channel angular pressing (ECAP), as illustrated by Figure 1, consists in the flow of the billet by channels with constant crosssections perpendicular toeachother. The material suffers simple shear deformation during the passage through of the intersection of channels which promotes changes in its microstructure and consequently on its mechanical properties.

The ECAP has fourfundamentals processing named routes A, B_A, B_C and C. The distinction between the routes is the type of rotation in relation to the load application direction of the material after each pass of the deformation. These rotations favor the activation of different slip systems producing differences in the microstructure of the processed material [3].

The route used in the this study will be to route C, in which the material undergoes a rotation of 180 ° between in each pass.

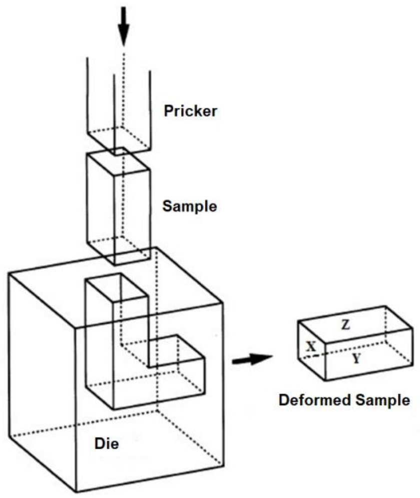

Fig. 1: Die of ECAP and orientation plans. Adapted from [4].

In this context, the AA1070 aluminum alloy research consisted of systematic analysis of its behavior after a deformation by ECAP along the 5 passes deformation using a route C, with the aid of micro printing for hardness tests in Vickers scale, generated data (force *vs.* displacement) during the ECAP Processing and by equation Hall-Petch, in order to quantify and compare the evolution of the mechanical properties after each pass deformation.

To laminyad and Dehghani [5] conducted a microstructural characterization and evaluated some mechanical properties of the same alloy processed by ECAP through the B_C route. Were observed two types of behavior: between the first and the fourth pass a microstructure evolved from elongated sub grains for fine and equiaxed grains and a contours fraction of high angle and crystallographic difference grew quickly until the fourth pass.Between the fourth and eighth pass the growth rate reduced and no significant change in grain size and mechanical properties was noted.

II. MATERIALS

The samples of test are AA 1070 aluminum alloy, provided by Novel is Company of Brazil Ltda., whose chemical composition and presented in Table 1. The material was casted to production of a plate with 610 mm of thicknessand then smoothened down by hot rolling up to a thickness of 32 mm whose output temperature was estimated at above 380 ° C.

Table1. Chemical composition of AA1070 aluminum alloy (contents expressed in% by weight)

Mn	Mg	Si	Pb	Fe	Ti	Cu	Ga	Al
-	-	0,07	0,002	0,18	0,02	-	0,001	99,72

III. EXPERIMENTAL

ECAP process

The ECAP processing consists of the passage of billets with 70x10x10 mm of dimensions throughthe die with equiangular channels of equal cross-section. The channels were lubricated with high performance grease of calcium sulfonate. In this study the route of processing usedis route C, which the sample is rotated 180º along its longitudinalaxis.

The ECAP processing was performed in the Laboratory ofmechanical tests atthe Federal Fluminense University (EEIMVR/UFF) using a traction and compression universal machine EMIC DL-60 with a maximum load capacity of 600 kN, a bipartite ECAP die steel H13 tool with two identical channels with dimensions 10x10 mm an angle of 90 ° and H13 tool steel punch.

The bend radius of the channels is 5 mm ($\Psi \approx 37°$) to facilitate the flow of the billet between the channels and reducing the pressing load. The deformation was performed at a speed of 5mm / min and a true strain accumulated $\varepsilon 5 = 5.95$. During processing were generated graphs of force versus deformation in order to evaluate the mechanical behavior of the samples in the course of deformation passes.

Vickers Hardness

In order to determine the evolution of mechanical properties was performed Vickers hardness test machine, using a micro hardness tester of Shimadzu Brand and HVM-2T model installed in the LMME EEIMVR / UFF. It was conducted a total of 225 measurements, distributed in a 15x15 array, over the entire cross section of the samples. The Vickers micro prints were performed with load of 0.1 kgf for 30 seconds.

IV. RESULTS AND DISCUSSION

In order to determine and quantify the strength of the material after each pass, we generate compressive strength curves x displacement. In the curve of force versus displacement of the ECAP process, Figure 2, it is shown an increasing compression force in the second pass from approximately 25KN to 35KN, resulting from growth of the mechanical strength of as received material, from the work hardening of the material caused by severe plastic deformation after the first pass. Note by the curves that in subsequent passes no significant changes in compressive strength, where it keeps constant. This suggests that the mechanical strength of the material has increased only up to the second pass, suggesting that this is effective pass to the ECAP Al AA1070 aluminum alloy.

This statement is in divergence with the observed for *Tolaminyad* and *Dehghani* [5], describing theirs work in the mechanical strength grows rapidly until the fourth pass and stagnate in subsequent passes for a pure aluminum alloy.

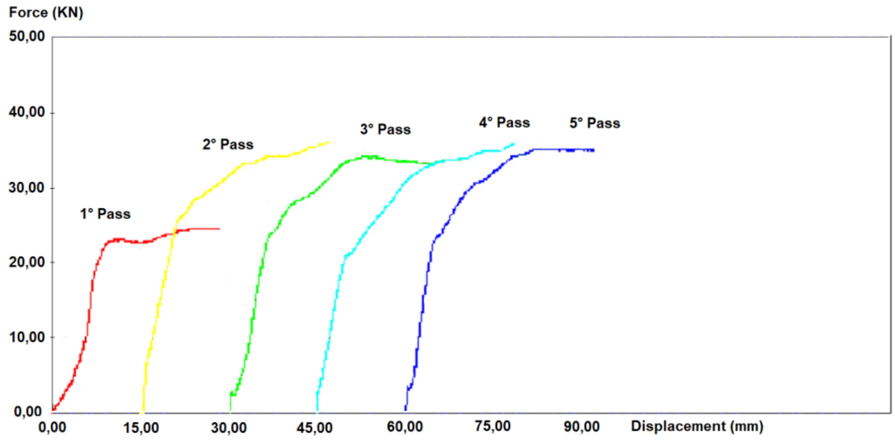

Fig.2. Curve Force versus displacement of E CAP Processing after 5 consecutive passes.

After the first pass was found an increase of approximately 50% of hardness compared to the as received material, result expected by the hardening arising from the E CAP process, found by Resende and Haugen [6, 7]. Table 2 shows the average of hardness values found in samples and Figure 3 shows the trend graph of the hardness of the material during the processing passes. It is observed that the values of the second to the fifth pass has virtually unchanged, featuring a steady state. Similar behavior was found by Resende and Haugen [6, 7] to evaluate the same league, but on different routes. This is a result which again leads to the thesis that the second pass is the effective pass to the Studied material.

Table 2. Evolutionofhardnessafterthe5 passes ECAP processing.

	Dureza (HV)	Desvio Padrão (HV)
MP	31,1	2,5
1° Passe	48,2	1,9
2° Passe	47,5	1,8
3° Passe	49,1	1,8
4° Passe	46,2	1,4
5° Passe	46,3	1,7

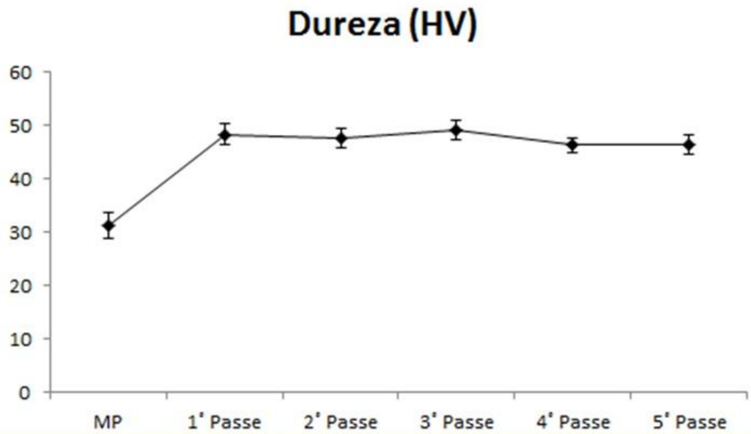

Fig. 3. Graphoftheevolutionofhardnessafterthe5 passes ECAP processing.

The steady state refers to theme chanical properties can be explained by Castro and Mendes [8, 9], which in their work, they presents trongevidence of micro structural competition between recry stallization and dynamic reco very during the E CAP deformation of the AA1070 Al alloy, stabilizing the process. Suchindications were found with greater intensity from the third pass. Soontheresults of Vickers hardness tests and the information generated during processing show is consistent with the micro structural evolution of the material.

The standard deviation of hardness measurements given in Table 2 show a reduction in theirvalues, suggesting a tendency to homogenize the material, but changes occuronly until the second pass. Studies about the evolution of aluminum homogeneity processed via ECAP made by Xu and Langdon [10] usingVickers hardness maps, suggest that after the first pass its hardness maps presented heterogeneously and became more homogeneous over the passes processing. Variousauthors [10, 11] alsoclaimthatthereis some difference between the hardness values and grains ize of the edges and the center of the samples in its crosssection. In ordertoclarifythesefacts were created hardness maps, with 225 measuresd is tributed evenly throughout the crosss ection of end to end sample. Figure 4 shows the obtained maps, which can be observed a tendency to homogenization when comparing the maps of the starting material with subsequent passes. This fact is according to the data found by Xu and Langdon [10], but is not observed any indication orevidence of hardness disparity between different regions of the sample seven significant differences in the2˚ mapsto 5˚ pass.

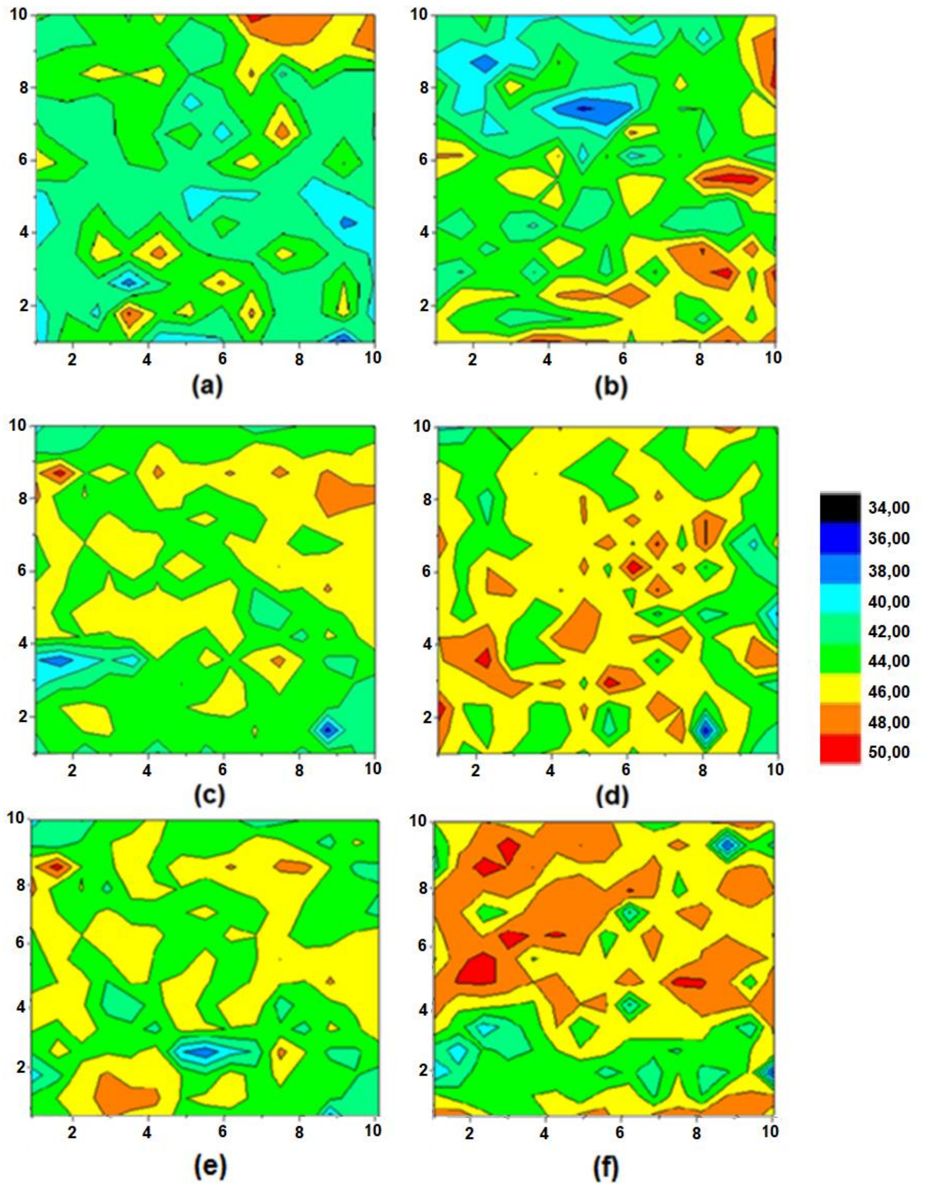

Fig. 4. Hardness maps (A) as received material and after (B) 1˚ Pass; (C) 2˚ Pass; (D) 3˚ Pass; (E) 4˚ Pass; (F) 5˚ Pass.

V. CONCLUSION

It follows that the E CAP process via route C has great effectiveness in increasing the mechanical properties of AA1070 aluminum alloy, increasing its strength by40% and the hardness by50% , respectively. These values are high when compared with obtained inconventional forming processes. Also concluded that the material becomes more homogeneous when processed via E CAP, as evidenced by the fall of the standard deviations and hardness maps. However pressing equiangular channels by route C for theAl AA1070 aluminum alloy is effective only up to the second pass processing, no significant changes in mechanical propertie seven in the homogenization of the material after the same.

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