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Effect of Intensive Plastic Deformation on Microstructure and Mechanical Properties of Aluminum Alloys

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Abstract-In work it was studied the influence of intensive plastic deformation on structure and mechanical properties of aluminum alloys. Intensive plastic deformation was carried out by using equal-channel angular extrusion. It is shown that the most efficient angle of intersection of the channels is the angle of *Φ*=120°, which ensures defect-free parts at the highest possible level of accumulated strain (*e*=8). It is established that the intensive milling grain structures in aluminum alloys AMG6 and AMC occurs at ECAE-12 passes, while the intersection angle of the channels of 120°. After ECAE-12 in aluminum alloys the grain refinement reaches to the size of ~1.0-1.5 μm. It is determined that as a result of equal channel angular pressing, the microhardness of alloy AMG6 increases almost 4 times in comparison with the initial state, the microhardness of alloy AMC increases by almost 4.5 times in comparison with the initial state. It is shown that ECAE-12 mass loss is reduced to 5.4 and 5.6 mg, which shows an increase in wear-resistance of aluminum alloys AMG6 and AMC 13-14 %.

Introduction

One of the main tasks of modern materials science is to obtain high-strength materials with increased strength and technological characteristics. The solution of this problem is an effective way to give metals and alloys with submicrocrystalline (QMS) and nanocrystalline (NC) structure. [1-5]. The most promising method of obtaining the QMS and NDT of materials is intensive plastic deformation (IPD) [1-3,6]. Intensive plastic deformation – is a complex physico-chemical process, in which, while changing the shape and structure of the initial state, it changes its physico-chemical and mechanical properties. With various types and modes of plastic deformation in crystalline materials with different type of crystal lattice is observed the basic phenomenon of fragmentation, i.e. the deformation refinement of structure of materials [3,5,7]. Obtained by using the method of IPD ultrafine-grained materials possess high strength and significant impact resistance compared to traditional compositions of materials, and these materials are currently the subject of extensive research throughout the world. The most widely used method of IPD, allowing providing high intensity and a more homogeneous strain state is equal channel angular pressing (ECAE). Method ECAE has several advantages over other methods of IPD that are associated with the implementation of the process of plastic deformation of the simple shear scheme. ECAE allows with minimal energy consumption to accumulate a large and uniform strain over the loop, without changing the cross section of samples [9,10].

In connection with the foregoing, the aim of this work was to study influence of ECAE regimes on the microstructure and mechanical properties of aluminum alloys AMG6 and AMC.

Material and Experimental Procedure

As research material was selected as aluminum alloys AMG6 and AMC. These alloys are widely used in modern aviation, aircraft, shipbuilding, railway transport, road transport, construction, petroleum and chemical industries. Chemical composition of aluminum alloys: AMC – 96.35-99% Al; 1-1.5% Mn; 0.6% Si; 0.7% Fe; 0.05-0,2%Cu; 0.1% Zn, AMG6-91.1-93% Al; 0.5-0.8% Mn; 0.4% Si; 0.4% Fe; 0.1%Cu; 0.2% Zn; 5.8-6.8% Mg.

Experimental studies of the structure and mechanical tests were carried out in laboratories of D. Serikbayev East Kazakhstan State Technical University, “Nanotechnologies and new materials” Scientific Research Institute, “IRGETAS” Regional laboratories of engineering profile by optical microscopy methods on the microscope ALTAMI-Мет1M, X-Ray analysis, X-Ray diffractometer X'pert PRO and microhardness testing on a PMT-3M and abrasive wear. Shooting diffraction patterns was performed using CuKα - radiation (λ=2.2897 A^{o}) with a voltage of 35 kV. Measurement of the samples microhardness was carried out according to Vickers method with a load on the indenter P=1N and holding time 10 sec. Tests of durability were carried out on experimental setup for testing the abrasion by friction are not rigidly attached to the abrasive particles according to the “rotating roller – flat surface” scheme in accordance with the State Standard 23.208-79 that corresponds to the American standard ASTM S 6568.

In the present work to produce ultrafine-grained structure in aluminum alloys was developed and manufactured universal equipment for equal channel angular pressing (ECAE) (figure 1). For aluminum alloys typical are not high temperature processing. They can be processed at room temperature, in which they have sufficient deformability. Accordingly, for pressing in such circumstances, there is reliable operation of equipment and the use of special techniques to ensure manufacturability of the process. A distinctive feature of this tooling is that it allows ECAE at different angles of intersection of channels. The snap-in has two stamps with angles of channels intersection - 90 and 120^{0}. Through the use of stamps, crossing the different angles you can vary the intensity of deformation effects in the loop. Given that during multi-cycle processing, the resource of plasticity of the sample is reduced, you may need to change the level of a single strain per cycle of treatment. The principle of operation of the snap-in is as follows. The sample is fed to the vertical channel of the molding and pressed into the punch in a horizontal channel. By subsequent pressing the second sample, or simulator (harvested from specially selected material) of the first sample is removed (ejected) from the horizontal channel. Processing cycles are repeated by the planned number of process cycles and route selected of pressing.

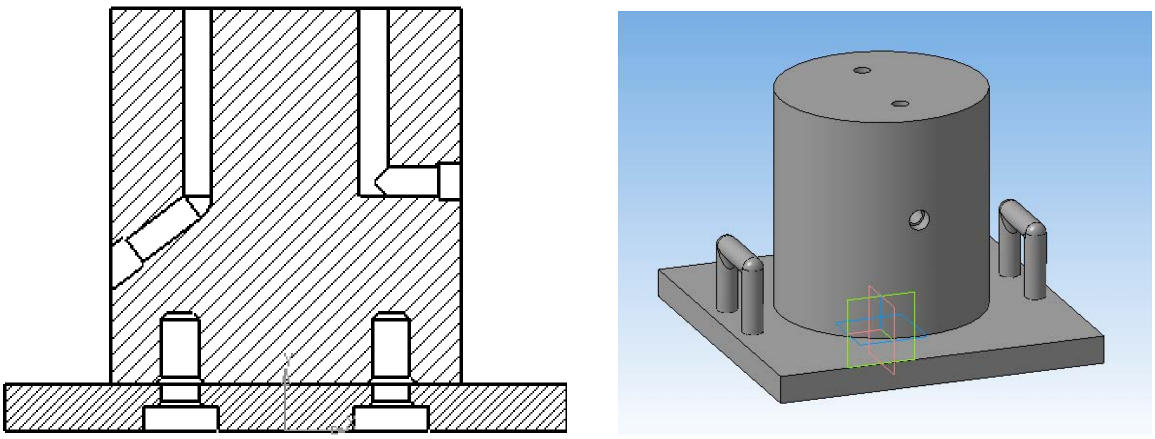

Fig. 1. The equipment for ECAE

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The study used an initial billet of aluminum alloy AMC and AMG6 with diameter -12 mm and length -50 mm. The diameters of the extrusion channels were as follows: the input (vertical) of 13 mm, output 12 mm. The angle of intersection of channels pressing were respectively 90 and 120°. Used routes pressing: B (90° rotation) and C (rotated 180°). ECAE was performed using tooling that was installed on a hydraulic press brand KNWP 30M. The pressed samples were produced with pressure up to 30 kg/sm^2, at the pressing time up to 40 sec. at each pass.

Results and Discussion

One of the objectives of this work is the determination of the ECAE, which provides a solid defect-free bulk billets with fine-grained structure and study the influence of process parameters on the forming structure. An important parameter of ECAE is the angle of intersection of channels - Φ. It defines the degree of deformation for one cycle of treatment (e) and accumulated strain (e_N) for several cycles. Study of the effect of intersection angles and channels on deformability is presented in table 1.

Table 1 - Influence of the intersection angles of channels in ECAE of AMG6 alloy at room temperature in the deformed state during multicycle processing

The intersection of angles channels, Φ°	Amount of deformation per one cycle, e	The maximum number of cycles to failure sample (N)	The maximum accumulated deformation (e_N)
90	1.15	4	4.6
120	0.67	12	8

Also studies have been conducted on the effect of the angle of intersection of channels in the deformation of AMG6 alloy. As a result of researches it is revealed that when the angle of intersection of the channels equal to 90 (e=1.15) billet destroyed already after the fourth cycle of compression. Optimal results were obtained by ECAE with an angle of intersection of the channels 120°, in which the number of processing cycles has reached 12, with e=8. In such regimes have the opportunity to obtain defect-free billet with a more uniform structure.

Research and comparative analysis showed that the most efficient angle of intersection of the channels is the angle of Φ=120°, which ensures defect-free parts at the highest possible level of accumulated strain (e=8).

The results of optical microscopy showed that aluminum alloys AMG6 and AMC in the initial state is mainly characterized by equiaxed shape of the grains (figure 2).

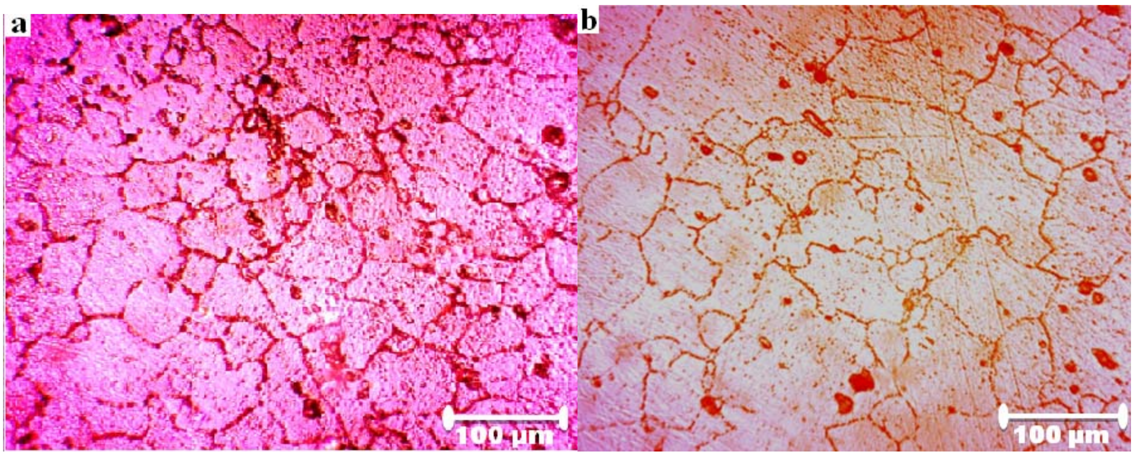

Fig. 2. Microstructure of aluminum alloys in the initial state:
(a) AMG6; (b) AMC.

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Determined that ECAE leads to a significant refinement of the aluminum alloys structure, depending on the cycles number. In figures 3 and 4 show microstructure alloys AMG6 and AMC after ECAE with different modes. From the presented results it is possible to highlight data corresponding to two passes ECAE. After ECAE-8 (120) and ECAE-12 (120) in aluminum alloys is the grain size of the starting material to the size of ~ 1.0-1.5 µm. These results show that the average grain size for the alloy AMC decreased by almost 13 times compared to the initial state, and for AMG6 alloy decreased by almost 17 times.

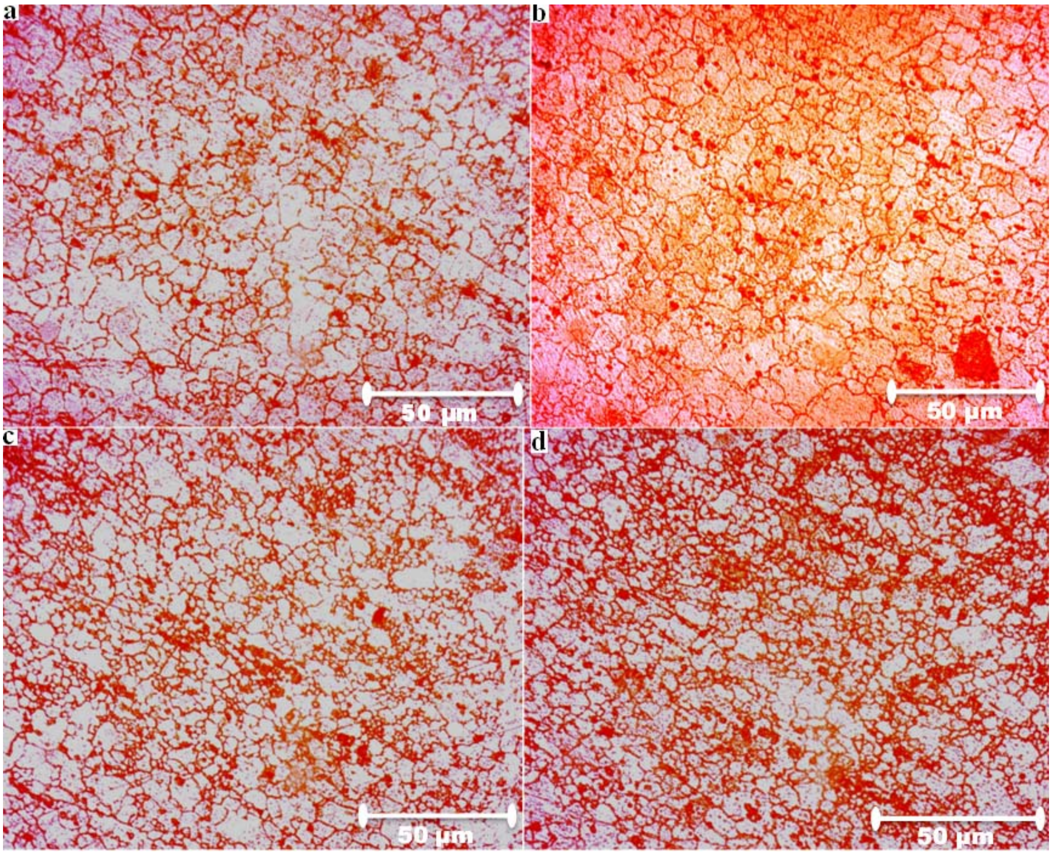

Fig. 3. The microstructure of the alloy specimens after ECAE AMC-4 (90) (a), ECAE-4 (120) (b), ECAE-8 (120) (c) and ECAE-12 (120) (d)

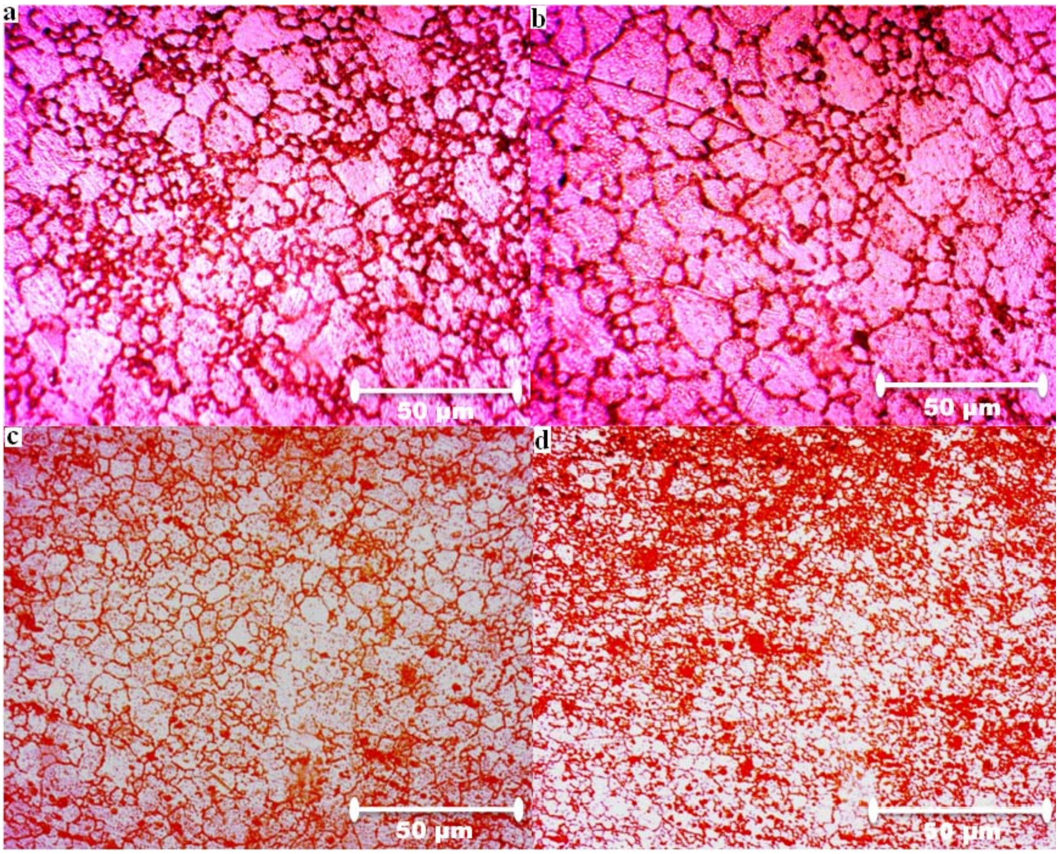

Fig. 4. The microstructure of alloy specimens after ECAE AMG6-4 (90) (a), ECAE-4 (120) (b), ECAE-8 (120) (c) and ECAE-12 (120) (d)

As shown by the results obtained, refinement of the structure at ECAE is accompanied with the increase of the microhardness of aluminum alloys AMG6 and AMC. Figure 5 shows histograms of the microhardness according to Vickers AMG6 and AMC aluminum alloys. After ECAE, an increase of the microhardness depending on the number of passes. While samples processed by ECAE when the angle of intersection of channels 900 microhardness higher than in samples processed by ECAE when the angle of intersection of channels 1200. However, ECAE with an angle of intersection of the 900 channels were not given the opportunity get blanks with defect-free structure with aisles greater than 4. But during ECAE with angles intersection of channels 1200 have the opportunity to obtain the billet with homogeneous defect-free structure when the number of passes to 12. Determined that as a result of ECAE (12 passes), the microhardness of AMG6 alloy increases to 1640 MPa, which is almost 4 times higher than in the initial state (Fig.5). As a result, the ECAE (12 passes), the microhardness of AMC alloy increases to 1820 MPa, which is almost 4.5 times higher than in the initial state.

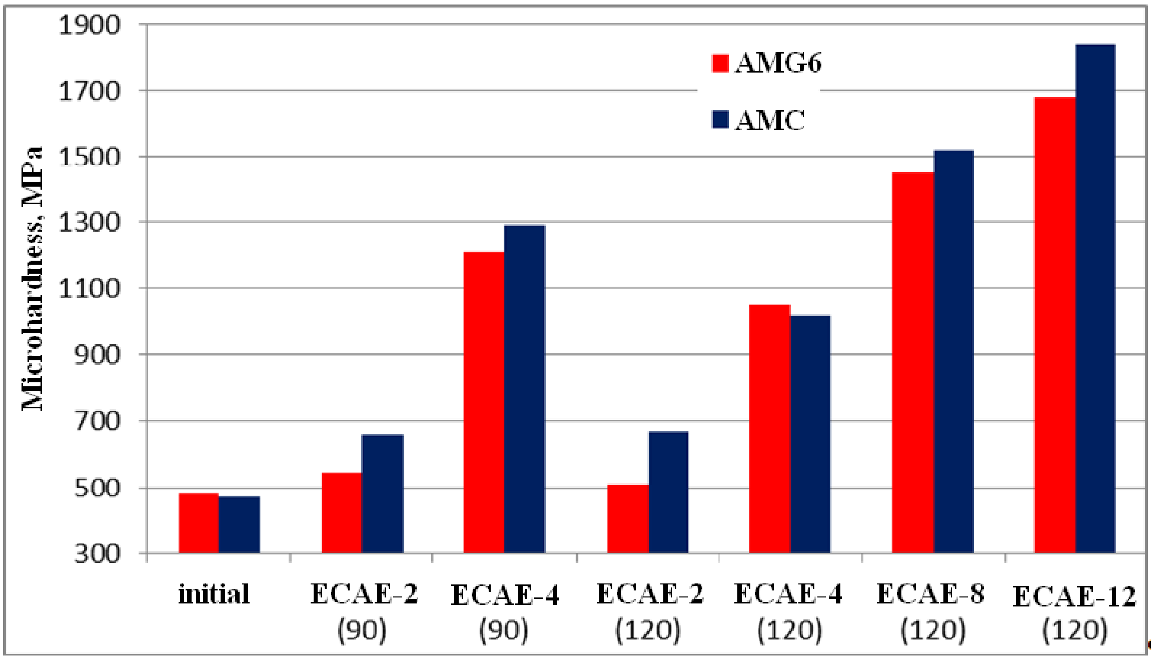

Fig. 5. The microhardness of the AMG6 and AMC alloys before and after ECAE

Figure 6 shows the values of the mass loss of AMG6 and AMC alloys samples before and after ECAE under different conditions. It is seen that the change in mass loss after ECAE are not significant at passages 2 and 4. Significant change is only observed after ECAE, 8 and 12 passes. After ECAE-12 mass loss is reduced to 5.4-5.6 ppm, which shows an increase in wear resistance of aluminum alloys AMG6 and AMC 13-14 %.

Properties of materials are determined by the pattern formed in the processing structure. We carried out a systematic study on the change of structure and mechanical properties (microhardness and wear resistance) of aluminum alloys, depending on the number of passes and the angle between channels pressing ECAE. It is shown that by varying the number of passes to obtain different grain sizes and different values of the mechanical characteristics.

Figure 7 shows a graph of the microhardness of the average grain size of AMG6 and AMC aluminum alloys. From the picture you can see the inverse dependence of the microhardness from the size of the grains. I.e. with the decrease of grains, the microhardness of the alloys increases. It is associated with a particular state of a crystal lattice in the grains and grain boundaries structure.

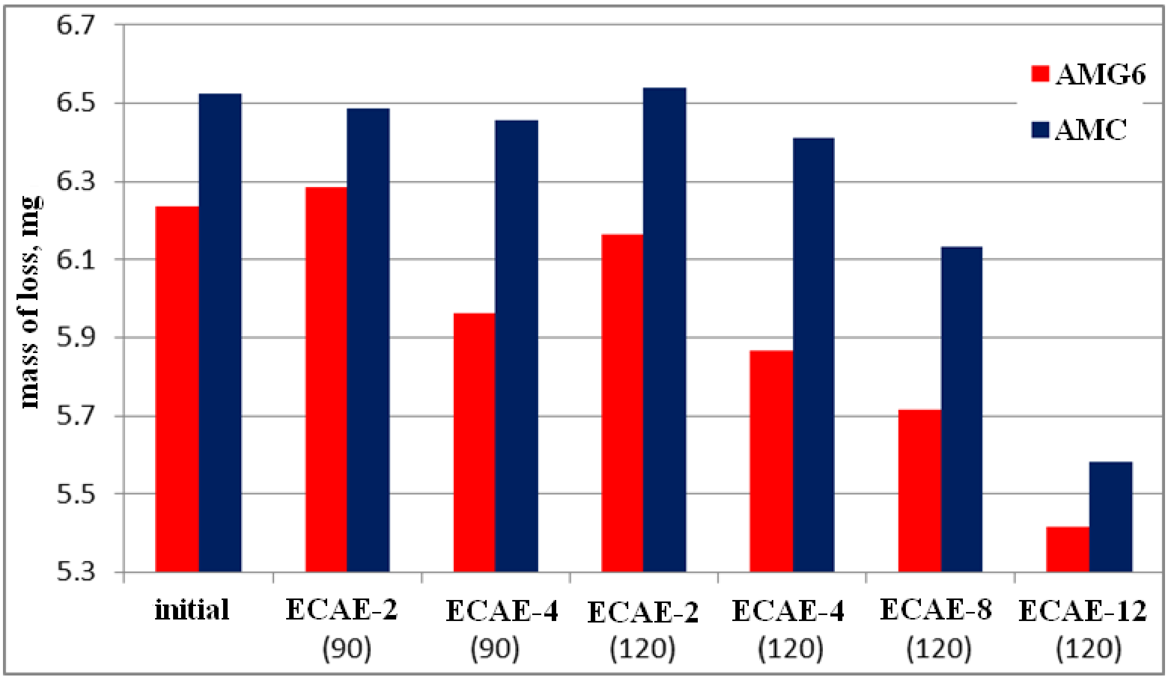

Fig. 6.The mass loss of AMG6 and AMC alloys samples before and after ECAE under different conditions.

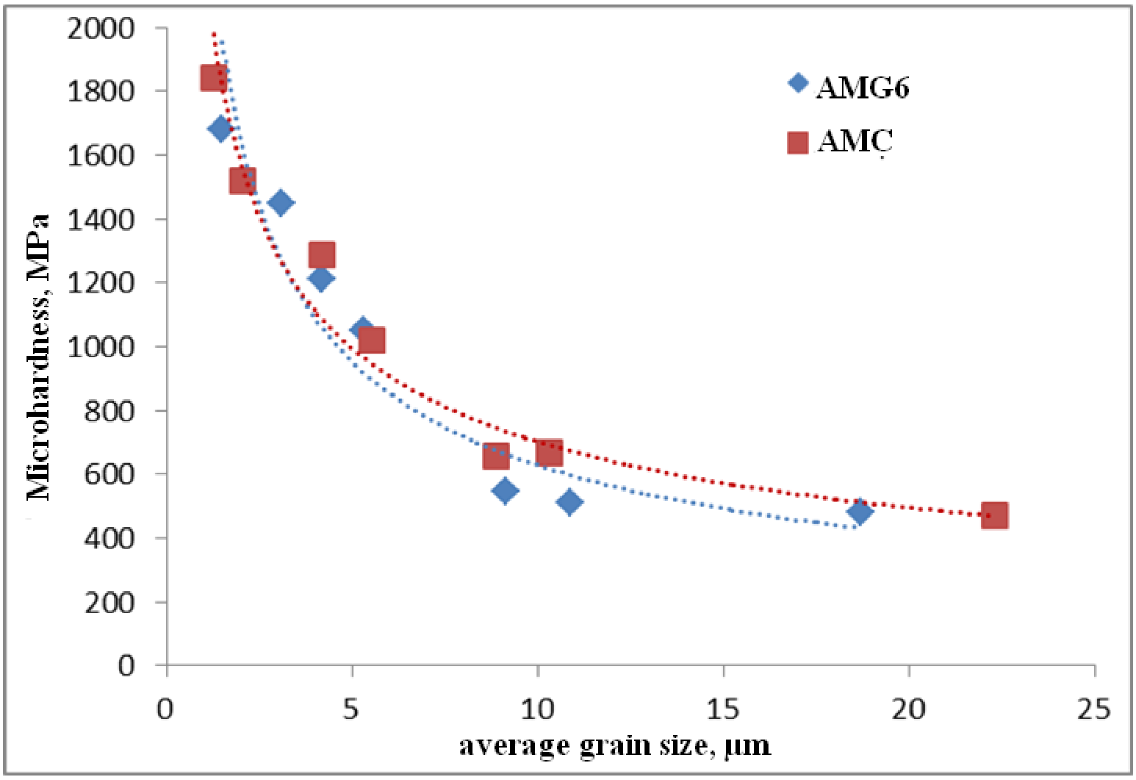

Fig. 7. A graph of the microhardness from the average grain size of AMG6 and AMC aluminum alloys

Conclusions

Thus, on the basis of the received research results about intensive plastic deformation influence on microstructure and mechanical properties of aluminum alloys we can make the following conclusions:

- it is established that the most intensive grinding grain structures in AMG6 and AMC aluminum alloys occurs at ECAE with 12passes, while the intersection angle of the channels of 120^0. After ECAE-12 in aluminum alloys the grain refinement reaches to the size ~ 1.0-1.5 µm;

- it is shown that during ECAE-12 with an angle of intersection of the channels 120° at *e*=8 allows to obtain a defect-free billet with a more uniform structure;

- determined that result in equal-channel angular pressing, the microhardness of AMG6 alloy increases almost 4 times in comparison with the initial state. Microhardness of AMC alloy increases by almost 4.5 times in comparison with the initial state. It is shown that with decrease in grain size - microhardness increases.

- it is shown that ECAE-12 mass loss is reduced to 5.4 and 5.6 mg, which shows an increase in wear resistance of AMG6 and AMC aluminum alloys to 13-14 %.

Acknowledgments

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