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ARTICLE

Study of Deformation of Aluminium Alloy in Equal Channel Angular Matrix with Quasi-small Channels Intersection Angle

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ABSTRACT

This article is described the various possible schemes of severe plastic deformation, by ECAP process that allows receiving metal with ultrafine-grained structure. The results of computer simulation and TEM investigations of aluminium alloy 6060 were presented. It is shown that the equal-channel angular pressing in the proposed matrix with a quasi-starched channel joint angle 45° provides the formation of a homogeneous subgrain structure with a size about 0.5 μm and has a positive effect on the mechanical properties of the aluminium alloy.

1. Introduction

It is not the first decade in the world there is a significant interest in the development of technologies aimed at obtaining metals and alloys with an increased level of physical and mechanical properties. One of the promising ways to improve the physical and mechanical properties of metal materials is the grinding of elements of grain and subgrain structure to ultra-fine-grained (UFG) or nanostructure. To achieve the microstructure grinding of metals and alloys in the pressure processing is possible by implementing in the process of deformation of severe plastic deformation (SPD) in the entire deformable volume.

The methods of SPD, in contrast to traditional methods of pressure processing, mainly focused on the formation, use to deep changes in the structure, phase composition and physical-mechanical properties. As a result of severe plastic action in metal materials, the length of grain and subgrain boundaries increases by orders of magnitude, the static and dynamic dilation of crystal lattice atoms changes markedly. Due to this, the strength characteristics of metals increase many times while maintaining sufficiently

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high plastic properties, a number of physical properties, including those that were previously considered insensitive to deformations, also change favorably [1].

Currently, the most widely used method of SPD is equal-channel angular pressing (ECAP) [2] in matrices of different designs [3-7]. This method under conditions of multi-cycle processing provides formation of ultra-fine-grained structure in billets with high coefficient of metal use.

But at the same time, for most of the tools that allow to implement SPD in the metal, the influence of the deformation process is most effective when the geometric characteristics of the working space of the tool provide uniformity of the stressed and strained states throughout the volume of the product. So for the ECAP process, the deformation intensity is mainly determined by the geometry of the channel. The main parameters of the process under study depend on it: the stress-strain state (SSS) of the material, the pressing force, the geometry of the deformable volume. The geometric characteristics of the working space of the tool determine the shape of the deformation center and have a noticeable effect on the flow of the deformable metal. Based on this, it is necessary to consider the shape and geometric factors affecting the SSS and to establish the optimal parameters of the shape and geometry of the matrix channel.

The analysis of the structure formation in the case of equal-channel angular pressing is extremely difficult from the point of view of its description by modeling methods, since the mechanical behavior of materials in the case of SPD is a non-obvious multifactorial process. Therefore, for the successful solution of the problem it is necessary to connect the possibilities of computer modeling at different levels (macro-, micro-, meso-) and, based on the physical understanding of the processes occurring in the SPD, to describe the evolution of the structural parameters of the SPD materials depending on the parameters of the SPD and ECAP modes. At the macro level, it is possible to describe the behavior of the material at a given deformation scheme, depending on its parameters. At meso-level the information can be obtained about the relationship of the emerging structure and properties of the materials obtained. Studies at the micro level allow us to understand the physical nature of the features of the processes [8].

Among the most successful modifications of tools for equal-channel angular pressing it is worth noting the process of pressing in the equal-channel step matrix, which allows to realize in one pass the double degree of deformation with its alternating character [9]. However, at the same time, the pressing force also grows. Reducing the pressing force is one of the most actual problems of all processes based on ECAP. Also, it is one of the significant obstacles to widespread implementation of such processes in the industry. The high value of pressing force is mainly due to the energy consumption for a high degree of deformation at the junction of matrix channels and to the friction between the pressed material and the matrix channel walls.

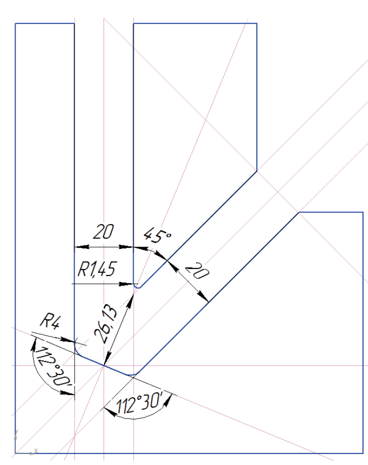
2. Computer Simulation

The decrease of pressing force due to the reduction of the deformation degree is clearly contrary to the purpose of the process, so many ways to reduce friction in the channels of the matrix were patented. As a rule, the researchers go by optimizing the shape of the channel, or replacing the sliding friction-rolling friction on different parts of the matrix.

Thus, the most logical way to improve the process is to recognize the way to reduce the pressing force while maintaining a high degree of deformation of the passage.

Based on these and some other considerations, the construction of an equal-channel matrix with a channel joint angle of 45° is proposed. The implementation of the channel joint angle is less than 90° in its pure form, for known reasons, is difficult. However, it is possible to implement this concept by dividing the deformation zone into several consecutive zones, as shown in figure 1.

The studies of the stress-strain state and energy-power parameters carried out on the basis of computer simulation of the deformation process of billets in equal-channel angular matrices of the new design in the DEFORM software complex allowed us to conclude that the 2nd version of the ECA matrix with a channel joint angle of 45° (Fig. 1, b) is the most successful. This option (option 2) provides a higher degree of accumulated deformation, with a uniform distribution of strain across the workpiece section, and together with option 3, obtaining a more correct shape of the front end of the workpiece compared to option 1.



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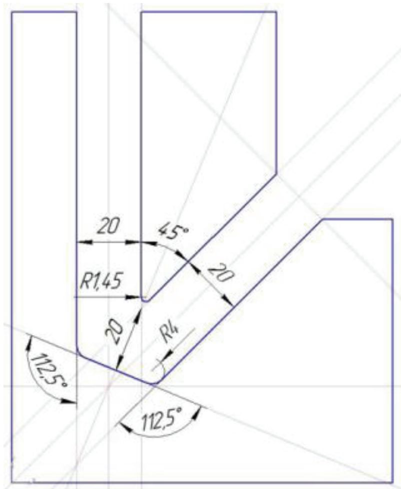

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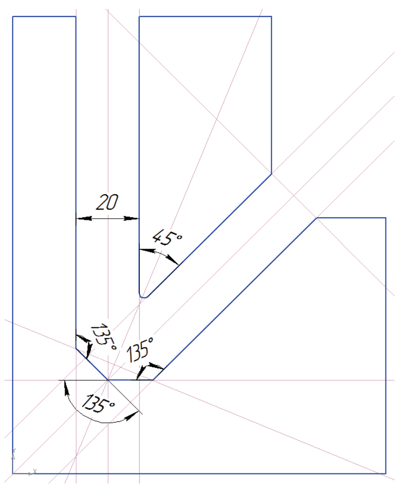

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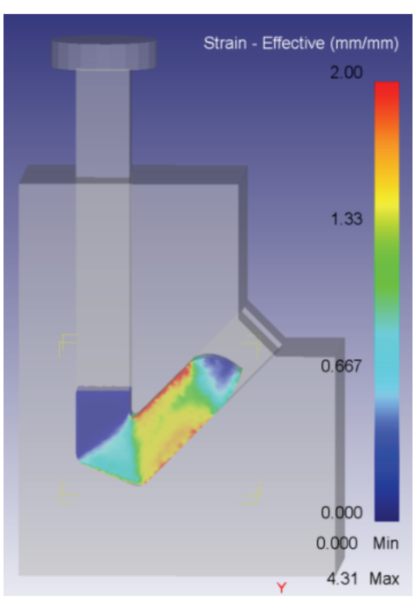

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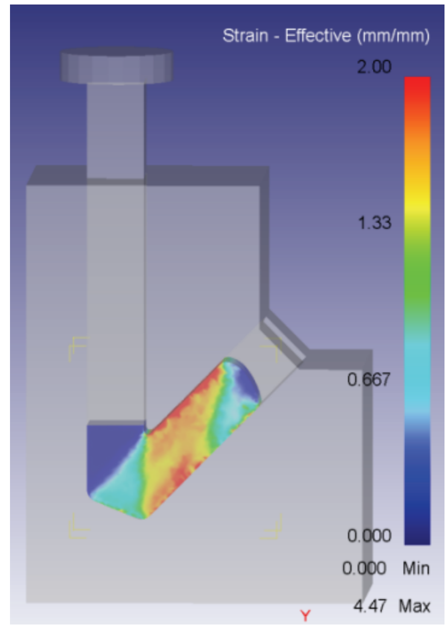

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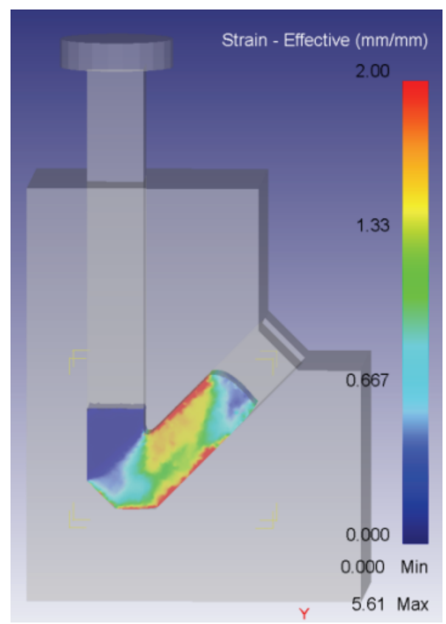

II (c)

I – construction of matrices; II - distribution of the effective strain; a – option 1; b – option 2; c – option 3.

Figure 1. Equal-channel angular matrix of a new design with an angle of intersection of channels 45°

3. TEM Investigations

To test the effectiveness of the developed technology, a laboratory experiment was conducted. The experiment was carried out on workpieces of aluminium alloy 6060

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cross-section 20×20 mm^2 and a length equal to 60 mm. To assess the effectiveness of a new matrix for ECAP it is necessary to compare the microstructure and mechanical properties of aluminium alloy before and after deformation in the matrix with the angle of channels intersection 45°, and most commonly used equal-channel angular matrix with the angle of intersection 90°. Therefore, the extrusion of aluminium billets was performed as in a conventional matrix with the angle of channels intersection 90° and a matrix of quasi-small the angle of the junction channels, in particular, in ECA matrix with the angle of channels intersection 45°, made on the 2nd option (figure 1, b). ECAP in both cases was carried out along the Bc route with a 90° rotation of the workpiece around the longitudinal axis. The friction between the tool and the workpiece was reduced by the use of palm oil with graphite as a lubricant. Deformation was carried out at room temperature, which also contributes to the production of ultra-fine-grained structure.

Aluminium alloys are traditionally divided into two classes – thermally hardened and thermally unbreakable. To achieve the greatest change in the microstructure and the maximum increase in strength, aluminium alloys should be subjected to heat treatment on a solid solution before ECAP. In addition, such preliminary processing of heat-treatable alloys allows to implement them after ECAP additional hardening during subsequent aging due to separation of the reinforcing nanoscale phase. Therefore, before the deformation of the workpiece were subjected to hardening at 550º C, with a delay of 15 minutes and accelerated cooling in water. The purpose of quenching is to completely transfer all Mg-Si particles into a solid solution of aluminium.

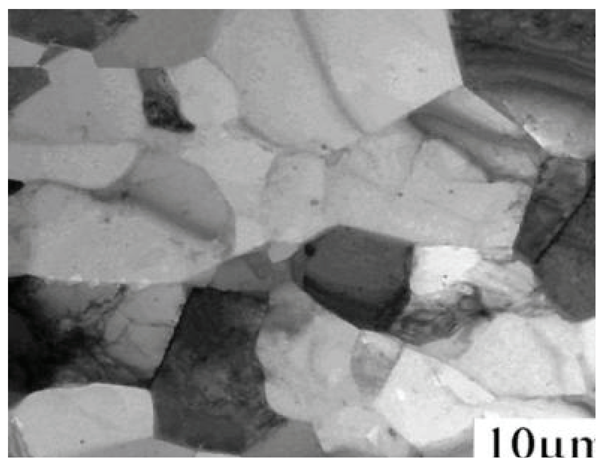
Preparation of samples for metallographic analysis was carried out on the Struers electrolytic sample preparation device. All samples were examined in the middle plane of the sample to avoid the influence of peripheral regions. The resulting samples were considered in two sections: transverse and longitudinal. The structure and phase composition of the alloy were analyzed by optical and transmission electron microscopy. Qualitative and quantitative analysis of the microstructure of the alloy matrix and primary phases was carried out using an optical microscope LEICA, equipped with a prefix to determine the microhardness of the individual phases, as well as software to determine the grain score and the number of phases on mechanically polished and etched with the Keller reagent thin sections.

The fine structure was studied using a transmission electron microscope (TEM) JEM2100 in the magnification range from 1000 to 50,000 times. Objects for TEM were prepared by jet polishing on the Tenupol-3 device at a temperature of -28°C and a voltage of 20V in a 20% solution of nitric acid in methyl alcohol.

To assess the mechanical characteristics of the alloy after ECAP used torsional-breaking machine MI40KU. We tested standard samples of cylindrical shape (diameter of the working part - 3 mm, length – 15 mm) according to GOST 1497-84. To carry out the tensile test, a sample for stretching was made from blanks on a lathe. The tensile velocity of the samples is 0.5 mm / min, which corresponds to a strain rate of 0.56 × 10-3 s-1.

4. Results and Discussion

Figure 2 shows TEM image of the structure of the samples. Figure 2a shows the microstructure of the alloy in its original state, after quenching at 550°C with cooling in water. The structure is a supersaturated solid solution based on aluminium and undissolved phases of eutectic origin. Photos of microstructure after 6 cycles of pressing, under different conditions of deformation are shown in figure 2 b-c.



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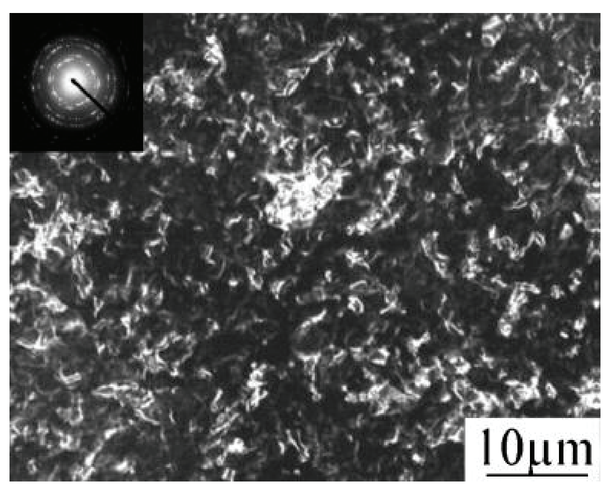

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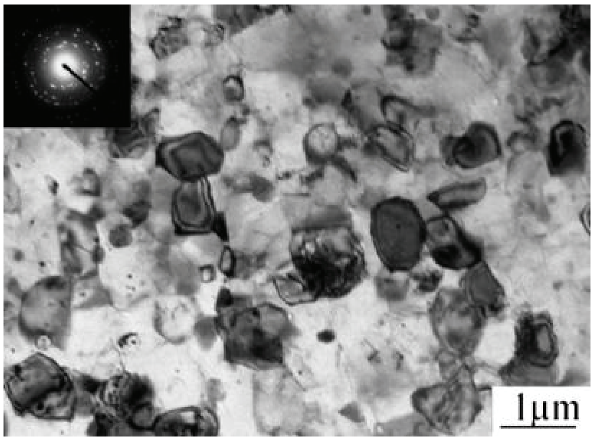

(c)

a – initial structure, b – ECAP with the angle of channels intersection 90°, c - ECAP with the angle of channels intersection 45°

Figure 2. Structure of aluminium alloy 6060

Metallographic analysis of the structure after 6 passes of ECAP in a matrix with a 90° channel joint angle showed that an ultra-fine-grained structure with an average grain size of 0.6-1.1 μm is formed in aluminium (Fig. 2b), after deformation in the matrix with an angle of 45° was obtained microstructure having an average grain size of 0.5 microns (Fig. 2c). Electron diffraction patterns, which are numerous reflexes, evenly distributed around the circle, which indicates that the formed states belong to the structures of the grain type, having predominantly large-angle disorientation. Figure 2c also shows that after deformation from the matrix to the angle of intersection of channels 45° structure of grain boundaries is more balanced and homogeneous.

ECAP with a channels intersection angle of 90° for 6 passes does not lead to the formation of a homogeneous structure by type, it contains dislocation cells, subgrains and grains, the average size of the structure elements is 0.6-1.1 μm, which is consistent with the data of [11-12]. That is, 6 passes at ECAP with a traditional deformation angle are not enough to obtain an equiaxed homogeneous ultra-fine-grained structure.

As a rule, in the ECAP process the part of consumed mechanical energy is converted into internal energy of the deformable workpiece. As a result, the workpiece temperature rises. And since aluminium has low energy of packaging defects, dynamic recrystallization does not occur. But reducing the angle of the matrix to quasi-starched leads to an increase in the deformation force, resulting in an increase in the rate of annihilation of dislocations in the body of grains and the number of dislocations decreases absorbed by the walls of subgrains.

After one pass of the ECAP with a channel joint angle 45°, the structure of the alloy was a highly elongated grain. But the resulting cellular structures had mainly small-angle boundaries. Increasing the number of passes to six ensures the transformation of subgrain boundaries into large-angle grain boundaries.

In addition to the study of structural changes during deformation, the mechanical properties of billets after each type of deformation under tension at room temperature were investigated.

Grinding grain size of aluminium alloys leads to their increased strength. Moreover, the introduction of high dislocation density in ultrafine-grained alloys in ECAP can lead to even greater hardening, but usually there is a decrease in their plasticity. Materials can be durable or plastic, but rarely have a high level of properties at the same time. The formation of the UFG state provides high strength of the alloy by reducing the grain size in accordance with the Hall-Petch dependence and the formation of dispersed precipitates in the aluminium matrix of hardening phases (dispersion hardening).

The results of tensile testing revealed that level of strength of workpieces subjected to pressing in the matrix with the angle of intersection of channels 45°, significantly higher than the same for samples subjected to conventional pressing in the matrix with an angle 90°. The values of tensile stress and yield stress increase in six passes for conventional ECAP (in the matrix with the angle of intersection 90°) from 250 to 462 MPa (absolute increase in the value of the tensile stress is 212 MPa) and from 206 to 420 MPa (absolute increase in the value of yield stress is 214 MPa). With the use of a matrix with a channel joint angle 45°, the tensile stress increases in six passes from 250 to 505 MPa (absolute increase in the tensile stress is 255 MPa), the yield stress increases in six passes and from 206 to 447 MPa (absolute increase in the yield stress is 241 MPa).

The plastic properties of aluminium samples in the ECAP process are reduced in both cases. So experimental studies of changes in the elongation in the tensile test showed that the level of plastic properties of aluminium after 6 passes falls in both cases almost 2 times.

5. Conclusion

In general, the studies have shown that the equal-channel angular pressing in the proposed matrix with a channel joint angle of 45°, that is, in the matrix with a quasi-starched channel joint angle, provides the formation of a homogeneous subgrain structure and has a positive effect on the mechanical properties of the aluminium alloy.

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References

[1] Рааб Г.И., Шибаков В.Г., Рааб А.Г. Перспективные методы ИПД для получения наноструктурированных металлических материалов [J]. Materials Physics and Mechanics, Vol. 25: 72-82.

[2] Sabirov, I., Enikeev, N.A., Murashkin, M.Y., Valiev, R.Z. Bulk Nanostructured Materials with Multifunctional Properties [M]. SpringerBriefs in Materials. 2015. Doi: https://link.springer.com/book/10.1007/978-3-319-19599-5.

[3] Ruslan Z. Valiev, Terence G. Langdon. Principles of equal-channel angular pressing as a processing tool for grain refinement [J]. Progress in Materials Science, DOI: 10.1016/j.pmatsci.2006.02.003.

[4] Zhang Xiaohua, Liu Xiaojing, Wang Jingze, Cheng Yuansheng. Effect of route on tensile anisotropy in equal channel angular pressing [J]. Materials Science And Engineering A, DOI: 10.1016/j.msea.2016.08.108.

[5] I. Sabirov, M.T. Perez-Prado, M. Murashkin, J.M. Molina-Aldareguia, E.V. Bobruk, N.F. Yunusova, R.Z. Valiev. Application of equal channel angular pressing with parallel channels for grain refinement in aluminium alloys and its effect on deformation behavior [J]. Int J Mater Form, DOI: 10.1007/s12289-010-0794-0.

[6] Zhao Xiaolian, Chen Na, Zhao Ningning. Numerical Simulation of equal channel angular pressing for multi-pass in different routes [J]. Applied Mechanics and Materials. DOI: 10.4028/www.scientific.net/AMM.268-270.373.

[7] Lezhnev S., Volokitina I., Koinov T. Research of influence equal channel angular pressing on the microstructure of copper [J]. Journal of Chemical Technology and Metallurgy, DOI: http://dl.uctm.edu/journal/node/j2014-6/14-Koinov-621-630.pdf .

[8] Смоляков А.А. Моделирование процесса получения нанокристаллической структуры в металлах с использованием равноканального углового прессования [D]. Уфа 2007.

[9] Naizabekov, A.B., Ashkeev, Zh.A., Lezhnev, S.N., Toleuova, A.R. Billet deformation in uniform-channel stepped die [J]. Steel in Translation, 35(2): 37-39.

[10] Найзабеков А.Б., Лежнев С.Н., Арбуз А.С. Конечно-элементное моделирование РКУ прессования с квазисверхмалыми углами стыка каналов [C] Международный научно-технический прогресс ОМД-2014 «Фундаментальные проблемы. Инновационные материалы и технологии»: 206-210.

[11] Sanghyun Lee, Suyong Kwon, Jong-Cheon Lee, Seoung-Won Lee. Thermophysical Properties of Aluminium 1060 Fabricated by Equal Channel Angular Pressing [J]. International Journal of Thermophysics, DOI: 10.1007/s10765-012-1176-2.

[12] A. Korchef, N. Njah, A.W. Kolsi. Microstructure investigation of equal channel angular pressed aluminium by X-ray diffraction and scanning electron microscopy [J]. Crystal Research and Technology. DOI: 10.1002/crat.200800131.