THE TECHNOLOGY OF EQUAL CHANNEL ANGLE BACKPRESSURE EXTRUSION FOR DEFORMATION IRON AND ALUMINIUM ALLOYS

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Abstract

This article is devoted to the development of the technology of equal channel angle backpressure extrusion for deformation iron and aluminium alloys. The developed tool allows to produce a high quality product at less degree of the accumulated shearing strain. The alloys presenting a sufficient interest for industrial use were chosen for investigation. At first simulation of the deformation process was made in DEFORM-3D complex program with Microstructure supplement. The results of the simulation showed sufficient refining of structural components in comparison with the initial grain size. The analysis of the obtained results shows that equal channel angle extrusion of alloys on either iron or aluminium base favours the improvement of metal quality. As a result of the realization of the proposed technology of processing 40Cr steel it became possible to obtain subultra fine-grained structure which is formed at a less number of cycles in comparison with the deformation of steel 35. The experiments showed that the developed technology makes it possible to obtain subultra fine-grained structure (300-400 nm) after 10 deforming cycles. The investigation showed that ECAEB has a similar effect on both aluminium and iron alloys. Besides, using equal channel angle extrusion it is possible to increase temporary resistance of such aluminium alloys as silumin system which belong to non-deforming cast alloys. The proposed technology of strengthening alloys of Al-Si-Fe-Mn system makes it possible not only to increase temporary resistance by 16.9% in comparison with the state of supplies of aluminium alloys but also to provide high ductility characteristics for this type of alloys whose relative permanent elongation is about 12-20%. Such combination of mechanical characteristics for this alloy is not only satisfactory but also desirable.

Keywords: equal channel angle backpressure extrusion, iron and aluminium alloys, deformation, subultra fine-grained structure, nanostructure.

1 Introduction

At present special attention is paid to making high-quality strong materials with the increased complex of physical and mechanical characteristics. One of the most popular ways of improvement of both strength and plasticity characteristics, or improvement of strength characteristics at a satisfactory level plasticity ones is several plastic deformation [1]. Equal channel angle extrusion (ECAE) takes a great part in making solid subultra fine-grained nanostructural materials. It is known that the use of backpressure promotes reduction of the required accumulated shearing strain for comminution of structural components and imparts the materials of the given property complex. One of the methods of carrying out backpressure equal channel angle extrusion is ECAE in the tool with step in the exit channel which was worked out by the scientists of RSE ”KSIU” (fig.1).

Iron and aluminium alloys are very important for industry and it is necessary for them to combine such operational characteristics as a complex of mechanical properties, high corrosion resistance, electric conductivity, chemical stability and stability and the stability of these characteristics along with the size of structural components. It is impossible to make the optimal combination of the above characteristics by traditional methods that is why the use of backpressure equal channel angle extrusion for deformation of iron and aluminium alloys presents a sufficient interest.

The purpose of equal channel angle extrusion in the tool with a step in the exit channel is in sufficient increase of the whole complex, of mechanical characteristics of carbon and low alloyed steels due to comminution of the structural components up to subultra- and nanolevel. Besides we would like to show that
using ECAE method it is also possible to achieve high strength and plasticity indexes for the alloys classified as rigid when deformed by conventional methods.

Structural steels 35, 40Cr and aluminium alloy AL9 were chosen for investigation, an alloy of Al-Si-Fe-Mn system being a cast aluminium alloy. Presence of inclusions in the metal structure creates sufficient difficulties for changing its form. Chemical composition of the above alloys is given in table 1.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Contents of chemical elements, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>35</td>
<td>the rest</td>
</tr>
<tr>
<td>40Cr</td>
<td>the rest</td>
</tr>
<tr>
<td>AL9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

1 Section. Pre-treatment

In order to prepare metal structures there was made thermal treatment according to the modes, given in table 2.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Termal treatment</th>
<th>Cooling medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>1) quenching</td>
<td>water</td>
</tr>
<tr>
<td></td>
<td>2) quenching</td>
<td>oil</td>
</tr>
<tr>
<td>40Cr</td>
<td>3) quenching</td>
<td>oil</td>
</tr>
<tr>
<td>AL9</td>
<td>4) ennealing</td>
<td>in furnace</td>
</tr>
<tr>
<td></td>
<td>5) quenching</td>
<td>water</td>
</tr>
</tbody>
</table>

The choice of thermal treatment for steels was attributed to maximum comminution of the structural components during quenching due to the formation of martensite. In this very case the growth of resistance to deformation is compensated by deformation at higher temperatures (800-850°C). The use of water and oil for steel 35 as a cooling medium is connected with different cooling properties and thus with different martensite needles.

Aluminium alloy AL9 is classified as rigid because of its tendency to cracking because of the presence of quasiprimary silicon particles. But taking into consideration that negative hydrostatic pressure [2,3], prevails in ECAE there is a possibility of hardening the alloy during its deformation.

As the result of primary extrusion of AL9 there appears anisotropy of the properties and elongation of the structural components along the bar axis.

Analysis of the alloy microstructure after annealing showed that complete dissolution of the phases in α-solid solution didn’t take place. This is caused by the fact that the concentration of chemical element in an alloy
exceeds their ultimate solubility in aluminium matrix. Well-defined boundaries of silicon colonies can be seen on the microsections after annealing both in longitudinal, and cross directions. In the metal structure after quenching there are inclusions of the two main types: fine-dispersed phase with the particles of 1-2 μm size and the particles of 3-10 μm size, which are quasiprimary silicon crystals.

So, as result of quenching, in the alloy structure appears a larger number of stress concentratory, that is why it was decided to deform the quenched samples at 200°C in order to reduce the resistance to deformation. The annealing aluminium samples were subjected to deformation at room temperature as it one of most conventional methods of deformation of aluminium alloys. The samples prepared by heat treatment were subjected to equal channel backpressure extrusion (Fig. 1) turning them 180° around longitudinal axis for sing changing deformation [4].

2 Structural changes in alloys during deformation

In order to estimate the effect of ECAE on the microstructure of alloy the authors made a simulation of changes of the structural components during deformation in DEFORM-3D program complex and Microstructure appendix. Grain of 30 μm size was taken as the initial one. Calculations were made for steel 35 (fig.2).

![Sample microstructure before the beginning deformation (a) and after 10 ECAE cycles (b - microstructure, c - histogram of grain size distribution)](image)

As a result of simulation it was determined that after ECAE grains of average 2.8 μm size can be seen, and also a small amount of grains of bigger or smaller sizes. A laboratory experiment according to the above modes was made after simulation.

The analysis of the microstructure changes shows that as the result of ECAE realization there take place comminution of the initial size both in longitudinal and cross directions. Moreover steel 35 samples cooled in water achieve more sufficient comminution of structural components at less degrees of the accumulated shearing strain in comparison with the ones cooled in oil. After 6 deformation cycles the size of the structural components of steel 35 samples is about 15 μm, and after 10 cycles they are 1-3 μm size.

It is seen in the photo that conducting 10 cycles of ECAE for steel 35 really allows to obtain the material with the level of structural components about 1-3 μm size which confirms the structure forming process in DEFORM-3D program complex and Microstructure appendix.

Figure 3 shows the microstructure studied under light microscope of X100 magnification. In the process of further deformation there takes place sufficient comminution of the structural components, accumulation of the crystalline structure defects redistribution of cementite and ferrite due to diffusion processes. However, study of the microstructure under light microscope does not give a complete picture for determination of the microstructure components because the microscope resolution does not allow to see and discriminate small separate structural components. To solve this problem microsection metallographic specimens were made and studied in "JEOL" (Japan) scanning electronic microscope which makes it possible to study surfaces in
the reflected electron spectrum. The results of the studies of steel 35 after 10 cycles of ECAE are given in fig.4, SEM x8000.

As the image in scanning electronic microscope is made by the secondary emission of electrons, emitted by the surface on which falls the flow of primary electrons continuously moving on this surface, the determination of the type of structural components can be made according to the distribution of the chemical elements, entering this or that phase. From the character of distribution of the chemical elements across the area of the microsection metallographic specimen (C and Fe) it is found that structurally free carbon and cementite don’t precipitate, dark interlayers are carbon aggregations, i.e. they are perlite grains. Iron is uniformly distributed across the whole studied area.

![Fig. 3](image1)

**Fig. 3** Microstructure of steel 35 after 6 ECAE cycles in cross (a) and longitudinal (b) directions (OMX100)

The results of the studies show that deformation in the tool with a step in the exit channel and accelerated cooling of steel 40Cr even after 6 cycles results in the comminution of grains up to 1-3 μm. During further shear deformation there take place crushing, partial dissolution and the turn of structural components, represented on fig. 5 a. Conducting 10 cycles of equal channel angle extrusion in the tool with a step in the exit channel, provides the formation of the microstructural components are 300-400 nm (fig. 5 b). The absence of sufficient difference in the sizes of grains and subgrains speaks in favour of complete and uniform processing of the structure which provides the absence of anisotropy of the made billets.

Conducting a great number of cycles for Al9 alloy is impossible due to the brittleness of silicon particles in the structure. Elastic wave formed by the front of moving dislocations effects the barriers and favours their shift to the zone of less stresses thus making gradient of the alloy chemical composition along the billet cross-section. In its movement separate phase components tend to minimization of the interface, thus connecting section microparticles into colonies moving as f common phase component.

![Fig. 4](image2)

**Fig. 4** Microstructure of steel 35 after 10 cycles of ECAP in cross direction, SEM X8000
It is seen from fig. 6 that interior and exterior zones of the billet differ after 2 cycles of ECAE. Moreover, differences are seen both in longitudinal and cross-sections. Density of the particles connected in a separate phase component decreases from the interior zone to the exterior one. Such redistribution of the phase components is the evidence of specific character of the flow of metal layers during deformation. At large magnification provided by a light microscope the boundaries of silicon colonies and the particles of quasiprimary silicon whose size are less than 2 μm. As the result of plastic deformation, the aluminium phase is deformed and the silicon particles due to its brittleness begin to divide and form cracks (fig. 6 b).

Increasing the number of ECAE you can see replacement of α-solid solution by the silicon phase to such a degree that the grain boundaries begin to form and reveal in the aluminium phase. After 3 ECAE cycles the grain size is 40-50 μm, the thickness of silicon colonies varies from 1 to 10 μm. After 7 ECAE cycles grain comminution can be within 5-20 μm, the thickness silicon colonies practically do not change. During deformation phase components take the part of stress concentrations, thus causing failure of the samples. Conducting short time annealing at recovery temperature has a positive effect for cutting residual stresses.

![Image](image1.png)

**Fig. 5** Microstructure of steel 40Cr after 6 cycles (a - SEM X4300) and 10 cycles (b - SEM X20000)

ECAE in cross direction, accordingly

![Image](image2.png)

**Fig. 6** Alloy microstructure in longitudinal direction after 2 ACAE cycles (a – exterior billet zone, b - interior billet zone) X1000

3 Mechanical properties of alloys after ECAE

The microstructure of the alloys obtained as the result of ECAE has a sufficient effect on their mechanical properties. During tensile test of steel 35 there arises the increase of ultimate strength. Moreover there is also insignificant growth of plasticity characteristic but less intensive. After conducting 10 cycles of ECAE ultimate strength increased by 36%, residual elongation grew by 45% and comprised 29% relative residual spread grew by 42% and comprised 64%. The graph of the changes of the changes of mechanical characteristics are given in fig.7.
When being deformed aluminium alloy demonstrated an increased tendency to crack forming. This could be seen in the appearance of cross cracks even after several cycles. The conducted investigation showed that the effect of ECAE on the cast aluminium alloys is similar to its effect on the deformed alloys. It is displayed in sufficient comminution of the sizes of structural components in comparison with the state supply and increase of the complex of mechanical characteristics.

Analysis of the curves in fig. 8 shows that the alloy has the highest plasticity (residual elongation 20%) after two deformation cycles at room temperature. Temporal resistance after two ECAE cycles and additional short time annealing between cycles is ≈455 MPa which is 16,9% higher temporal resistance of aluminium roads in the state of supply. The alloy behaviour in the elastic zone after all studied processing methods coincide. Transition on the plastic zone is implemented under similar stress values. The greater the number of ECAE cycles the more plastic becomes the metal in cross direction.

Thus it is seen that conducting even 2 cycles favours the increase of the quality of the cast aluminium alloys which proves the expedience of conducting such processing. a larger number of ECAE cycles is not expedient because of sufficient embrittlement of the alloy and drop of temporal resistance. 3 cycles of ECAE at 20°C doesn’t lead to further strengthening of the alloy, residual elongated reducing 50% in contrast with the state after 2 cycles of ECAE at 20°C.

Conducting ECAE at 200°C causes gradual growth of strength characteristics up to 3 cycles of ECAE, plasticity being of the same value about 13%. As a result of conducting 4 cycles of ECAE there appears a surface crack and the sample is completely divided into 2 parts after 5 cycles of ECAE. Furthermore, a sudden fall of $\sigma_B$ and $\delta$ after 4 cycles and a certain growth of these parameters after 5 cycles (not given in the fig.) can be seen. The growth of the values of mechanical characteristics after 5 cycles of ECAE can be explained by a positive effect of ECAE and healing defect due to shear deformation. It is not expedient to continue deformation because it will cause new crack and a final division of the sample.

On the diagrams in fig.8 a “saw-like” deformation can be seen at value 3,5-6% in the deformed state. Exhibition of Portevena-Le-Shatellie effect is explained by the change of the speed of the movement of dislocation due to the barriers on way of sliding and also due to the role of other defects including the ones arising directly during tension of the sample [5].

Conclusions: The analysis of the received results show that equal channel angle extrusion of alloys both on the basis of iron and on the basis aluminium favours the increase of metal quality. The growth of strength characteristics and a certain growth of plastic ones are caused due to sufficient comminution of the structural components. As the result of realization of the proposed processing technology for steel 40Cr there was obtained a subultra fine-grained structure formed at a less number of cycles in comparison with deformation of steel 35.
Besides, the use of equal channel angle extrusion can increase temporal resistance of such aluminium alloys as silumins in spite of the fact that they belong to rigid cast alloys. The proposed technology of strengthening system Al-Si-Fe-Mn alloy make it possible not only to sufficiently increase temporal resistance by 16.9% in comparison to the state of supply of aluminium alloy but also to provide high plasticity characteristics for this type of alloys whose residual elongation is about 12-20%. This combination of mechanical characteristics for this alloy is not only satisfactory but also very desirable.

LITERATURE


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