V. A. ANDREYACHSHENKO, A. B. NAIZABEKOV

ISSN 0543-5846
METABK 55(3) 353-356 (2016)
UDC – UDK 669.215:539.374:620.16.18.17=111

MICROSTRUCTURAL AND MECHANICAL CHARACTERISTICS OF AlSiMnFe ALLOY PROCESSED BY EQUAL CHANNEL ANGULAR PRESSING

Received – Primljeno: 2015-05-11
Accepted – Prihvaćeno: 2015-10-20
Original Scientific Paper – Izvorni znanstveni rad

In the present research, equal channel angular pressing (ECAP) was conducted. The defectness degree of the alloy for one pass and maximum strain was determined. Ultra fine grained AlSiMnFe alloy was produced by refining grained annealed bulk by multi-pass ECAP at room temperature. The results reveal two regimes: from 1 to 2 passes the microstructure evolves to a equiaxed of ultrafine grains and from 2 to 4 passes there is no strict change in the average grain size.

Key words: aluminium alloy, ECAP, microstructure and mechanical characteristics

INTRODUCTION

Recently more and more scientists are being involved in the problem of receipt, research and hardening of alloys based on AlSiFe [1-3]. Increased interest to this alloy is explained by its characteristics, namely high mechanical properties together with low ratio of thermal expansion, stability of mechanical characteristics at increased temperatures, low weight in comparison with alloys based on Fe. Except this use of goods made of this alloy is possible not only in automotive industry, but also in aircraft and space building. Authors of the work [4, 5] mention better mechanical properties of the alloy at its modifying. Authors of the work [6-8] also mention positive influence of FeAlSi system alloy, addition of such elements as Cr and Mn, which can change the morphology of alloy microstructure, containing primary silicon, α-iron and eutectics, or during prevention of peritectic reaction – from primary silicon, δ-iron and eutectics.

The target of this work is the study of microstructure and mechanical characteristics of alloy, subjected to equal channel angular pressing (ECAP).

MATERIALS AND METHODS

In this research alloy of Al – 93,72 wt.%, Si – 4 wt.%, Mn – 1,12 wt.%, Fe – 0,5 wt.% was used. For the conducting of the experiment there was installation for ECAP built with the angle of channels crossing equal to 135°.

V.A. Andreyachshenko, Faculty of Nanotechnology and Metallurgy, Karaganda state technical University, Karaganda, Kazakhstan
A.B. Naizabekov, Mining and Metallurgy Faculty, Rudny Industrial Institute, Rudny, Kazakhstan

One of the most important characteristics of deformation process is the value of plasticity Λ_f and/or level of shear deformation Λ. Plasticity, in its turn, depends on several factors, such as index of stressed condition σ_{av}/T, intensity of tangential stress T, Lode index μ_σ, temperature, etc.

For the estimation maximum possible number of cycles, at which there will no macroscopic cracks in the sample, it is necessary to determine absolute plasticity of studied alloy.

For the determination of maximum number of deformation cycles, at which there is no formation of defects, not healed by the heat treatment, we shall use the methodology, given in the work [9, 10]. After definition of the maximum number of deformation cycles the application of physical experiment started.

Application of ECAP was carried out on a route C, i.e. with tilting of the sample by 180° around the longitudinal axis. Deformation of preliminarily annealed samples was carried out at ambient temperature for avoiding of grains growth resulted from heating.

For an estimation of microstructure evolution at ECAP samples were prepared according to standard technique. Microstructure researches was carried out at transmission electronic microscope JEOL JEM2100. For determination of mechanical characteristics of the alloy standard samples for stretching test were cut. Tests were conducted by torsion tensile machine MI40KU with the speed of traverse moving of 0,5 mm/minute. Microhardness determination was carried out at the optical microscope Leica equipped microhardness gauge Anton Paar.

RESULTS AND DISCUSSION

After testing with variation of σ_{av}/T parameter there was dependence of Λ_f from stressed condition index σ_{av}/T

built and coefficients, necessary for estimation of metal damage level after the ECAP application were defined: $\lambda = 0{,}7556$; $\beta = -1{,}882$; $\alpha = 1{,}06$. For α 135° angle of channels joint at the tool damage level is defined as . Thus, as a result of ECAP application at the tool with an angle of channels joint, equal to 135°, damage level of the metal for one cycle is equal to 0,48. Hence, without appearance of visible macrocracks directly at the ECAP carrying out of 2 deformation cycles is possible.

At the organization of physical experiment it has been revealed that blank piece after 2 cycles of ECAP has no surface defects and cracks. After 3 cycles of ECAP formation of cracks is observed, and theoretical calculations, thus, have been experimentally confirmed.

As a result of annealing there is coarse-grained structure formed in the alloy. Thus inclusions, appearing at the annealing, cause a bending of grain border at its migration, interfering, thus, with grain growth. Besides this, particles positioning in one line is observed.

During the study it was revealed that as a result of ECAP application there is a plasticity change observed. At Figure 1 there are diagrams of Λ_f dependence on the deformation level after ECAP. The value of plasticity Λ_f was determined from data of tensile test:

$$\Lambda_f = 1{,}73 \ln (1 - 100/ A_5) \qquad (1)$$

where:
A_5 … relative residual elongation / %

As per data given at figure 1 it is visible that all curves are well approximated by the quadric polynomial. Thus, increase of deformation temperature up to 200 °C causes not only increase of plasticity values in comparison with deformation at 20 °C, but also extremum displacement to the area of smaller deformation values.

Extremum occurrence at curves of plasticity dependence on deformation degree is connected first of all with the structural changes proceeding under the influence of ECAP. Carrying out of one cycle of ECAP only promotes grain crushing (Figure 2*a*). However originally grains have no equiaxed form.

There is also elongation of grains along one direction observed. Considerable quantity of small inclusions promotes crushing of grains, carrying out quite often the function of germs or centers of fine grains formation. As a result of 2 cycles of ECAP application (Figure 2*b*) microstructure that is uniform at all sections of the sample is formed. Thus there is a crushing of grains extended after the first cycle of ECAP and kind of their turning from each other. Then as a result of 2 cycles of ECAP the uniform sub-ultra-fine grain structure with some grains less than 0,5 μm is formed.

As a result of ECAP application at 200 °C the almost uniform sub-ultra-fine grain structure of all section of the sample is observed. Thus after 2 cycles equiaxed grains take a laminar form along all the section of the sample.

Decrease in plasticity as a result of 1 cycle of ECAP carrying out at ambient temperature is explained by crushing of grains that reduces length of free dispositions run. Besides this, after 1 cycle of deformation elongation of grains is observed, that also causes sample hardening. Thus, essential localization of deformation at stretching test it is not observed.

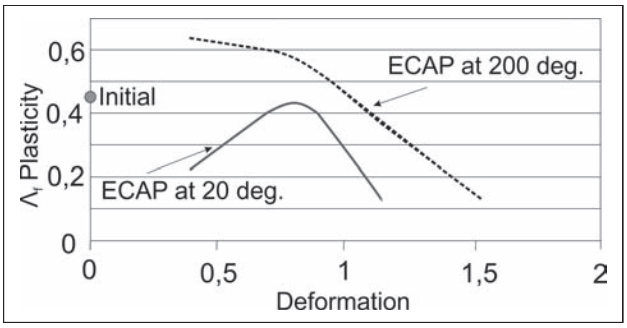

Figure 1 Influence of deformation level at the alloy plasticity

As a result of 2 cycles of deformation carrying out there is a formation of uniform sub-ultra-fine grain microstructures that causes extremum occurrence on deformation curves at ambient temperature.

Further decrease in plasticity is caused by influence of inclusions that are less plastic, than the basic matrix. After 3 cycles of ECAP there is some elongation of grains observed again, and their size is equal from 0,4 to 1 μm.

The increase in deformation degree up to 1,146 after 3 cycles of deformation causes formation of balls of dispositions in grains generated earlier, promoting a fragmentation of latter. Thus crushing of grains becomes less intensive in comparison with 1st and 2nd cycles of deformation. But, however, there is a considerable quantity of small angle fragments in grains is observed. Separate grains thus are almost free from dispositions.

Besides this, destruction of inclusions which are present in the structure of metal is observed, that can serve as the reason of microcracks formation that causes plasticity decrease.Higher values of plasticity during the deformation at 200 °C is connected also with influence of secondary phases and with higher mobility of dispositions after rise in temperature. Extremum displacement to the area of smaller deformations is connected with formation of more uniform sub-ultra-fine grain structures after 1st cycle of ECAP already (Figure 2*c*). At increase in degree of deformation 2 processes reducing plasticity are carrying out: hardening of developed disposition structure and blistering of particles of the secondary phases which are present in the structure of metal. Plasticity decrease at increase in quantity of cycles of deformation from 2 to 4 at 200 °C is caused by formation of laminar structure.

Results of mechanical characteristics definition are given in the Table 1. Carrying out of one cycle of ECAP already causes increase of strength of the alloy from 386,36 to 414,26 MPa. Thus relative residual elongation decreases by ~2 %. At the further deformation there is decrease in strength with plasticity increase by means of structural changes is observed. As a result in the course of repeated ECAP relative residual elongation reaches enough high value and makes about 20 % in samples af-

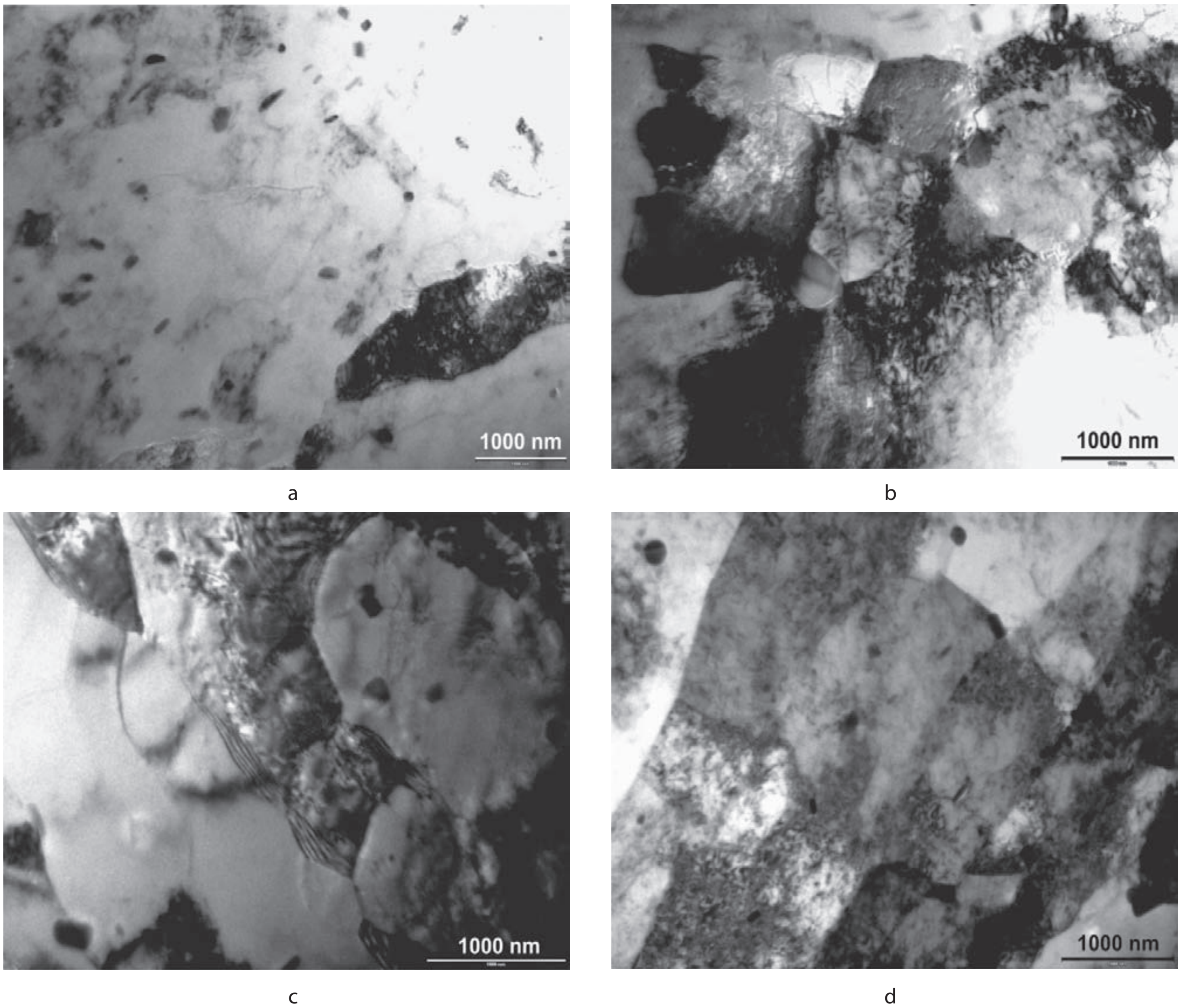

Figure 2 Microstructure of ECAP *a*) 1 cycle at the temperature of 20 °C, *b*) 2 cycles at the temperature of 20 °C, *c*) 1 cycle at the temperature of 200 °C, *d*) 2 cycles at the temperature of 200 °C TEM / Transmission electron microscope (TEM)

ter two cycles of ECAP. Application of additional intermediate annealing provides growth of strength during the increase in quantity of deformation cycles also. Temporary resistance after two cycles of ECAP and carrying out of additional short-term annealing between cycles is ≈ 455 MPa that is exceeding temporary resistance of aluminum bars in an initial condition by 16,9 %.

In the Table 2 value of strength for samples after carrying out of heat treatment and subsequent ECAP for samples deformed at 20 and 200 °C is shown. Samples deformed at ambient temperature, show essential growth of the durability characteristic already after the first cycle of deformation. After the second cycle of ECAP durability decrease is observed. On 3rd cycle of ECAP there is no essential change of strength observed. Increase of strength after 1 cycle of deformation is going together with plasticity falling, as it is seen from table 2, spasmodic increase of plasticity after 2 cycles and its falling after 3 cycles almost by 50 % in comparison with 2nd cycle of ECAP is observed later. For samples deformed at 200 °C, on the contrary, after 1 cycle of ECAP durability falling is observed, but after carrying out of further deformation durability starts to increase smoothly and surpasses the initial heat treatment condition by 8 %. However, the plasticity after the second cycle starts to decrease, and falls to the condition corresponding to 1st cycle of ECAP.

Table 1 **Mechanical properties of alloy of AlSiMnFe system**

Treatment mode	Number of cycles	Mechanical properties	
		R_m / MPa	A_5 / %
Initial condition	-	386,36	18,25
ECAP at 20 °C	1 cycle	414,26	16,07
	2 cycles	370,84	20,64
	3 cycles	371,08	10,01
ECAP at 200 °C	1 cycle	275,13	12,42
	2 cycles	390,91	13,95
	3 cycle	417,52	12,37

CONCLUSION

At the conducting of researches there was conducted ECAP for samples made of an aluminum alloy as per route C at two temperature modes: ambient temperature and at 200 °C. Maximum possible quantity of cycles of deformation has been estimated by the calculation with the usage of damage criterion. At the experiment organization theoretical calculations were proved. Besides this, during ECAP there is a change of plasticity of the alloy. It was revealed that quantity of cycles of deformation has the essential impact on a microstructure and mechanical properties of the alloy. As a result of ECAP realization there are structural changes with the formation of ultra-fine-grain and sub-ultra-fine grain structures. Creation of a certain structural condition provides either high hardness characteristics, or high characteristics of plasticity.

REFERENCES

[1] S. P. Gupta, Intermetallic compound formation in Fe–Al–Si ternary system: Part I, Materials Characterization 49 (2003) 269– 291.

[2] S. P. Gupta, Intermetallic compound formation in Fe–Al–Si ternary system: Part II, Materials Characterization 49 (2003) 293– 311.

[3] B. Zuo, N. Saraswati, T. Sritharan, H.H. Hng, Production and annealing of nanocrystalline Fe–Si and Fe–Si–Al alloy powders, Materials Science and Engineering A 371 (2004) 210–216.

[4] E. R. Wang, X. D. Hui, S. S.Wang, Y. F. Zhao, G. L. Chen, Improved mechanical properties in cast Al–Si alloys by combined alloying of Fe and Cu, Materials Science and Engineering A 527 (2010) 7878–7884.

[5] X. Fang, G. Shao, Y.Q. Liu, Z. Fan, Effects of intensive forced melt convection on the mechanical properties of Fe containing Al–Si based alloys, Materials Science and Engineering A 445–446 (2007) 65–72.

[6] L. G. Houa, C. Cui, J. S. Zhanga, Optimizing microstructures of hypereutectic Al–Si alloys with high Fe content via spray forming technique, Materials Science and Engineering A 527 (2010) 6400–6412.

[7] H. J. Huang, Y. H. Cai, et al., Influence of Mn addition on microstructure and phase formation of spray-deposited Al–25Si–xFe–yMn alloy, Materials Science and Engineering A 502 (2009) 118-125.

[8] M. Rajabi, A. Simchi, et al., Microstructure and mechanical properties of Al–20Si–5Fe–2X (X=Cu, Ni, Cr) alloys produced by melt-spinning, Materials Science and Engineering A 492 (2008) 443-449

[9] A. B. Naizabekov, V. A. Andreyachshenko Evalution of possible mechanical property improvement for alloy of the Al-Fe-Si-Mn system by equal-channel angular pressing, Metallurgist 57 (2013) 1-2, 159-163.

[10] A. B. Naizabekov, V. A. Andreyachshenko, J. Kliber Processing 21th International Conference on metallurgy and materials conference Metal, Brno; Czech Republic,2012, TANGER; VSB - TU OSTRAVA; ASM Int; Czech Soc New Mat & Technologies (CSNMT), 391-395.

Note: The translator for the English language is Margulan Sharip, Karaganda, Kazakhstan