Journal of Metals, Materials and Minerals. Vol.17 No.2 pp.23-27, 2007

Microstructure and Mechanical Properties of EN AW 6082 Aluminium Alloy Prepared by Equal-Channel Angular Pressing

Martin FUJDA [1] and Tibor KVAČKAJ [2]

[1]*Department of Materials Science, Faculty of Metallurgy, Technical University of Košice, Slovak Republic*
[2]*Department of Metal Forming, Faculty of Metallurgy, Technical University of Košice, Slovak Republic*

Received Oct. 3, 2007
Accepted Nov. 2, 2007

Abstract

The mechanical properties and microstructure of EN AW 6082 aluminium alloy subjected to severe plastic deformation (SPD) and natural ageing are compared with those of extruded and artificially aged state (initial state) and quenched state of alloy after solution annealing. Quenched state of alloy was deformed at room temperature by equal channel angular pressing (ECAP) following route C up to three passes. Polyedric microstructure of quenched state was considerably changed by SPD. Deformation bands with different amount of deformation were observed in microstructure of ECAPed state, which indicated non-uniform deformation across the cross-section of ECAPed specimen. Ultimate tensile strength (UTS) and especially yield strength (0.2% YS) were considerably increased by SPD, but plasticity was decreased. Increase of strength of ECAPed state was first of all evoked by the deformation strengthening.

Key words : EN AW 6082 aluminium alloy, severe plastic deformation, ECAP, mechanical properties, microstructure, deformation strengthening, precipitation

Introduction

In aluminium alloys, it is difficult to obtain the ultra-fine structures with grain size <10μm using the conventional recrystallization process and thermo-mechanical treatments. This is due to the physical properties of these alloys.(1) Despite this fact, it is possible to obtain ultra-fine grain structures of aluminium alloys with grain size <1 μm by applying bulk forming processes based on severe plastic deformation (SPD)(2-4) The severe plastic deformation is currently a subject of considerable attention, because it allows for obtaining Al-based alloy structures not only at submicron, but also at nanometre level.(5) The result of such grains refinement is first of all the improvement in mechanical properties.(6-8) SPD also increases markedly the density of lattice defects in the solid solution of Al-based alloys and thus accelerates the precipitation process of strengthening particles during the subsequent ageing. SPD can be realised through several processes, for example: equal-channel angular pressing (ECAP)(9) high pressure torsion (HPT)(10) accumulative roll-bonding (ARB) (11) and constrained groove pressing (CGP) (12), etc.

ECAP is the technology most frequently used in research and development of ultra-fine structure formation, because it provides potential for industrial processing of semi-products produced by both conventional and powder metallurgy. ECAP technology has been used frequently in research of the severe plastic deformation effect on the structure and properties of AlMgSi alloys, and recently in research of mainly high-strength Al-based alloys EN AW 6061 and 6082 (3 and 13 - 18). Authors of these works used various combinations of heat treatment procedures (solution annealing, artificial ageing) and severe plastic deformation by the ECAP process and achieved a significant increase in strength by refinement of the solid solution grains with increased dislocation density in combination with strengthening precipitation of β′ - Mg_2Si phase nano-particles.

The aim of the present work was to analyse the effect of the applied heat treatment, severe plastic deformation by the ECAP process and natural ageing on mechanical properties and microstructure of extruded and artificially aged EN AW 6082 aluminium alloy.

Materials and Experimental Procedures

The experiments were carried out on the EN AW 6082 aluminium alloy the chemical composition of which is presented in Table 1.

Table 1. Chemical composition (wt. %) of the investigated EN AW 6082 aluminium alloy

Mg	Si	Mn	Fe	Cr	Zn	Cu	Al
0.87	0.90	0.85	0.19	0.09	0.03	0.08	Bal.

Material in the form of extruded rods subjected to artificial ageing was used as the initial state (IS). Prior to deformation in an ECAP die, specimens of the analysed alloy in the initial state were solution annealed at 550°C (holding time 1.5 h), and cooled to the ambient temperature by water quenching. The quenched specimens were then subjected to deformation in an ECAP die with the parameters: $\Phi = 90°$ a $\Psi = 37°$. Pressing of specimens of size ∅ 10 mm x 80 mm in the ECAP die was realised at ambient temperature by route C (turning the specimen by 180°) up to three passes corresponding to deformation ratio $\varphi = 3,5$ [18 and 19]. After severe deformation the specimen was subjected to natural ageing for 800 h. Structural characteristics of the initial state of the investigated alloy, its state after quenching, deformation in the ECAP die and natural aging were analysed with using a light microscope in the central zone of the specimen cross-section prepared by common metallographic methods (etchant: Kroll). The influence of the applied heat treatment, severe plastic deformation by ECAP process and natural ageing on the mechanical properties of the analysed alloy was evaluated by tensile tests and Vickers hardness measurement (HV 10). The tensile tests were carried out on short specimens (Figure 1) using a deformation rate of 2.5×10^{-4} s^{-1}. Subsequently, characteristics of the strength (yield strength: 0.2%YS; ultimate tensile strength: UTS), elongation (El.) and reduction in area (Re.) were determined.

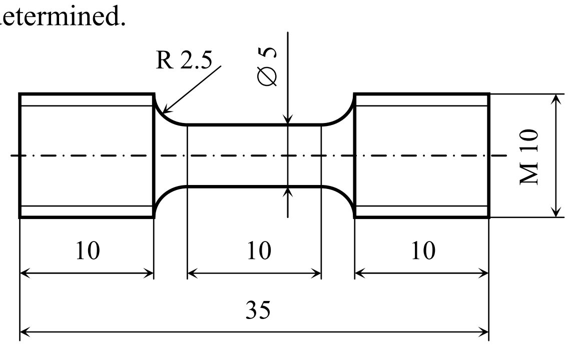

Figure 1. The shape and parameters of short specimens for the tensile tests

Results and Discussion

The structure of the analysed alloy initial state showed presence of irregular intermetallic particles of Al(FeMn)Si phase, undissolved particles of β - intermetallic phase (Mg_2Si) and a considerable quantity of fine dispersive particles probably of AlMnSi phase of size < 1μm, and documented in the work [20]. Their role is to prevent the solid solution grains growth of Al-based alloy [21]. Solution annealing of the analysed alloy at 550°C resulted in a slight spheroidisation and growth of intermetallic particles of Al(FeMn)Si and, particularly, in complete dissolving of the β (Mg_2Si) phase particles [20]. Microscopic analysis showed that severe plastic deformation by the ECAP process had practically no effect on the character of intermetallic particles regarding their shape, size, quantity and distribution. The microstructure of the solid solution of the initial state was polyedric with grains oriented in the direction of deformation during extrusion process (Figure 2). The solid solution grain size of the investigated alloy in its initial state was 6 μm.

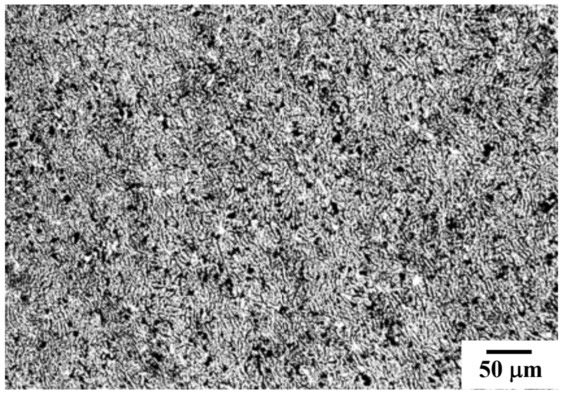

Figure 2 Microstructure of initial state

In the course of solution annealing we observed recrystallization of the solid solution with negligible growth of grains to 7.3 μm confirmed by equiaxed structure of the quenched state shown in Figure 3. Any considerable increase in the grains size was prevented by fine dispersed particles, probably of AlMnSi, which inhibited the recrystallisation process.[19] The severe plastic deformation of the quenched alloy by the ECAP process evoked a significant change in its microstructure as shown in Figure 4. Deformation bands with different amount of deformation are evident in the microstructure. These indicate non-uniform deformation across the cross-section of

ECAP-processed specimens caused by a low number of passes (max. 3) of specimen through the ECAP die. Character and parameters of the solid solution structure of the deformed specimen could not be evaluated by light microscopy, due to severe plastic deformation of the solid solution, and additional analysis by electron microscopy should be carried out.

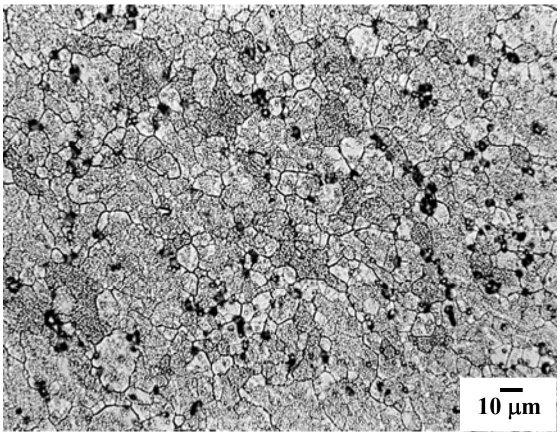

Figure 3. Microstructure of quenched state

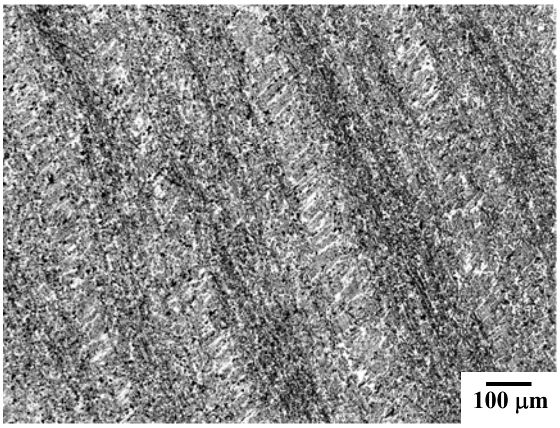

Figure 4. Microstructure of ECAPed state

The effect of the applied heat treatment and subsequent severe plastic deformation on mechanical properties of the analysed Al-based alloy was obviously reflected in the measured hardness values and characteristics of strength and plasticity presented in Table 2 and the tensile stress-strain curves shown in Figure 5. Presence of recovery processes in the solid solution during solution annealing of the analysed alloy initial state and elimination of the strengthening effect of sub-microscopic particles of β (Mg_2Si) phase through their dissolution is indicated by a significant (-43.9%) decrease in hardness value and characteristics of strength (0.2% YS: - 62.6%; UTS: - 26%) and increase in plasticity (El.: +9.5%) in the quenched state of alloy in comparison with its initial state. Recrystallisation of the solid solution was confirmed also by a considerable decrease in the ratio 0.2% YS/UTS. Severe plastic deformation of the quenched state by ECAP process (deformation $\varphi = 3.5$) caused a significant increase in Vickers hardness (from 66.1 to 130.3) of the alloy and the respective value increased slightly to 139.5 due to the natural ageing of the investigated alloy. After severe plastic deformation of the alloy and its natural ageing for 800 h following the ECAP process we observed a significant increase in characteristics of strength, particularly the yield strength (0.2% YS: +19.7 %; UTS: + 8.6%), while its plasticity decreased markedly (El.: -6.6%; Re.: - 20.4%) in comparison with the initial state. The increase in ratio 0.2% YS/UTS from 0.88 measured in the initial state to 0.97 for the past-ECAP state indicated that the increase in strength was first of all the consequence of a more expressive deformation strengthening of the solid solution by the ECAP process in comparison with the conventional process of extrusion and artificial ageing. This statement is confirmed by a comparison of the shapes of the tensile stress - strain curves obtained for initial and ECAPed states (Figure 5). These latter showed more uniform deformation during tensile tests of specimens prepared from the analysed alloy initial state in comparison with those specimens subjected to severe plastic deformation in the ECAP die and natural ageing.

Table 2. Mechanical properties of analysed alloy states

alloy state	0.2% YS [MPa]	UTS [MPa]	El. [%]	Re. [%]	HV 10
initial	340	385	19,6	38,6	100
quenched	127	285	29,1	38,9	66,1
ECAPed	-	-	-	-	130,3
ECAPed + aged	407	418	13	18,2	139,5

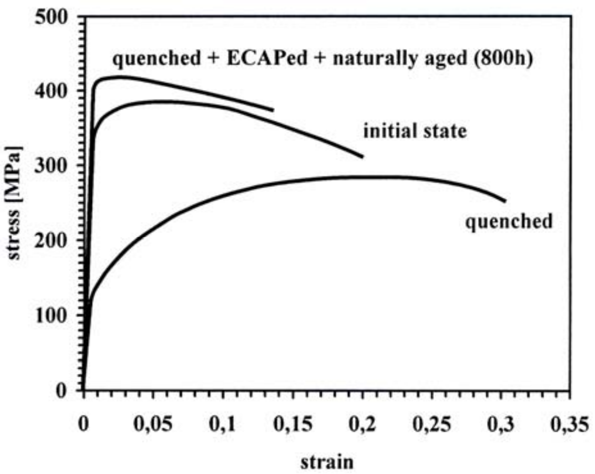

Figure 5. Tensile stress-strain curves for the analysed states of investigated aluminium alloy

Conclusion

During solution annealing of the extruded and artificially aged EN AW 6082 aluminium alloy, the dissolving of strengthening sub-microscopic particles of β (Mg_2Si) phase and recrystallization processes of the solid solution took place without significant grains growth. The result was a considerable decrease in strength values and increase in plasticity of the analysed alloy after quenching from the temperature of solution annealing. Severe plastic deformation (φ = 3.5) of the solution annealed EN AW 6082 aluminium alloy as the course of the ECAP process resulted in considerable, but non-uniform deformation of the solid solution at the microscopic scale. The character and distribution of the present intermetallic particles though, were not affected by this deformation. The increase in strength (0.2% YS: +19.7 %; UTS: +8.6%), ratio (0.2% YS /UTS) and hardness value, as well as the decrease in plasticity (El.: -6.6%; Re.: - 20.4%) resulted from comparison of mechanical properties of severely deformed and naturally aged states in comparison with the initial one. This difference was first of all the consequence of more intensive deformation strengthening of the solid solution by the ECAP process in comparison with the conventional process of extrusion and subsequent artificial ageing of the investigated EN AW 6082 aluminium alloy.

Acknowledgment

This work was supported by the Scientific Grant Agency of the Slovak Republic as grant project No. 1/3217/06, and by the Slovak Research and Development Agency as project APVV-20-027205.

References

1. Humphreys, F. J. and Hatherly, M. 1996. *Recrystallization and Related Annealing Phenomena.* Oxford : Elsevier : 205

2. Valiev, R. Z., Krasilnikov, N. A. and Tsenev, N. K. 1991. *Mater. Sci. Eng.* A **137** : 3317.

3. Horita, Z., Fujinami, T., Nemoto, M. and Langdon, T. G. 2001. Improvement of mechanical properties for AI alloys using equal-channel angular pressing. *J.Mater. Process. Technol.* **117** : 288 – 292.

4. Furukawa, M., Horita, Z., Nemoto, M., Valiev, R. Z. and Langdon, T. G. 1996. *Mater. Character.* **37** : 277.

5. Valiev, R. Z., Estrin, Y., Horita, Z. and Langdon, T. G., Zehetbauer, M., Zhu, Y.T: *JOM.* **58** : 33.

6. Lowe, T.C., Valiev, R.Z. 2000. *Investigations and Applications of Severe Plastic Deformation.* Kluwer : Dordrecht, the Netherlands.

7. Zehetbauer, M. J. and Valiev, R. Z. 2004. *Nanomaterials by Severe Plastic Deformation.* Weinheim, Wiley-VCH.

8. Horita, Z. 2005. *Nanomaterials by Severe Plastic Deformation.* Uetikon-Zurich : Trans Tech Publications.

9. Segal, V. M., Reznikov, V.I., Dobryshevskiy, A. E. and Kopylov, V. I. 1981. *Rus. Metall.* **1** : 99.

10. Islamgaliev, R. K., Yunusova, N. F., Sabirov, I. N., Sergueeva, A. V. and Valiev, R. Z. 2001. Deformation behaviour of nanostructures aluminum alloy processed by severe plastic deformation. *Mater. Sci. Eng. A – Structural Materials Properties Microstructure and Processing.* **319** : 877 – 881.

11. Saito, Y., Utsunomiya, H., Tsuji, N. and Sakai, T. 1999. Novel ultra-high straining process for bulk materials–Development of the accumu- lative roll–bonding (ARB) process. *Acta Materialia*. **47(2)** : 579 – 583.

12. Zhu, Y. T., Jiang, H., Huang, J. Y. and Lowe, T.C. 2001. *Mater. Trans* A. **32** : 1559.

13. Kim, W. J. and Wang, J. Y. 2007. Microstructure of the post-ECAP aging processed 6061 AI alloys. *Mater. Sci. Eng.* A-*Structural Materials Properties Micro-structure and Processing.* **464(1-2)** : 23 – 27.

14. Cherukuri, B., Nedkova, T. S. and Srinivasan, R. 2005. A comparison of the properties of SPD-processed AA-6061 by equal-channel angular pressing, multi-axial compressions/ forgings and accumulative roll bonding. *Mater. Sci. Eng. A-Structural Materials Properties Microstructure and Processing.* **410** : 394 – 397.

15. Werenskiold, J. C. and Roven, H. J. Microstructure and texture evolution during ECAP of an AIMgSi alloy: Observations, mechanisms and modelling. 2005. *Mater. Sci. Eng.* A-*Structural Materials Properties Micro-structure and Processing.* **410 – 411** : 174 – 177.

16. Roven, H. J., Nesboe, H., Werenskiold, J. C. and Seibert, T.2005. Mechanical properties of aluminium alloys processed by SPD: Com-parison of different alloy systems and possible product areas. *Mater. Sci. Eng.* A-*Structural Materials Properties Micro-structure and Processing*. **410 - 411** : 426 – 429.

17. Leo, P., Cerri, E., De Marco, P. P. and Roven, H. J. 2007. Properties and deformation behaviour of severe plastic deformed alumi-nium alloys. *J. Mater. Process. Technol.* **182(1-3)** : 207 – 214.

18. Zrník, J., Nový, Z., Kvačkaj, T., Bernášek, V, Kešner, D. and Slámová, M. 2004. *Acta Metall. Slovaca.* **10** : 277.

19. Iwahashi, Y., Wang, J., Horita, Z., Nemoto, M. and Langdon, T. G. 1996. *Scr. Mater.* **35** : 143.

20. Fujda, M. and Vojtko, M.2007. *Acta Metall. Slovaca*, **13, SI, 1** : 585.

21. Parson, N., Hankin, J., Hicklin, K. and Jowett, C. 2000. *Proceedings of the 7th International Aluminum Extrusion Technology Seminar*, vol. **1.** Washington, DC : Aluminum Association : 1.