Proceedings of the 9th International Conference on Aluminium Alloys (2004)
Edited by J.F. Nie, A.J. Morton and B.C. Muddle

Grain Refinement of Al Alloy by Compressive Torsion Processing

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Keywords: Al alloy, sever plastic deformation, grain refinement, compressive torsion processing,

Abstract

A compressive torsion processing in which compressive and torsional loadings are applied simultaneously is of great advantage to give severe plastic deformation without change in shape of work pieces. Compressive torsion processing was applied to two aluminum alloys (pure Al, Al-5%Mg). The possibility of grain refinement and the effects of some processing conditions on the refinement were investigated. Starting grain size was homogenized to around 50 to 150 μm. After processing, at the optimal conditions, uniform fine grain of around 1 ~ 5 μm were obtained in both aluminum alloys. Vickers hardness was improved by approximately 1.5 ～ 2 times.

1. Introduction

It has been known that grain size affects some material characters like toughness, ductility, elongation and deformability. In recent years, ultra-fine (sub-micron) grains can be obtained by severe plastic deformation (SPD) and SPD processes are developing actively such as equal-channel angular pressing (ECAP) [1-2] and accumulative roll-bonding (ARB) [3]. We have developed a SPD process named compressive torsion processing (CTP) [4-8] using axial rotation movement of compressing dies. In the CTP, share deformation can be given to the cylindrical specimen very intensely, continuously and in a short time without change in shape of work pieces. Therefore the CTP has a great advantage on grain refinement of metal by the SPD. In the present work, CTP was applied to two aluminum alloys (pure Al, Al-5%Mg) to investigate the possibility for grain refinement. And the effects of some processing conditions were examined for both materials.

2. Experiment Procedures

2.1 Compressive Torsion Processing

In the CTP, the cylindrical specimen is subjected simultaneously to compressive and torsional loading in a cylindrical container under different temperature conditions. The processing device shown in Figure 1 is built in the hydraulic press with rotational motion to realize the simultaneous compressive and torsional loading.

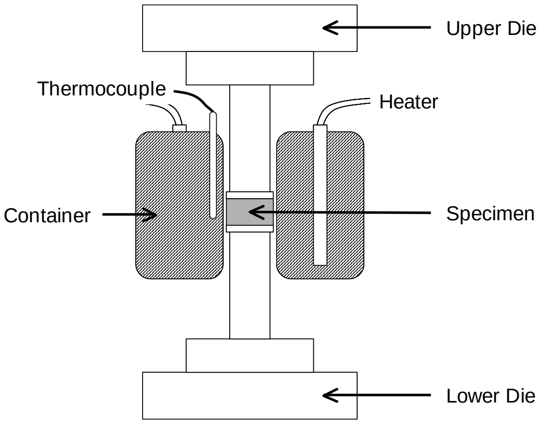

Figure 1: Schematic diagram of apparatus for compressive torsion processing.

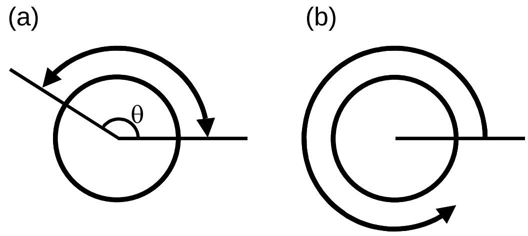

Figure 2: Two types rotation mode, (a) cyclic reverse, (b) monotonic.

By using the rotational press, the compressive and torsional loading can be independently controlled. The upper and lower dies can be rotated in reverse direction to each other under two types of rotation mode shown in Figure 2. One is cyclic reverse rotation within a given rotation angle and another is monotonic rotation. Top faces of upper and lower dies are rugged within 1mm depth so that the torsional loading can be sufficiently imparted to the specimen. In the present work, various torsional lording are applied under constant temperature and compressive pressure.

2.2 Materials and Testing

The materials used in this study were extruded bars of commercially pure aluminum and Al-5%Mg alloy whose chemical compositions were shown in Table 1.

A cylindrical specimen (ϕ25×10 mm) was annealed for 5 min at 618K, and the starting grain sizes of both materials were homogeneous at around 50 to 150 μm. In all experiments, reverse loading, the displacement angle is set at 3600 degree and processing time is fixed for two minutes. The effects of torsional loading conditions, cyclic reverse loading changing angle and monotonic loading on the grain refining effect were investigated. In monotonic loading, the effect of processing temperatures was investigated. The microstructure was examined by optical microscopy after etching treatment. The Vickers hardness (Hv) of the sample was measured by using a load of 500g for 15s.

Table1: Chemical composition of using aluminum alloy (mass%).

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
pure Al	<0.25	<0.40	<0.05	<0.05	<0.05	−	<0.05	<0.03	>99.50
Al−5%Mg	0.033	0.040	0.002	0.007	4.724	0.002	0.001	0.012	Bal

3. Results and Discussion

3.1 Effect of Torsional Lording Condition

Figure 3 shows the appearance of specimens (a) before and (b) after CTP. As shown in the figure the specimens have almost maintained the initial cylindrical shape though the surfaces changed a little because of the rugged die face.

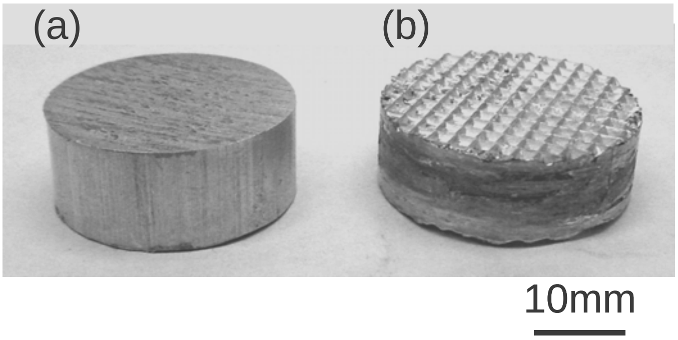

Figure 3: Appearance of Al specimens processed by CTP, (a) before and (b) after. CTP.

Figure 4 shows the optical micrographs of cross-sections of the pure Al specimens after CTP. Both samples are processed at 573K and 100MPa, but torsional loadings are different. Figure 4 (a) is cyclic reverse with the rotate angle of 90 degree, and (b) is monotonic rotation. Fain grains (about 5～10μm) are observed for both samples. But the distribution of fine gain area in which grain size is under 10μm is very different. In Figure 4 (a), fine grains under 10μm are observed only in upper and lower areas that make contact with dies. In contrast, Figure 4 (b) shows almost all the area was covered by fine grains. Figure 5 shows the fraction of the fine grain area under 10μm of several torsional lording conditions at 573K and 100MPa. In the case of cyclic reverse rotation, the fine grain area is enhanced by increasing cyclic reverse angle. However it is 60% at most by cyclic reverse loading condition. For monotonic from cyclic reverse loading, the fraction of fine area increases considerably to about 90%. Because the shear deformation is transferred gradually from the point of contact with the dies in this process, in the case of cyclic reverse loading the plastic flow doesn't spread to center but accumulates only near the point of contact with the dies. While in the case of monotonic loading, plastic flow is transferred more effectively to the center part.

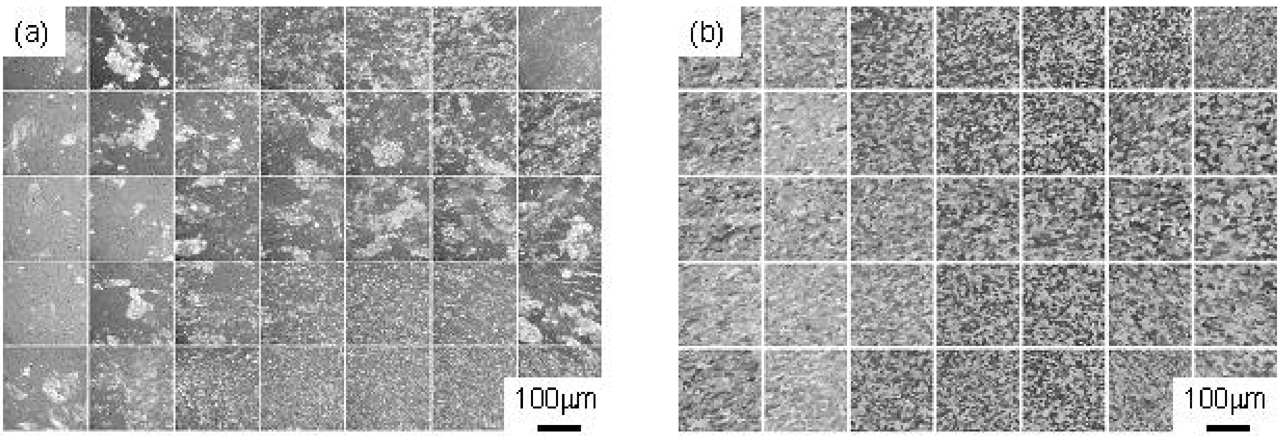

Figure 4: Optical micrographs of the microstructure of PURE AL after CTP, processing temperature at 573K and compressive loading 100MPa (a) cyclic reverse lording within 90°, (b) monotonic rotate lording.

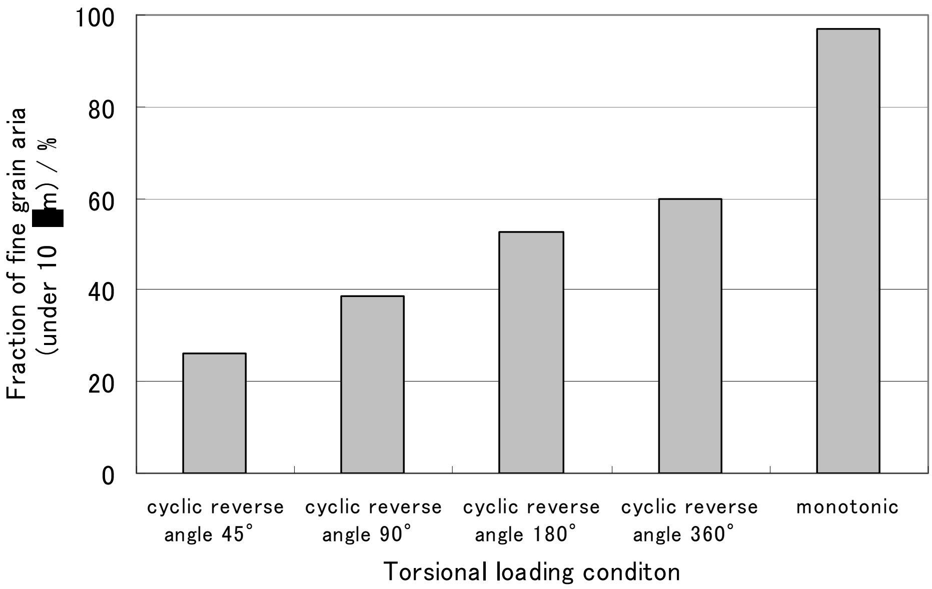

Figure 5 Fraction of fine grain area of several torsion conditions.

3.2 Effect of Processing Temperature

Figure 7 and Figure 8 show the effect of temperature on grain size of pure Al and Al-5%Mg alloy respectively. Because it is difficult to transfer the shear deformation to the center part when an alloy with high flow stress is processed at low temperature, the Al-5%Mg alloy was processed under higher compressive pressure (200MPa) than the pure Al. In both alloys the grain size was reduced at lower processing temperature. The several micron grain size was obtained at room temperature. Comparing pure Al and Al-5%Mg alloy, grain size is slightly large for Al-5%Mg alloy at same processing temperature. Because of high compressive pressure, heat generation in processing becomes high and the grain might be growth in the Al-5%Mg alloy. Figure 9 shows effect of processing temperature on Vickers hardness of both processed alloys. With decreasing processing temperature, the hardness increased remarkably as well as grain size decreased. At room temperature, the hardness was increased by approximately 1.5 ～ 2 times each alloy, while it was hardly changed at 573K in spite of a decrease in grain size as shown in Figures. 7 and 8.

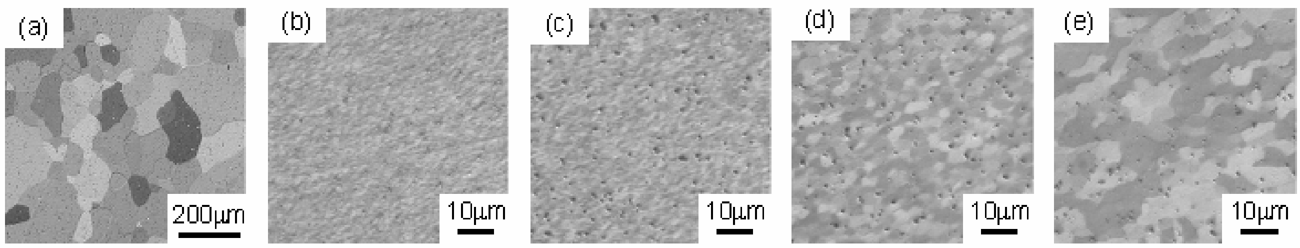

Figure 7: Optical micrographs of the microstructure of pure Al changing processing temperature after 10 rotations and compressive loading under 100Mpa. (a) before CTP, (b) room temperature, (c) 373K, (d) 473K, (e) 573K.

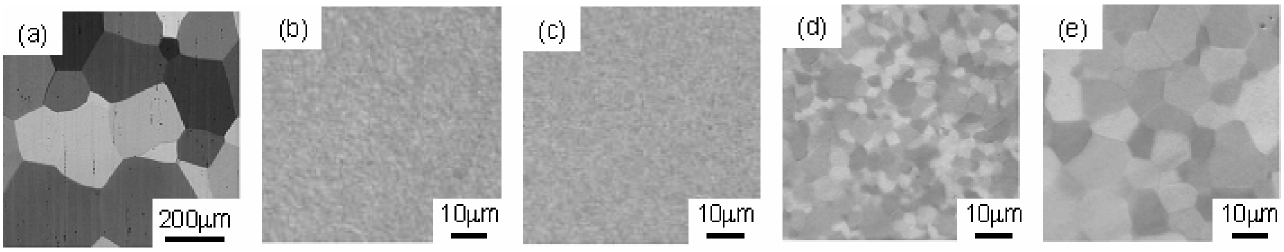

Figure 8: Optical micrographs of the microstructure of Al-5%Mg alloy changing processing temperature after 10 rotations and compressive loading under 200Mpa. (a) before CTP, (b) room temperature, (c) 373K, (d) 473K, (e) 573K.

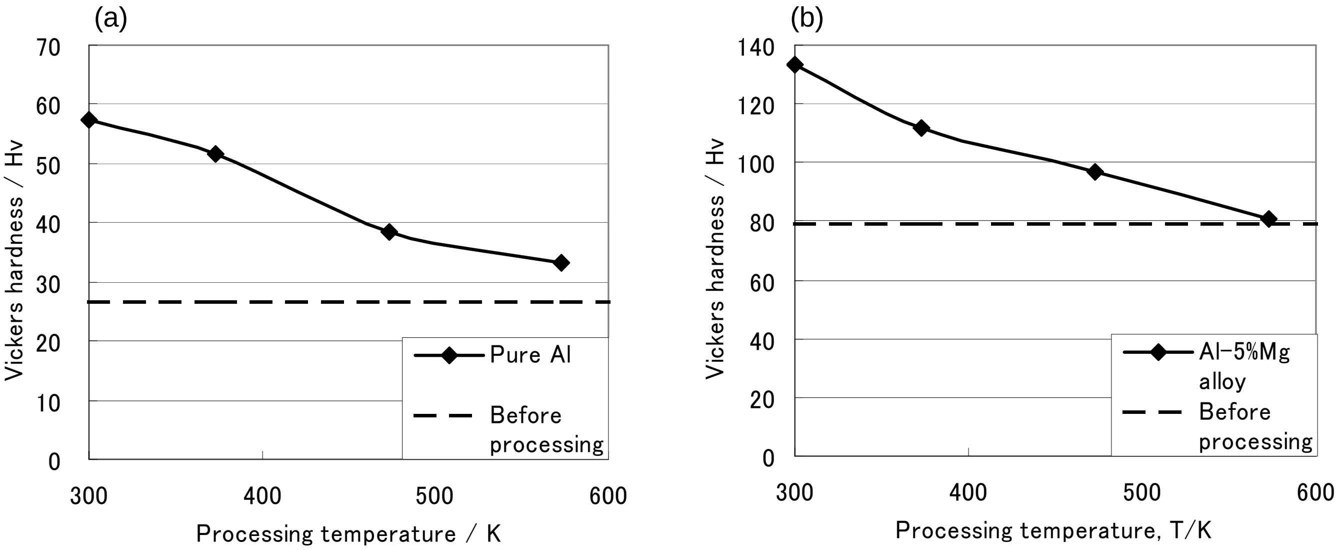

Figure 9: Effect of processing temperature on Vickers hardness, (a) pure Al at 100MPa, (b) Al-5%Mg at 200MPa.

4. Conclusions

Simultaneous torsional straining whole compression loading is very useful for grain refinement of pure aluminum and Al-5%Mg alloys. In compressive torsion processing, monotonic rotation straining is very effective in spreading fine grains (under 10μm) over more than 90% of area in vertical section of a cylindrical specimen. Processing temperature affects the grain size and the uniform fine grain of around 1 ~ 5 μm was obtained at room temperature in both aluminum alloys, and hardness was increased by approximately 1.5 ～ 2 times.

Reference

[1] V.M. Segal, V.I. Reznikov, A.E. Drobyshevsky and V.I. Kopylov: Russian Metallurgy-Metally, 1 (1981), 99.
[2] R.Z. Valiev, N.A. Krasilnikov and N.K. Tsenev: Mater. Sci. Eng., A137 (1991), 35.
[3] Y. Saito, H. Utsunomiya, N. Tsuji, T. Sakai: Acta Mater., 47 (1999), 579.
[4] E. Maeda, N. Kanetake, T. Choh, j. JSTP.,37 (1996), 1291.
[5] N. Kanetake, E. Maeda, T. Choh, Proc 1998 PM World Congress, (1998), 55.
[6] E. Maeda, N. Kanetake, T. Choh, j. JSTP.,39 (1998), 45.
[7] E. Maeda, N. Kanetake, T. Choh, j. JSTP.,40 (1999), 35.
[8] E. Maeda, N. Kanetake, T. Choh, j. JSTP.,40 (1999), 40.