HIGH STRENGTH NANOSTRUCTURED Al-Zn-Mg-Cu-Zr ALLOY MANUFACTURED BY HIGH-PRESSURE TORSION

Chao An[1], Huimin Lu[1*], Shilai Yuan[1]
[1]Beihang Univ., School of Materials Sci. & Eng.; 37 Xueyuan Road, Beijing 100191, China
[*]Corresponding Author: lhm0862002@yahoo.com.cn

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Abstract

7085 aluminium alloy (Al-7.5 Zn-1.6 Mg-1.5 Cu-0.12 Zr) is processed by high-pressure torsion (HPT) at imposed pressure of 2 GPa and torsion turns of 3, 6, 9 and 12 turns. The microstructures and mechanical properties of 7085 Al alloy under different torsion conditions are systematically investigated, and the refinement mechanism is discussed. The microstructures of the alloy are analyzed by transmission electron microscope (TEM) and scanning electron microscope (SEM). Mechanical properties are studied by tension test and vickers indentation. The results indicate that after HPT treatment, the grains of Al alloy are refined remarkably. Nanometer grains of sizes between 50~250 nm are obtained. The tensile strength and hardness increase obviously and there is some fluctuations in elongation. When the pressure is 2 GPa and the torsion turn is 12 turns, the optimum performance are accomplished, which tensile strength is 699 MPa and microhardness is 260HV0.2.

Introduction

It is well known that significant grain refinement can be achieved after processed by severe plastic deformation (SPD), such as equal-channel angular pressing (ECAP) and high-pressure torsion (HPT) [1]. HPT refers to the processing of metals whereby samples are subjected to a compressive force and concurrent torsional straining [2]. HPT can refine the grain size in alloys down to nanometer level, and as a result, the strength of commercially valuable alloys is extended without sacrificing much ductility [3]. The original fundamental principles of HPT were proposed by Professor Bridgman first in 1943, however it has become of the general scientific interest only within the last 20 years [4]. Furthermore, it is only within approximately the last 5 years that the properties of materials fabricated by HPT have started appearing in the scientific literature [3]. Much progress has been made by researchers during these years. It has been suggested that HPT process can refine grains to achieve bulk ultra-fine grain (UFG) [2]. With increasing numbers of revolutions, a gradual evolution into a reasonably homogeneous microstructure in many materials can be achieved [5]. The transition towards a stable microstructure with increasing strain suggests that there is a saturation grain size associated with the structural refinement [6]. But in addition to this great success, researchers pay more attention to high-purity metals or relatively simple metallic alloys than more complex alloys [5].

Our present work consists in studying the evolution of grain structure and properties during HPT process in 7085 Al alloy using a combination of hardness measurements, tensile tests and microstructure observations.

Experimental Details

Preparation of Materials

In our experiment, the ingot of 7085 Al alloy was smelted with ultrapure Al, Cu and Zn (99.999%), Mg (99.95%) and Zr (99.87%) using a vacuum arc-melting furnace. Disks having thicknesses of 2.5 mm and diameters of 10 mm were cut from the ingot. Sealed the disks in tubes with ultrapure Argon, the disks are given homogenizing treatment at 440 °C for 12 h, then at 470 °C for 24 h, and they are air cooled to room temperature.

HPT Process

HPT process of disks was conducted at room temperature with an applied pressure of 2 GPa. The facility has a spherical depression at the center of the lower anvil with a depth of 1.0 mm and a diameter of 10 mm. During the process, the rotation speed was 1 revolution per minute, and disks were processed for 3, 6, 9 and 12 revolutions separately.

Microstructure and Mechanical Properties Analyses

Disks were mechanically polished carefully, then the values of Vickers microhardness, Hv, were evaluated by an HXZ-1000 microhardness tester systematically with a load of 50 gf and a dwell time of 10 s. Microhardness measurements were taken along diameter from edge to edge at positions 0.5 mm apart with each other. At each position, four separate hardness measurements are executed, and then their average values are calculated. Tensile tests were conducted using SANS 5504 universal testing machine with a tensile rate of 0.05 mm min^{-1} at room temperature. On account of the small size of disks, the tensile specimens are limited to be miniature correspondingly. These specimens were cut from the disks with diameter of 10 mm at the position of 1.7 mm away from the center. Their total length was 6.75 mm, and the dimensions of the working segment were 3.75 mm, 0.85 mm, 0.80 mm in length, width and height respectively. After tensile tests, the fracture surfaces of fractured specimens were analyzed by JSM-5800 scanning electron microscope (SEM), and the acceleration voltage was 20 KV. For transmission electron microscope (TEM), specimens with a diameter of 3 mm were punched out from the edge of the disks. They were polished by abrasive paper until the thickness was about 50 μm. The polished specimens were further thinned in a solution of 25% (volume fraction) HNO_3 and 75% CH_3OH at a temperature of 253 K (-20 °C) with a voltage of 15 V using a twin-jet electropolishing apparatus. The specimens were observed by JEM 2100 LaB6 TEM, and the acceleration voltage was 200 KV.

Results and Discussion

Vickers Microhardness

The value of Vickers microhardness is 180HV0.2 before HPT process. As demonstrated in Figure 1, there is a significant increase of the values both at the center and at the edges of the samples processed by HPT after 3 turns. This reflects the great influence of HPT process on Hv. Along with the continued increase of torsion revolutions, the value of Vickers microhardness increases relatively small. When the disks are processed by HPT after 6 turns and 9 turns, their corresponding lines show that the values of Hv increase as a whole from the centers to the edges of the disks. The reason is when it is getting closer to the peripheral regions, the processing strain increases. Processing strain displays great importance in the influence of Hv values during HPT process, but the function of torsion is not conspicuous when the overall values of microhardness increase.

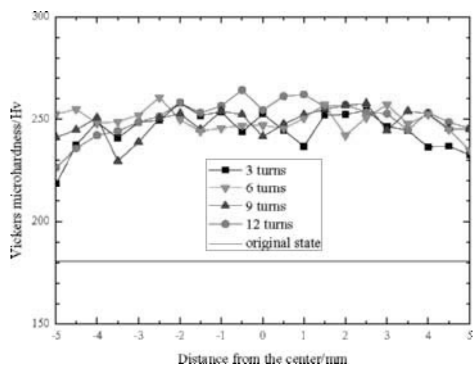


Figure 1. The average Vickers microhardness, Hv, versus distance from the center of the disks of original state of 7085 Al alloy and processed by HPT after various turns under pressure of 2 GPa.

Tensile Tests

Figure 2 demonstrates the strength-displacement curves of tensile specimens cut from disks in different HPT process conditions. The tensile strength of 7085 Al alloy without HPT process presents low value, which is only 377 MPa. As displayed in Figure 2, the tensile strength is significantly promoted along with the increase of torsion revolutions. When the alloy is processed by HPT after 3 turns the tensile strength is 546 MPa, which is apparently high comparing with the original state. As the torsion revolutions increase to 12, the value of tensile strength reaches up to 699 MPa. As a conclusion, reasonable HPT process can improve the tensile strength greatly. Figure 2 also presents the variation of elongation. Before HPT process, the elongation is only 10.1%, and it increases to 23.7% when the torsion turns is 12, which is very abnormal. Generally speaking, the ductility deteriorates after mechanical treatment, and elongation is always adverse with tensile property. There are two possible reasons. Firstly, there are some flaws in the original alloy, and the tensile specimen tends to crack from these flaws, as a result, the tensile property and ductility are affected. The alloy is compacted under enormous pressure during HPT process, and this may decrease flaws. Secondly, as illustrated before, HPT process can refine grains, which can improve tensile property and ductility at the same time. This will be explained in the following discussion.

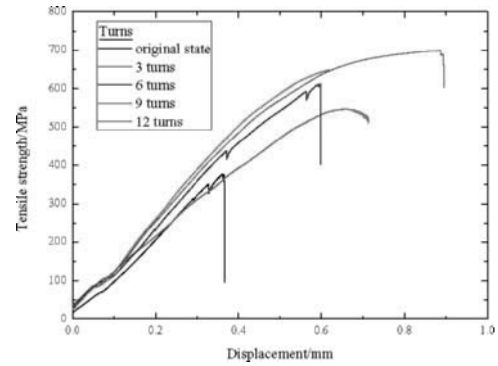
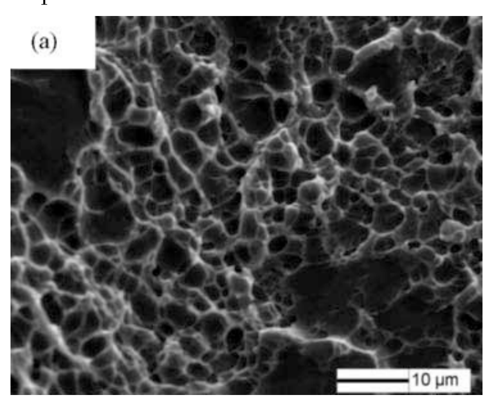


Figure 2. Tensile strength versus displacement curves of tensile tests for original state sample and disks processed by HPT after various turns under pressure of 2 GPa.

Fractography Analysis

Figure 3 presents fractographs of tensile specimens in different process conditions. Obviously, the tensile fracture surfaces are distinctly characterized by ductile rupture. As observed in Figure 3 (e), the number of dimples is not so much. Simultaneously, there exist some long fissures on the surface. As a result, it can be summarized that the sample without HPT process in this experiment has low ductility. This is pretty much exactly the same as the result obtained by tensile test before. From Figure 3 (a), (b), (c) and (d), many obviously equiaxed dimples on the matrixes can be fined. Dimples in Figure 3 (a) are homogeneous than in Figure 3 (b), but not abundant as well. From Figure 3 (c) and (d), many small and deep dimples abound, and some small dimples exist in the bigger ones. These characteristics indicate the samples processed by HPT after 6 and 12 revolutions have good toughness. The analysis of fractographs corresponds with the aforementioned strength-displacement curves.



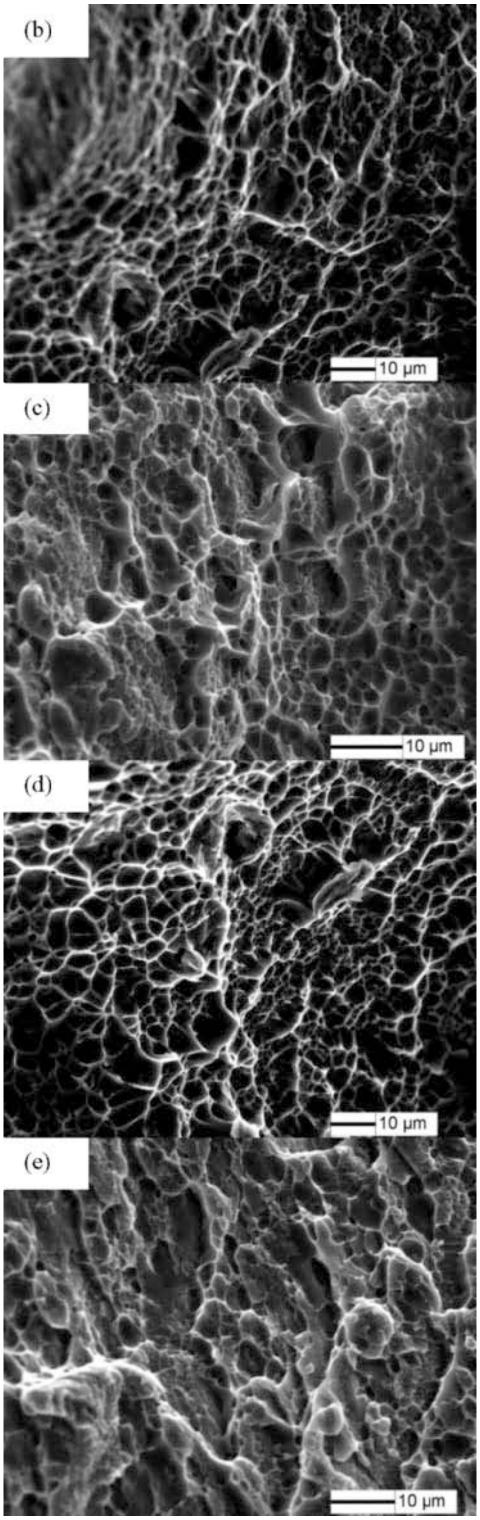


Figure 3. SEM fractographs after tensile test of disks processed by HPT through 3 turns (a), 6 turns (b), 9 turns (c), 12 turns (d) under pressure of 2 GPa and disk in original state (e).

Microstructures of The 7085 Al Alloy After HPT Process

TEM micrographs and SAED patterns of Al 7085 alloy processed by HPT through 3 turns (a), 6 turns (b), 9 turns (c) and 12 turns (d) under pressure of 3 GPa are presented in Figure 4. Scale bar width of the SAED patterns inserted in the four pictures is 51/nm. Rings with many diffracted beams in the SAED patterns indicate there are many ultra-fine grains with multiple orientations in the matrix. The average grain sizes measured is ~200 nm in Figure 4 (a), ~100 nm in the other three pictures. Furthermore, most grains in Figure 4 (d) have sizes of about 50 nm. Therefore, HPT process can refine grains to nanometer level. The small grains found in Figure 4 (d) can also explained the excellent tensile strength and ductility of the disks processed by HPT after 12 turns.

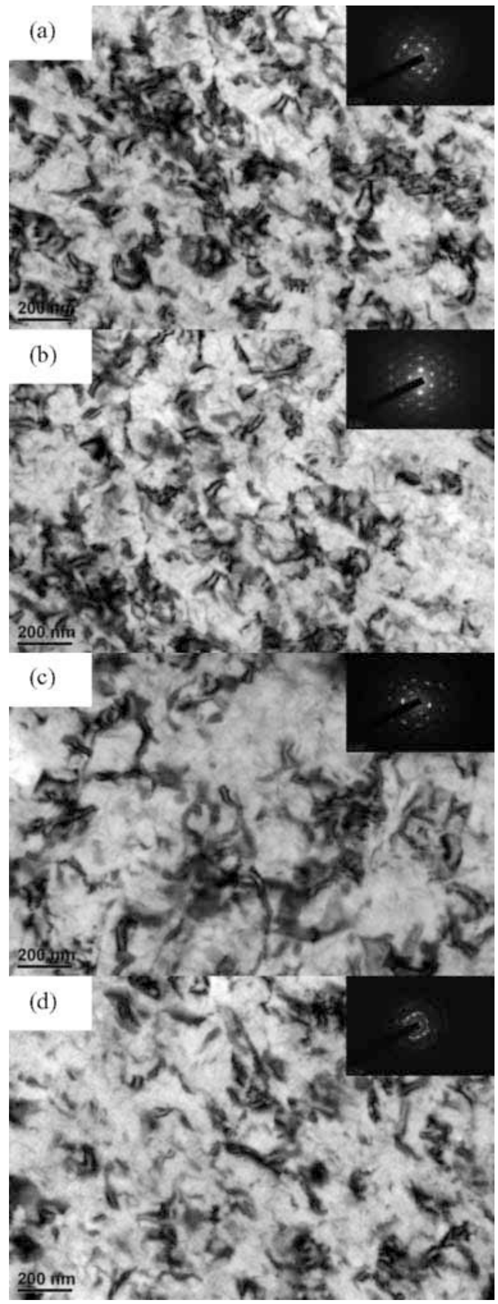


Figure 4. TEM micrographs and SAED patterns of Al 7085 alloy

processed by HPT through 3 turns (a), 6 turns (b), 9 turns (c) and 12 turns (d) under pressure of 2 GPa. Scale bar width of the SAED patterns inserted 51/nm.

Conclusions

HPT process can effectively refine microstructure of Al alloy. 7085 Al alloy with grain sizes between 50~200 nm is successfully fabricated using this method. When the pressure is 2 GPa and torsion revolutions are 12 turns, grains with size of ~50 nm are obtained.

Vickers microhardness analysis demonstrates that HPT process can significantly increase the values of the disks. Values of Hv increase as a whole from the centers to the edges of the disks because of the processing strain increases in the peripheral regions. Torsion revolutions do not present conspicuous effect when the overall values of microhardness in the disks increase.

HPT process promotes tensile strength of the alloy signally. When disks are processed by HPT under 2 GPa after 12 turns, the tensile strength reaches 699 MPa. Because of the refined grains, ductility of the alloy is improved simultaneously.

References

[1] Yuki Ito, Zenji Horita, "Microstructural Evolution in Pure Aluminum Processed by High-pressure Torsion," *Materials Science and Engineering A*, 503 (2009), 32-36.

[2] Alexander P. Zhilyaev, Terence G. Langdon, "Using High-pressure Torsion for Metal Processing: Fundamentals and Applications," *Progress in Materials Science*, 53 (2008), 893-979.

[3] PV Liddicoat et al., "Nanostructural Hierarchy Increases the Strength of Aluminium Alloys," *Nature Communications*, 1 (2010), 63

[4] P.W. Bridgman, "On Torsion Combined with Compression," *Journal of Applied Physics*, 14 (6) (1943), 273.

[5] ZC Duan et al., "Influence of High-pressure Torsion on Microstructural Evolution in an Al–Zn–Mg–Cu Alloy," *Journal of Materials Science*, 45 (2010), 4621–4630.

[6] R. Pippan et al., "The Limits of Refinement by Severe Plastic Deformation," *Advanced Engineering Materials*, 8 (11) (2006), 1046-1056.