Rare Metal Materials and Engineering
Volume 50, Issue 7, July 2021
Available online at www.rmme.ac.cn

Science Press

Cite this article as: Sun Shineng, Liu Jiatao, Li Xiaolai, et al. High Ductility Zn-6Al Alloys with Fine-Grained Microstructure Processed by Low Temperature Backward Extrusion[J]. Rare Metal Materials and Engineering, 2021, 50(07): 2263-2267.

LETTER

High Ductility Zn-6Al Alloys with Fine-Grained Microstructure Processed by Low Temperature Backward Extrusion

Sun Shineng[1], Liu Jiatao[2], Li Xiaolai[3], Ye Guo[1], Weng Yuming[1], Lu Ziting[1], Lou Dongfang[3]

[1] Institute of Innovative Science and Technology, Shenyang University, Shenyang 110044, China; [2] Chinalco Shenyang Non-Ferrous Metals Processing Co., Ltd, Shenyang 110108, China; [3] School of Materials Science and Engineering, Northeastern University, Shenyang 110819, China

Abstract: To investigate the effect of different extrusion temperatures (350 and 200 °C) on the tensile properties of backward extruded Zn-6Al alloys at room temperature, the microstructure and mechanical properties were studied using scanning electron microscope (SEM), electron back-scattered diffraction (EBSD), and electronic universal testing machine. The results show that with the decrease of extrusion temperature from 350 °C to 200 °C, the elongation of backward extruded Zn-6Al alloys increases from 98% to 198% at the strain rate of 10^{-3} s^{-1} due to the fine grains, high Schmid factor and non-lamellar structure.

Key words: Zn-Al alloy; extrusion; microstructure; mechanical properties; deformation mechanism

Zn-Al alloy, as an eco-friendly material, is widely used in commercial applications, such as hardware components, bearing bush, and bathroom accessories[1-3]. According to the phase diagram of Zn-Al binary alloy, the eutectic contains 6wt% Al at the eutectic temperature of 381 °C[4]. The Zn-6Al alloys with 6wt% Al are widely applied due to high wear resistance and excellent fluidity. However, as a structural material, because of their poor formability and the difficulty for subsequent deep processing, the mechanical properties of Zn-6Al alloys are slightly inferior to those of Al alloys, which seriously restricts their industrial application, and results in numerous researches on the mechanical properties of Zn-6Al alloys[5-7].

Although Zn-6Al alloy is a casting alloy, it also attracts attention of scholars as a wrought alloy[8-10]. For the wrought Zn alloys, it is generally known that grain refinement is one of the most valid methods to improve the mechanical properties[11-13]. Fine-grained Zn alloys are usually achieved by the severe plastic deformation processes, such as the equal channel angular pressing (ECAP) and high pressure torsion (HPT) [14,15]. The temperature is an important factor in grain refinement because it is a typical thermal activation process. For industrial alloys, the convention low temperature deformation process (extrusion) is still an effective method for grain refinement, but it requires that the alloys have a certain low temperature plastic deformation ability[16]. Demirtas et al[17] found that the Zn-5Al alloy is refined down to the size of 110~540 nm by the ECAP technique at room temperature and exhibits a large elongation of 520% at the strain rate of 1×10^{-3} s^{-1}. Moreover, Zhang et al[18] found that Zn-5Al alloys processed by extrusion at high temperature (280 °C) have coarse grain and lamellar structure with low elongation of 38% at a strain rate of 1.4×10^{-4} s^{-1}. Therefore, lamellar-free structure and grain refinement are the key factors to improve the mechanical properties of Zn-6Al alloys.

In this study, a low temperature backward extrusion process for Zn-6Al alloys was studied. The influence of extrusion temperature on microstructure evolution and mechanical properties was investigated. Zn-6Al alloys show outstanding mechanical properties after the simple process, which is con-

Received date: December 15, 2020
Foundation item: Joint Research Fund Liaoning-Shenyang National Laboratory for Materials Science (2019JH3/30100018); Key R&D Project of Liaoning Province (2020JH210100011); Liaoning Province Natural Science and Foundation of China (2019-MS-236); Innovation and Entrepreneurship Training Program for College Students (202011035017)
Corresponding author: Sun Shineng, Ph. D., Institute of Innovative Science and Technology, Shenyang University, Shenyang 110044, P. R. China, E-mail: 83290252@163.com

ducive to their further application.

1 Experiment

Al and Zn (purity of 99.99wt%) were used to prepare the Zn-6Al alloys. The alloys were melted in high purity graphite crucible and cast into an iron mold with an internal diameter of 60 mm. The cast ingots were homogenized at 350 °C for 5 h, and then quenched in water. The homogenized samples were machined into the ones with 480 mm in diameter and 1000 mm in length. The samples were backward extruded to bars of 12 mm at extrusion temperatures of 350 and 200 °C, separately, and then air cooled to room temperature.

For microstructure observation, samples from all alloys were prepared using standard grounding and polishing techniques. The alloys were ground with 800#~2000# SiC papers and then polished into a mirror-like surface by diamond paste of 0.5 μm. The microstructure was observed using a JSM-6510A scanning electron microscope (SEM) at an acceleration voltage of 20 kV. The textures were characterized by an Oxford HKL Channel 5 software with electron back-scattered diffraction (EBSD) detector operating in the JSM-7001F SEM. The measured step was set as 0.1 μm.

2 Results and Discussion

2.1 Microstructure of extruded Zn-6Al alloys

Fig. 1 shows the SEM images of Zn-6Al alloys after extrusion at different temperatures. The Zn-6Al alloys consist of both Zn-rich η phase (bright contrast) and Al-rich α phase (dark contrast). Microstructure of the alloy after extrusion at 350 °C mainly consists of granular structure (Fig. 1a). However, it is worth noting that some regions include lamellar structure as well (Fig. 1a and 1b). Low extrusion temperature (200 °C) produces a microstructure comprising grainy η phase and α phase. The refined α phase is distributed along the phase boundaries of η phase due to the well-defined interface structure of the two phases[19]. No lamellar structure can be observed in the microstructure of Zn-6Al alloys treated by low temperature backward extrusion (Fig. 1c and 1d). Thus, the microstructure after extrusion at 350 °C has more lamellar structure regions than that of Zn-6Al alloys extruded at 200 °C does, which means that the extrusion temperature plays an important role in the transformation from lamellar to granular morphology.

The EBSD maps of the Zn-6Al alloys extruded at 350 and 200 °C are shown in Fig.2. It can be observed that with increasing the extrusion temperature, the average grain size increases from 0.89 μm (200 °C) to 1.07 μm (350 °C). It indicates that the grain size can be significantly refined by decreasing the extrusion temperature during backward extrusion process. This result is in good agreement with the effect of extrusion temperature on the grain size of Mg alloys[20-22]. Fig.2b and 2d depict the (0001) pole figures of the Zn-6Al alloys extruded at 350 and 200 °C, respectively. It can be observed that the randomization of texture improves obviously with increasing the extrusion temperature, resulting in the decrease in the maximum basal texture intensity from 12.43 (200 °C) to 10.72 (350 °C).

As shown in Table 1, with increasing the extrusion temperature, the fraction of dynamic recrystallization decreases from 53.8% (200 °C) to 43.9% (350 °C). The Schmid factor of basal slip is lower for the extrusion process at 350 °C (0.135) and higher for the extrusion process at 200 °C (0.207). With increasing the extrusion temperature from 200 °C to 350 °C, the average Schmid factor for prismatic slip increases from 0.419 to 0.436.

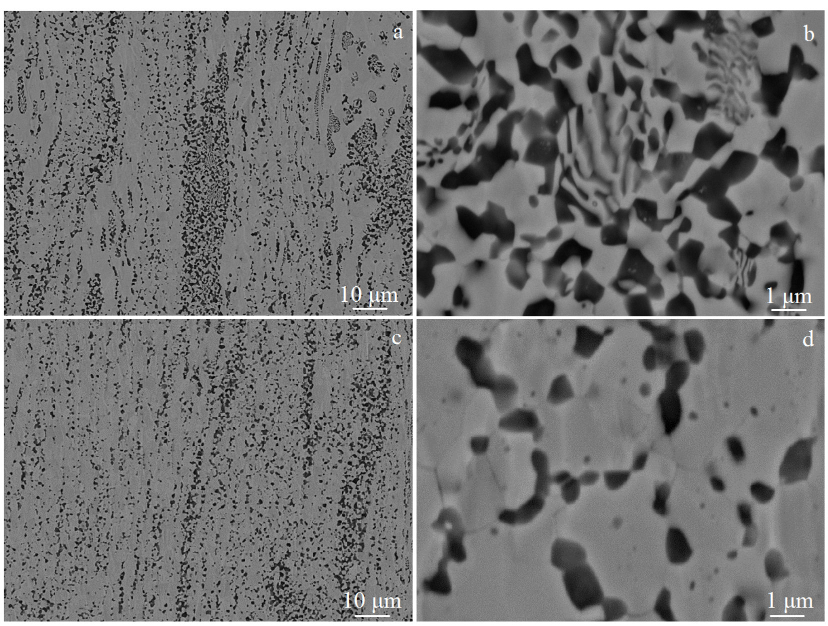

Fig.1 SEM images of Zn-6Al alloys extruded at 350 °C (a, b) and 200 °C (c, d)

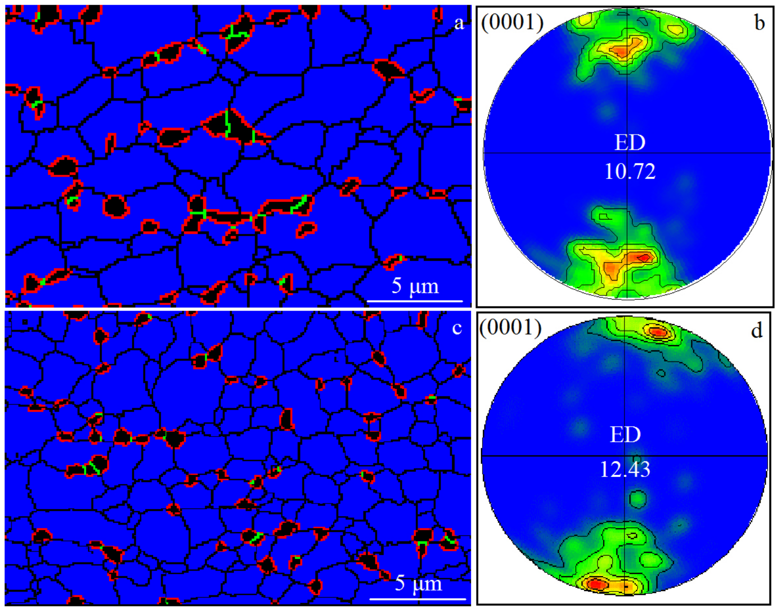

Fig.2 EBSD maps (a, c) and (0001) pole figures (b, d) of Zn-6Al alloys extruded at 350 °C (a, b) and 200 °C (c, d)

Table 1 Dynamic recrystallization fraction and Schmid factor of basal and prismatic slip of Zn-6Al alloys extruded at 350 and 200 °C

Temperature/°C	Dynamic recrystallization/%	Schmid factor	
		Basal slip	Prismatic slip
350	43.9	0.135	0.436
200	53.8	0.207	0.419

2.2 Mechanical properties of extruded Zn-6Al alloys

The engineering strain-stress curves obtained after tensile deformation with different strain rates of as-extruded Zn-6Al alloys at different extrusion temperatures are shown in Fig. 3. The stresses are very sensitive to the strain rate, and the increase of strain rate results in the increase in stress. The results show that the mechanical properties of Zn-6Al alloys considerably improve with decreasing the extrusion temperature. The Zn-6Al alloys extruded at 200 °C with fine-grained structure exhibit a good ductility. With decreasing the strain rate from 10^{-1} s^{-1} to 10^{-3} s^{-1}, the ultimate tensile strength of Zn-6Al alloys extruded at 200 °C decreases, while the elongation of as-extruded Zn-6Al alloys increases. The elongation is 68%, 90%, and 198% at the strain rate of 10^{-1}, 10^{-2}, and 10^{-3} s^{-1}, respectively. The ultimate tensile strength and elongation of Zn-6Al alloys extruded at 350 °C have the similar change trend.

After the tensile test, the SEM images of fracture surfaces of Zn-6Al alloys extruded at 350 and 200 °C are shown in Fig. 4. The fracture morphologies show the ductile fracture. With decreasing the extrusion temperature from 350 °C to 200 °C, the number of fine dimples of as-extruded Zn-6Al alloys increases (Fig. 4b and 4d). It is also confirmed that the low extrusion temperature can improve the ductility of Zn-6Al

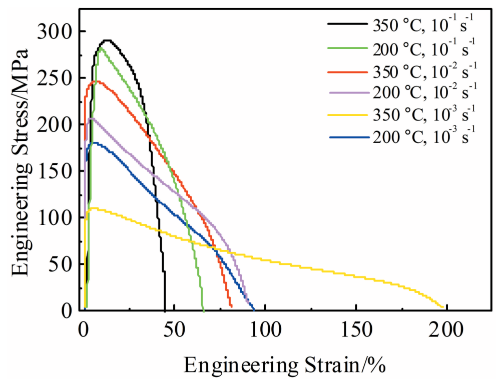

Fig.3 Engineering stress-strain curves of backward extruded Zn-6Al alloys at different extrusion temperatures

alloys.

Significant improvement in ductility of Zn-6Al alloys at room temperature is attributed to the following factors. Firstly, the small α phase mainly accumulates along the boundaries of relatively coarse η phases (Fig. 1). Such microstructure of the alloys may play an important role for prohibition of grain growth of η phases at relatively low recrystallization temperature, thereby, maintaining the stable structure. In addition, no obvious plastic deformation effect is observed in both grains due to the dynamic recrystallization during backward extrusion. Because both grains can be easily dynamically recrystallized at room temperature during extrusion deformation. Secondly, the growth of dynamically recrystallized grains can be affected by the extrusion temperature during backward extrusion. As the extrusion temperature decreases from 350 °C to 200 °C, the grain is refined from 1.07 μm to

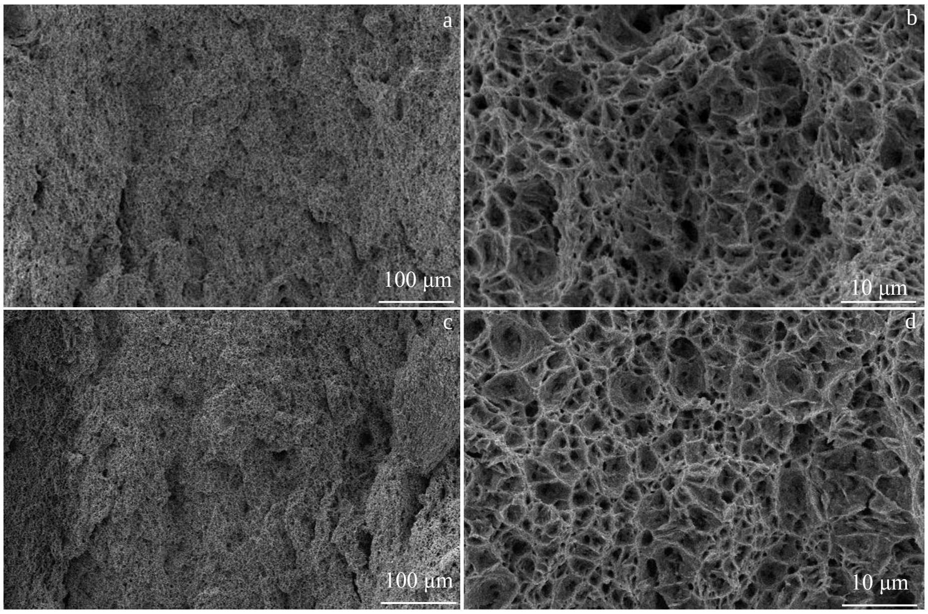

Fig.4 Tensile fracture morphologies of Zn-6Al alloys at 350 °C (a, b) and 200 °C (c, d) with the strain rate of 10^{-3} s^{-1}

0.89 μm in size (Fig.2). A similar result has been reported for the Mg alloys extruded at low temperature[23]. Thirdly, the outstanding ductility is related to the fine-grained structure and high Schmid factor for prismatic slip which activates the non-basal slip of dislocation (Table 1)[24]. Therefore, the fine-grained structure of Zn-6Al alloys is obtained by the simple extrusion process at a low extrusion temperature. The excellent ductility of Zn-6Al alloys is mainly attributed to the fine-grained structure and high Schmid factor for prismatic slip.

3 Conclusions

1) With the decrease in extrusion temperature from 350 °C to 200 °C, the lamellar structure disappears and the average grain size gradually decreases from 1.07 μm to 0.89 μm.

2) The Zn-6Al alloys extruded at 200 °C exhibit the maximum elongation of 198% due to the fine-grained and non-lamellar structure.

3) The excellent ductility of Zn-6Al alloys is mainly related to the fine-grained structure and high Schmid factor for prismatic slip.

References

1 Langdon T G. *Journal of Materials Science*[J], 2009, 44(22): 5998

2 Sun S N, Ren Y P, Wang L Q *et al*. *Materials Science and Engineering A*[J], 2016, 676: 336

3 Demirtas M, Purcek G, Yanar H *et al*. *Materials Science and Engineering A*[J], 2018, 730: 73

4 Yang L J, Zhang Y M, Zeng X D *et al*. *Corrosion Science*[J], 2012, 59: 229

5 Li S W, Gao B, Yin S H *et al*. *Applied Surface Science*[J], 2015, 357: 2004

6 Wang Y Q, Kong G, Che C S. *Corrosion Science*[J], 2016, 112: 679

7 Kang N, Na H S, Kim S J *et al*. *Journal of Alloys and Compounds*[J], 2009, 467(1-2): 246

8 Prosek T, Hagström J, Persson D *et al*. *Corrosion Science*[J], 2016, 110: 71

9 Gutiérrez-Menchaca J, Torres-Torres D, Garay-Tapia A M. *Journal of Alloys and Compounds*[J], 2020, 829: 154 511

10 Wei X Y, Ren L Y, Geng X Y *et al*. *Materials Characterization* [J], 2019, 147: 295

11 Sun S N, Wang H L, Yang B *et al*. *Material Science and Technology*[J], 2020, 36(7): 805

12 Uesugi T, Kawasaki M, Ninomiya M *et al*. *Materials Science and Engineering A*[J], 2015, 645: 47

13 Zhao L C, Wang X, Wang T B *et al*. *Materials Letters*[J], 2019, 247: 75

14 Kumar P, Xu C, Langdon T G. *Materials Science and Engineering A*[J], 2006, 429(1-2): 324

15 Choi I C, Yoo B G, Kraft O *et al*. *Materials Science and Engineering A*[J], 2014, 618: 37

16 Wang L Q, He Y F, Zhao H *et al*. *Journal of Alloys and Compounds*[J], 2018, 740: 949

17 Demirtas M, Purcek G, Yanar H *et al*. *Journal of Alloys and Compounds*[J], 2015, 623: 213

18 Zhang Y M, Yang L Y, Zeng X D *et al*. *Materials and Design*[J]. 2013, 50: 223

19 Xu C J, Wu Y T, Li S *et al*. *Journal of Materials Science and Technology*[J], 2020, 40: 39

20 Nakata T, Mezaki T, Xu C *et al*. *Journal of Alloys and Compounds*[J], 2015, 648: 428

21 Lü Binjiang, Peng Jian, Tong Xiaoshan *et al*. *Rare Metal Materials and Engineering*[J], 2013, 42(4): 841 (in Chinese)

22 Hu G S, Zhang D F, Dong Y F *et al*. *Rare Metal Materials and Engineering*[J], 2016, 45(5): 1111

23 Pan H C, Ren Y P, Fu H *et al*. *Journal of Alloys and Compounds*[J], 2016, 663: 321

24 Xia D B, Chen X, Huang G S *et al*. *Scripta Materialia*[J], 2019, 171: 31

低温挤压制备高塑细晶Zn-6Al合金

孙世能[1]，刘家涛[2]，李笑来[3]，叶　国[1]，翁誉铭[1]，卢紫婷[1]，娄东方[3]

(1. 沈阳大学 科技创新研究院，辽宁 沈阳 110044)

(2. 中铝沈阳有色金属加工有限公司，辽宁 沈阳 110108)

(3. 东北大学 材料科学与工程学院，辽宁 沈阳 110819)

摘　要：研究了不同挤压温度（350和200 ℃）对反挤压Zn-6Al合金室温拉伸性能的影响。利用扫描电镜、电子背散射技术以及电子万能试验机对Zn-Al合金的微观组织和力学性能进行了详细的研究。结果表明，由于具有细晶组织、高的施密特因子和无层片状组织，随着挤压温度从350 ℃降低至200 ℃，在应变速率为10^{-3} s^{-1}时，反挤压Zn-6Al合金的伸长率从98%提高至198%。

关键词：Zn-Al合金；挤压；微观组织；力学性能；变形机制

作者简介：孙世能，男，1987年生，博士，沈阳大学科技创新研究院，辽宁 沈阳 110044，E-mail：83290252@163.com