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STUDY OF EXTRUSION TEMPERATURE ON EXTRUDABILITY OF Al-Zn-Cu BASED ALLOY

In this study, the extrusion characteristics of Al-2Zn-1Cu-0.5Mg-0.5RE alloys at 450, 500, and 550°C were investigated for the high formability of aluminum alloys. The melt was maintained at 720°C for 20 minutes, then poured into the mold at 200°C and hot-extruded with a 12 mm thickness bar at a ratio of 38:1. The average grain size was 175.5, 650.1, and 325.9 μm as the extrusion temperature increased to 450, 500 and 550°C, although the change of the phase fraction was not significant as the extrusion temperature increased. Cube texture increased with the increase of extrusion temperature to 450, 500 and 550°C. As the extrusion temperature increased, the electrical conductivity increased by 47.546, 47.592 and 47.725%IACS, and the tensile strength decreased to 92.6, 87.5, 81.4 MPa. Therefore, the extrusion temperature of Al extrusion specimen was investigated to study microstructure and mechanical properties.

Keywords: Aluminum, Extrusion, EBSD, Mechanical property

1. Introduction

The Al-Zn-Cu-Mg alloys are known to offer an attractive combination of properties for structural applications. These alloys generally have a high strength and high specific strength, largely attributed to highly efficient precipitation strengthening. The Al-Zn-Mg-Cu alloy increases the content and ratio of the addition elements (Zn, Cu, Mg) and reaches a very high strength [1]. Until recently, however, their application has been limited by technical issues such as a poor formability and low thermal conductivity. Unfortunately, the above addition elements generally reduce electrical conductivity, so strength and electrical conductivity are mutually exclusive [2-4].

High-conductivity Al alloys are widely used for parts such as electrical materials, electrical conductors, transmission lines, communication cables and automotive wires. For the application and use of these various parts, high conductivity and manufacturing process technology development should be preceded. Recently, interest in energy conservation such as electric vehicles, motors, and LEDs is increasing, and application of heat dissipation parts is required. It is necessary to develop alloys with excellent heat dissipation characteristics and strength while minimizing alloy elements that reduce electrical conductivity [5-7].

The formation of recrystallization texture in FCC crystal structure has a lot of interest, especially in cube texture. The change of texture according to the deformation can be the dominant part of recrystallization [8]. It is known that non-Cube texture is developed in hot extruded commercial high purity aluminum, and processing materials with strong Cube texture have many advantages [9].

In this study, the microstructure, mechanical properties, and electrical conductivity characteristics of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloys at 450, 500, and 550°C were investigated for the high formability of aluminum alloys.

2. Experimental

Alloying elements were filled in graphite crucibles and cast. The melt was maintained at 780°C for 20 minutes and then poured into the mold at 200°C using a high induction furnace to produce Al-2wt.%Zn-1wt.%Cu-0.5wt.%Mg-0.5wt.%RE alloy. The extrusion billet was held for solution treatment by water quenching after heat treatment at 570°C for 4 hours. The billet was a 12 mm-diameter rod, hot-extruded at 550°C, showing a reduction of 38:1. The heat-treated billet was hot-extruded at 500°C at 38:1 extrusion ratio to produce a 12 mm diameter extruded material.

To observe the microstructure, the specimen was polished with a diamond suspension of 3 μm and 1 μm, and silica was used for final polishing. Microstructure analysis of Al alloys was performed using field emission scanning electron microscopy

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(FESEM) and electron backscatter diffraction (EBSD). The mechanical properties of extruded Al alloy specimens were evaluated using universal testing machine according to ASTM standard. The electrical conductivity was measured by eddy current method at room temperature.

3. Results and discussion

The SEM-BSE image of As-extruded Al-2wt.Zn-1wt.%Cu-0.5wt.%Mg-0.5wt.%RE alloy was shown in Figure 1. In the extruded Al alloy microstructure, the secondary phase causes severe deformation in the extrusion direction. The phase fractions were 2.88, 2.79 and 2.69% as the extrusion temperature increased to 450, 500 and 550℃, and the phase fractions were not changed significantly.

EBSD analysis was performed to investigate the grain size and texture of As-extruded Al-2wt.Zn-1wt.%Cu-0.5wt.%Mg-0.5wt.%RE alloy was shown in Figure 2. The EBSD map and grain rotation angle were parallel to the extrusion direction. As the extrusion temperature increased to 450, 500 and 550℃, the grain size was 175.5, 650.1 and 325.9 um. The grains of extruded specimen at 450℃ were observed finely, and the average grain size of extruded specimen at 500℃ was considered to increase due to the increase of the strain texture with a coarse size. The recrystallization of the equiaxed grains were confirmed at the extrusion temperature of 550℃.

The misorientaion angle of the Al-2wt.Zn-1wt.%Cu-0.5wt.%Mg-0.5wt.%RE alloy extruded according to the temperature increase is shown in figure 3. The LGB(low angle boundary-orange, green, blue color) of 0-15 degrees and HGB (high angle boundary-black color) of 15-180 degrees were divided. The LGB fraction of as-extruded specimen at 450℃ was 34.3% and the HGB fraction was 65.7%. The fraction of LGB in specimens at 500℃ with orange, green and blue color was increased to 59.5% and the non-recrystallized particles increased in a band shape along the extension direction. The fraction of HGB in specimen of 550℃ increased to 75.8%, and most of the recrystallization grains were observed.

Figure 4 shows the EBSD pole figure (PF) and orientation distribution function (ODF) analysis of the extruded Al-2wt.Zn-1wt.%Cu-0.5wt.%Mg-0.5wt.%RE alloy according to temperature increase. The texture of extruded specimens at 450 and 500℃ had (001) <100> cube and (110) <111> α fiber texture. On the other hand, developed cube texture was confirmed in the case of the extruded specimen at 550℃. It is considered that the result of the increase of recrystallization driving force due to the increase of extrusion temperature.

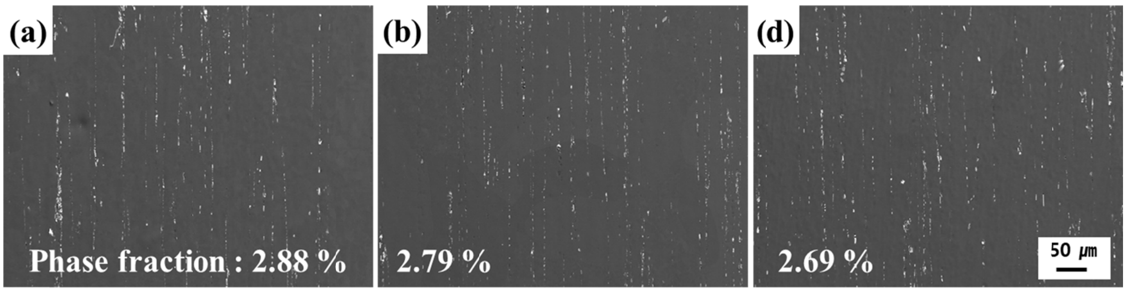

Fig. 1. SEM image of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at (a) 450, (b) 500, (c) 550℃

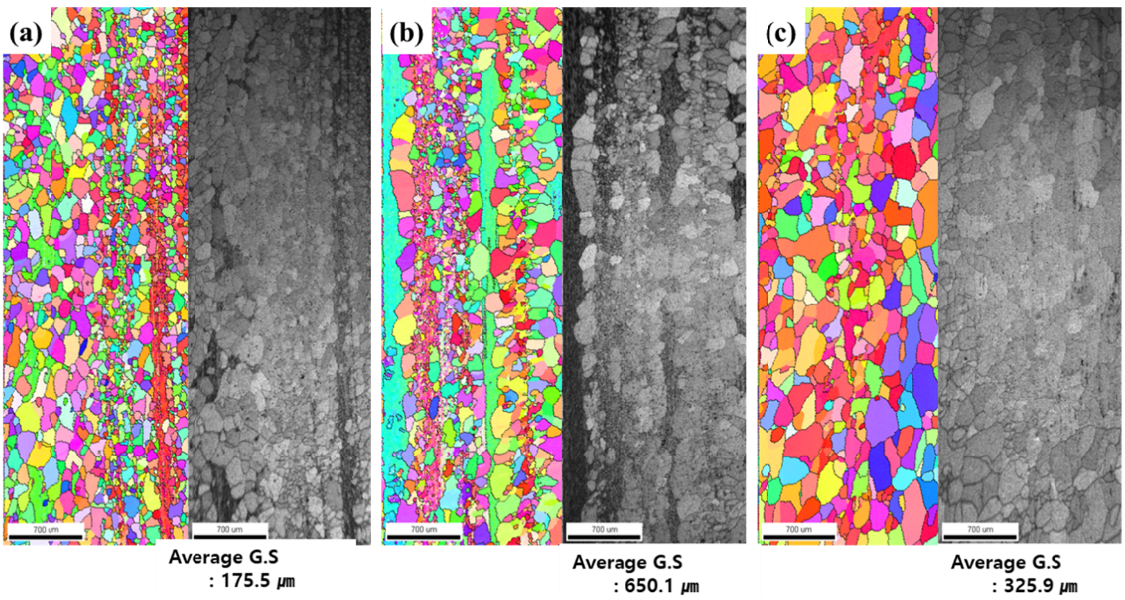

Fig. 2. IFP and IQ image of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at (a) 450, (b) 500, (c) 550℃

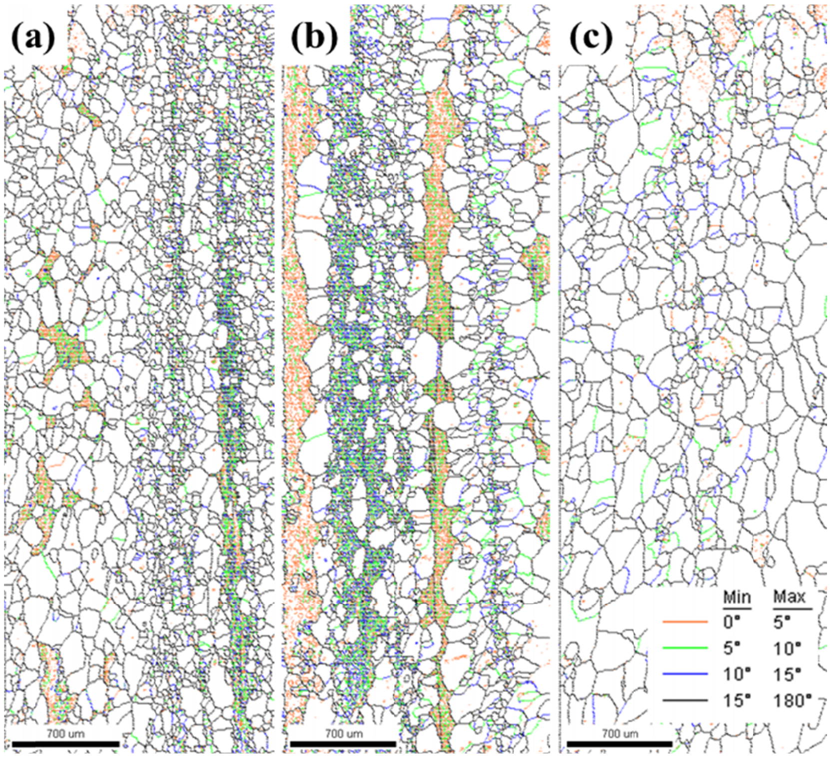

Fig. 3. Misorientation angle of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at (a) 450, (b) 500, (c) 550°C

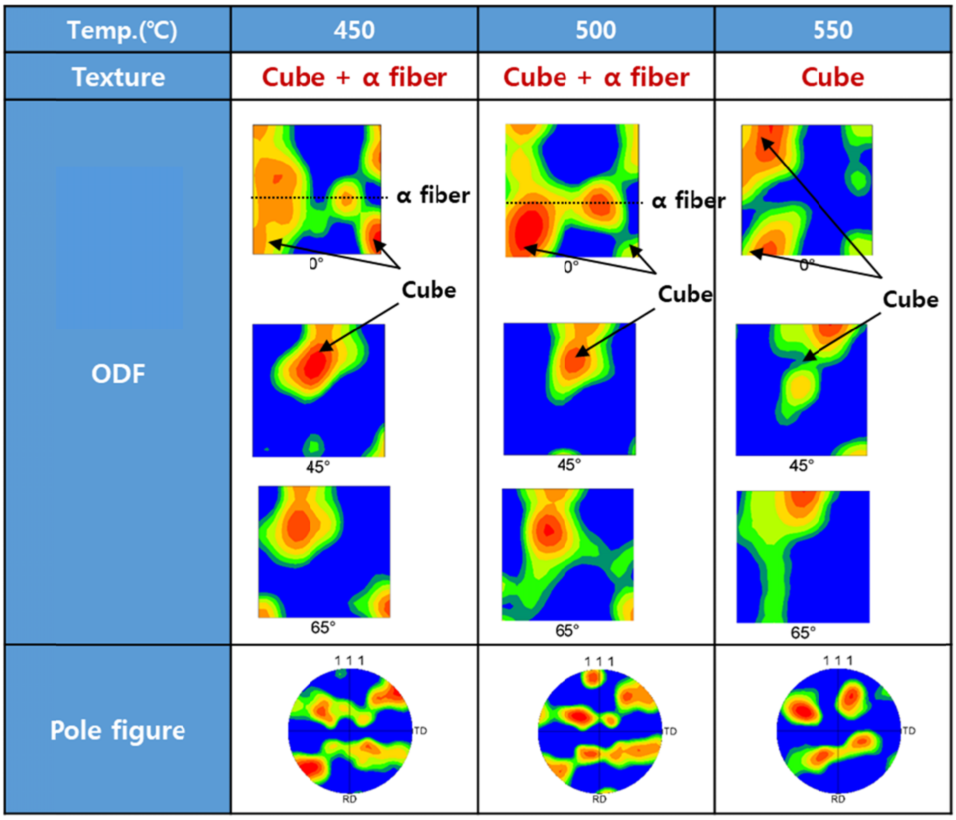

Fig. 4. ODF and PF maps of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at 450, 500 and 550°C

Figures 5 and Table 1 show results in electrical conductivity due to the different extrusion temperature. As the extrusion temperatures increased to 450, 500 and 550°C, the electrical conductivity tended to increase to 47.546, 47.592 and 47.725% IACS. Although the change of the conductivity value was not large, it is considered that the reduction of HGB fraction and recrystallization due to the increase of extrusion temperature.

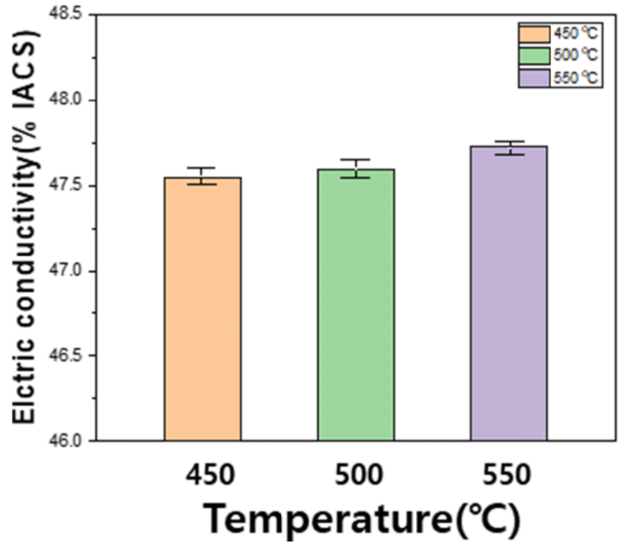

Fig. 5. Electric conductivity of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at 450, 500 and 550°C

TABLE 1

Electric conductivity of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at 450, 500 and 550°C

Mark	Alloys	Temp. (°C)	Electric conductivity (%IACS)	Error range
1	Al-2Zn-1Cu-0.5 Mg-0.5RE	450	47.546	0.05
2		500	47.592	0.06
3		550	47.725	0.04

The tensile properties of as-extruded Al-2wt.Zn-1wt.% Cu-0.5wt.%Mg-0.5wt.%RE alloys were shown in Figure 6 and Table 2. As the extrusion temperature increased to 450, 500, and 550°C, the yield strength decreased to 92.6, 87.5 and 81.4 MPa, and the tensile strength decreased to 206.6, 197.3 and 189.5 MPa. In addition, the elongation decreased to 27.98, 27.04 and 28.15%. Strain to the maximum load, uniform elongation, was resulted to decrease with increasing temperature. Uniform strain during tensile test can be used effectively as a measure of n-value, which relates to ductility. As the extrusion temperature increased to 450, 500, and 550°C, the n-value decreased to 0.3308, 0.32267 and 0.32048. It is considered that the specimen with alpha texture formed by extrusion at low temperature is due to the strength improvement than the specimen with recrystallization texture at high temperature.

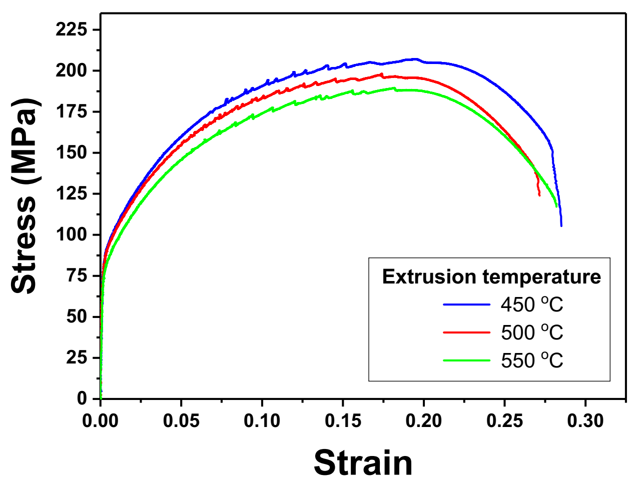

Fig. 6. Tensile test of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at 450, 500 and 550°C

TABLE 2

Tensile test of as-extruded Al-2Zn-1Cu-0.5Mg-0.5RE alloy on different temperature at 450, 500 and 550°C

Mark	Temp. (°C)	YS (MPa)	TS (MPa)	Elongation (%)	Uniform Elongation (%)	n-value
1	450	92.6	206.6	27.98	19.82	0.33808
2	500	87.5	197.3	27.04	19.44	0.32267
3	550	81.4	189.5	28.15	19.27	0.32048

4. Conclusions

As the extrusion temperature increased to 450, 500 and 550°C, the particle diameter was 175.5, 650.1 and 325.9 um. The fraction of LGB increased to 59.5% at 500°C, resulting in large grains. In the 550°C specimen, most of the recrystallized particles were observed because the fraction of 15 degrees or more increased to 75.8%. The specimens extruded at 450°C and 500°C had (001) <100> cube and (110) <110> α fiber texture, while the specimens extruded at 550°C had developed cube texture. As the extrusion temperature increased to 450, 500, and 550°C, the electrical conductivity increased to 47.546,47.592, 47.725%IACS, the yield strength decreased to 92.6, 87.5, 81.4 MPa, and the tensile strength decreased to 206.6, 197.3 and 189.5 MPa.

Acknowledgments

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REFERENCES

[1] J. Hirsch, K. Lucke, Acta Metall. **36**, 11 (1988).
[2] R.D. Doherty, K. Kashyap, S. Panchanadeeswaran, Acta Metall. **41**, 10 (1993).
[3] J. Hjelen, R. Ørsund, E. Nes, Acta Metall. **39**, 7 (1991).
[4] T. Warner, Mater. Sci. Forum. **519**, (2006).
[5] R.Z. Valiev, M.Y. Murashkin, I. Sabirov, Scr. Mater. **76** (2014).
[6] M.Y. Murashkin, I. Sabirov, X. Sauvage, R.Z. Valiev, J. Mater. Sci. **51**, 1 (2016).
[7] X. Sauvage, E.V. Bobruk, M.Y. Murashkin, Y. Nasedkina, N.A. Enikeev, R.Z. Valiev, Acta Mater. **98** (2015).
[8] S.H. Cho, J.Y. Lee, ASC Mater. Lett. **6**, 4 (2010).
[9] B.P. Huang, Z.Q. Zheng, Acta Metal. **46**, 12 (1998).