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The effect of extrusion and high-pressure torsion on the properties of Alumix-231

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ABSTRACT

The mechanical properties and microstructure of commercial Al–15Si–2.5Cu–0.5Mg (Alumix-231®) alloy was subjected to extrusion (EXTR), hot extrusion into rods at 565 °C at an extrusion ratio of 4:1 and high-pressure torsion (HPT) processing, one of the most severe plastic deformation (SPD) techniques, with an anvil rotation speed of 0.5 rpm under a quasi-hydrostatic pressure of 5 GPa. Afterwards, the microstructures of specimens were systematically investigated using XRD, SEM, EBSD, and TEM. Also, tensile properties of Alumix-231 processed by EXTR and HPT were determined at room temperature. The HPT specimen shows refined microstructure (around average 165 nm) having more spherical and homogeneously distributed eutectic silicon second phases in Al metal matrix as compared to EXTR specimen. The hardness values are greater on the surface of the HPT specimen (239.1 Hv) as compared to that EXTR specimen (71.2 Hv) and increase with distance from the center of HPT specimen (198.3 Hv). Tensile strength and ductility of HPT specimen increased approximately 2 times than that of EXTR sample, respectively. The results indicate that the morphological changes in eutectic silicon especially after HPT play a critical role in enhancing or limiting the overall properties of the Alumix-231 material.

1. Introduction

HPT processing [1–3] is very effective for fabricating extremely small grains with high-angle boundaries, compared with other SPD techniques such as equal-channel angular pressing (ECAP) [4,5] and accumulative roll bonding (ARB) [2]. The equivalent strain (ε_{eq}), which increases with the distance from the center of the HPT specimen, is an important factor to achieve grain refinement in HPT processing [6]. Therefore, grain refinement begins in the periphery of the disk specimen in HPT processing and spreads to the center of the disk specimen with increasing ε_{eq}. Although there is disadvantage due to anisotropic imposed ε_{eq} across diameter of the disks specimen, which leads to microstructural variations on the disk specimen [6], HPT processing has been effective to achieve good grain refinement and homogenization in pure Al [7], an Al–Mg–Sc [6], and an aluminum based metal matrix composites (MMCs) [8].

Al–Si eutectic alloys are widely used in many industries, especially the automobile industry because of their good wear resistance, high tensile strength at elevated temperatures and good castability. Conversely, these alloys show a low fracture toughness due to the microstructure, which consists of eutectic silicon second, phases in aluminum-based matrix. On the other hand it is reported that the size, morphology [9,10] and distribution [10,11] of silicon phases in the Al based metal matrix have strongly effects to mechanical strength [10,11], hardness [11], and ductility [10] of Al–Si alloys. Likewise, significant improvements in strength, ductility, and great wear resistance of Al–Si alloys were achieved by HPT processing with the grain refinement and modifying the eutectic silicon second phases [11–13]. Therefore, the effects of extrusion and HPT processing on microstructure and mechanical properties of commercial hypoeutectic Alumix-231 alloy have been investigated in this study.

2. Experimental procedures

2.1. Material

The chemical composition (in wt%) of hypoeutectic Alumix-231 powders used in the present study is given in Table 1. The Alumix-231 powders with an average size of about ~70 μm at

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Table 1
The specified chemical compositions (w/o) of Ecka Granules Alumix-231 alloy.

	Al	Si	Cu	Mg	Fe
Nominal target	Bal.	14–16	2.4–2.8	0.5–0.8	N/A

D50 and ~157 μm at D90 were produced by inert gas atomization.

2.2. Sample preparation

The Alumix-231 powders were also cold-pressed at room temperature under a pressure of 200 MPa in a cylindrical steel die with a diameter of 100 mm using a hydraulic press. The cold-pressed Alumix-231 was then heated to 410 °C at a rate of 10°/min in a furnace, followed by a 40-min soak to remove the lubricant that was added to the powder blend. The de-lubricated specimen was then heated to sintering temperature (565 °C) and isothermally held for 1 h before the hot extrusion in a controlled manner. Next, this sintered specimen was hot extruded into rods with dimensions of 90 mm × 250 mm × 20 mm at 565 °C at an extrusion ratio of 4:1. After cooling of the hot extruded specimens at room temperature, they were machined into disk specimens with diameters of 20 mm and thicknesses of 0.80 mm parallel to the extrusion direction of the HPT processing by electro-discharge machining (EDM). Additionally, these disk specimens were subjected to HPT processing at 5 whole rotations (N) with an anvil rotation speed of 0.5 rpm under a pressure of 5 GPa at room temperature. The HPT processing is schematically illustrated in Fig. 1 [6]. The disk specimen was placed in the holder of the lower anvil, and a lubricant (WC) was placed around the holder. The equivalent strain (ε_{eq}) for HPT processing is given by the following equation [1]:

$$\varepsilon_{eq} = \frac{2\pi rN}{t\sqrt{3}} \quad (1)$$

where r is the distance from the center and t is the thickness of disk specimens. Hereafter, the extruded Alumix-231 specimens are referred to as the EXTR specimens, and the EXTR disk specimens subjected to HPT processing are referred to as the HPT specimens.

2.3. Microstructural evaluations

The X-ray diffraction (XRD) analysis, transmission electron microscopy (TEM) and electron back scattering diffraction (EBSD) observations of the HPT specimen were performed at half-radius

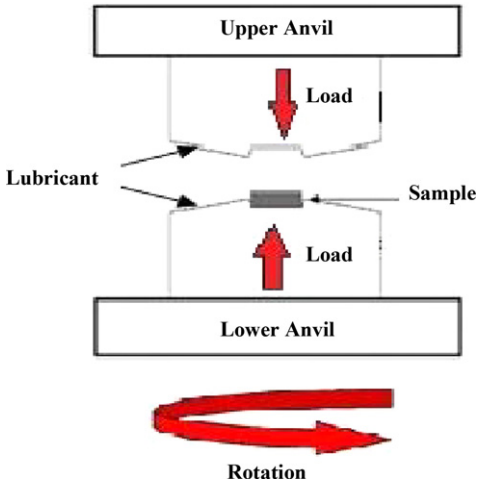

Fig. 1. Schematic illustration of the HPT processing showing the loading of the testing [6].

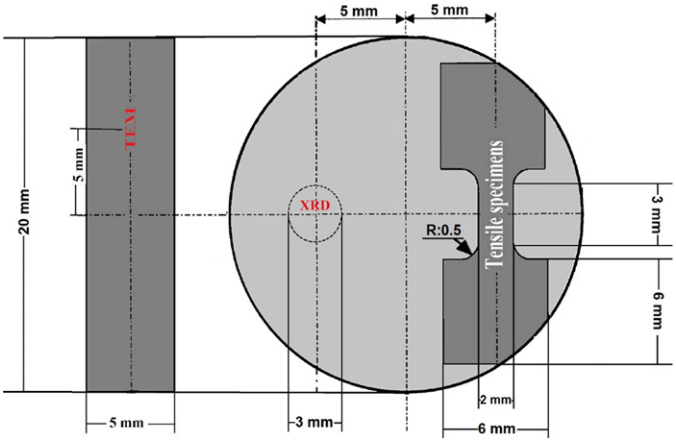

Fig. 2. Schematic illustration of the positions of analysis and measurement, and the dimensions on the surface and cross-section of the HPT specimen.

(R/2), where medium strain was imposed in the HPT specimen, as illustrated in Fig. 2. The microstructure of each specimen was studied by XRD (Philips, X'Pert Pro MRD, Germany) using Cu Kα radiation with a tube voltage of 40 kV and a tube current of 40 mA. A Hitachi 4300 scanning electron microscope equipped with a backscatter diffraction camera (EBSD) was used to obtain statistical information including information on the size and distribution of grains on the nature of the microstructure occurred during processing. The experimental data were collected using a scanning electron microscope (SEM) operating at 20 kV, a 10 nA beam current, and a 10 step size with a Tex-SEM Laboratories orientation imaging system. Samples for EBSD analysis were mechanically ground and then electrolytic ally polished to a mirror-like finish. The deformed microstructures were cleaned using the grain dilation method. TEM specimens were extracted at the half radius (R/2) position on the cross-section of HPT disks specimens and then wet polished using water-proof emery papers of up to 2400 and were then buff polished to obtain the mirror-like surface using colloidal SiO_2 suspension. Subsequently they were ion milled after grinding. TEM analysis was performed using a field emission transmission electron microscope (Jeol JEM 2100F, Japan) operating at 200 kV.

The grain size was measured using bright-field images of the TEM micrographs. The microstructure of HPT specimen has nano-sized grains, around average 165 nm with having subgrains having non-uniform shape. Determination of the eutectic silicon second phase size from the XRD patterns was conducted using the Williamson–Hall analysis method [14] of which the equation is defined as

$$\beta_s \cos\theta = \frac{k\lambda}{d} = 2\varepsilon \sin\theta \quad (2)$$

where β_s is the specimen broadening, k is the Scherrer constant (= 1.05), λ is the wavelength of the X-ray, d is the crystallite size, θ is the Bragg angle, and ε is the internal strain. (For Al, with FWHM calculation, while the grain size is 39 in 44th EXTR peak, it decreases to 34 in HPT.)

2.4. Mechanical tests

Hardness measurements were taken using a Shimadzu hardness tester (Shimadzu HMV-2TADW-XY, Japan) equipped with an intender. A load of 200 g and a dwell time of 10 s were used in all tests. The HPT specimen was carefully polished to a mirror finish as mentioned above. The hardness measurements were taken along the diameters at positions separated by ~2.5 mm on the surface of the HPT specimen. At every point, the average hardness was determined from three separate measurements clustered around the