Effect of Extrusion Casting and Refining Process on Strength and Elongation of 4032 Aluminum Alloy

Wanneng Liao[1]* Chenxing Zhang[1] Zhongde Shan[1] Wenzhe Song[2] Xixi Dong[1]
1 College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China
2College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China

*Corresponding address: e-mail: liaowanneng@sina.com

ABSTRACT: The 4032 aluminum alloy is a high-Si deformation aluminum alloy, that is commonly generated through forging due to the difficulties involved in its direct casting. In this work, the 4032 aluminum alloy is innovatively prepared via a squeeze casting process, and the Al-6Nb-1.5Ti-0.5B refining agent is incorporated to enhance its mechanical properties. A range of analytical techniques are subsequently employed to analyze the grain refinement mechanism of Al-6Nb-1.5Ti-0.5B under squeeze casting conditions. It was found that the microstructure of the aged 4032 aluminum alloy after refinement treatment was mainly composed of α-Al grains measuring <100 μm in size, in addition to a eutectic Si phase, that is accompanied by stacked dislocations and diffusely distributed Q′-AlCuMgSi and θ′-AlCu phases. The yield strength of the alloy reached 340 MPa, its tensile strength was 404 MPa, and the elongation was 4.1 %. In the presence of the Al-6Nb-1.5Ti-0.5B refiner, the generation of nucleation cores (e.g., MAl(M = Ti, Nb)) in the melt led to a significant reduction (~50 %) in the α-Al grain size of the aged 4032 aluminum alloy (i.e., 95.1 ± 21.0 μm), compared with the standard alloy. After the T6 heat treatment of the refined 4032 aluminum alloy, the size of the precipitation phase was reduced by 36.8 %, and fine silicon particles with a spherical morphology and a more random distribution were observed.

Keywords: 4032 aluminum alloy; Squeeze casting; Al-Ti-Nb-B refiner; Strength; Elongation

2 Introduction

Due to their excellent casting, mechanical, and thermophysical properties, Al-Si alloys have been widely used in the aerospace and automotive industries to prepare components such as engine parts, and compressor scroll discs, among others [1,2]. The α-Al grains present in Al-Si alloys prepared via conventional casting processes tend to be extremely coarse, resulting in poor mechanical properties, especially in the context of elongation [3,4]. To address this issue, elements such as Sr, Sb, and Na are commonly added to the Al-Si alloys to promote melt metamorphism and alter the Si morphology [[5], [6], [7]]. In addition, a range of processes have been investigated to prepare Al-Si alloy castings and to study their mechanical properties following melt metamorphism. For example, Dong et al. [8] reported a high-strength and high-toughness Al-Si alloy fabricated by high-pressure die casting (HPDC); however, the extremely fast filling rate, associated with high-pressure die casting, led to porosity defects in the alloy. In another study, Raju et al. [9] prepared Al-12Si alloys by spray casting; however, this process was expensive and produced only small batches. Moreover, the ultimate tensile strength of the produced Al-12Si alloy reached only 148 MPa.

Thus, we herein report the combinat

ion of squeeze casting with Al-Ti-Nb-B refiners to enhance the mechanical properties of eutectic Al-Si alloys. More specifically, 4032 aluminum alloys were prepared via the squeeze casting in the presence and absence of the Al-6Nb-1.5Ti-0.5B refiners (5.96 wt% Nb, 1.38 wt% Ti, 0.584 wt% B, and a residual amount of Al). The microstructure and mechanical properties of the two alloys in the as-cast and T6 heat-treated states are systematically studied and compared. In addition, the mechanism responsible for the observed microstructure refinement and property strengthening in the 4032 eutectic alloy containing the Al-Ti-Nb-B refining agent is revealed.

1 Experimental procedure

The 4032 aluminum alloy (12.74 wt% Si, 0.33 wt% Fe, 1.29 wt% Cu, 1.00 wt% Mg, 1.15 wt% Ni, 0.059 wt% Ti, residual Al) was melted in a 60 kg capacity crucible using a resistance furnace. During the melting process, the temperature of the resistance furnace was controlled at 720 °C. A total of 30 kg of the alloy melt was prepared, and this melt was homogenized for 1 h. Subsequently, the Al-10Sr intermediate alloy was added, and the alloy melt was subjected to outgassing and smelting for 15 min. After resting for 15 min, the desired alloy melt was obtained (see Fig. 1). In addition, A specimen also added the 1 % weight percentage Al-6Nb-1.5Ti-0.5B refiner (5.96 wt% Nb, 1.38 wt% Ti, 0.584 wt% B, residual Al) when adding Al-10Sr intermediate alloy.

3 Result and discussion

The 4032 aluminum alloy was prepared by squeeze casting both in the presence and absence of a refiner. For this purpose, the following parameters were employed: injection speed of 0.1 m/s, squeeze pressure of 150 MPa, pouring temperature of 710 °C, and mold temperature of

220 °C, respectively. The yield strength of the refiner-free 4032 aluminum alloy (hereinafter referred to as alloy CS1) in the as-cast state was determined to be 169 MPa, the tensile strength was 249 MPa, and the elongation was 1.55 %. Subsequently, alloy CS1 was subjected to T6 heat treatment, according to the following parameters: solid-solution temperature of 525 °C, solid-solution heating insulation time of 2.5 h, aging temperature of 175 °C, aging insulation time of 10 h. After the T6 heat treatment (hereinafter referred to as alloy AS1), the tensile strength of the alloy increased to 364 MPa, the yield strength increased to 334 MPa, and the elongation remained relatively constant at 1.56 %. The above process was then repeated in the presence of the Al-6Nb-1.5Ti-0.5B refiner. As a result, the yield strength of the obtained alloy (hereinafter referred to as alloy CS2) increased to 185 MPa, the tensile strength increased to 285 MPa, and the elongation increased to 2.37 %. After the subsequent T6 heat treatment (hereinafter referred to as alloy AS2), a yield strength of 340 MPa was achieved, along with a tensile strength of 404 MPa, and an elongation of 4.10 %. These results are summarized in Table 1. Considering the process outlined above, it appeared that the use of a high pressure combined with the Al-6Nb-1.5Ti-0.5B refiner synergistically improved the strength and toughness of the alloy. Indeed, the tensile strengths of the CS2 and AS2 alloys were increased by 14.4 and 11.0 %, respectively, compared to the CS1 and AS1 alloys, while the elongation increased by 52.9 and 162.8 %, respectively. In addition, the stress-strain curves for the various alloys are shown in Fig. 2(a), wherein it can be seen that the prepared alloys exhibit excellent mechanical properties. A comparison of their mechanical properties with those of previously reported high-silicon aluminum alloy castings is presented in Fig. 2(b).

4 Conclusion

A 4032 deformed aluminum alloy was prepared by squeeze casting both in the presence and absence of the Al-6Nb-1.5Ti-0.5B refining agent, and the synergistic effect between this process and the incorporation of Al-6Nb-1.5Ti-0.5B was investigated in terms of the alloy's microstructure and mechanical properties. Following the squeeze casting, the refined and unrefined alloys were subjected to T6 heat treatment. It was found that the yield strength of the aged and refined alloy reached 340 MPa, while its tensile strength was 404 MPa, and its elongation was 4.1 %. These results imply that the final obtained alloy was imparted with excellent strength and toughness properties simultaneously.

Acknowledgments

This work is supported by the National Key R&D Program of China (No.2022YFB3404204), the National Natural Science Foundation of China (52105361), the Natural Science Foundation of Jiangsu (BK20210314), China Postdoctoral Science Foundation (2023T160314).

References

[1] Y. Bai, L. Zhao, Y. Wang, et al.Fragmentation of in-flight particles and its influence on the microstructure and mechanical property of YSZ coating deposited by supersonic atmospheric plasma spraying. J. Alloys Compd., 632 (2015), pp. 794-799, 10.1016/j.jallcom.2015.01.265

[2] M.Y. Murashkin Nanostructured Al and Cu alloys with superior strength and electrical conductivity . Mater. Sci., 51 (2016), pp. 33-49, 10.1007/s10853-015-9354-9