Effect of Magnetic Fields by Helmholtz Coils on the Investment Casting A356 Al-Si Alloy with Grain Refiner Al-5Ti-B

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A356 aluminum alloy stands as a versatile choice across industries like aviation, electric vehicles, automobiles, and defense, boasting strong mechanical traits. The incorporation of silicon and magnesium augments its casting features, while the introduction of magnesium brings about age-hardening behavior through the precipitation of Mg_2Si post-T6 heat treatment. Nonetheless, its mechanical attributes, particularly ductility, fatigue, and tensile strength, confront limitations due to the presence of dendritic α-Al structure and uneven distribution of eutectic Si particles. Addressing these concerns, the investment casting process undergoes alterations via the inclusion of Al-5Ti-B grain refiners, coupled with electromagnetic stirring during solidification. In this context, the study presents the integration of Al-5Ti-B master alloy to enhance nucleation sites during solidification, complemented by an external magnetic field generated by Helmholtz coils to intensify convection stirring during A356 alloy's investment casting. This amalgamation yields marked enhancements in the alloy's mechanical properties including hardness, ultimate tensile strength, and yield strength signified by a 12.6%, 11.8%, and 15.6%, respectively.

Keywords: *A356 Al-Si alloy, magnetic field, investment casting, Helmholtz coils, grain refiner, T6 heat treatment, eutectic Si*

1. Introduction

The aluminum-silicon (Al–Si) alloy finds extensive utility in aerospace, military weaponry, and automotive components due to its exceptional corrosion resistance, lightweight nature, low density, remarkable formability, low coefficient of thermal expansion, and comprehensive mechanical properties[1]. Critical to its performance, the solidification conditions experienced during casting profoundly influence microstructures, overall performance, and casting quality. Parameters such as surface morphology, α-Al grain size, and eutectic silicon phase morphology exert pronounced effects on the mechanical attributes of Al–Si alloys[2]. The tensile properties of Al–Si cast alloys are primarily governed by the size of α-Al dendritic cells, while the presence of eutectic silicon particles significantly impacts fracture behavior and tensile ductility. Furthermore, an essential microstructural facet within the dendritic ingot of Al–Si alloys, especially during the investment casting process, involves grain refinement. The mechanical characteristics of cast Al-Si components are notably shaped by grain refinement and intermetallic phases. Challenges arise from unmodified eutectic silicon, porosity, dendrites, and coarse grains dispersed irregularly within the Al–Si eutectic system, collectively contributing to lower mechanical properties. To enhance the microstructure of A356 alloy in the investment casting process, the introduction of Al-5Ti-B grain refiners is carried out during manufacturing[3]. Additionally, electromagnetic stirring during solidification imparts vigorous melt flow to eliminate newly formed dendrites near the solidification front[4]. These disrupted dendrites serve as novel nucleation sites, leading to grain refinement and the generation of a non-dendritic microstructure in the final cast ingots. This is realized by incorporating a commercial Al-5Ti-B master alloy as a grain refiner, augmenting nucleation sites within the solidification process, coupled with the application of a low-cost external magnetic field via Helmholtz coils to intensify (3.1 mT and 10.7 mT) convection stirring during the investment casting of A356 alloy. Heat treatment in the T6 condition is necessary to enhance mechanical properties through precipitation hardening[5].

2. Experimental method

The A356 alloy with grain refiner, Al-5Ti-B, were melted at 710°C in an electrical resistance furnace, with inert argon gas introduced via a rotary graphite degasser for 5 minutes. The ceramic mold was held at 800°C for 30 minutes. Ceramic mold pouring occurred at room temperature with applying an external magnetic fields by Helmholtz coils that it connected to an autotransformer supplied AC voltage (60 Hz) of 0, 200, and 600 V, resulting in magnetic fields of 0, 3.1, and 10.7 Mini-Tesla (mT), respectively[6]. Magnetic field strength measurement utilized a Tesla meter (KANETEC TM-801). Two as-cast specimens were obtained post each casting. T6 heat treatment involved solid solution at 540°C ± 2°C for 5 hours, followed by quenching for a supersaturated Al-Si alloy. Precipitation hardening aging was done at 165°C for 8 hours. Metallography analyze used an Olympus BX41 optical microscope. Image-J software analyzed the grain size at 100X magnification. Hardness testing used a Mitutoyo HM-101 Vickers hardness tester (1 Kg load). A SHIMADZU AG-I 100KN tensile machine (1 mm/min strain rate) assessed mechanical properties including UTS, YS, and elongation. X-ray diffraction (Rigaku D/Max-2500V) examined A356 alloy's crystal structure, with parameters: 30 KV voltage, 50 mA current, 20 to 80 scanning range, and 1.5/min scanning rate.

3. Result and discussion

Figure 2. illustrates how applying magnetic fields during the investment casting process led to a significant reduction in average grain sizes. For both non-refined (NR) and Al-5Ti-B added cases, the grain sizes decreased from 295.1 to 183 µm and 220.2 to 161.2 µm, respectively. The external magnetic field induced grain refinement in the α-Al phase during the solidification of A356 alloys. The

magnetic field effect caused a shift from continuous and coarse grain structures to discontinuous and smaller fibrous ones, including changes in eutectic silicon morphology, due to forced convection from the Lorentz force[7].

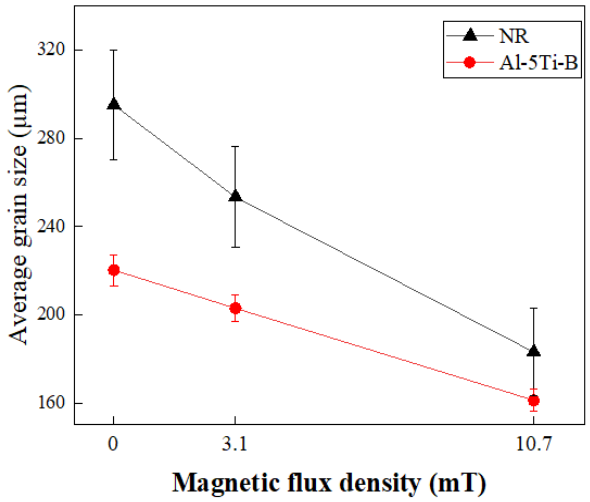

Figure 2. Average grain size and standard deviation for non-refined and Al-5Ti-B of A356 alloy with different magnetic field.

Figure 3 provides mechanical properties of investment-cast A356 alloy, including ultimate tensile strength (UTS) and yield strength (YS). When the magnetic field increased to 10.7 mT, A356's mechanical characteristics improved by 11.8%, and 15.6% in terms of UTS, and YS, respectively. This enhancement resulted from the magnetic field's positive impact on microstructures of A356, including α-Al grain refinement and eutectic silicon spheroidization. Increased grain boundary presence in smaller α-Al grains, along with uniform eutectic silicon dispersion, hindered dislocation movement, contributing to higher hardness.

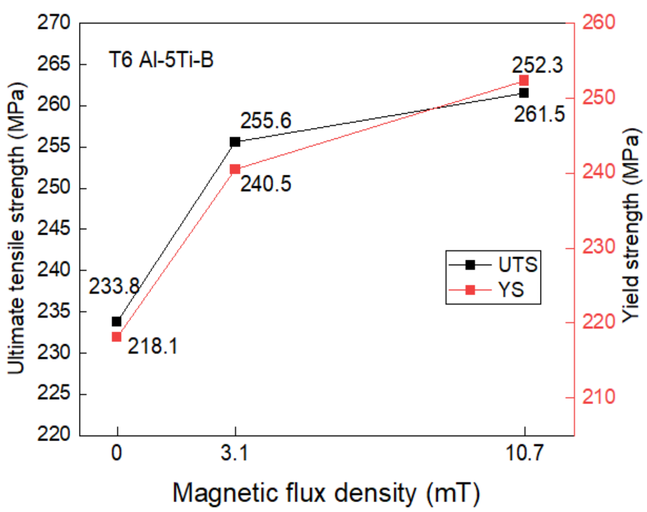

Figure 3. The correlation between ultimate tensile strength and yield strength after T6 Al-5Ti-B with the magnetic field.

4. Conclusions

This study introduces the utilization of Helmholtz coils to apply an external magnetic field during the investment casting of A356 alloys. The investigation comprehensively examines the effect of magnetic fields, grain refiners, and T6 heat treatment on the microstructural and mechanical attributes of A356 alloys. The key findings are outlined below.

1. The presence and amplification of a magnetic field during the investment-casting process induce noteworthy alterations in the microstructures of A356 alloys. These modifications encompass the refinement of α-Al (alpha-aluminum) grains.
2. The addition of a small quantity of Al-5Ti-B to A356 alloys also triggers microstructural modifications, leading to improved mechanical properties in comparison to alloys without a grain refiner.
3. Following the microstructural changes brought about by the magnetic field, the mechanical attributes of T6 heat-treated A356 ingots with Al-5Ti-B exhibit enhancements across various parameters, including ultimate tensile strength and yield strength.

Acknowledgments

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