Evaluation of Al-12%Si Alloy with 30 wt% Scrap for Al Piston Alloys

Minji Kim [1, 2], Dong-Gyu Lee[1], Jeong-Keun Lee[3], Soong-Keun Hyun[2] and *Kyung-Taek Kim[1]

1. Institute of Intelligent Manufacturing & Materials Technology, Korea Institute of Industrial Technology, Incheon 21999, Republic of Korea；2. Manufacturing Innovation School, Inha University, Incheon 22212, Republic of Korea

3. DONG YANG PISTON Co., Ltd., Ansan 15420, Republic of Korea

*Corresponding address: e-mail: kkt@kitech.re.kr

Abstract: In this study, the mechanical properties of recycled aluminium alloys for automotive pistons were investigated by comparing with the Primary Alloy (PA, Al-12%Si) and Scrap-added Alloy (SA) with the same chemical composition. The tensile strength of PA and SA was measured to be 285.1 MPa and 281.4 MPa, respectively, indicating that the addition of scrap caused only a negligible decrease in tensile strength. Fatigue tests were conducted using ultrasonic fatigue testing equipment under room temperature (22 ℃) and high-temperature (200 ℃) conditions. Both alloys met the high-cycle fatigue (HCF) criteria, with fatigue lives of 1.51 × 108 cycles for PA and 1.03 × 108 cycles for SA. Notably, SA had superior fatigue property under high-temperature conditions compared to PA. These results confirmed the potential of using recycled materials in high-temperature cyclic loading environments. These results demonstrated that cast aluminum alloys with scrap can be applied to actual industrial applications and may serve as a basis for future sustainable material technologies.

Keywords: Al alloy; Al scrap; Gas bubbling filtration; Tensile test; High-cycle fatigue test

1 Introduction

Aluminum alloys are widely used across various industries due to their light-weight and high specific strength, and their applications continue to expand. In particular, the automotive industry is actively researching the recycling of aluminum materials to achieve carbon neutrality goals [1-3].

Recycling aluminum scrap is a key strategy for reducing energy consumption and carbon reduction. However, residual oxides, inclusions, and porosity in the molten metal during the recycling process can adversely affect the microstructure and degrade mechanical properties [4]. Therefore, verifying the tensile and fatigue properties of recycled cast alloys is essential before they can be applied to actual components.

In this study, we evaluated the tensile and fatigue properties of a conventional Al-12%Si alloy for automotive pistons (referred to as the Primary Alloy, PA) and a scrap-added Alloy (SA), in which 30 wt% of aluminum scrap with the same chemical composition.

2 Experimental procedures

Both PA and SA alloys had the same Al-12%Si chemical composition, with SA containing an additional 30 wt% of scrap. The alloys were melted at 720 ℃ and subjected to a Gas Bubbling Filtration (GBF) process by injecting Ar gas, followed by casting at 700 ℃. After casting, a T5 heat treatment was applied. The test specimens were machined from the head section of cast pistons.

A tensile test was conducted at room temperature (22 ℃) according to the ASTM E8 standard using a universal testing machine. 10 specimens were tested for each alloy. Fatigue tests were performed in the high-cycle fatigue regime under both room temperature and high-temperature (200 ℃) conditions using an ultrasonic fatigue testing system. The fatigue tests at room temperature were conducted at 20 kHz with a stress amplitude of 120 MPa and a stress ratio of R= −1. The high-temperature fatigue tests were conducted at 80 Hz. 15 specimens were tested per condition.

3 Results and discussion

3.1 Tensile properties of PA and SA

The tensile strengths of PA and SA were measured to be 285.1 MPa and 281.4 MPa, respectively, as shown in Figure 1. Even with the addition of 30 wt% scrap alloy, the decrease in tensile strength was approximately 1.3%, which did not result in a significant difference. This result suggests that the optimization of the GBF process effectively minimized casting defects [3]. The fact that the scrap-added alloy exhibited tensile properties comparable to those of PA demonstrate its meaningful potential for industrial applications.

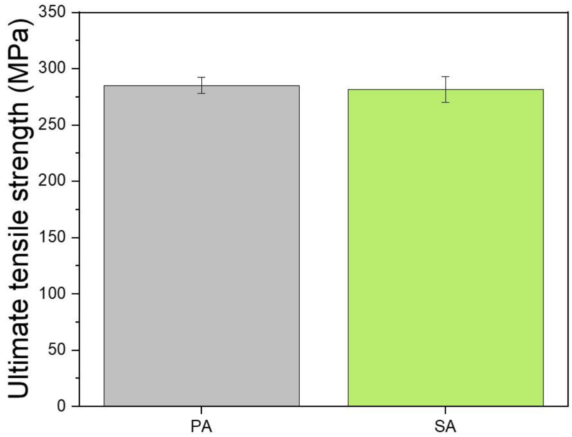

Fig. 1: Tensile strength of Primary Alloy and Scrap-added Alloy.

3.2 High-cycle fatigue properties at room temperature

As shown in Figure 2, the average fatigue life of the PA was 1.51×10^8 cycles, whereas that of SA was 1.03×10^8 cycles. Although the PA exhibited a slightly longer fatigue life than the SA, both alloys sufficiently satisfied the high-cycle fatigue criterion of 10^7 cycles. Notably, despite the addition of 30 wt% scrap, the SA still achieved a fatigue life exceeding 1.0×10^8 cycles, indicating that the influence of scrap addition on fatigue properties was limited. In general, the HCF properties of cast aluminum alloys at room temperature are strongly influenced by internal defects such as porosity, which can cause local stress concentrations and serve as initiation sites for fatigue cracks [5]. Therefore, implementing melt-cleaning processes to minimize such internal defects can positively affect the enhancement of fatigue resistance [6]. The result that the SA alloy in this study met the HCF requirement supports the findings of previous research and suggests that adequate fatigue life can be achieved even when using scrap containing alloys.

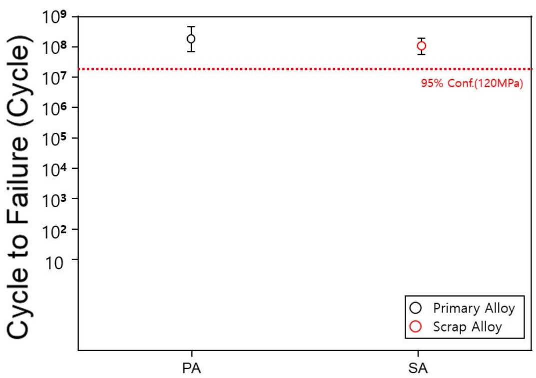

Fig. 2: High-cycle fatigue behavior of Primary Alloy and Scrap-added Alloy at room temperature

3.3 High-temperature fatigue properties

Figure 3 presents the fatigue S-N curves of the PA and SA at the high-temperature conditions (200 °C), measured fatigue life 5.66×10^6 and 7.65×10^6 cycles, respectively. In contrast to the results at room temperature, the SA demonstrated superior fatigue properties at the high-temperature cyclic loading. The fact that SA, despite containing 30 wt% scrap, maintained high fatigue resistance under such conditions indicates that the use of recycled materials does not inherently compromise mechanical properties. Rather, it suggests that sufficient durability can be ensured through appropriate process control. These results are consistent with the findings of G.Nicoletto et al., who reported that the high-temperature fatigue properties of Al-Si cast alloys can be improved by optimizing casting and heat treatment conditions [7].

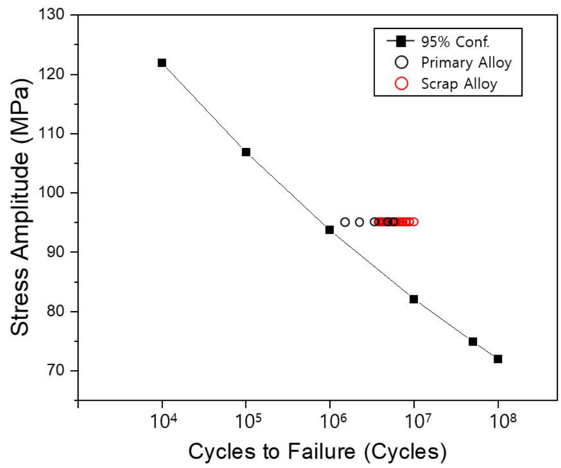

Fig. 3: High-temperature fatigue S-N curves of Primary Alloy and Scrap-added Alloy.

4 Conclusions

This study evaluated the tensile and fatigue properties of a recycled aluminum alloy (SA), which contained 30 wt% scrap and a conventional Al-12%Si alloy (PA). Both alloys exhibited comparable tensile strengths. While PA showed slightly superior fatigue life at room temperature, SA demonstrated better fatigue properties at the high-temperature conditions. These results indicate that, with appropriate GBF processing and heat treatment, cast alloys incorporating aluminum scrap can achieve sufficient mechanical properties. The findings support the industrial applicability of aluminum scrap recycling for automotive casting components. Future work will focus on evaluating mechanical properties and durability with varying scrap content.

Acknowledgments

This research was funded by Korea Institute of Industrial

Technology (project no. UR250059)

Conflicts of interest:

Authors Minji Kim, Dong-Gyu Lee, and Kyung-Taek Kim were employed by Korea Institute of Industrial Technology. Author Jeong-Keun Lee was employed by the company DONGYANGPISTONCo., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

[1] Krall P, Weißensteiner I, Pogatscher S. Recycling aluminum alloys for the automotive industry: Breaking the source-sink paradigm. Resour. Conserv. Recycl., 2024, 202: 107370, https://doi.org/10.1016/j.resconrec.2023.107370

[2] Kim M, Kim K I, Lee J K, Kim K T. Effect of GBF process conditions on the microstructural characteristic, melt quality and mechanical properties of Al-Si alloys with scrap addition. Mater., 2025, 18: 943, https://doi.org/10.3390/ma1805943

[3] Jang H S, Kang H J, Lee G H, Yoon P H, Park J Y, Choi Y S, Shin S. Effect of gas bubbling filtration treatment conditions on melt quality of AlSiMgCu alloy. Metals, 2021, 11: 841, https://doi.org/10.3390/met11050841

[4] Widyantoro D D, Fatriansyah J F, Firmansyah M R, Prasetyo Y. Removal of oxide inclusions in aluminium scrap casting process with sodium based fluxes. MATEC Web Conf., 2019, 269: 07002, https://doi.org/10.1051/matecconf/201926907002

[5] Osmond P, Le V D, Morel F, Bellett D, Saintier N. Effect of porosity on the fatigue strength of cast aluminium alloys: From the specimen to the structure. Procedia Eng., 2018, 213: 630–643, https://doi.org/10.1016/j.proeng.2018.02.059

[6] Murakami Y. Effects of small defects and nonmetallic inclusions on fatigue strength. 1st ed. Cambridge: Woodhead Publishing, 2002.

[7] Nicoletto G, Riva E, Di Filippo A. High temperature fatigue behavior of eutectic Al-Si alloys used for piston production. Procedia Eng., 2014, 74: 157-160, https://doi.org/10.1016/j.proeng.2014.06