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Technical Report

The effects of Mg amount on the microstructure and mechanical properties of Al–Si–Mg alloys

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ABSTRACT

In this study, the effects of magnesium (Mg) addition to A356 aluminum alloy at different amounts on the microstructure and mechanical properties of this alloy were examined. For the experimental studies, three different alloys (0.43, 0.67 and 0.86 wt%) having various amounts of Mg were prepared through casting process in the form of plates. The plates were homogenized and cooled in the furnace. All the samples were treated with aging process (T6) and then tensile samples were prepared from the homogenized samples. The samples treated with T6 process were characterized by optical microscopy, laser confocal microscopy, Scanning Electron Microscope (SEM), Energy Dispersive Spectrometer (EDS) and X-Ray Diffraction (XRD) examinations as well as hardness measurements and tensile tests. The phases which were formed in the microstructures for different amounts of Mg were examined. It was observed that iron-rich intermetallic compounds were also formed in addition to the phases resulting from the aging process. Fe-rich intermetallic compounds, observed from the fracture surfaces, were found to reduce the tensile strength the alloy. The results also indicate that the tensile strength and hardness of the alloy increase with increasing Mg amount.

1. Introduction

Al–Si alloys are used in many engineering applications due to their properties such as; low density, high corrosion resistance and good castability. However, the biggest disadvantage of these alloys is the lack of heat treatment capability. Therefore Mg is added into the alloy to improve the heat treatment capability of this alloy and provides a good engineering alloy. In many studies it was reported that formation of secondary phase (Mg_2Si precipitate) in the structure with the aging heat treatment increases significantly the mechanical properties of the alloy [1–4]. Secondary phase precipitates (Mg_2Si) which settle among the aluminum dendrites with the aging heat treatment result in precipitation hardening [2,5–7]. Thus, the Al–Si–Mg alloys with increased mechanical properties are used in many fields particularly in automotive and aviation industries. Thirugnanam et al. examined effect of Mg on the fracture characteristic of cast Al–7Si–Mg alloys [5]. Shabestari and Moemeni studied the effect of copper and solidification conditions on the microstructure and mechanical properties of Al–Si–Mg alloys [8] Yao and Taylor examined characterization of intermetallic particles formed during solution treatment of an Al–7Si–0.4 Mg–0.12Fe alloy [9]. Basavakumar et al. investigated influence of grain refinement and modification on microstructure and mechanical properties of Al–7Si and Al–7Si–2.5Cu cast alloys [10]. Zhu et al. studied effects of T6 heat treatment on the microstructure, tensile properties, and fracture behavior of the modified A356 alloys [11]. Some previous studies reported that the mechanical properties of cast Al–Si–Mg alloys depend on many parameters such as chemical composition, solidification conditions, shape and dimension of silicon particles in the structure, whether the modification and grain refining process are carried out or not and dendrite arm space [8–14]. Increasing amount of Mg in these alloys reduces eutectic temperature by increasing the effect of precipitation hardening. Thus, Si present in the eutectic becomes more heterogenous. In consequence of reaction of Mg with Fe which is slightly found in the alloy, iron rich (Fe-rich) intermetallic compounds are formed. These Fe-rich intermetallic compounds are defined as β (Al_5FeSi) [15,16] and π ($Al_9FeMg_3Si_5$ or $Al_8FeMg_3Si_6$) [17] phases. These compounds which are formed in the microstructure depending on the Mg amount of the alloy can be found in various shapes and volumes. In addition to β intermetallic compound, π intermetallic compound is also formed in the microstructure depending on Mg amount existing in the alloy. These Fe-rich intermetallic compounds reduce the tensile strength and ductility of materials [18,19]. In this study, three different alloys were produced containing various amounts of Mg (0.43%, 0.67% and 0.86%) and the effect amount of Mg on the microstructure and mechanical properties were examined.

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Table 1
Chemical analysis of the produced alloys.

Alloy code	Si	Mg	Fe	Cu	Mn	Zn	Ti	Na	Al
1	7.07	0.43	0.32	0.003	0.032	0.033	0.113	0.0002	Balance
2	6.89	0.67	0.306	0.003	0.0342	0.009	0.111	0.0005	Balance
3	7.147	0.86	0.355	0.007	0.0328	0.038	0.093	0.0001	Balance

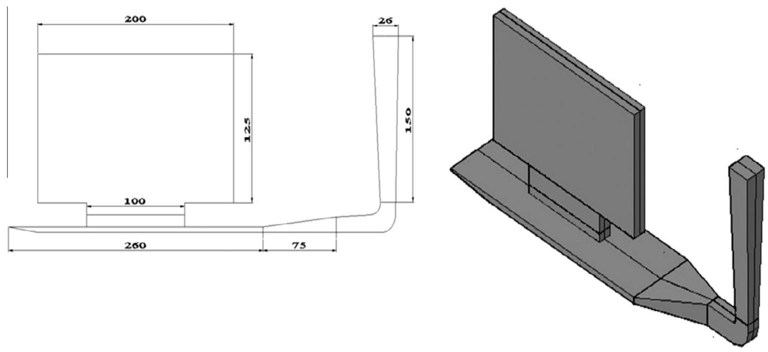

Fig. 1. Schematic view of the cast plates.

2. Experimental procedure

In experimental studies, AFS 60-65 coded Quartz, alkali phenolic resin and hardener were used for preparation of molds. Melting processes were carried out in an electric resistance furnace. Following the melting process, degasing process was carry out by injecting argon gas into liquid metal for 5 min at 1 bar pressure and 750 °C in the furnace. Mg (99.5% purity) was added into (alloy code 2 and 3) the molten A356 aluminum alloy (alloy code 1) at different amounts to obtain the chemical compositions given in Table 1.

After the melting and degasing processes were completed, the liquid material was cast into the mold at 730 °C. A bottom pouring crucible was used in order to prevent the entrance of slags into the mold. The dimensions of the plates produced at the end of casting process are shown schematically in Fig. 1.

The cast plates with different Mg amounts were cooled in the furnace after homogenized for 6 h at 540 °C in order to decrease internal stress and segregations. Following the homogenization heat treatment process, tensile samples were prepared from the plates according to ASTM: B557M-10 standards. Aging process was applied to the prepared tensile samples. After all the samples were solution-treated for 8 h at 540 °C, they were quenched into water. After a natural aging process was applied to the saturated solid solution for 24 h at room temperature, an artificial aging process was also carried out for 10 h at 170 °C. The aged samples were subjected to standard metallographic processes for characterization works and were etched with 95 ml H_2O, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF (keller) solution for 15 s. The etched samples were characterized by optical microscope (Olympus GX51), laser confocal microscope (OlympusLext OLS3000), image analysis system (MSQ Plus 6.5), scanned electron microscope (SEM + EDS/Tescan-FEI NovananoSEM 600), X-ray diffraction (XRD/Inel Equinox 100), density measurements (Archments), hardness measurements (AffriSystem VRSD-251/HV2) and tensile tests (Shimadzu AG-IS/50 kN). Hardness values were calculated by taking the average of

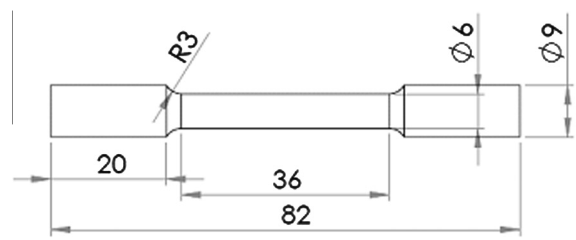

Fig. 2. Sizes of tensile sample.

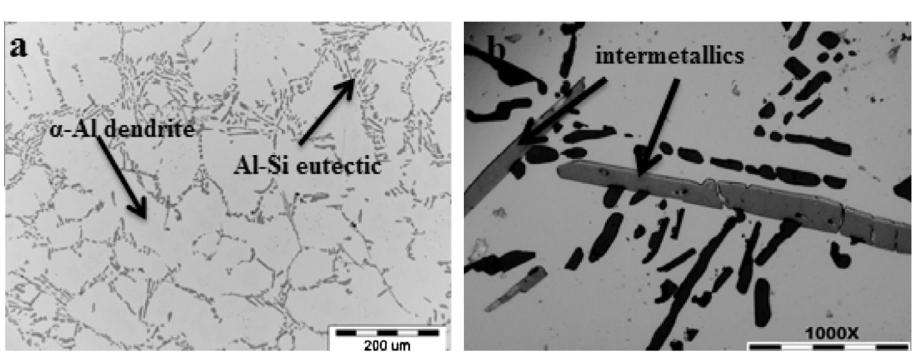

Fig. 3. Optical microscope images of the aged Al–Si–Mg (A356) (a) alloy (Alloy 3) (b).