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Effect of Manganese and Iron Content on Morphology of Iron Intermetallic Phases in AlSi7Mg0.3 Alloy

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Abstract

Iron is presented as an impurity in Al-Si alloys and occurs in the form of the β-Al_5FeSi phase formations. The presence of iron and other elements in the alloy causes the formation of large intermetallic phases. Due to the high brittleness of this phase, it reduces the mechanical properties and increases the porosity. Manganese is used to inhibit the formation of this detrimental phase. It changes the morphology of the phase to polyhedral crystals, skeletal formations, or Chinese script. The present article deals with the influence of various amounts of manganese (0.1; 0.2; 0.4; 0.6 wt. %) on the formation of iron-based intermetallic phases in the AlSi7Mg0.3 alloy with different levels of iron content (0.4; 0.8, 1.2 wt. %). The increase of iron content in each alloy caused the creation of more intermetallic compounds and this effect has been more significant with higher concentrations of manganese. In alloys where the amount of 1.2 wt. % iron is present, the shape of eutectic silicon grain changes from angular to short needle type.

Keywords: AlSi7Mg0.3, needle Al_5FeSi phase, Manganese, Morphology

1. Introduction

The amount of iron and manganese plays an important role in establishing the mechanical properties of Al-Si alloys. To assess the influence of iron and manganese during the crystallization of melt, it is necessary to determine how the individual intermetallic phases are formed. The crystallization type of Al_5FeSi phase is often associated with abnormal eutectic crystallization, which can be described by the reaction:

$$Liq + \rightarrow \alpha_{Al} + Al_5FeSi \quad (1)$$

Liq - liquid
α_{Al} – aluminium matrix

Iron is a major impurity in aluminium alloys and its content depends mainly on the purity and quality of the primary materials. The β-Al_5FeSi phase is the most occurring compound at higher iron contents. This phase significantly affects the mechanical properties, reduces tensile strength, hardness and fracture toughness. The presence of β-Al_5FeSi long plate formations also supports the initiation of fatigue cracks. At the same time, this phase is formed prior to the curing of the eutectic Al-Si and results in the occurrence of porosity in the castings. Iron intermetallic based phases formed during solidification may occur in different morphologies: β-Al_5FeSi-needles, α-$Al_{15}(FeMn)_3Si_2$ - Chinese script, polyhedral crystals. The amount, size and shape of these iron phases depends to a large extent on the cooling rate, the chemical composition and the iron content of the melt [1-3].

Manganese is an effective element in modification of needle intermetallic particles. After the addition of manganese the Al(FeMn)Si phase forms (preferably) with a cubic crystallographic lattice. Its composition ranges from $Al_{15}(FeMn)_3Si_2$ to $Al_{16}(FeMn)$

$_4Si_3$. Reducing the amount of β-Al_5FeSi phase, due to the addition of manganese, increases the corrosion resistance of the alloys based on Al-Si-Mg, reduces the porosity and increases the fatigue resistance of castings. To understand the modifying effect of Mn on the iron phase morphology, the following reaction is important:

$$Liq + Al_5FeSi \rightarrow \alpha_{Al} + Si + Al_{15}(FeMn)_3Si_2 \qquad (2)$$

This reaction creates the β-Al_5FeSi plates which cause the brittleness of high silicon alloys transformed into the $Al_{15}(FeMn)_3Si_2$ phase. The content of manganese in the elimination process of iron must be sufficient to prevent Al_5FeSi formation even in later solidification phases [4-6]. The recommended ratio of manganese addition to eliminate the negative effect of iron is according to most authors, 0.5 Mn/Fe, or if the content of iron exceeds 0.45 wt. %, the addition must be not less than half the Fe content [7]. However the estimation of accurate ratio of Mn/Fe according to the previous researches is not exactly known. The increase of Mn/Fe ratio does not necessarily promote β-Al_5FeSi phase precipitation to the α-phase. There is also a risk of sludge phase creation if the alloy contains required amount of iron, manganese and chromium, also according to the sludge factor:

$$SF = [\% Fe] + 2. [\% Mn] + 3. [\% Cr] \qquad (3)$$

These phases do not form during solidification but are located in the melted alloy at relatively low temperature or after rapid cooling of the melt. Sludge phases negatively affect the wear lifetime of casting machines and moulds [8].

2. Experiments methodology

The influence of manganese on eliminating the negative effect of iron was investigated in AlSi7Mg0.3 alloy. For this purpose secondary alloys were casted, where the content of iron was elevated as follows - 0.4; 0.8; 1.2 wt. %. These samples, with the weight of approximately 300 grams, were used for the preparation of alloys that contained an elevated amount of manganese. Manganese was added in amount of 0.1; 0.2; 0.4; 0.6 wt. %. The chemical composition of AlSi7Mg0.3 alloys with different amount of iron and elevated amount of manganese are shown in tab. 1-3.

Table 1.
Chemical composition of AlSi7Mg0.3 alloy with 0.4 wt. Fe and different amount of Mn

Alloy	Si wt %	Fe wt %	Mn wt %	Mg wt %	Cr wt %	Mn/Fe
A1	6.889	0.339	0.149	0.348	0.002	0.44
A2	6.892	0.343	0.263	0.348	0.002	0.77
A3	6.673	0.347	0.408	0.308	0.002	1.18
A4	6.583	0.345	0.677	0.352	0.003	1.96

Table 2.
Chemical composition of AlSi7Mg0.3 alloy with 0.8 wt. Fe and different amount of Mn

Alloy	Si wt %	Fe wt %	Mn wt %	Mg wt %	Cr wt %	Mn/Fe
B1	6.732	0.779	0.183	0.354	0.002	0.23
B2	6.245	0.778	0.231	0.332	0.002	0.30
B3	6.353	0.731	0.334	0.300	0.002	0.46
B4	6.111	0.781	0.656	0.296	0.003	0.84

Table 3.
Chemical composition of AlSi7Mg0.3 alloy with 1.2 wt. Fe and different amount of Mn

Alloy	Si wt %	Fe wt %	Mn wt %	Mg wt %	Cr wt %	Mn/Fe
C1	6.344	1.138	0.110	0.302	0..002	0.10
C2	6.205	1.198	0.330	0.334	0,002	0.28
C3	6.011	1.110	0.347	0.290	0.002	0.31
C4	5.929	1.129	0.538	0.283	0.002	0.48

The effects of manganese on the type and morphology of the excluded iron based phases was observed. The higher iron content was achieved by adding AlFe10 master alloy. Manganese was added in the form of AlMn20 master alloy. Iron and manganese were added to the melt with a temperature of 780 °C. The melting of each alloy was done in an electric resistance furnace containing a graphite crucible with protective coating. The samples were poured into a metal mould which was preheated to a temperature of 200 ± 5 ° C. All alloys were casted at a temperature of 760 ± 5 ° C. During the experiments the melted alloy was not further purified, modified or grain refined. Standard metallographic preparation (cutting, grinding, and polishing) was applied to prepare samples before etching. Samples were etched with 20 ml of H_2SO4 + 100 ml H_2O solution for light microscopy and 0.5 wt. % HF solution for EDX a SEM analysis.

3. Results

The important aspect to be taken into account when recycling alloys, and especially adding manganese to the alloy is the iron, manganese and chromium concentration. The increased content of these elements in the alloy has a higher tendency to form sludge units. The segregation factor, which gives the number of these formations, was calculated for each alloy according to (3). Figure 1 and 2 shows the dependence of the chemical composition in the alloy on the segregation (sludge) factor.

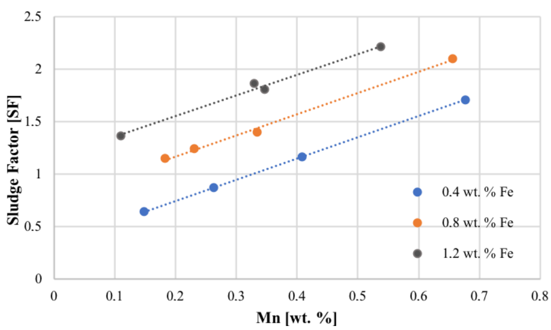


Fig. 1. Influence of manganese for each level of iron in AlSi7Mg0.3 alloy

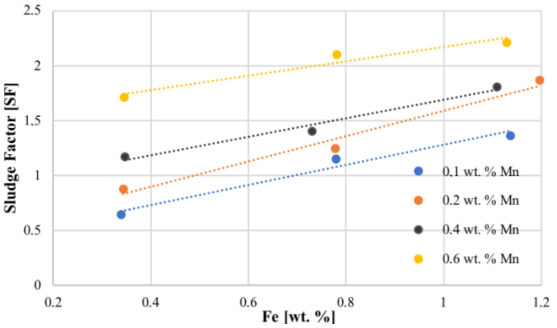
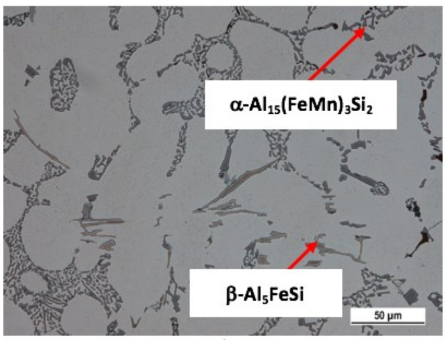


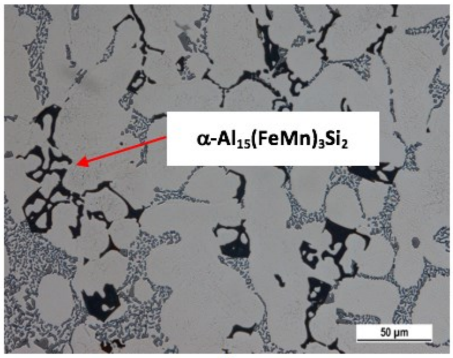
Fig. 2. Influence of iron for each level of manganese in AlSi7Mg0.3 alloy

As can be seen in Figure 1 with an increasing amount of manganese we can expect the creation of sludge formations in the structure of the alloy. The susceptibility of forming these compounds also increases with the increasing content of iron. Figure 2 shows the dependence of iron content on the sludge factor. There can be expected the same process like in the previous case, where the formation of these particles increase not only with the increasing iron content but also with the increasing content of manganese.

The metallographic study was focused on the description of individual structural compounds, depending on the amount of manganese concentration and the different levels of iron. The microstructure of sample A1 with 0.4 wt. % Fe, 0.1 wt. % Mn is formed of small needles of β-Al_5FeSi phase together with the small particles of the $Al_{15}(FeMn)_3Si_2$ phase evenly distributed near the eutectic silicon. The higher Mn content in the alloy with 0.2 wt. % Fe caused β-Al_5FeSi fragmentation, which occurs in aluminium matrix. Increasing the Mn/Fe ratio caused the reduction of the β-Al_5FeSi phase length. The α-$Al_{15}(FeMn)_3Si_2$ is evenly distributed at the borders of dendrites (Figure 3a). A larger amount of skeleton formations α-$Al_{15}(FeMn)_3Si_2$ phase in Mn 0.4 wt. % and 0.6 wt. % are observed. The β-Al_5FeSi phase occurs in very small dimensions (Figure 3b)



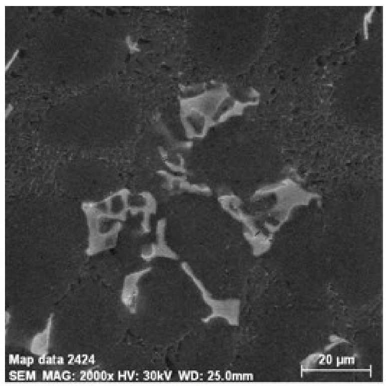
a)



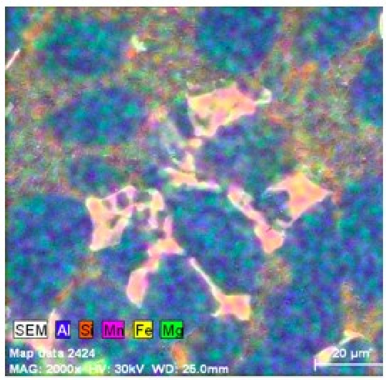
b)

Fig. 3. Microstructure of AlSi7Mg0.3 alloy: a) A2, b) A3

At the iron content of about 0.8 wt. % the skeletal particles of α-$Al_{15}(FeMn)_3Si_2$ phase began to occur at a level higher than Mn>0.2. Larger number of skeleton formations in 0.6 wt. % Mn were observed. At a manganese content 0.3 wt. % the intermetallic particles of the β-Al5FeSi phase are not present, but the structure is predominantly composed of small α-$Al_{15}(FeMn)_3Si_2$. Mapping of this particle is shown in Figure 4, where after increasing the Mn content to 0.6 wt.% the phase got finer and gained a Chinese script shape.



a) REM



b) mapping

Fig. 4. Mapping of $Al_{15}(FeMn)_3Si_2$ phase in the AlSi7Mg0,3 alloy with 0.8 wt. % Fe after adding 0.6 wt. Mn (sample B4)

In the microstructures with 1.2 wt. % Fe almost all additions of Mn change the morphology of eutectic silicon. The similar effect can be observed, when pre-modifying the structure, where the higher content of modifier acts negatively to the shape of silicon. Next the observed alloys contain elongated thin grains which, by their shape, reminding angular grains locally short needles (Fig.5). The intermetallic phases are excluded in a shape of small platelets at Mn 0.1 wt. % and with the increasing Mn content, beside the β-Al_5FeSi phase, skeleton formations and Chinese script are presented.
Table 4 shows the measured average lengths and the predominantly occurring morphology of the excluded intermetallic phases in the investigated alloys. Since the iron content in each alloy increases, it creates more intermetallic compounds.

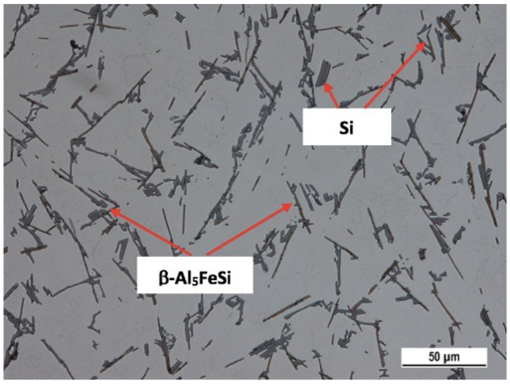


Fig. 5. Morphology of eutectic silicon in AlSi7Mg0.3 alloy with 1.2 wt. % Fe and 0.1 wt. % Mn (sample C1)

The effect of iron is more significant in alloys, which have a higher concentration of manganese. As can be seen in Table 4, the size of intermetallic phases increases with the increasing content of iron and manganese. The alloys with 0.4 wt. % Fe and 0.1; 0.3 wt. % Mn contain the needle-like shape or plate phases. The change of morphology occurs at Mn/Fe >1,18 ratio. At the higher content of iron about 0.8 wt. % skeletal formations or Chinese script began to occur at lower Mn/Fe ratio in comparison with the alloys with 0.4 wt. % Fe. The alloys with the highest content of iron and Mn of 0.4 wt. % and 0.6 wt. % have a predominantly α-$Al_{15}(FeMn)_3Si_2$ phase at a relatively low Mn / Fe ratio compared to an alloy with lower Fe content.

Table 4.
Average length and morphology of intermetallic phases in investigated alloys

Alloy	Average Lengh [μm]	Phase	Alloy	Average Lengh [μm]	Phase	Alloy	Average Lengh [μm]	Phase
A1	19.956	Needles or platelest (ß-Al_5FeSi)	B1	40.747	Needles (ß-Al_5FeSi)	C1	31.663	Needles (ß-Al_5FeSi)
A2	24.148	Needles or platelest (ß-Al_5FeSi)	B2	46.949	Needles (ß-Al_5FeSi)	C2	49.211	Needles (ß-Al_5FeSi) or Chinesse script (α-$Al_{15}(FeMn)_3Si_2$)
A3	24.202	Skeletal formations or platelets (α-$Al_{15}(FeMn)_3Si_2$)	B3	41.686	Skeletal formations (α-$Al_{15}(FeMn)_3Si_2$)	C3	40.949	Needles (ß-Al_5FeSi) or Chinesse script (α-$Al_{15}(FeMn)_3Si_2$)
A4	22.172	Platelets (ß-Al_5FeSi)	B4	44.803	Skeletal formations or Chinesse script (α-$Al_{15}(FeMn)_3Si_2$)	C4	75.726	Skeletal formations or Chinesse script (α-$Al_{15}(FeMn)_3Si_2$)

4. Conclusions

The creation and character of intermetallic phases in AlSi7Mg0.3 is conditional from content of iron to manganese (Mn/Fe). The effect of iron is related to the morphology of the formed phases amplifies along with higher levels of manganese. The size and number of intermetallic phases increases not only with increased content of iron, but manganese also. At a relative equal ratio of Mn/Fe it is not sure that phases with the same or similar morphology will occur. In the alloy with higher Fe content and equal Mn/Fe ratio, in comparison with the alloy that has lower Fe content, there is a bigger possibility that skeleton or Chinese script phases will form.

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