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Influence of Iron in AlSi10MgMn Alloy

M. Žihalová *, D. Bolibruchová
Department of Technological Engineering, Faculty of Mechanical Engineering, University of Žilina,
Univerzitná 8215/1, 010 26 Žilina, Slovakia
*Corresponding author. E-mail address: maria.zihalova@fstroj.uniza.sk

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Abstract

Presence of iron in Al-Si cast alloys is common problem mainly in secondary (recycled) aluminium alloys. Better understanding of iron influence in this kind of alloys can lead to reduction of final castings cost. Presented article deals with examination of detrimental iron effect in AlSi10MgMn cast alloy. Microstructural analysis and ultimate tensile strength testing were used to consider influence of iron to microstructure and mechanical properties of selected alloy.

Keywords: AlSi10MgMn alloy, Iron, Iron-based intermetallic phase

1. Introduction

Material selection at most industrial applications is strongly influenced by reduction of castings cost. Reduction of cost at the parts made of aluminium alloys can be obtained by using secondary (recycled) alloys. The main disadvantage of secondary alloys is higher amount of iron that is considered to have detrimental effect to properties of most aluminium alloys.

Iron is highly soluble in liquid aluminium and its alloys but it has very little solubility in the solid, and so it tends to combine with other elements to form intermetallic phase particles of various types. In the absence of Si, the dominant phases that form are Al_3Fe and Al_6Fe, but when Si is present, the dominant phases are Al_8Fe_2Si (known as alpha- or α-phase) and Al_5FeSi (known as beta- or β-phase) [1]. The equilibrium hexagonal form of Al_8Fe_2Si is only thermodynamically stable in high purity Al-Si-Fe alloys [2]. Phase Al_5FeSi is the most common iron phase in Al-Si alloys. The platelet-like morphology of the Al_5FeSi phase allows it to act as a stress raiser, consequently undermining the mechanical properties of the cast part. The threshold amount of iron, leading to the formation of primary Al_5FeSi that can undermine the properties is > 0.7 wt. %. When the phase forms in the eutectic structure (Fe < 0.7 wt. %) it is believed to even slightly enhance tensile properties. However it must be noted that the percentage of iron quoted to form primary or secondary Al_5FeSi depends on cooling rate and silicon content [3]. If Mg is present with Si, an alternative phase can form, π-$Al_8FeMg_3Si_6$ [4]. Phase π-$Al_8FeMg_3Si_6$ occurs in script-like morphology and it has a negative impact on ductile properties of Al-Si-Mg alloys [2]. For the more usual Al-Si-Mg cast alloys of modest Mn contents, the $Al_{15}(Fe,Mn)_3Si_2$ phase often has an appearance of Chinese script in section, being irregular or convoluted. If Fe and Mn are sufficiently high, primary $Al_{15}(Fe,Mn)_3Si_2$ phase may appear as hexagonal, star-like, or dendritic crystals. These primary crystals have been thought not to embrittle the alloy, but appreciably reduce the machinability. Since many commercial Al alloys contain Mn, either as an impurity or as an intentional addition it is to be expected that the cubic $Al_{15}(Fe,Mn)_3Si_2$ phase will be formed rather than the hexagonal Al_8Fe_2Si [2]. In normal compositions of cast hypoeutectic and eutectic Al-Si alloys containing Fe, Mn and Mg, the three main Fe-rich phases are $Al_{15}(Fe,Mn)_3Si_2$, Al_5FeSi and $Al_8FeMg_3Si_6$ [2].

Influence of iron to AlSi10MgMn cast alloy properties has not been well characterised yet. Standardised amount of iron in Al-Si alloy (> 0.7 wt. %), which is considered to have a negative influence to alloys properties, don´t have to decrease properties of AlSi10MgMn alloy. Due to elements like Mn and Mg present in

Table 1.
Chemical composition (wt. %) of AlSi10MgMn alloy

Si	Mg	Mn	Fe	Ti	Zn	Cu	Al	Mn/Fe
10.220	0.277	0.108	0.448	0.046	0.029	0.047	88.790	0.24

Table 2.
Chemical compositions of samples after addition of Fe

Sample No.	Iron addition (ppm)	Si (wt. %)	Mg (wt. %)	Mn (wt. %)	Fe (wt. %)	Ti (wt. %)	Zn (wt. %)	Cu (wt. %)	Al (wt. %)	Mn/Fe
1	15,000	10.080	0.312	0.115	0.537	0.045	0.036	0.060	88.776	0.21
2	20,000	10.090	0.309	0.115	0.600	0.044	0.036	0.059	88.710	0.19
3	30,000	10.020	0.321	0.114	0.705	0.044	0.036	0.059	88.660	0.16
4	40,000	9.890	0.306	0.112	0.837	0.044	0.036	0.056	88.662	0.13

alloy, there is a possibility of formation less deleterious phases script-like morphology instead of platelet-like phases. After better examination of iron influence it can be possible to make high quality castings even at higher amount of Fe.

2. Experimental methods and materials

Aluminium alloy AlSi10MgMn was used as the experimental material. The chemical composition of the alloy is given in Table 1.

Four melts were performed in order to get alloys with higher amount of Fe at the experiments. For each experiment, the alloy was melted in a graphite crucible in electric resistance furnace T15 type. Iron addition to the AlSi10MgMn alloy was 15,000, 20,000, 30,000 and 40,000 ppm, respectively. Required amount of iron was added in form of AlFe10 master alloy at alloying temperature 780 ± 5 °C. The melt was not further modified, grain refined or purified. After a complete dissolution and homogenisation of the alloy, the melt was stirred, skimmed and poured (pouring temperature 760 ± 5 °C) into permanent mould.

Chemical composition of alloy with different addition of Fe is given in Table 2. Iron content in alloys exceeded maximal allowed value for AlSi10MgMn alloy (0.5 wt. %) according to STN 42 4331 standard. Another important characteristic parameter of Al-Si alloys is Mn to Fe ratio. Manganese addition is the most often required in amount at least half of amount of iron (Mn/Fe = 0.5). Mn to Fe ratio has in every sample value lower than advised minimal value. Castings made of alloys were used for tensile and metallography specimens.

3. Results

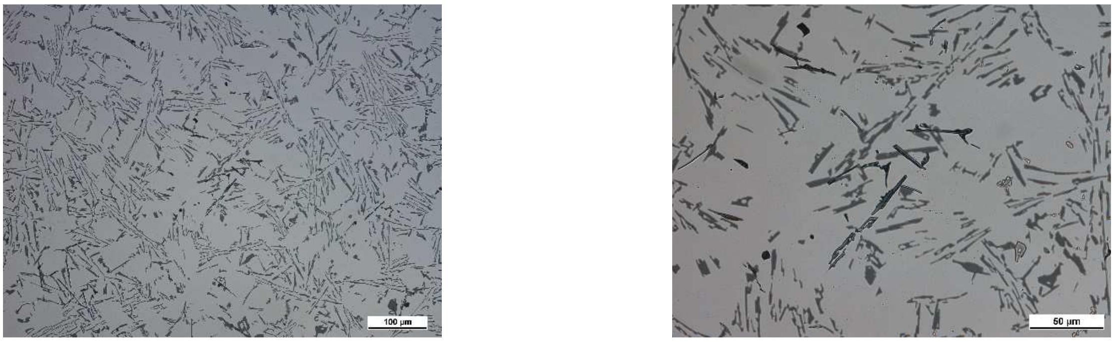
3.1. Microstructure

Experimental samples were prepared to microstructural evaluation by standard metallographic procedure. Figure 1 shows the typical microstructure of AlSi10MgMn alloy. Microstructure of the alloy contains iron based intermetallic particles mainly in form of “needles” of Al_5FeSi phase. After iron addition higher number of script-like particles can be seen in the microphotographs (Figure 2 and 3). Script-like particles present in microstructure can be iron intermetallic phases that contains Mn and/or Mg, probably mainly $Al_{15}(Fe,Mn)_3Si_2$ phase and in lower number phase $Al_8FeMg_3Si_6$.

When the iron level in alloy exceeded 0.7 wt. % (iron addition of 30,000 ppm), platelet particles Al_5FeSi started to grow in number and extent (Figure 4b). Microstructure of alloy with iron addition of 40,000 ppm also contains iron intermetallic particles mainly in form of “needles” (Figure 5).

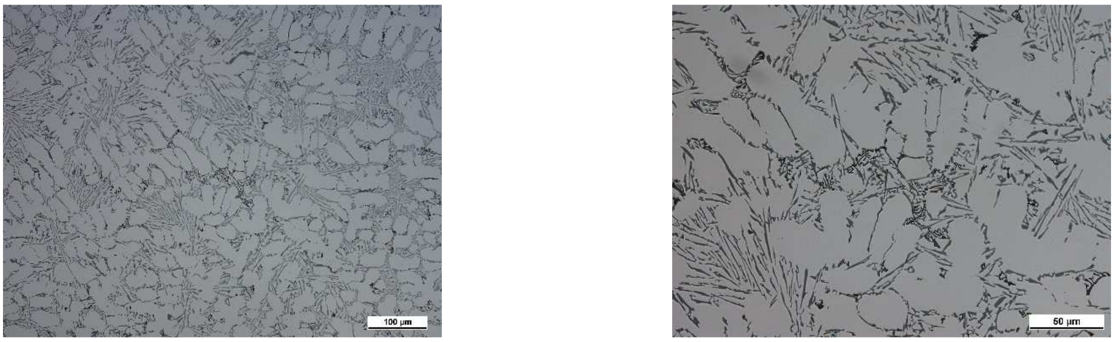
3.1. Tensile properties

The ultimate tensile strength (UTS) of AlSi10MgMn alloy with different iron addition is given in Table 3. UTS measures were performed on 10 mm diameter experimental samples. WDW 20 testing machine was used for UTS measuring. Ultimate tensile strength of samples with iron addition up to 30,000 ppm had values higher than minimal value defined by STN 42 4331 standard (min. 180 MPa for castings without heat treatment). Sample after iron addition 20,000 ppm reached value 215 MPa, which represent maximal value from all samples. After this value, UTS of samples decreased. Minimal value (172 MPa) was measured at sample with iron addition 40,000 ppm (0.837 wt. % of iron in alloy).



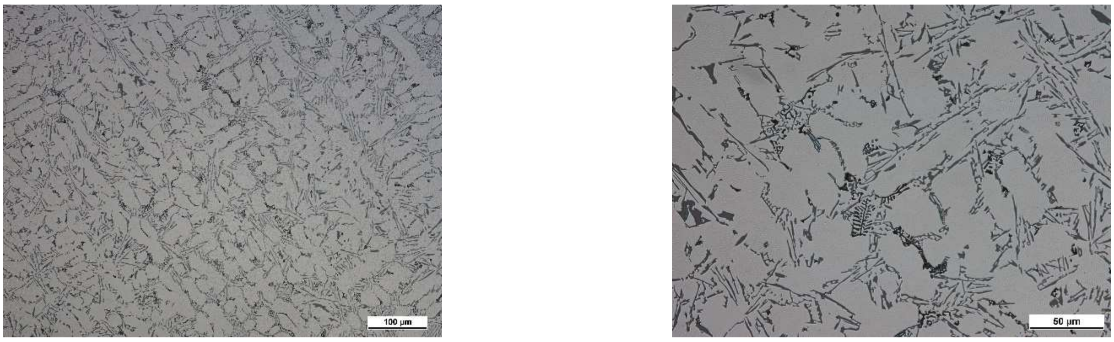
a) magnification 200x b) magnification 500x

Fig. 1. Microstructure of AlSi10MgMn alloy without iron addition, etch. 20 ml H_2SO_4 + 100 ml H_2O



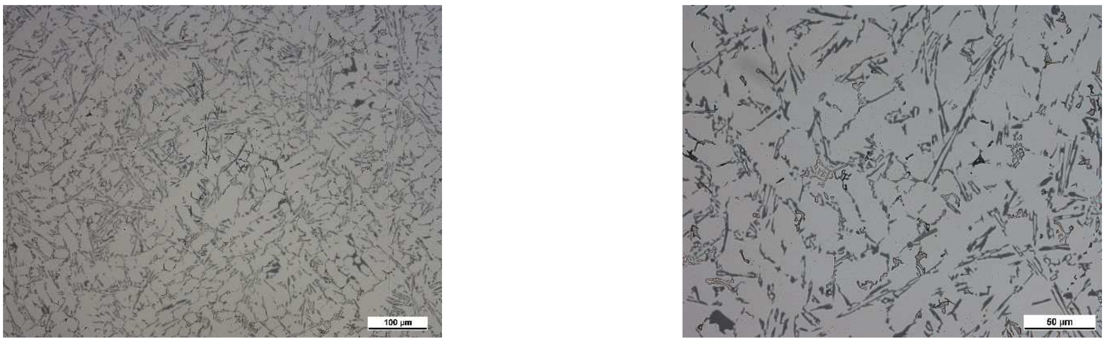
a) magnification 200x b) magnification 500x

Fig. 2. Microstructure of AlSi10MgMn alloy with 15,000 ppm of iron addition, etch. 20 ml H_2SO_4 + 100 ml H_2O



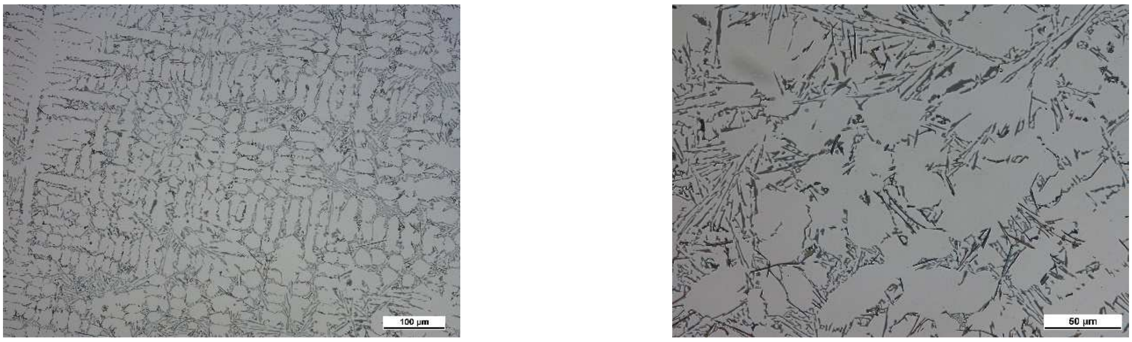
a) magnification 200x b) magnification 500x

Fig. 3. Microstructure of AlSi10MgMn alloy with 20,000 ppm of iron addition, etch. 20 ml H_2SO_4 + 100 ml H_2O



a) magnification 200x b) magnification 500x

Fig. 4. Microstructure of AlSi10MgMn alloy with 30,000 ppm of iron addition, etch. 20 ml H_2SO_4 + 100 ml H_2O



a) magnification 200x   b) magnification 500x

Fig. 5. Microstructure of AlSi10MgMn alloy with 40,000 ppm of iron addition, etch. 20 ml H_2SO_4 + 100 ml H_2O

Table 3.
Ultimate tensile strength of AlSi10MgMn alloy with different iron addition

Sample No.	Iron addition (ppm)	Ultimate tensile strength (MPa)
1	15,000	190
2	20,000	215
3	30,000	205
4	40,000	172

4. Conclusions

Iron addition in AlSi10MgMn alloy caused presence of higher number of script-like particles in the microstructure as in alloy without iron addition. When the iron addition exceeded 30,000 ppm, more platelet-like particles started to show but still less in number than in original alloy.

Measuring of ultimate tensile strength showed increasing of UTS to 20,000 ppm of iron addition. After iron level exceeded 0.7 wt. %, UTS started to decrease, but at the addition of 30,000 ppm of Fe it still had a value of 205 MPa. Iron addition in amount higher than this value caused decrease of ultimate tensile strength to 172 MPa at the addition of 40,000 ppm.

Iron addition up to 20,000 ppm do not negatively influenced microstructure and ultimate tensile strength of AlSi10MgMn cast alloy. Iron level higher than 0.8 wt. % (40,000 ppm iron addition) caused significant decrease of UTS and also higher number of platelet-like particles.

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