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Structural analysis of iron based intermetallic phases in secondary AlSi6Cu4 cast alloy

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Abstract
The use of secondary aluminum alloys is increasing because it contributes to the decrease of production costs. However, these alloys contain bigger amount of iron. Iron has a negative effect and therefore its elimination is necessary in order to add some elements, which are also called correctors of iron. The most frequently used corrector is manganese. Another quite often used correctors are chromium, potassium, magnesium, vanadium. In the following work, vanadium is used as a corrector of iron phases. The application of vanadium in aluminum alloys has a positive impact on their mechanical properties, increases the tensile strength, ductility and hardness. As experimental material AlSi6Cu4 alloy was used. It was alloyed by master alloy AlFe10. After adding to the master alloy the iron content, the critical value in the alloy exceeded. Vanadium was added to AlSi6Cu4 alloy in different quantities. The image analysis (software NIS-Elements) was used for quantifying the amount of iron based intermetallic phases and determination of average values.

1. Introduction

Nowadays, life cycle assessment is increasingly developing in metallurgy. It is related to a new recycling technology, i.e. metal extraction from secondary materials, and to the fact, that metal production belongs mostly to large environmental pollution sources (PETRÍK J. 2011). The problem with utilization of Al-scrap as a material for cast Al-Si alloys is in that the scrap is, unfortunately, contaminated with iron as a rule. Fragments of iron are intensively dissolved in melt Al-Si. Iron has a negative influence on strength and the plastic properties, and corrosion resistant (TILLOVÁ E. 2015, KUCHARIKOVÁ L. 2016).

Primary Al-alloy typically contains between 0.03 - 0.15 wt.% of Fe. Sometimes Fe is purposely added to alloys in the amount 0.3 - 0.5 wt.% of Fe which prevents sticking of casting to the metal mould (for casting under pressure), increases the strength and, in larger quantities, also heat resistance. In case of larger amount, such as 0.3 - 0.5 wt.% of Fe, it causes, first of all, formation of Fe-intermetallic phases (e.g. Al_5FeSi). The size and density of Fe-based intermetallic phases are increased with the increase of % of Fe, also the dimensions of the defects and porosity of casting. The larger content of Fe causes the decrease of ductility, too.

The Fe-rich phase (β-Al_5FeSi) is the most harmful one for the mechanical properties of Al-Si based cast alloys. This phase, like most other intermetallic particles, is brittle. Its morphology is plate-like, appearing as needles in the optical micrographs. These characteristics, brittleness and plate-like morphology, greatly affect the of decrease the strength and ductility of the cast alloys. It is, therefore, important to avoid or at least to control the formation of this phase (DARWISH A. 2010, BORKO K. 2016, JI S. 2013, TAYLOR J.A. 2012, TILLOVÁ E. 2009 and TILLOVÁ E. 2011).

Fe-levels above the critical level for the Si-content of the alloy should be avoided as these can cause a serious loss of ductility in the final cast product and decreased casting productivity through increased rejects due to shrinkage porosity, and particularly “leakers”. The critical Fe-content (in wt.%) for an alloy can be calculated using (RANA R.S. 2012, TAYLOR J.A. 2012) (1):

$$Fe_{crit.} \approx 0.075 \text{ x (wt.\% Si)} - 0.05 \qquad (1)$$

The negative effect of Fe can be partly eliminated by superheating of the melt, by increasing of cooling rate or by addition of Fe-correctors as Mn, Be, V, Mo, etc.

Mn is widely used as an alloying addition to neutralize the effect of Fe and modify the needle-like Al_5FeSi phase to less harmful morphologies (script-like, Chinese script) - $Al_{15}(FeMn)_3Si_2$ (ASHTARI P. 2003, TAYLOR J.A. 2012, RANA R.S. 2012). Mn not only decreases the detrimental Fe effect but also increases creep resistance and heat resistance. The recommended amount of Mn to remove the negative impact of Fe is more than half of the Fe content. The addition of Mn to melts with high Fe levels can also facilitate the formation of sludge, if the sludge factor (derived by % Fe + 2% Mn + 3% Cr) exceeds a particular value for a given alloy and melt holding temperature.

Be addition changes the morphology of Fe-rich compounds to Chinese scripts and polygons (RANA R.S. 2012).

V, Cr, Mo, W and Ni are infrequently recommended as Fe-modifier (BOLIBRUCHOVÁ D. 2013, 2014, PETRÍK J. 2011, HERNANDEZ-RODRIGUEZ A. 2014, ŽIHALOVÁ M. 2016). Cr can make formation negative so called "sludge" phases in alloy with high amount of iron that cannot be removed from final alloy. Application of vanadium in Al-Si alloys has positive effect for mechanical properties, increases the tensile strength, ductility and hardness. High amount of V has a lower tendency to the formation of „sludge" phases like Cr. The present study is part of a larger research project which was conducted to study of secondary Al-Si cast alloy. The article describes the evaluation of Fe-rich phases in secondary AlSi6Cu4 cast alloy modified by vanadium.

2. Experimental material

As an experimental material secondary AlSi6Cu4 cast alloy was used. The real chemical composition of used alloy obtained by spectral analysis is presented in Tab.1.

The base alloy was enriched by master alloy AlFe10 to obtain the higher Fe-amount. After adding AlFe10 the iron content in the alloy exceeded the critical value ~ 0.4 wt.%. In the next step vanadium was added in to the alloy in quantity 0.5; 1.0; 1.5 and 2.0 wt.%.

Table 1. Chemical composition of AlSi6Cu4 alloy in wt.%

Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**
6.43	0.34	3.43	0.232	0.229	0.03
Ti	**Zn**	**Pb**	**Ca**	**Cd**	**Al**
0.16	0.07	0.04	0.0014	0.0004	rest

Source: own study

Metallographic samples were sectioned from the tensile test bars (after testing), standard prepared for metallographic observations (wet ground on SiC papers, DP polished with 3 μm diamond pastes followed by Struers Op-S) and etched by H_2SO_4 for the highlight of iron based intermetallic phases (BORKO K. 2016, TILLOVÁ E. 2011). The microstructures were studied using an optical microscope (Neophot 32). The image analysis (software NIS-Elements) was used for quantifying the amount of Fe-phases and determination of average values. Samples were evaluated at 500x magnification and the results were set as the average value of at least 20 fields shown (BORKO K. 2016, ŠVECOVÁ I. 2017).

3. Results

Microstructure of experimental material after alloying by the master alloy AlFe10 is documented in Fig. 1. The microstructure consists of dendrites of α-phase, eutectic Si and intermetallic phases on base copper (Al_2Cu) and iron (Al_5FeSi, $Al_{15}(FeMn)_3Si_2$; polyedric crystals (AlFeMn) were observed locally, too. Length of Fe-needles was observed local more than 100 μm.

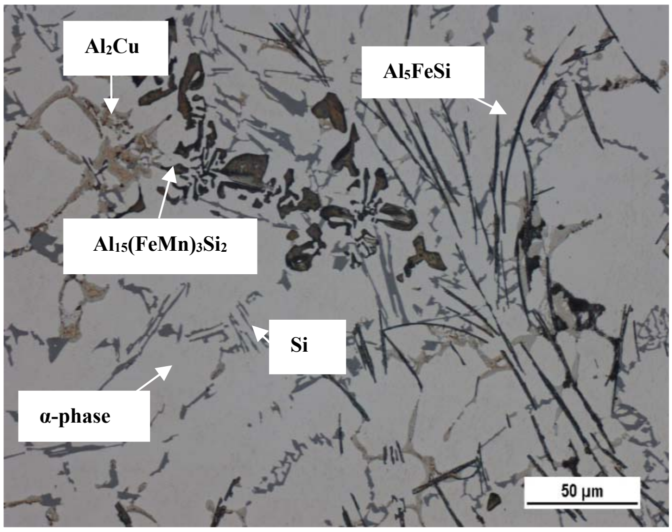


Fig. 1. Microstructure of AlSi6Cu4 alloy (alloyed by master alloy AlFe10) without vanadium, etch. H_2SO_4

Source: own study

The influence of various amounts of vanadium on the structure of AlSi6Cu4 alloy is documented in Fig. 2. In the alloy with a content of 0.5 wt.% V (Fig. 2a) occur massive skeleton Fe-phases ($Al_{15}(FeMn)_3Si_2$) and the relative long needles Al_5FeSi (local more than 50 μm).

Vanadium (0.5% V) simultaneously with Mn in this alloy caused high amount of skeleton/Chinese script Fe-phases, more than needle-like Fe-phases. With the increasing amount of vanadium (1; 1.5 and 2%) occurred to the progressive shortening and thinning of the needle-like Fe-based intermetallic phase Al_5FeSi from 35.48 μm to 24.01 μm. The overall volume of Fe-phases in alloy decreases too. The results of the quantitative evaluation of the vanadium influence on to the Fe-phases are documented in Tab. 2.

In the alloy with a content of 1.0 wt.% of V (Fig. 2b) mainly the needles Al_5FeSi are observed. They are thinner and shorter and skeleton-like/Chinese script phases were in very smaller volume compared to alloy with 0.5 wt.% of V. Fine and short Al_5FeSi needles are observed at the interface of the Al-dendrites or eutectic Si particles, indicating that this alloy is well modified.

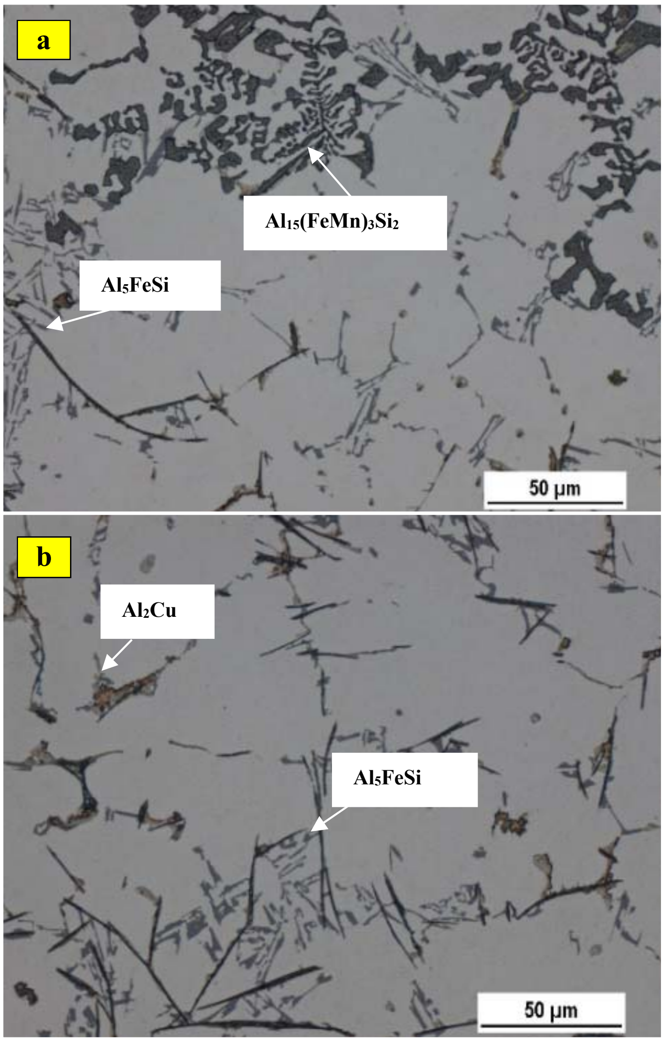
Experimental alloy with 1.5 wt.% of V (Fig. 2c) contains intermetallic phases in needles form - Al_5FeSi and skeleton-like/Chinese script - $Al_{15}(FeMn)_3Si_2$. Skeleton/Chinese scripts like phases are fine and were observed in larger aggregation.

The alloy with 2 wt.% of V contains, besides Fe-phases mentioned above, a larger volume of the phases (Fig. 2d - white round), whose exact chemical composition was not detected up to now, but their morphology (star-like or exploded) is similar to "sludge" phases. This alloy contains the small fine skeleton phases $Al_{15}(FeMn)_3Si_2$ and short needles Al_5FeSi, too.

Table 2. Influence of vanadium on to the Fe- phases

	wt.% of V			
	0.5	1.0	1.5	2.0
the average length of Fe-needles, µm	35.48	34.23	28.66	24.01
% of iron phases	4	2.50	2.80	3

Source: own study



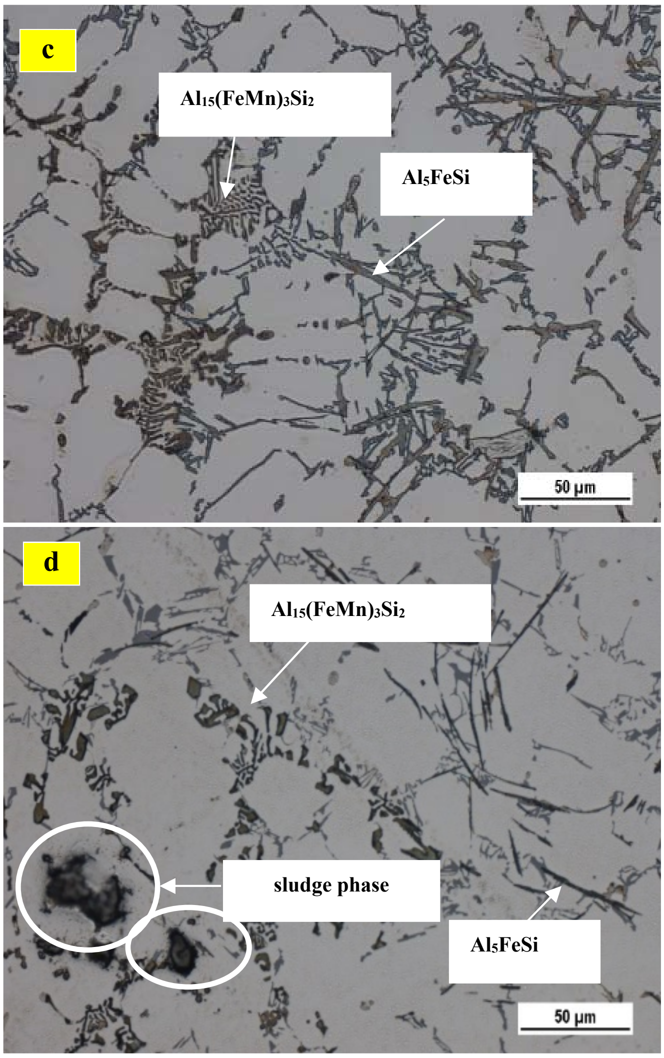


Fig. 2. Effect of V to morphology of Fe-phases, etch. H_2SO_4
a) 0.5% V b) 1% V c) 1.5% V d) 2 hm.% V

Source: own study

4. Conclusion

Addition of vanadium to secondary AlSi6Cu4 cast alloy shows the following conclusions:

- shortening and thinning of the needle-like phase Al_5FeSi;
- the smallest amount of iron based intermetallic phase was observed in the alloy with 1 wt.% of V;
- higher wt.% of V (more than 1%) has not effect on the another amount elimination of Fe-phases;
- needle-like Al_5FeSi phase were observed in the structure of each experimental materials; $Al_{15}(FeMn)_3Si_2$ were observed in the structure of wt. 0.5; 1.5 and 2% of V and "sludge" phases were observed in the structure with 2% of V.

Acknowledgements

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二次 AlSi6Cu4 铸造合金中铁基金属间相的结构分析

关键词

铁基金属间化合物

阶段

钒

铝合金

抽象

二次铝合金的使用正在增加，因为它有助于降低生产成本。然而，这些合金含有较大量的铁。铁具有负面影响，因此消除是必要的，以便添加一些元素，这也被称为铁的校正剂。最常用的校正器是锰。另一个经常使用的修正器是铬，钾，镁，钒。在以下工作中，钒用作铁相的校正剂。钒在铝合金中的应用对它们的机械性能，拉伸强度，延展性和硬度有正面的影响。作为实验材料使用 AlSi6Cu4 合金。它由母合金 AlFe10 合金化。添加到母合金中铁含量后，合金中的临界值超标。将钒以不同的量添加到 AlSi6Cu4 合金中。使用图像分析（软件 NIS-Elements）来量化铁基金属间相的量和测定平均值。