STRUCTURAL ANALYSIS OF SECONDARY AlZn10Si8Mg CAST ALLOY

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Abstract
Using recycled aluminum cast alloys is profitable in many aspects. Requiring only 5 % of the energy to produce secondary metal as compared to primary metal and generates only 5 % of the green house gas emissions, the recycling of aluminum is therefore beneficial of both environmental and economical point of view. Secondary AlZn10Si8Mg (UNIFONT® - 90) cast alloy are used for engine and vehicle constructions, hydraulic unit and mold making without heat treatment. Properties include good castability, very good mechanical strength and elongation, light weight, good wear resistance, low thermal expansion and very good machining. Improved mechanical properties are strongly dependent upon the morphologies, type and distribution of the second phases, which are in turn a function of alloy composition and cooling rate. The presence of additional elements as Mg, Mn, Fe, or Cu allows many complex intermetallic phases to form, which make characterization non-trivial. These include, for example, Mg_2Si, Al_2CuMg and AlFeMn phases, all of which may have some solubility for additional elements. Phase's identification in aluminum alloys is often non-trivial due to the fact that some of the phases have either similar crystal structures or only subtle changes in their chemistries. A combination different analytical techniques (light microscopy upon black-white and colour etching, scanning electron microscopy (SEM) upon deep etching and energy dispersive X-ray analysis (EDX)) were therefore been used for the identification of the various phases.

Keywords: aluminium alloys, microstructure, microscopy and microanalysis techniques, intermetallic phases

1 Introduction

The increase of amount in recycled metal is a positive trend, as secondary aluminum produced from recycled metal requires only about 2.8 kWh/kg of metal produced while primary aluminum production requires about 45 kWh/kg produced. It is aluminum industry's advantage to maximize the amount of recycled metal, for both the energy-savings and the reduction of dependence upon overseas sources. The remelting of recycled metal saves almost 95 % of the energy needed to produce prime aluminum from ore, and thus, triggers associated reductions in pollution and greenhouse emissions from mining, ore refining, and melting. Increasing the use of recycled metal is also quite important from an ecological standpoint, since producing aluminum by recycling creates only about 5 % as much CO_2 as by primary production [1, 2, 3].

Aluminum cast alloys are extensively used in the automotive industry due to their excellent castability, good mechanical properties, machinability and wear resistance. Recycled Al-Zn-Si casting alloys can often be used directly in new cast products for mechanical engineering, in hydraulic castings, textile machinery parts, cable car components, mould construction or big parts without heat treatment [4].

Due to the increasing utilization of recycled aluminum cast alloys the necessity for strict microstructural control arises to remove the deleterious impact of impurity elements; which is considered to impair the overall properties of Al-Zn-Si based casting alloys. By implementing adaptable alloying- and process technology, the mechanical properties will therefore be radically enhanced, leading to larger application fields of complex cast aluminum components such as safety details. Generally, the mechanical and microstructural properties of aluminum cast alloys are dependent on the composition; melt treatment conditions, solidification rate, casting process and the applied thermal treatment. The mechanical properties of Al-Si and Al-Zn-Si alloys depend, besides the Si, Zn, Mg and Fe-content, more on the distribution and the shape of the silicon particles [5]. The presence of additional elements in the Al-Si or Al-Zn alloys allows many complex intermetallic phases to form, such as binary phases (e.g. Mg_2Si, Al_2Cu), ternary phases (e.g. Al_2CuMg, Al_5FeSi, AlFeMn, $A_{17}Cu_4Ni$ and AlFeNi) and quaternary phases (e.g. cubic α-$Al_{15}(FeMn)_3Si_2$ and $Al_5Cu_2Mg_8Si_6$) [6-9], all of which may have some solubility for additional elements.

The present study is a part of larger research project, which was conducted to investigate and to provide a better understanding morphology and composition of complex microstructures containing intermetallic phases formed in the secondary (recycled) aluminum cast alloy.

2 Experimental methodology and used materials

As an experimental material was used secondary (scrap-based - recycled) unmodified AlZn10Si8Mg alloy (UNIFONT® - 90) with very good casting properties, good wear resistance, low thermal expansion and very good machining [10, 11]. Alloy contains relatively high Si, and their impurity limits tend to be relatively loose. Test bars (ø 20 mm with length 300 mm) were produced by process sand casting in foundry Zátor, Ltd. Czech Republic. Sand casting is the simplest and most widely used casting method. The melt was not modified or refined. Chemical composition of the alloy is given in **Table 1.**

Table 1 Chemical composition of AlZn10Si8Mg alloy

Zn	Si	Cu	Fe	Mn	Mg	Ti	Ni
9.6	8.64	0.005	0.1143	0.181	0.452	0.0622	0.0022
Cr	Hg	Ca	Cd	Bi	P	Sb	Al
0.0014	0.0006	0.0002	0.0001	0.0003	0.0001	0.0007	rest

The only intentional and controlled additions of Zn to Al-casting alloys are in the 7XXX series, and those are not yet suitable for die casting or any of its variations. Otherwise, zinc is present merely as an acceptable impurity element in many secondary (scrap-based) die casting alloys. As such, zinc is quite neutral; it neither enhances nor detracts from an alloy’s properties. It should be recognized that zinc is a relatively dense (heavy) element, and as such it increases an alloy’s mass density. High-zinc secondary alloys usually seem attractive because they cost somewhat less than low-zinc versions. However, that attractiveness can be deceiving if the cost differential is too small; it can make little sense to purchase lower cost alloys if doing so means shipping a higher weight of material with each casting [4, 10].

AlZn10Si8Mg cast alloy is a self-hardening alloy that is particularly used when good strength values are required without the need for heat treatment. With these alloy types, the mechanical properties are achieved after storage of approximately 7 to 10 days at room temperature. Particular attention should be paid to the high 0.2 % yield strength. The low iron content has a particularly beneficial effect on the mechanical properties, which can also be traced to good fatigue strength. The sand casting alloy AlZn10Si8Mg achieves high values for tensile strength (R_m = 220 - 250 MPa), offset 0.2 % yield stress ($R_p0.2$ = 190 - 230 MPa), however the low ductility limits (A_5 = 1 - 2 %), hardness HB 90 - 100 and fatigue resistance (80-100 MPa) [4, 10].

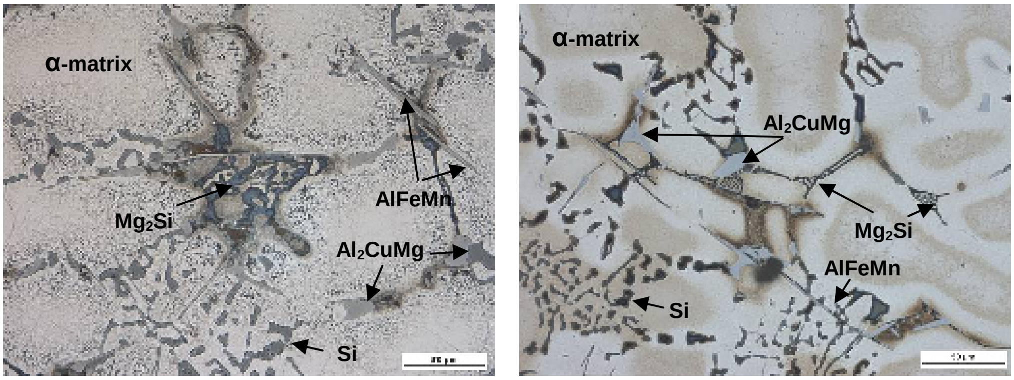
Cast samples were sectioned from the test bars (in transversal and longitudinal direction). The samples (1.5 cm x 1.5 cm) were polished and standard prepared for metallographic observations. The microstructures were studied using an optical microscope (Neophot 32) under 100x, 500x and 1 000x magnification. Samples were first etched by standard reagents (HF, Fuss, Dix-Keller, and H_2SO_4) and next by colour reagent (MA, Weck-Al and Murakami) [12-14].

Some samples were also deep-etched for 30 s in HCl solution in order to reveal the three-dimensional morphology of the silicon phase [12, 15]. The specimen preparation procedure for deep-etching consists of dissolving the aluminum matrix in a reagent [12] that will not attack the eutectic components or intermetallic phases. The residuals of the etching products should be removed by intensive rinsing in alcohol. The preliminary preparation of the specimen is not necessary, but removing the superficial deformed or contaminated layer can shorten the process.

The various phases reported in this work were identified using scanning electron microscope VEGA LMU II linked to the energy dispersive X-ray spectroscopy (EDX analyzer Brucker Quantax). All phases were analyzed by EDX technique.

3 Results

Typical microstructures of the as-cast alloy are shown in **Fig. 1**. The microstructure of recycled AlZn10Si8Mg cast alloy consists of a primary phase, α-solid solution, a eutectic mixture of α-matrix and spherical phases (probably silicon) and variously type's intermetallic phases. The α-matrix precipitates from the liquid as the primary phase in the form of dendrites and is nominally comprised of Al and Zn.

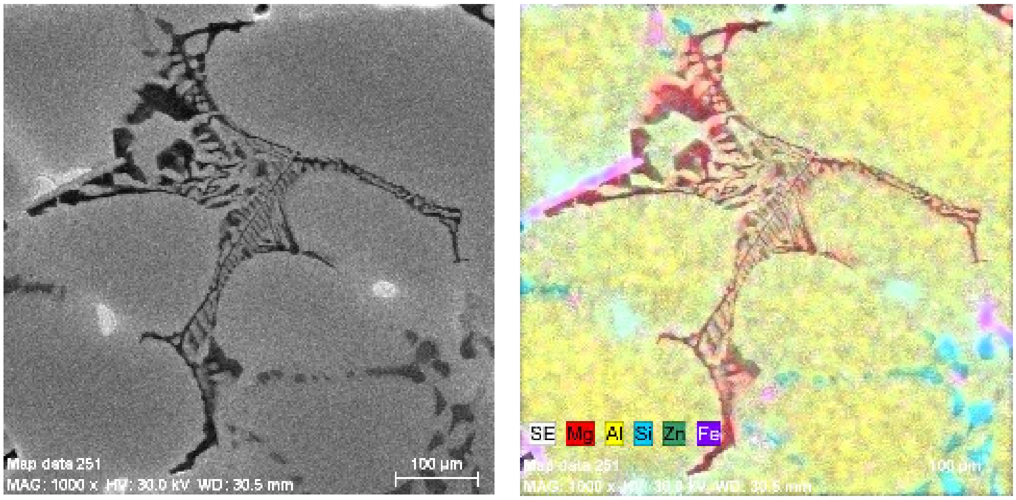


a) etch. Fuss b) etch. Weck-Al

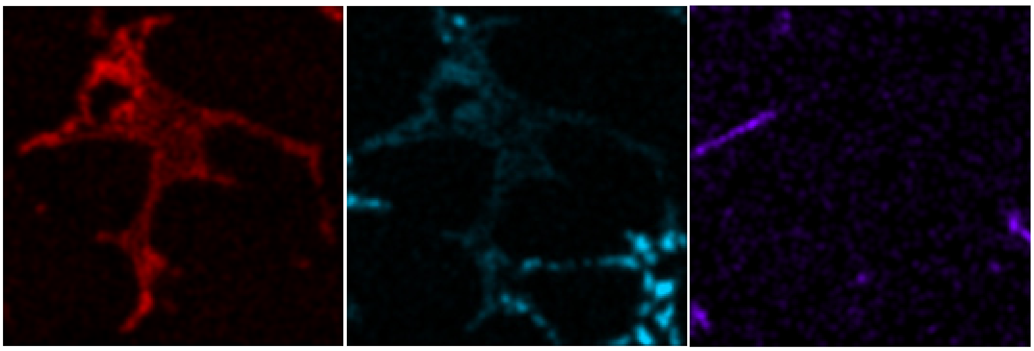
Fig.1 Microstructure of AlZn10Si8Mg alloy (as-cast state)

In the commercial 7XXX aluminum alloys a wide range of intermetallic particles formed during solidification - in the interdendritic regions and at the grain boundaries. In this aluminum alloys

besides the intentional additions, metals such as Mg, Fe, Mn and Cu are always present. Even not large amount of these impurities causes the formation of a new phase component. The exact composition of the alloy and the casting condition will directly influence the selection and volume fraction of intermetallic phases. **Figures 1a** and **1b** show tree types of intermetallic compounds. These intermetallic particles had different morphologies, such as platelet or needles, skeleton- or script-like or "Chinese script" too and oval.
Optical microscopy and SEM observation with EDX analysis (combination of identification chemical data of each phase with mapping) have been combined to produce a simple method for phase identification. **Figure 2** shows a SEM image and X-ray mapping of the microstructure of phases in AlZn10Si8 alloy.



a) SEM image of phases, etch. Dix-Keller b) mapping



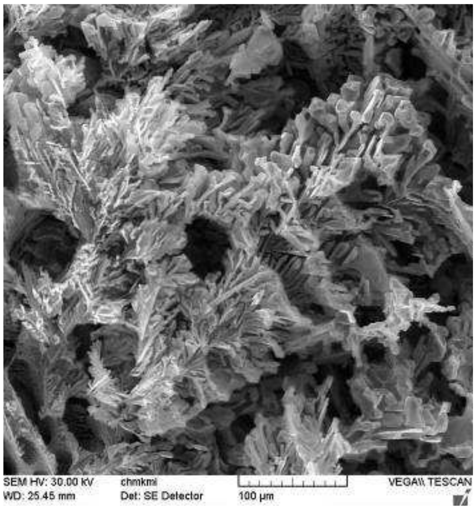
c) map of the distribution of Mg d) map of the distribution of Si e) map of the distribution of Fe

Fig.2 EDX phase analysis

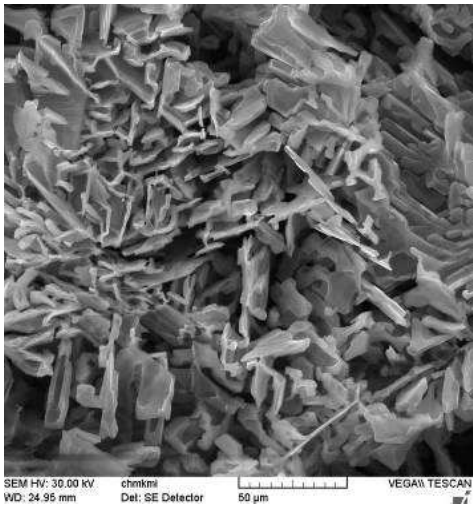
Fe-containing intermetallics, such as AlFeMn phases, are formed between the α-dendrites. The morphology of this Fe-rich phase is plate-like (thin grey needles in **Fig. 1** and **Fig. 2a,** violet needles in **Fig. 2b**) with a thickness of a few tenths of micrometers and other dimensions of the order of 10 μm. It is these plate-shaped precipitates that are considered most deleterious to mechanical properties (particularly ductility), Fe-needles also reported to reduce the castability, the corrosion resistance, and the machinability of Al- casting alloys. Platelets act as potential sites for crack initiation that, consequently, results in decohesion failure [12, 16, 17]. Thus, control of these phases (e. g. quantitative analysis [18, 19]) is of considerable technological importance.

Addition of Mg to Al-Zn-Si alloys leads to formation Mg-intermetallic compounds. Mg-phases can in Al-Zn-Si alloy solidify in two different forms: Mg_2Si and Al_2CuMg. The Mg_2Si phase was identified by EDX analysis as individual skeleton-like or script-like so called “Chinese script” morphology (black phase) - **Fig. 1** and **Fig. 2**. Oval round-like particles was detected as S-phase (Al_2CuMg - light grey phase). Phases AlFeMn and Mg_2Si are formed by impurities during solidification and can also be found, which are detrimental to the mechanical properties, as they act as stress-raisers.

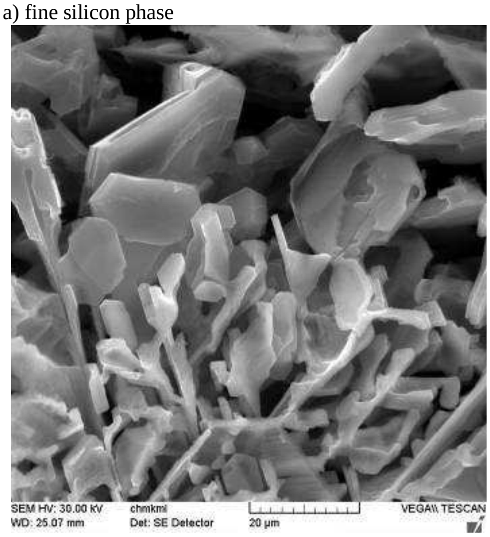
Next intermetallic phases besides these few phases were neither by using colour contrast in optical microscopy not observed.



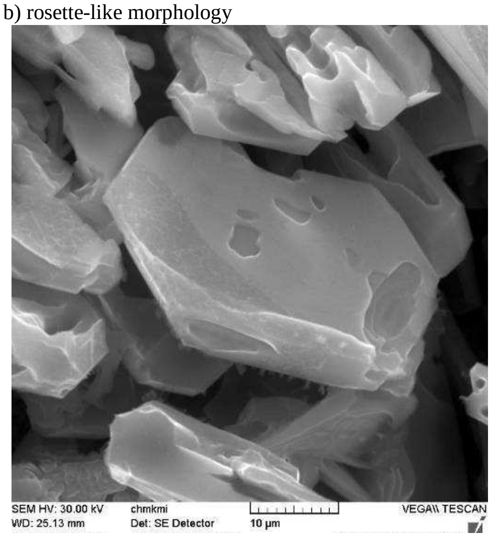
a) fine silicon phase



b) rosette-like morphology



c) different orientation of fine Si

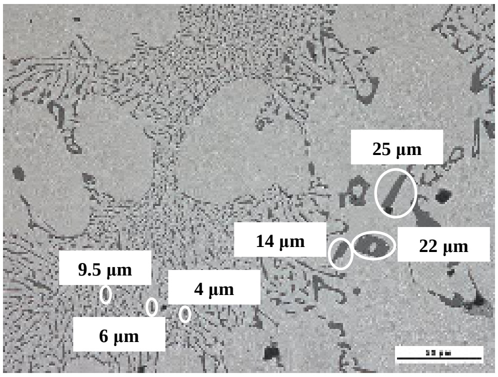


d) detail of fine hexagonal Si-plate

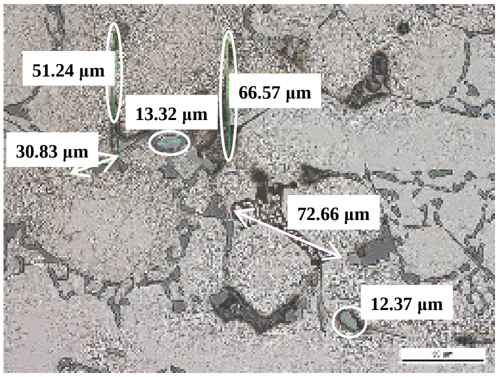
Fig.3 Morphology of Si particles, deep-etch. HCl, SEM

The EDX analysis revealed that the spherical phases in eutectic (**Fig. 1** and **Fig. 2**) are really the eutectic silicon. The silicon precipitates, present in commercial Al-cast alloys, are almost pure, faceted crystals. **Figure 3** shows the three-dimensional morphology of eutectic silicon observed by SEM on the deep-etched samples. The silicon phase exhibits a typical fine and rosette-like, rather than plate-like form. The centre of a rosette could be the centre of a eutectic cell/grain, indicating the nucleation of the eutectic phases could be independent to the surrounding primary α-aluminum dendrites. This result about Si morphology is in accordance with previous reports for unmodified Al-Si alloys [12, 15, 20].

Quantitative metallography [18, 19] was carried out on an Image Analyzer NIS - Elements to quantify phases (eutectic Si, intermetallic phases) morphology. **Figure 4a** shows that the size of eutectic Si particles in eutecticum was from 4 μm to 14 μm. Coarsening of Si particles was observed on edge of α-phase dendrite (size was from 14 μm to 75 μm). The length of Fe-needles was from 30.83 μm to 76.62 μm, of Mg_2Si from 12.56 μm to 72.66 μm and of Al_2CuMg phase from 5.52 μm to 22.69 μm (**Fig. 4b**).



a) Quantitative measurement of eutectic Si, non-etch.



b) Quantitative measurement of phases, etch. HF

Fig.4 Quantitative metallography of AlZn10Si8Mg alloy

4 Conclusion

Understanding of metal quality is of superior importance for control and prediction of casting characteristics. The results are summarized as follows:

The secondary AlZn10Si8Mg cast alloy used in this study possessed a complex as-cast microstructure. By using various instruments (light microscopy, SEM) and techniques (black-white, colour and deep etching, EDX) a wide range of intermetallics phases were identified.

The microstructural analyses show that all alloying elements are forming intermetallic phases. Zn is present in solid solution α. Fe enters the intermetallic phases regardless of its concentration in the alloy. Mn usually is present in the Fe- containing phases and often substitutes part of Fe. Mg forms intermetallic phases with Si or Cu. Cu makes the intermetallic phases form more compact, Mg skeleton -like and Fe needle-like. Si is present a typical fine rosette-, rather than plate-like form.

The size of phases measured by quantitative metallography was approximately 20 μm for eutectic Si, 65 μm for needles AlFeMn, 40 μm for Mg_2Si phases and 13.5 μm for Al_2CuMg phases.

Acknowledgements

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