PHASES AND STRUCTURE CHARACTERISTICS OF THE NEAR EUTECTIC AL-SI-CU ALLOY USING DERIVATIVE THERMO ANALYSIS

L.A. Dobrzanski¹,a, M. Krupinski²,b, K. Labisz³,c, B. Krupinska⁴,d

and A. Grajcar⁵,e

¹-⁴ Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, Konarskiego St. 18a, 44-100 Gliwice, Poland

¹-⁵ Division of Constructional and Special Materials, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, Konarskiego St. 18a, 44-100 Gliwice, Poland

aleszek.dobrzanski@polsl.pl, bmariusz.krupinski@polsl.pl, ckrzysztof.labisz@polsl.pl, dbeata.krupinska@polsl.pl, eadam.grajcar@polsl.pl

Keywords: List the keywords covered in your paper. These keywords will also be used by the publisher to produce a keyword index.

Abstract. For determining of the micro-structural changes taking place in a near eutectic Al-Si-Cu aluminium cast alloy during heating and cooling process the UMSA device (Universal Metallurgical Simulator and Analyzer) was used. In this work the dependence between the regulated cooling speed and structure on the basis of the thermo-analysis was carried out. The thermal analysis was performed at a cooling rate in a range of 0,2 ºC to 1,25 ºC. The changes were examined and evaluated qualitatively by optical and electron scanning microscopy methods and the EDS microanalysis. During the investigation the formation of aluminium reach (α-Al) dendrites was revealed and also the occurrence of the α+β eutectic, the ternary eutectic α+Al₂Cu+β, as well a iron and manganese containing phase was confirmed. The performed investigation are discussed for the reason of an possible improvement of thermal and structural properties of the alloy. The achieved results can be used for liquid metal processing in science and industry – for example foundry for developing and obtaining of a required alloy microstructure and properties influenced by a proper production conditions.

Introduction

The investigated alloy has become popular in automotive industry owing to their low weight and some casting and mechanical qualities. The main component of aluminum alloy casting is Si. The eutectic structure in Al-Si cast alloys and Si concentration largely affect the porosity (pore volume). The novel universal metallurgical simulator and analyzer (UMSA) (Fig. 1) technology platform is capable of collecting in situ and analyzing on-line, the thermal characteristics of metallurgical treated melts and solidifying and heat-treated test samples, using precision-controlled heating and cooling rates while simulating industrial conditions. For this reason on the crystallization curve occurs some characteristic inflexion points coming from exothermic or endothermic reactions of the crystallizing phase transformations. It is difficult to determine unequivocally the crystallization temperature of the phases occurred on the crystallization curve. The determination is possible using the first derivative curve of the cooling line in function of time, that mines using the differential ATD curve called also derivative curve [1-4].

High purity Al-Si-Cu hypoeutectic alloys exhibit three main solidification reactions during the solidification process, starting with the formation of aluminum dendrites followed by the development of two main eutectics. The presence of alloying and impurity elements such as Cu, Mg, Mn and Fe leads to more complex constituents (including intermetallic) that are characterized by metallographic techniques [5-8].
Fig. 1. UMSA device generator used for the thermal derivative analysis with gas flow control unit for regulated quenching and inert gas input.

**Experimental conditions**

The experimental alloy used in this investigation was the W319 aluminium grade cast alloy with chemical composition showed in Table 1. The material used for investigation has been supplied in form of cut parts of an block engine from the automotive industry. The alloy was heat treated according to the standard steps for this aluminium grade – an proper choose solution heat treatment and ageing.

Table 1. Chemical composition of AC-AlSi7Cu3Mg aluminum cast alloy according to the PN-EN 1706:2001 used for investigation

<table>
<thead>
<tr>
<th>Mass concentration of the element, in wt. %, AA standard</th>
<th>Si</th>
<th>Cu</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Ti</th>
<th>Zn</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>6,5-8</td>
<td>3-4</td>
<td>0,3-0,6</td>
<td>0,2-0,65</td>
<td>≤ 0,8</td>
<td>≤ 0,25</td>
<td>≤ 0,65</td>
<td>≤ 0,3</td>
</tr>
</tbody>
</table>

For performing of the thermal analysis and solidification process the UMSA (Fig. 1) device was used with low-density ceramic crucibles for improving of the thermal inertia of the system. For temperature measurement a chromel-alumel thermocouple was applied. The cooling rate was set experimentally to low = 0,2 °C/s, middle = 1 °C/s and high = 1,25 °C/s.

**Investigation results**

Investigation performed using the optical microscope reveal the microstructure of the investigated cast aluminium alloy, the optical micrographs of samples cooled with different cooling rate are presented on figures 3 to 8. On each of the figures the tree main phases, occurred in the alloy, can be discovered. Namely that are the primary Si phase. Etched with HF acid the Si phase is colored dark gray and appears in the shape of very irregular, longitudinal sharp-edged structures. This phase consists of the primary Si precipitation. The next described phase also well known in the literature is the Al₂Cu phase. This phase appears light gray in the etched optical micrographs for every applied cooling rate, the precipitation is longitudinal shaped with a eutectic-like structure. This phase is also present over the whole structure. On the basis of the investigation, especially on the cooling curve analysis of Fig. 2. and literature study, also an iron and manganese containing phase is confirmed, some result achieved using EBSD analysis give the Al₁₇(Fe,Mn)₄Si₂ or more exactly
\( \text{Al}_{17}\text{(Fe}_{3.2}\text{Mn}_{0.8})\text{Si}_2 \) formula as a possible solution, but future investigation should be performed to analyze exactly the phase formula. The \( \text{Al}_2\text{Cu} \) and iron/manganese containing phase seems to be not uniformly and shows some areas that are etched black. Investigation using scanning electron microscope and EDS analysis can help to solve this problem. The optical micrographs at various cooling rates are shown in Figs 3 to 8. That figures present the structural changes find in samples with different cooling rate compared to the structure of as cast alloy. It is seen that the size of the phase decreases with increasing cooling rate.

As a result of SEM investigation a micrograph of the \( \text{Al}_2\text{Cu} \) phase (Fig. 13), Si phase (Fig. 11) and iron and manganese containing phase (Fig. 9) are presented. EDS microanalysis (Fig. 10, 12, 14) on the scanning electron microscope was used to identify the chemical composition of the phases present in the alloy. On Figure 13 there is presented an not identified magnesium containing phase, Bäckerund gives as a possible solution the \( \text{Mg}_2\text{Si} \) phase that fore.

The hardness was measured with Rockwell hardness tester primary with the HRF scale with a load of 60 kg and converted automatically to the HB scale. A minimum of 10 indentations was made on each of the heat treated samples.

Mechanical properties (Fig. 15) of the aluminum alloys are strongly dependent on the effect of applied cooling rate. Investigations results shows, the increase the cooling rate from influence the increase of the achieved hardness value. For the lowest cooling rate the hardness obtain the value of 69 HB and increase to 75 HB by a middle cooling rate. For the highest applied cooling rate the hardness value achieves the value of 92 HB.

Fig. 2. Temperature – time curve, baseline and the first derivative vs. temperature curve obtained from the crystallization process, the marked points correspond to the metallurgical reactions occurred or the investigated alloy
Fig. 3. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 0.2 °C/s

Fig. 4. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 0.2 °C/s

Fig. 5. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 0.5 °C/s

Fig. 6. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 0.5 °C/s

Fig. 7. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 1.25 °C/s

Fig. 8. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy, cooling rate 1.25 °C/s
Fig. 9. SEM micrograph of the iron and manganese containing phase of the investigated aluminium alloy

Fig. 10. EDS point wise analysis of the investigated aluminium cast alloy, marker 1 in figure 9

Fig. 11. SEM micrograph of the silicon phase – gray colored

Fig. 12. EDS point wise analysis of the investigated aluminium cast alloy, marker 1 in figure 11

Fig. 13. SEM micrograph of the unknown magnesium containing phase of the investigated aluminium alloy

Fig. 14. EDS point wise analysis of the investigated aluminium cast alloy, performed of the whole area presented in figure 13
Summary

The assurance of adequate properties of usable and technological elements made during the casting process is dependent on obtaining the right structure of casts as well as the size and shape of their particles. Solidification condition, particularly affected by the cooling rate influences the morphology of the phases occurred in the investigated Al alloy. With increasing cooling rate the size of the phases decreases, and the distribution is more homogenous, because of an increased number of nucleus that affect the number and that for size of the precipitations. Generally a structure and phase refinement can be state according to the choose cooling rate. Three different types of phases are confirmed in this alloy, these are the primary silicon phase, the Al₂Cu and a manganese and iron containing phase.

Acknowledgements

This scientific work is fragmentary financed within the framework of scientific financial resources in the period 2007-2008 as a research and development project R15 0702 headed by Prof. L.A. Dobrzański.

References


Fig. 15. Hardness measurement results