Quantitative Microstructural Analysis of Direct Chill Casting of Aluminium Alloy by use of QEMSCAN

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Abstract

Materials characterization provides comprehensive solutions for understanding the intrinsic properties and behaviours of various materials. Quantitative microstructural analysis is crucial in elucidating the fundamental aspects of metal forming, thereby aiding in the design and optimization of materials for specific applications. In the present article, we analyse the direct chill casting of an aluminium alloy using an advanced characterization technique known as QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscopy). This technique allows for a detailed examination of the microstructural features formed during the direct chill casting process and their subsequent impact on the mechanical and physical properties of the final product. The analysis reveals the formation of unique microstructural characteristics, such as grain size and distribution, which significantly influence the performance and reliability of the cast products. Additionally, we present a case study that demonstrates an innovative method for analysing an Al-Mg-Si alloy casting using QEMSCAN. This method proves to be highly effective for routine testing and quality control of cast products, ensuring consistency and high standards in production.

Keywords: Materials characterization, Quantitative microstructural analysis, Direct chill casting, Aluminium alloy, QEMSCAN.

1. Introduction

Aluminium alloys, particularly the AA 6063 series, are widely used in industries such as construction, automotive, and aerospace due to their excellent extrudability, corrosion resistance, and mechanical properties. Direct chill (DC) casting is a prevalent method for producing aluminium alloy billets, offering advantages in scalability and microstructural control. However, the microstructural features formed during DC casting, such as the distribution and morphology of intermetallic phases (e.g., beta-Al_5FeSi and alpha-$Al_{12}(Fe,Mn)_3Si$), significantly influence the alloy's downstream processing and final properties.

Quantitative microstructural analysis is essential for understanding these features and their impact on material performance. Traditional techniques, such as optical microscopy and standard scanning electron microscopy (SEM), provide limited quantitative data. In contrast, QEMSCAN, which integrates Field Emission Scanning Electron Microscopy (FE-SEM) with Mineral Liberation Analysis (MLA) software, enables precise, automated, and quantitative analysis of microstructural phases.

N. C. W. Kuijpers et al. [6] has elaborated five different quantitative techniques for measurement of Beta to Alpha transformation. Four of the methods are based on morphological characteristics and the fifth one was based on XRD pattern measurement of intermetallic extracted from the matrix. The present work is an unique method based on SEM and EDS technique along with the use of a powerful mineralogical software MLA.

This study leverages QEMSCAN to investigate the microstructural characteristics of DC-cast AA 6063 billets, focusing on the beta-to-alpha phase ratio and its implications for extrusion performance. Additionally, the effect of homogenization treatment on phase transformation is quantified to optimize processing conditions.

2. Experimental Methodology

The AA 6063 alloy primarily contains aluminium, magnesium, and silicon, forms alpha (Mg_2Si) and beta (Mg_2Si) phases during solidification. The beta phase, which is brittle and plate-like, can hinder extrudability, while the alpha phase, with its more equiaxed morphology, is desirable for improved formability. Homogenization treatments are commonly applied to transform beta phase into alpha phase, enhancing the alloy's suitability for extrusion. Understanding and quantifying these phase transformations is essential for optimizing alloy performance.

2.1 Material & Casting

AA 6063 aluminium alloy billets were produced via direct chill casting. The alloy composition, determined using inductively coupled plasma optical emission spectroscopy (ICP-OES), is presented in Table 1.

Table 1. Composition of the material.

Alloy	Si	Mg	Mn	Ca	Fe	Zn	Ni	Ti
6063	0.55 %	0.55%	0.07%	0.026%	0.18%	0.02%	0.005%	0.018%

The casting parameters are given below in Table 2.

Table 2. Casting parameters.

Casting parameters	**Values**
Billet diameter	7 inches
Casting speed	126 mm/min
Water flow rate	78 L/min
Water temperature	38 °C
Metal pouring temperature	705 °C

2.2 Homogenization Treatment

Samples underwent a three-stage homogenization cycle:

a. Ramp up to 580 °C at 50 °C/h
b. Hold at 580 °C for 6 hours
c. Controlled furnace cooling at 30 °C/h to 300 °C, followed by air cooling

This cycle is intended to promote transformation of the metastable β-AlFeSi phase into the more rounded α-AlFeSi phase.

The micrographs of both as cast and homogenized sample are shown in Figures 1 and 2.

4. Conclusions

This study demonstrates the efficacy of QEMSCAN as a powerful tool for quantitative microstructural analysis of DC-cast AA 6063 aluminium alloy billets. The key findings are:

a. As-cast billets exhibit a high beta-to-alpha phase ratio with needle-like beta-Al_5FeSi particles detrimentally affecting extrudability.
b. Homogenization treatment at 580 °C for 6 hours reduces the beta-to-alpha ratio achieving more than 90 % conversion of beta to alpha phase.
c. QEMSCAN provides detailed quantitative data on phase fractions and morphologies, enabling precise optimization of casting and processing parameters.
d. The technique can be used as a practical industrial tool for billet certification and process optimization

These findings signify the importance of advanced characterization techniques in aluminium alloy design for specific applications.

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