

3D evaluation of Fe-rich intermetallics in DC-cast 6xxx aluminium alloy billets of varying size and recycled content using X-ray Tomography

J. Lazaro-Nebreda^{1*}, P. Shurkin¹, N. Barekar², E. Frutos Myro¹, T. Subroto², C. Barbatti^{2,3}, G. Scamans^{1,4}

¹ Brunel Centre for Advanced Solidification Technology (BCAST), Brunel University London, Uxbridge, UK

² Constellium University Technology Centre, Brunel University London, Uxbridge, UK

³ Constellium Technology Centre (C-TEC), Voreppe, France

⁴ Innoval UK, Catcliffe, Rotherham, UK

Corresponding author: *jaime.lazaronebreda@brunel.ac.uk

Introduction

The increasing use of recycled aluminium in industrial applications is requiring greater tolerance to impurity elements, such as iron which tends to form Fe-rich intermetallic compounds (Fe-IMCs) during solidification [1,2]. Fe-rich intermetallic compounds (Fe-IMCs) in 6xxx DC-cast aluminium alloys have a critical role in both billet quality and extrusion performance and as recycled content increases a greater amount is expected, making their control increasingly important during industrial processing.

Their morphology and distribution are also strongly influenced by the solidification conditions, which can vary with billet diameter due to differences in cooling rate. Larger billets tend to have a slower and non-uniform cooling rate, potentially leading to inhomogeneities in microstructure. Coarser and more interconnected Fe-IMCs could potentially raise issues related to extrudability and productivity.

Understanding how these intermetallic particles form and evolve in billets of different types is essential to prevent processing issues and optimize alloy design and casting conditions, especially when incorporating end-of-life recycled aluminium to formulate the alloy.

Conventionally, Fe-rich intermetallic compounds are assessed using 2D characterization techniques such as optical microscopy or scanning electron microscopy (SEM), which can provide valuable information on particle size and morphology but may not fully capture the true three-dimensional morphology of the particles and their spatial distribution within the billet.

In this study, advanced 3D characterization techniques were used to assess the real 3D geometry [3,4] of the Fe-rich intermetallic compounds in DC billets of different types.

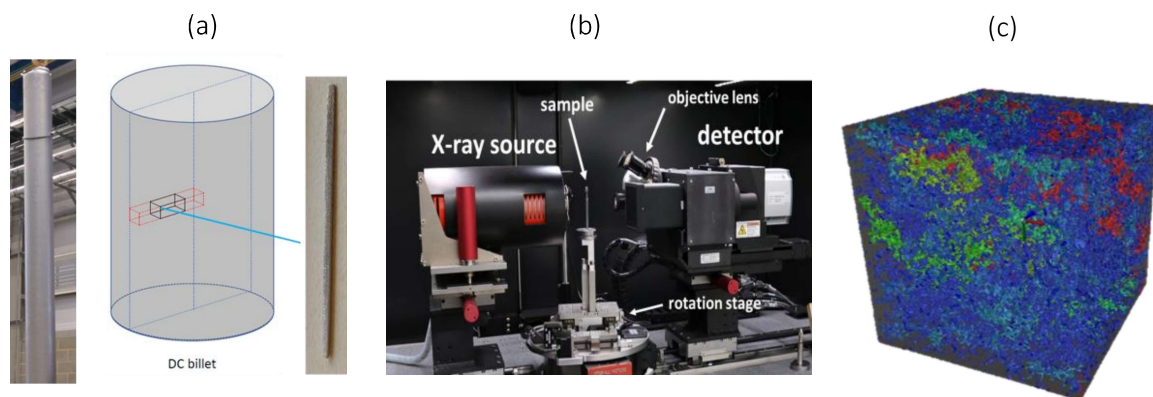


Figure 1. Experimental approach to study (a) AA6xxx DC billets by (b) X-ray tomography to assess (c) the 3D shape and network of Fe-IMC, with each connected region in a different colour.

Experimental methodology

Samples extracted from the DC billets were analysed using a Zeiss Xradia Versa X-ray computed tomography system. This system enabled high-resolution three-dimensional reconstruction of the Fe-IMCs in DC-cast 6xxx billets of different diameters and recycled content. The scans were reconstructed with a spatial resolution of approximately 1-1.5 μm , enabling the detailed visualisation of the Fe-rich intermetallic particles and their networks. A schematic of this process is shown in Figure 1.

Following reconstruction and segmentation, advanced image analysis tools including Fiji (ImageJ) and VGStudio Max were used to quantify particle size, morphology, and interconnectivity, providing insights into the effect of billet size and alloy composition on intermetallic distribution. Complementary electron microscopy observations provided validation against conventional characterisation techniques.

Results and discussion

The 3D analysis revealed that increasing billet diameter leads to thicker and more elongated particles, while billets with higher impurity level exhibit a greater volume fraction of intermetallics, both affecting the tendency for clustering and interconnectivity.

These observations complement previous 2D analysis results obtained by SEM and optical microscopy and suggest that connectivity can provide additional insight beyond the commonly assessed volume fraction or particle size alone, while they highlight the importance of considering billet size, casting conditions and recycling practices in industrial casting to ensure microstructural consistency and maintain extrusion productivity.

Impact and Industrial relevance

From an industrial perspective, increasing recycled content and increasing billet diameter both affect the extension of the Fe-IMC networks. Such microstructural changes may influence billet quality, material flow during extrusion and overall process productivity.

Consequently, an improved understanding and control of Fe-rich intermetallic morphology is becoming increasingly important as the aluminium industry seeks to increase recycled content while maintaining product quality and manufacturing efficiency.

The present work demonstrates the capability of X-ray computed tomography or similar 3D analysis techniques to provide quantitative three-dimensional information that cannot be obtained from conventional two-dimensional methods.

References

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