ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Issue 1/2015

47 – 50

10/1

Three Dimensional Morphology of β-Al_5FeSi Intermetallics in AlSi Alloys

P. Mikołajczak [a, b, *], **L. Ratke** [c]
[a] Institute of Materials Technology, Poznan University of Technology, Piotrowo 3, 60-965 Poznan, Poland
[b] Institut für Materialphysik im Weltraum, German Aerospace Center DLR,
[c] Institut für Werkstoff-Forschung, German Aerospace Center DLR,
Linder Höhe, 51147 Köln, Germany
*Corresponding author. E-mail address: Piotr.Mikolajczak@put.poznan.pl

Received 17.06.2014; accepted in revised form 22.07.2014

Abstract

Iron is the most common and detrimental impurity in casting alloys and has been associated with many defects. The main consequence of the presence or adding of iron to AlSi alloys is the formation Fe-rich intermetallics with especially deleterious β-Al_5FeSi. β-Al_5FeSi phases are most often called needles on 2D micro sections, whilst platelets in 3D geometry. The x-ray tomography results have demonstrated Fe-rich phases with shapes different from simple forms such as needles or platelets and presented bent and branched phases. β grown as complicated structure of bent and branched intermetallics can decrease feeding ability, strengthen pores nucleation and eutectic colonies nucleation leading to lower permeability of mushy zone and porosity in the castings.

Keywords: Aluminum alloys, Intermetallics, β-Al_5FeSi, X-ray tomography, Morphology, Solidification

1. Introduction

Aluminium alloys replace materials used in traditional areas such as construction, transportation, packaging, aerospace and machinery. AlSi casting alloys demonstrate sound castability and high specific strength, excellent corrosion resistance, good thermal and electrical conductivity. The properties of AlSi-based alloy castings are influenced by many factors originating from process design or metal quality, such as local thermal conditions, feeding capacity, applied pressure, dissolved hydrogen, inclusions, modifying elements and minor additions.

The main impurities that exist in recycled Al–Si foundry alloys are iron, manganese, copper, and zinc. Iron is considered the most harmful element since its presence enhances the precipitation of many iron intermetallic phases [1]. The main microstructural consequence of adding or presence of iron in Al–Si foundry alloys is the formation of the β-Al_5FeSi phases. These phases cause porosity [2], lower fluidity [3], act as stress concentrators [4] and promote crack initiation and lower fatigue life. β-Al_5FeSi intermetallics increase hardness, reduce impact strength, machinability, but lower soldering of the casting in permanent molds and high pressure die casting. One of the methods being discussed to minimize the negative effect of iron and gain better quality of the castings is artificial melt flow, generated e.g. by rotating magnetic field (RMF) [5,6].

In the last years materials characterization evolved thanks to development in three dimensional visualization. Till now only a few x-ray studies have been performed on the β phases in AlSi alloys [7,8,9]. The present paper studies 3D morphology of β-Al_5FeSi with the Phoenix nanotom® s in order to obtain information on the micro scale. An advantage and exceptionality of current study is that the specimens of AlSiFe alloys were processed in directional solidification facility Artemis-3 [6].

2. Methodology

This study comprises three aluminum alloys with 9 wt.% Si and 0.2, 0.5 and 1.0 wt.% Fe prepared from pure components: Al (99.999% Hydro Aluminium Deutschland GmbH), Si (Crystal Growth Laboratory, Berlin, Germany) and Fe from ferroaluminum (50 wt.% Al-50 wt.% Fe, Goodfellow Cambridge Ltd, UK). The melt was prepared in an electric resistance furnace using a graphite crucible and degassed with argon. No modifier was used. Specimens with 8 mm diameter and 120 length were processed in Artemis-3 facility, which allows directional solidification of metal alloys under controlled conditions [5]. The cylindrical specimens were solidified directionally upwards with a temperature gradient G=3 K/mm and solidification velocity v=0.04 mm/s, with and without fluid flow induced inside the specimen by a rotating magnetic field (RMF) with 6 mT at a frequency of 50 Hz, inducing first azimuthal flow and additionally secondary flows in radial and axial directions.

The six solidified samples were cut at a height of 50 mm from the bottom to the shape of a needle with quadratic cross section (Fig. 1) with dimension of 0.9×0.9×8.0 mm. The three dimensional measurements were done with x-ray tomography system Phoenix nanotom® s (General Electric - Measurement and Control) with 180 kV / 15 W ultra high performance nanofocus x-ray tube producing a volume of 2304×2304×2304 voxels and a pixel size of 1.0 µm (Fig. 1 and 2). Image corrections and ring artefact corrections were applied before the final three dimensional reconstruction. The information gathered in a full scan was reconstructed in “datos|x-reconstruction v 1.5.022” software (GE Sensing and Inspection GmbH) and the image analysis was performed using VGStudio Max 1.2, and processed with Gauss filter. Volume segmentation was carried out by choosing suitable gray levels applying global thresholding.

3. Results and Discussion

Fig. 3a shows a big 700 µm β-Al$_5$FeSi platelet, which is curved along a short, about 100 µm long section (Fig. 3a and b – the bending is marked by a white dotted line rectangle). Actually, the structure could be described as rectilinear but having a bent β-Al$_5$FeSi with curvature in one part. Fig. 3 clearly shows a continuous β platelet (parts labeled A, B and C) and not a connecting point of two phases, which was analyzed in detail in 3D reconstructions. Fig. 4a, b demonstrates a more complex curvature, where the branch at C is rectilinear while branches A and B are curved variably. What has been verified is that features A, B, C and D constitute one phase and not several connected β-Al$_5$FeSi, and platelet branches have clearly been formed with the presence of dendrites. The part E is a separate intermetallic precipitate.

Figs. 5a,b and 3b present very slightly deformed β platelets without a clearly marked bend radius. In this case the β-Al$_5$FeSi edge shaped by dendrites are visible, which proves dendrites of being located near β phases. Three arrows (Fig. 3b and 5a,b) indicate probable places of interaction with a dendrite causing deformation. Deformations of intermetallics, like for example loss of their plate-like form, can be caused by constantly growing dendrites, their secondary and tertiary arms. Phases presented are relatively big and thick, therefore bending relates to large phases and it is likely that forces driving the process are strong with regard to this process scale. In the Fig. 5 the branching effect can be observed, which shows three combined phases C, D and E and suggests that C was the first platelet to nucleate and provide ground for phase D and E to grow on.

β-Al$_5$FeSi phases are most often called needles on 2D micro sections, whilst platelets in 3D geometry. The x-ray tomography results have demonstrated Fe-rich phases with shapes different from simple forms such as needles or platelets and presented bent (Fig. 3,4 and 5) and branched (Fig. 5) phases. Such intermetallics can form complicated and interconnected structures.

The most common and serious defect in aluminum castings is porosity, which is a result of two phenomena, insufficient feeding and/or hydrogen precipitation during solidification.

Let us first discuss the effect of Fe-rich phases on feeding. Large reduction in interdendritic permeability can lower the feedability of the alloy [11] and prevent the fluid flow to fill the cavities and compensate the shrinkage. Taghaddos [12] studied the effect of iron-intemetallics on the fluidity of 413 aluminum alloys and proved that fluidity decrease with increasing Fe.

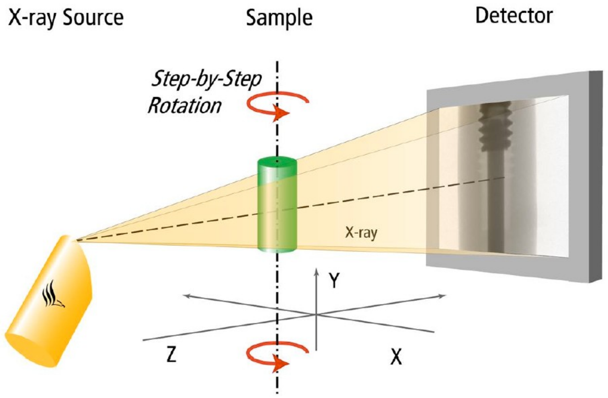

Fig. 1. Principle of CT scanning by Phoenix nanotom® s [10]

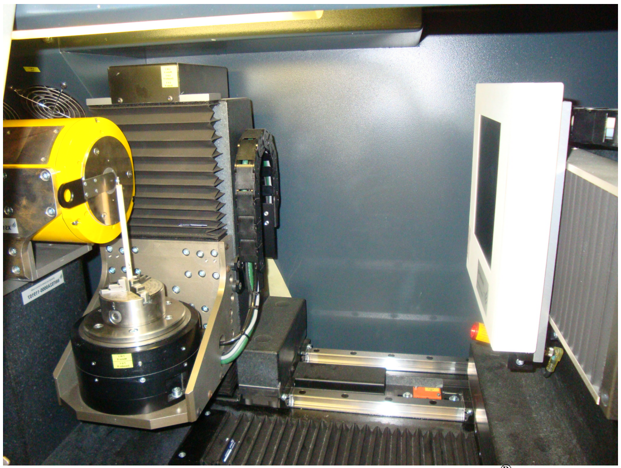

Fig. 2. Measurement chamber by Phoenix nanotom® s with the installed needle specimen (dimensions 0.9×0.9×8.0 mm)

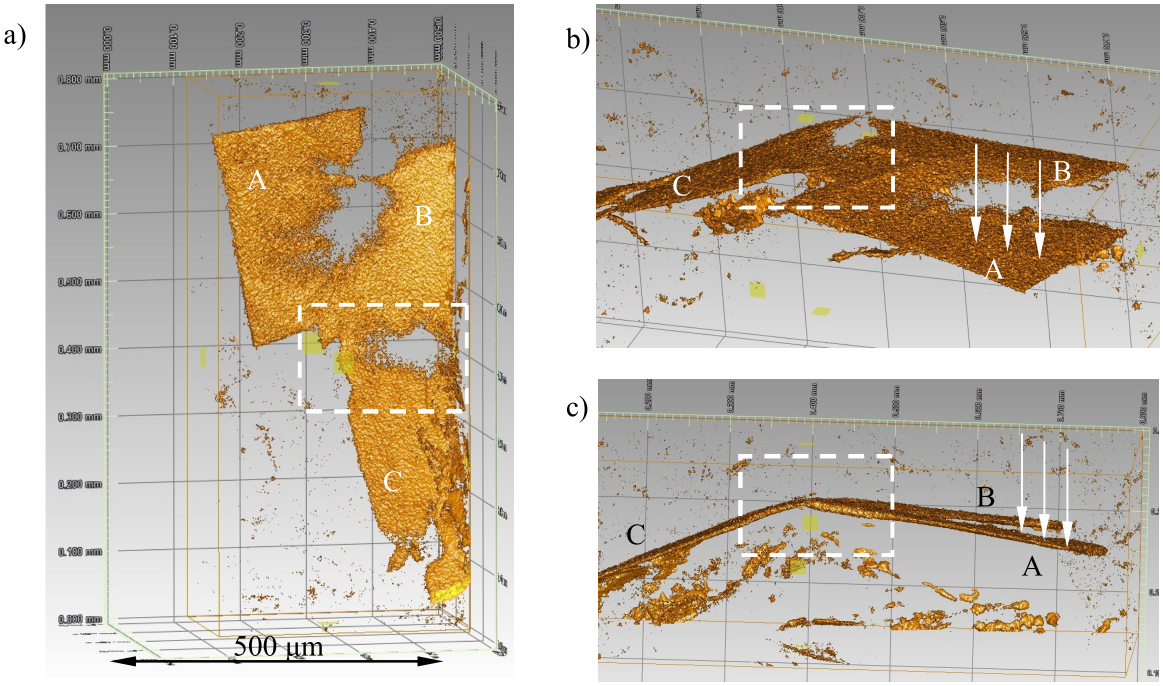

Fig. 3. 3D x-ray microtomography of the bent and interacting β-Al_5FeSi (in cyan) in Al-7 wt.% Si-1.0 wt.% Fe alloy solidified without melt flow

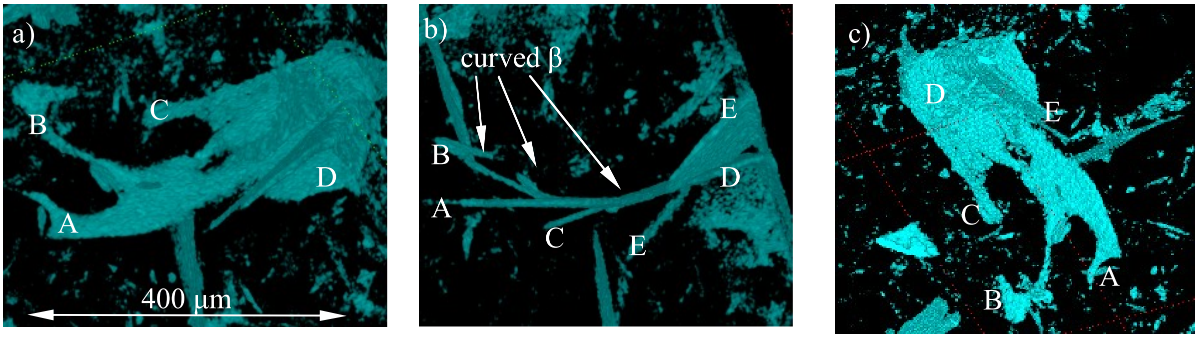

Fig. 4. Three projections of the same group of bent β-Al_5FeSi (in cyan) in Al-7 wt.% Si-1.0 wt.% Fe alloy solidified without melt flow. 3D x-ray microtomography

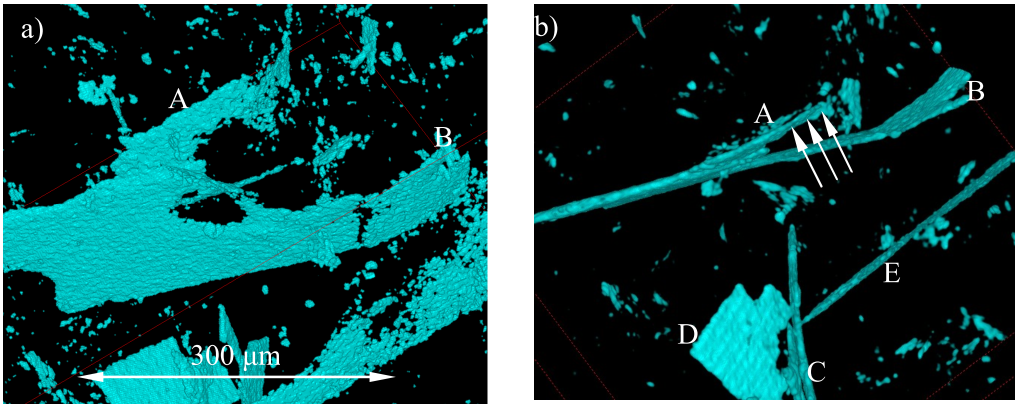

Fig. 5. 3D x-ray microtomography of the bent and branched β-Al_5FeSi (in cyan) in Al-7 wt.% Si-1.0 wt.% Fe alloy solidified without melt flow

It was found [11] that increase in Fe content increases porosity, e.g. increasing Fe content from 0.2% to 2.5% increases porosity per area from 0.5 to 4% in AlSi alloys. It is generally believed that pores are heterogeneously nucleated at the nonwettable foreign substrates and/or at the growing S/L interface [13]. Taylor [14] proposed a model of iron-related porosity based upon the suggestion that β platelets nucleate eutectic silicon and this causes a decrease in permeability. Therefore occurrence of intermetallics, especially large and complicated β-Al_5SiFe (bent and branched) can cause intensive pore nucleation and nucleation of eutectic colonies leading to an increase in porosity in castings.

Existence of β-Al_5SiFe promotes fatigue crack initiation [3], increasing Fe-content reduces fatigue life in long lifetime (>10^6 cycles) [15] as was measured and calculated for 10 and 50 μm long β phases. The β-Al_5FeSi platelet size is essential to alloy ductility and tensile strength in A 356.2 alloy [16]. There it was found that increasing β platelet size from 25 μm to 200 μm causes a significant decrease in elongation (from 14% to 1%) and ultimate tensile strength from 260 MPa to 180 MPa. The large and complicated β phases found out in current study proves that this detrimental effect of β can be even larger.

4. Conclusions

X-Ray tomography investigations have presented bent and branched intermetallics that in AlSi alloys formed around and in interaction with dendrites

Grown large and complex group of β intermetallics can cause reduction of the melt flow between dendrites, strengthen pores nucleation and eutectic colonies nucleation leading to lower permeability of mushy zone and porosity in the castings.

Considering a reduced feedability, increased pore nucleation and crack promotion due to intermetallics suggests a re-design of feeders and rethinking of feeding paths in the castings. Also mechanical properties of the alloys seems to be strong influenced by interconnected Fe-rich phases.

Acknowledgements

This work was carried out in the framework of the project "iPhaseFlow" (contract number PIEF-GA-2009-235874) within the confines of Marie Curie Intra European Fellowship, supported by Seventh Framework Program of the European Union.

References

[1] Skjerpe, P. (1987). Intermetallic Phases Formed during DC-Casting of an Al-0.25 Wt Pct Fe-0.13 Wt Pct Si Alloy. *Metallurgical Transactions A*. 18(A), 189-200. DOI: 10.1007 /BF02825700.

[2] Dinnis, C.M., Taylor, J.A. & Dahle, A.K. (2006). Iron-related porosity in Al–Si–(Cu) foundry alloys. *Mater. Sci. Eng*. A(425), 286-296. DOI: dx.doi.org/10.1016/j.msea.2006.03.045.

[3] Taghaddos, E., Hejazi, M.M., Taghiabadi, R. & Shabestari, S.G. (2009). Effect of iron-intermetallics on the fluidity of 413 aluminum alloy. *Journal Alloy Compound*. 468, 539-545. DOI: dx.doi.org/10.1016/j.jallcom.2008.01.079.

[4] Firouzdor, V., Rajab,i M., Nejati, E. & Khomamizadeh, F. (2007). Effect of microstructural constituents on the thermal fatigue life of A319 aluminum alloy. *Mater. Sci. Eng.* A, 454-455. DOI: dx.doi.org/10.1016/j.msea.2007.01.018.

[5] Steinbach, S. & Ratke, L. (2007). The Influence of Fluid Flow on the Microstructure of Directionally Solidified AlSi-Base Alloys. *Metall. Mater. Trans.* 38(A), 1388-1394. DOI: 10.1007/s11661-007-9162-1.

[6] Mikolajczak, P., Ratke, L. (2012). The role of fluid flow and intermetallic phases in the formation of the primary Al-phase in AlSi alloys. *IOP Conf. Ser.: Mater. Sci. Eng.* 27, 012024 DOI:10.1088/1757-899X/27/1/012024.

[7] Timpel, M., Wanderka, N., Grothausmann, R. & Banhart, J. (2013). Distribution of Fe-rich phases in eutectic grains of Sr-modified Al–10 wt.% Si–0.1 wt.% Fe casting alloy. *Journal of Alloys and Compounds*. 558, 18-25. DOI: dx.doi.org/10.1016/j.jallcom.2012.12.009.

[8] Terzi, S., Taylor, J.A., & Cho, Y.H. (2010). In situ study of nucleation and growth of the irregular α-Al/β-Al_5FeSi eutectic by 3-D synchrotron X-ray microtomography. *Acta Mater.* 58, 5370-5380. DOI: dx.doi.org/10.1016/j.actamat.2010.06.012

[9] Dinnis, C.M. Taylor, J.A. & Dahle, A.K. (2005). As-cast morphology of iron-intermetallics in Al–Si foundry alloys. *Scripta Materialia. 53*, 955-958. DOI: dx.doi.org/10.1016/j.scriptamat.2005.06.028

[10] General Electric – Measurement & Control. Retrieved August 21st 2011 from www.ge-mcs.com.

[11] Moustafa, M.A. (2009). Effect of iron content on the formation of β-Al_5FeSi and porosity in Al–Si eutectic alloys. *Journal of Mater. Proc. Tech*. 209, 605-610. DOI: dx.doi.org/10.1016/j.jmatprotec.2008.02.073

[12] Taghaddos, E, et al. (2009). Effect of iron-intermetallics on the fluidity of 413 aluminum alloy. *Journal Alloy Compound*. 468, 539-545. DOI: dx.doi.org/10.1016/j.jallcom.2008.01.079

[13] Mohanty, P.S. et. al. *Metall. Mater. Trans*. A. 24(A), August 1993-1845.

[14] Taylor, J.A. et al. *Metall. Mater. Trans*. A, vol. 30A, June 1999-1643.

[15] Yi, J.Z. et al. (2004). Effect of Fe-content on fatigue crack initiation and propagation in a cast aluminum–silicon alloy (A356–T6). *Mater. Sci. Eng. A*. 386, 396-407. DOI:dx.doi.org/10.1016/j.msea.2004.07.044.

[16] Ma, Z. et al. (2008). A study of tensile properties in Al–Si–Cu and Al–Si–Mg alloys: Effect of β-iron intermetallics and porosity. *Mater. Sci. Eng. A*(490), 36-51. DOI: dx.doi.org/10.1016/j.msea.2008.01.028.