New progress on the understanding of heterogeneous nucleation and phase transformation of Fe-containing intermetallics in Al alloys

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Fe, as an inevitable impurity element, has limited solubility in Al. Coarse Fe-containing intermetallic compounds (Fe-IMCs) usually form during the casting process. The control of Fe-IMC formation to improve the properties of recycled Al alloys is of both scientific and technological interest [1].

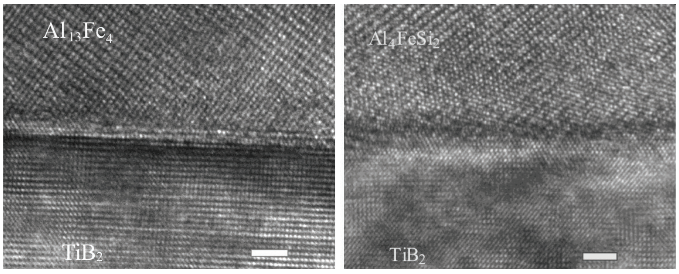

FIGURE 1. High resolution TEM images showing the direct evidence of Fe-IMCs nucleated on the modified TiB_2 particles (a) $Al_{13}Fe_4$//TiB_2, and (b) δ-Al_4FeSi_2//TiB_2.

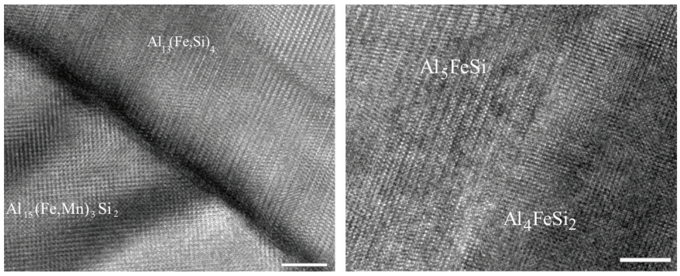

FIGURE 2. High resolution TEM images showing the direct evidence of phase transformation between (a) $Al_{13}(FeSi)_4$//α-$Al_{15}Fe_3Si_2$ (b) Al_5FeSi//δ-Al_4FeSi_2.

So far there is no effective method for refining Fe-IMCs during casting. One of the approaches to overcome the detrimental effect of Fe-IMCs in some Al alloys is heat treatment. For example, the β-AlFeSi with a plate-like morphology was transformed into smaller particles by solid solution treatment. However, understanding of the mechanisms of phase transformation among different Fe-IMCs remains a challenge. As reported in the literature, more than 20 types of Fe-IMCs may exist in different Al alloys. These Fe-IMCs may be easily confused with one another in the as-cast microstructure (phase identification) or after heat treatment (phase transformation). Based on the recent advances in the understanding of pre-nucleation and interfacial segregation [2-3], this research aims to develop an effective approach to refine Fe-IMCs through better understanding of heterogeneous nucleation during solidification and phase transformation during heat treatment.

The major advances on heterogeneous nucleation and phase transformation can be summarised as follows:

(1) Technology development: In the 2017 LiME Report, we reported the significant refinement of α-$Al_{15}(Fe,Mn)_3Si_2$ phase by adding TiB_2 particles with Fe segregation on their surface. In this report, we report the refinement of $Al_{13}Fe_4$, β-A_5FeSi, δ-Al_4FeSi_2, $Al_6(Fe,Mn)$ by the modified TiB_2. Direct evidence for nucleation of Fe-IMCs on the modified TiB_2 was found (Figure 1). Based on this advance, a new grain refiner was developed.

(2) Theoretical advance: the conception of composition templating for the heterogeneous nucleation of compounds were developed [3].

(3) A serial phase reactions such as β-Al_5FeSi→δ-Al_4FeSi_2+Al, β-Al_5FeSi→α-$Al_{15}Fe_3Si_2$+Al, $Al_{13}Fe_4$→$Al_{15}Fe_3Si_2$+Al were identified and investigated on atomic level by HRTEM (Figure 2). The direct evidence for heterogeneous nucleation was observed and the high resolution interfaces were observed by TEM. The mechanisms of phase transformations were firstly explained, and the α-$Al_{15}Fe_3Si_2$ phase with new crystal structure generated during the phase transformation were observed and identified.

(4) Heterogeneous nucleation of Fe-IMCs on natural in-situ oxides were investigated. We found direct evidence for heterogeneous nucleation of long plate-like in-situ $MgAl_2O_4$ particles in Al-Mg-Si alloys.

Future work will focus on:

(1) Further refinement of the Fe-IMCs to achieve the desirable size. For example, refine the size of the β-Al_5FeSi to less than 5 μm and the size of α-$Al_{15}(Fe,Mn)_3Si_2$ to less than 2 μm.

(2) Further study on the mechanisms of phase transformation variation under different solidification conditions (e.g., cooling rate and temperature). For example, the eutectoid reaction of primary $Al_{13}Fe_4$→$Al_{15}Fe_3Si_2$+Al only happens at the very slow cooling rate (0.01K/s), and the peritectic reaction of primary $Al_{13}Fe_4$ +L→$Al_{15}Fe_3Si_2$ is unsteady at a faster cooling rate (3.5K/s), and no phase transformation happens on the primary $Al_{13}Fe_4$ when the cooling rate is increased to 1000K/s.

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