Evolution of Iron-containing Compounds in Al-Cu Alloys during Heat Treatment

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Abstract. The evolution of iron-containing compounds in Al-Cu 206 cast alloy during solution treatment has been investigated. Results show that platelet β-Fe and Chinese script α-Fe are the two iron-containing compounds in as-cast condition. Little change is observed on β-Fe during solution treatment. However, fine blocky post β-Fe begins to form on α-Fe when solution treated at 520°C for 8hrs. When soaking time is extended to 24 hrs, α–Fe is found to decompose to fine branches while post β-Fe present as clusters on these branches. Al-Cu-Mg-Si Q phase is observed to form at the edge of decomposed α-Fe, possibly the result of Si from decomposed α-Fe.

1 Introduction

Precipitation-hardened Al-Cu cast alloy is widely used in the aerospace and auto industries because of its high strength and good elevated temperature properties. During the heat treatment, Al_2Cu eutectic phases will dissolve into matrix during solution heat treatment (SHT) and then precipitate as θ' or θ phase during aging process to strengthen alloy. Though the optimal strength and ductility can be reached at T6 with mounts of θ', T4 or T7 process is often applied to 206 cast alloy in order to increase the stress corrosion resistance [1].

Iron-containing compounds often precipitate during solidification due to the low solubility of iron in Al [2]. The platelet β-Fe (Al_7Cu_2(FeMn)) and Chinese script α-Fe ($Al_{15}(FeMn)_3(SiCu)_2$) are often reported in 206 cast alloys at 0.15%Fe and 0.3%Fe [3-5]. Recently, Chinese script Al_m(FeMn) and platelet Al_3(FeMn) are experimentally observed in 206 cast alloys at 0.5%Fe [6,7]. For the evolution of these iron-containing compounds during heat treatment, it is reported that platelet β-Fe cannot be eliminated within the range of normal solution treatment [3,8] while Al_m(FeMn) is reported to transform to Al_3(FeMn) in AA5182 alloy during homogenization [9]. However, little work is reported about the evolution of Chinese script α-Fe during heat treatment in 206 cast alloy, especially during solution heat treatment performed at higher temperature.

In present work, the evolution of iron-containing compounds in 206 cast alloy during solution treatment has been investigated. It is found that blocky post β-Fe begins to

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precipitate on α-Fe with the increase of soaking time and Chinese script α–Fe finally decomposes to fine branches with clusters of post β-Fe. Al-Cu-Mg-Si Q phase is also observed at the edge of decomposed α-Fe.

2 Experimental

Commercial 206 cast alloy with Al-4.61 wt. %Cu-0.32 wt. %Fe- 0.31 wt. %Mn-0.11 wt. %Si-0.31 wt. %Mg is casted in this work. The casting process can be found in Ref. 4. After solidification, the samples were sectioned for the following solution treatment: (1) Ramping from room temperature to 510^{o}C in 1.5 hrs. (2) Holding at 510^{o}C for 2hrs. (3) Ramping from 510^{o}C to 520^{o}C in 0.5 hr. (4) Holding at 520^{o}C for 2hrs, 8hrs, 12hrs and 24 hrs. (5) Quenching into 65^{o}C water. The microstructures were observed using Scanning Electron microscopy (SEM) equipped with Energy-dispersive X-ray spectroscopy (EDS) as well as Electron Back-Scattered Diffraction (EBSD) and confirmed with Differential Scanning Calorimeter (DSC) heated at 10 K/min.

3 Results and discussion

The microstructures of as-cast alloy and EDS results of different phases are shown in Fig. 1. Combined with the morphology and EDS results, it can be found that there are three kinds of phases: dark Chinese script $Al_{15}(FeMn)_3(SiCu)_2$ (α-Fe), gray platelet $Al_7Cu_2(FeMn)$ (β-Fe) and light Al_2Cu networks. Besides, the volume fraction of β-Fe is low due to the high addition of Mn, which is in consist with the results of Kamga *et al*.[4] and Tseng *et al*.[10].

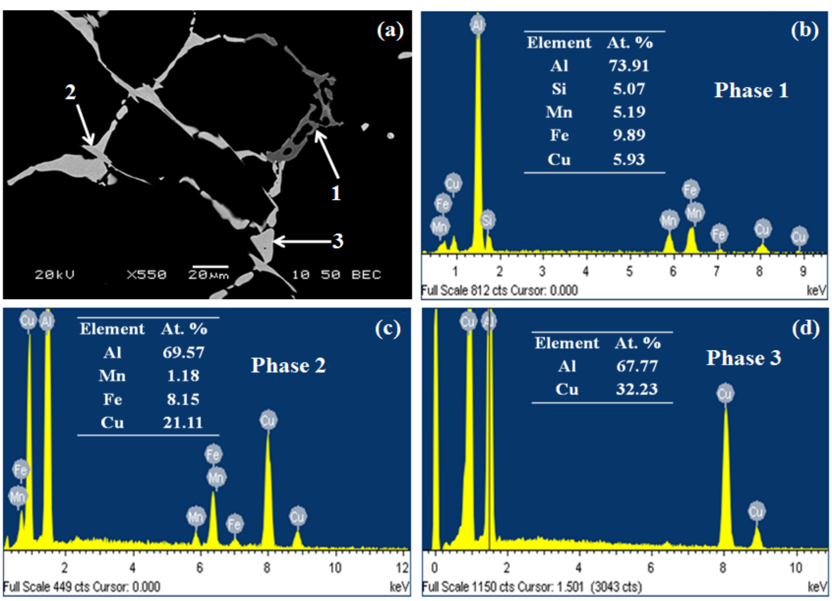

Fig. 1 Microstructures in as-cast alloy and EDS results of the phases

Fig. 2 shows the microstructures of alloy after solution treated at 520^{o}C for various soaking time. It can be found that only part of Al2Cu has been dissolved into matrix and there is no change on iron-containing compounds when solution treated for 2hrs, shown in Fig. 2a, possibly resulted from the incubation time for phase transformation [9]. However, almost all the Al2Cu is observed to dissolve into the matrix when extended to 8hrs, as shown in Fig. 2b. Besides, some blocky phase is observed to begin to precipitate on α-Fe with fine size and low volume. This phase has similar composition with β-Fe and is named as post β-Fe in this paper in order to distinguish with the β-Fe formed during solidification. The size and volume of post β-Fe increase with the prolonging soaking time. As shown in Fig. 2c, many post β-Fe nucleate on α-Fe and grow along the edge of α-Fe while some post β-Fe present as a cluster, possibly resulted from the phase ripening and coalescence. After holding for 24 hrs shown in Fig. 2d, the Chinese script α-Fe seems to have decomposed to fine branches and mounts of post β-Fe present as clusters among these fine branches. However, compared with the morphology and size of β-Fe holding for 8hrs (Fig. 2e) and 24hrs (Fig. 2f), little change is observed on the morphology and size of platelet β-Fe.

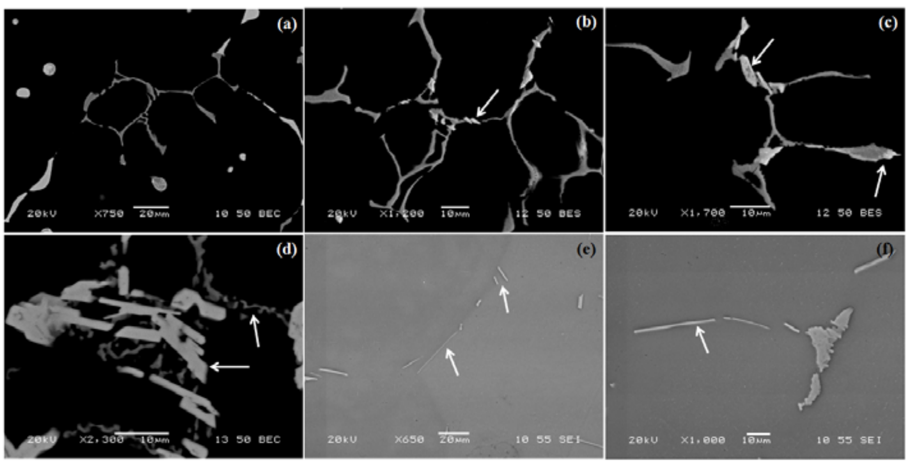

Fig. 2 Microstructures of alloy after solution treat at 520°C for:
(a) 2hrs, (b) and (e) 8hrs, (c) 12 hrs, (d) and (f) 24 hrs

DSC analysis was also performed to check the present phase in as-cast and after solution treated alloys and the heating curves are shown in Fig. 3. The peaks for Al_2Cu, β-Fe and α-Fe are clearly shown in as-cast alloy, confirming the microstructures shown in Fig. 1. After solution treated at 520°C for 24hrs, the peak of Al2Cu disappears due to the dissolution into the matrix but post β-Fe and α-Fe are still present in alloy. Besides, the onset temperature of post β-Fe is higher and the peak intensity is stronger than that of β-Fe, indicating the high volume of new precipitated post β-Fe.

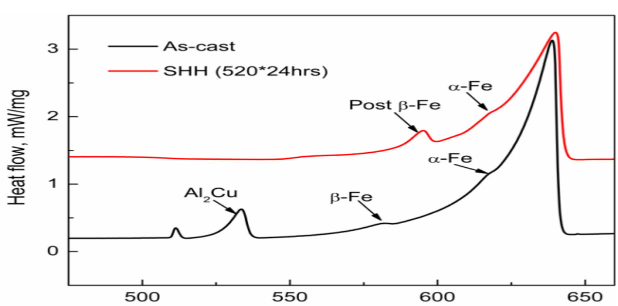

Fig. 3 DSC heating curve for alloys of as-cast and after solution treated

All the results of SEM and DSC show that Chinese script α-Fe will transform to blocky post β-Fe if solution treated for sufficient time, i.e. 24 hrs in Fig, 2d. Fig. 4a shows two fine post β-Fe nucleated on α-Fe when solution treated at 520°C for 8hrs. It is observed that the fine blocky post β-Fe often nucleates between the boundary of α-Fe and matrix, resulted from the high free energy on the interface. Besides, it is reported that the planar disregistry between β-Fe and α-Fe is only 6% [5], much lower than 12%, indicating the likely of nucleation of β-Fe on α-Fe. Once nucleated, the blocky post β-Fe will grow into the branches of α-Fe along some preferred directions. For post β-Fe, the lateral growth is faster than the thickening. As shown in Fig.4a, the thickness of post β-Fe is about 1μm while the length is about 3~4 μm. However, the post β-Fe starts ripening and coalescence with the prolonging solution time. As shown in Fig. 4b, in which the alloy is solution treated at 520°C for 24hrs, it is found that size of post β-Fe is much bigger than that in Fig. 4a, especially in length direction, resulted from the ripening of particles. Besides, some post β-Fe which has similar lateral growth direction starts to coalescence and presents as clusters. α-Fe has decomposed to fine branches, which can be observed among the clusters of post β-Fe.

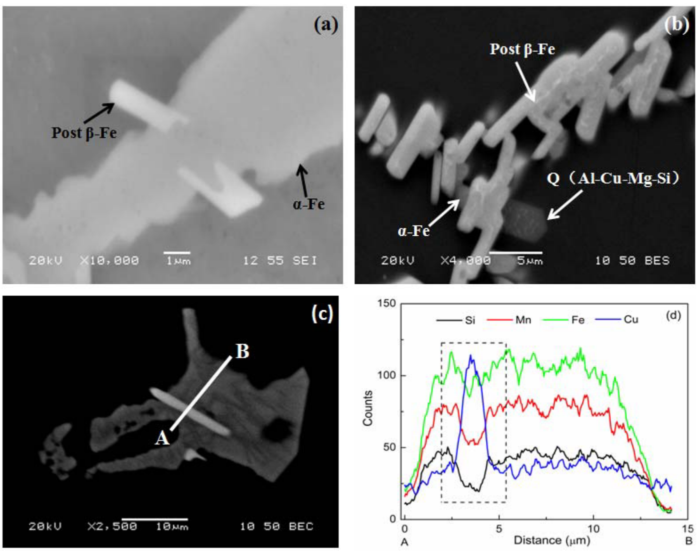

Fig. 4 Phase transformation between post β-Fe and α-Fe and the distribution of elements

Fig. 4c and Fig. 4d show the phase transformation from α-Fe to post β-Fe and the distribution of elements in two phases. It is found that the differences between post β-Fe and the α-Fe matrix is the content of Cu and Si. The content of Cu is much higher but little content of Si has been detected in post β-Fe (Counts of Si is nearly to 0). The content of Fe and Mn also is lower in post β-Fe. Since the lower diffusion rate of Cu [11] and high content of Cu in post β-Fe, the phase transformation from α-Fe to post β-Fe is likely to be controlled by the diffusion of Cu. In as-cast alloy, more Cu element is present in the Al_2Cu networks. During the solution treatment, almost all the Al_2Cu has been dissolved into matrix, as shown in Fig. 2b, and the matrix is enriched with Cu solute. With the prolonging soaking time, it is possible for Cu to diffuse to the edge of α-Fe and then form post β-Fe. Additional, Q phase ($Al_5Cu_2Mg_8Si_6$) is observed to form at the edge of α-Fe after solution treated at 520°C for 24 hrs, as shown in Fig. 4b, attributed to the Si from the decomposed α-Fe.

Though the size of blocky post β-Fe is fine, they will consume Cu during the transformation from α-Fe and decrease the effective Cu content in supersaturated solution, weakening the following precipitation hardening effect. Therefore, the soaking time should be controlled to avoid the formation of mounts of β-Fe. According to the present work, the soaking time should not be more than 8hrs at 520°C.

4 Conclusion

(1). The solidification microstructures in as cast alloy were investigated and Al_2Cu, β-Fe and α-Fe are found to be the dominant phases.

(2). During the solution treatment at 520°C, almost all the Al_2Cu can be dissolved into matrix when holding for 8hrs while fine blocky post β-Fe begins to form at the edge of α-Fe. After holding for 24 hrs, α-Fe has been decomposed to fine branches with clusters of post β-Fe present on these branches and Q phase is observed to precipitate at the edge of α-Fe, possibly resulted from the Si from decomposed α-Fe. However, little change is observed on the morphology and size of β-Fe.

(3). The soaking time on 206 cast alloy should not be more than 8hrs at 520°C to avoid formation of post β-Fe with high volume fraction.

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References

1. Baker, H. *Properties and selection: Nonferrous alloys and pure metals*. American Society for Metals: Metals Park, Ohio, 1979.
2. Belov, N.A.; Aksenov, A.A.; Eskin, D.G. *Iron in aluminum alloys: Impurity and alloying element*. Taylor & Francis: London, 2002.
3. Tseng, C.J.; Lee, S.L.; Wu, T.F.; Lin, J.C. Effect of fe content on microstructure and mechanical properties of a206 alloy. *Mater. Trans., JIM* **2000**, *41*, 708-713.
4. Kamguo Kamga, H.; Larouche, D.; Bournane, M.; Rahem, A. Solidification of aluminum-copper b206 alloys with iron and silicon additions. *Metall. Mater. Trans. A* **2010**, *41*, 2844-2855.
5. Liu, K.; Cao, X.; Chen, X.G. Solidification of iron-rich intermetallic phases in al-4.5cu-0.3fe cast alloy. *Metall. Mater. Trans. A* **2011**, *42*, 2004-2016.
6. Liu, K.; Cao, X.; Chen, X.G. A new iron-rich intermetallic--almfe phase formed in al-4.6cu-0.5fe cast alloy. *Metall. Mater. Trans. A* **2012**, *43*, 1097-1101.
7. Liu, K.; Cao, X.; Chen, X.G. Precipitation of iron-rich intermetallic phases in al-4.6cu-0.5fe-0.5mn cast alloy. *J. Mater. Sci.* **2012**, *47*, 4290-4298.
8. Couture, A. Iron in aluminum casting alloys-a literature survey. *Int. Cast Met. J.* **1981**, *6*, 9-17.
9. Li, Y.J.; Arnberg, L. A eutectoid phase transformation for the primary intermetallic particle from alm(fe,mn) to al3(fe,mn) in aa5182 alloy. *Acta Mater.* **2004**, *52*, 2945-2952.
10. Tseng, C.J.; Lee, S.L.; Tsai, S.C.; Cheng, C.J. Effects of manganese on microstructure and mechanical properties of a206 alloys containing iron. *J. Mater. Res.* **2002**, *17*, 2243-2250.
11. Du, Y.; Chang, Y.A.; Huang, B.; Gong, W.; Jin, Z.; Xu, H.; Yuan, Z.; Liu, Y.; He, Y.; Xie, F.Y. Diffusion coefficients of some solutes in fcc and liquid al: Critical evaluation and correlation. *Mater. Sci. Eng., A* **2003**, *363*, 140-151.