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Homogenization of twin-roll cast A8006 alloy

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Abstract: Microstructure and hardness of twin-roll casting (TRC) process and direct-chill casting (DC) for A8006 alloy with and without homogenization were investigated by means of scanning electron microscopy (SEM), X-ray diffraction analysis and Vickers hardness measurement. The results show that the eutectic phase of the homogenized TRC alloy becomes fine as the microstructure of the as-cast TRC alloy is refined. The short rodlike eutectic phase of the as-cast TRC alloy is dispersed homogeneously, which is similar to the morphology of eutectic phase of the homogenized DC alloy. After homogenization, elements Fe and Mn in DC and TRC alloys are diffused from eutectic phase to Al matrix, resulting in the decrease of microhardness. The formability of the as-cast TRC alloy is superior to that of the homogenized DC alloy. For TRC A8006 alloy, the homogenizing cycle can be removed from the subsequent processing.

Key words: A8006 alloy; twin-roll casting; homogenization; microstructure

1 Introduction

Due to the good combination of rapid solidification and hot rolling into a single operation to fabricate thin strips or sheets directly [1−3], twin-roll casting (TRC) process has advantages of low capital investment and low operational cost, and has attracted global metal producers as the sheets or strips produced have a fine solidification microstructure [4,5]. This process can provide the cooling needed for solidification and the rolling necessary for mechanical reduction. So, it has the potential benefits in both economic and metallurgical fields [6−8].

The 8000 alloy series are special aluminum alloys, in which most typical designations are A8006 (AlFeMn), A8011(AlFeSi), and A8018(AlFeSiCu) alloys [9]. These alloys can be rolled up to thin sheets and foils with hundreds of microns, and have been successfully used in packaging and microelectronics industry. A8006 alloy is widely used for high strength house foil and closure stock, typically sold in O-temper. At present, a significant proportion of A8006 alloy is produced by TRC process, which is usually homogenized prior to cold rolling [10]. A homogenization processing has a critical contribution by allowing the precipitation of excessive alloying elements in solid solution before subsequent thermomechanical processing [7,11−12]. However, the high solidification rate encountered in TRC not only favors the supersaturation and metastable condition but also hinders microsegregation of the alloying elements [13,14]. TRC processed AlFe thin strips show some marked differences with respect to conventional cast strips in their response to an annealing treatment [15,16]. Therefore, it is possible to remove the homogenizing treatment from TRC process.

So far, the literatures on the investigation of the homogenization of the as-cast sheets or strips in terms of microstructure and final properties are scant. The removal of the homogenizing cycle from TRC process is of a significant commercial benefit. In this investigation, the performance of TRC and direct-chill casting (DC) processed A8006 alloy, with and without homogenizing cycles, was studied in terms of microstructure and Vickers hardness.

2 Experimental

The sheets of TRC and DC processed A8006 alloy for this study were provided by Technology Strategy Consultants Materials Engineering Ltd., UK, with nominal composition listed in Table 1.

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Table 1 Nominal composition of A8006 alloy (mass fraction, %)

Fe	Mn	Si	Cu	Mg	Cr
1.487	0.347	0.171	0.06	0.009	0.002

Zn	Ti	B	Na	Al
0.004	0.011	$<10^{-6}$	$<10^{-6}$	Bal.

All tests were made at Department of Engineering Materials, The University of Sheffield. A7 Machine DSC equipment was used during dynamic analysis with a scanning rate of 5 °C/min and an alumina crucible. Samples of sheet with the thickness of 5.30 mm under as-cast conditions were homogenized at 580 °C for 240 min. After homogenization, the samples were prepared by the conventional metallographic techniques, followed by polishing with colloidal silicon. The microstructure of the samples were characterized on a Samscan MK II scanning electron microscope (SEM) equipped with an energy dispersive X-ray analyzer (EDS). The lattice parameters were determined by the X-ray diffraction patterns on a Siemens D500 X-ray diffractometer using Cu $K_{\alpha 1}$ radiation in a 2θ range of 20°−90°. Microhardness test was performed on a Vickers hardness meter (0.1 kg).

3 Results

Before the homogenization, the temperature of homogenization was determined by the DSC test, and the DSC curve is shown in Fig. 1. The result shows that there is no significant change in the heat flow if the temperature is below 540 °C. At the first time (<540 °C), the phase transformations are produced without supply of energy such as spinodal decomposition. At the temperatures above 540 °C, the changes in DSC curve can be ascribed to the nucleation of a new phase.

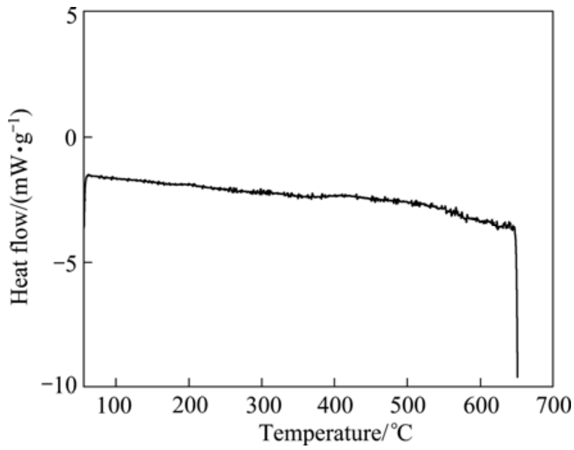

Fig. 1 Dynamic analysis on DSC with phase transformation of A8006 alloy

After DSC analysis, the homogenization was made to study the microstructural evolution. From Figs. 2 and 3, it is evident that the eutectic phase of DC processed alloy is refined, and the eutectic phase of TRC processed alloy becomes much finer as the microstructure of as-cast TRC processed alloy is refined. Secondary

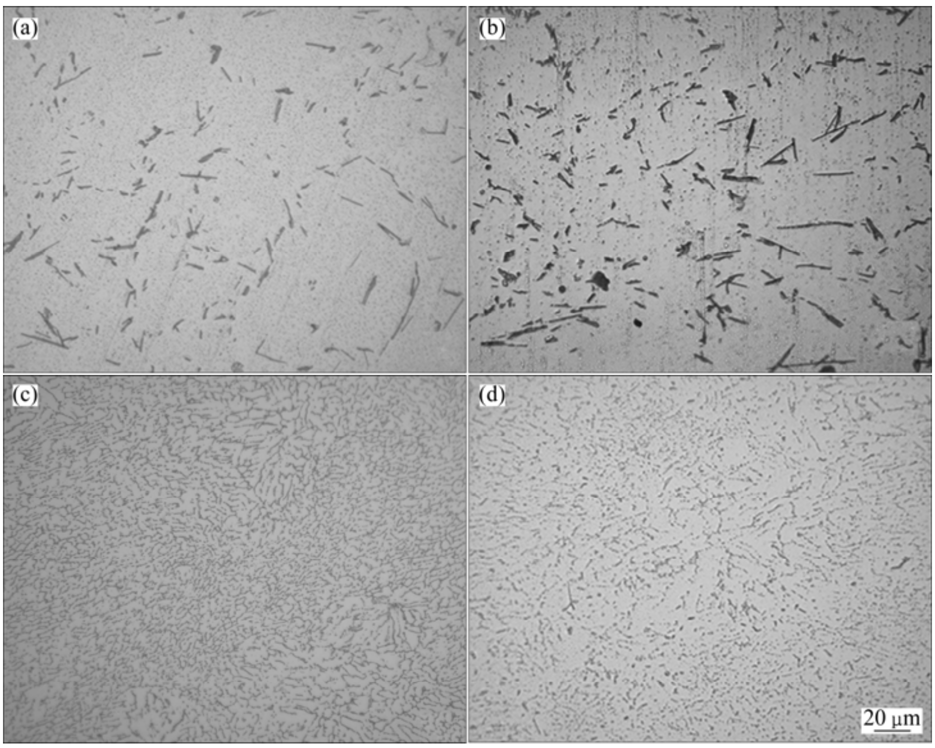

Fig. 2 Optical micrographs of DC and TRC processed A8006 alloys with and without homogenization: (a) DC; (b) DC and homogenization; (c) TRC; (d) TRC and homogenization

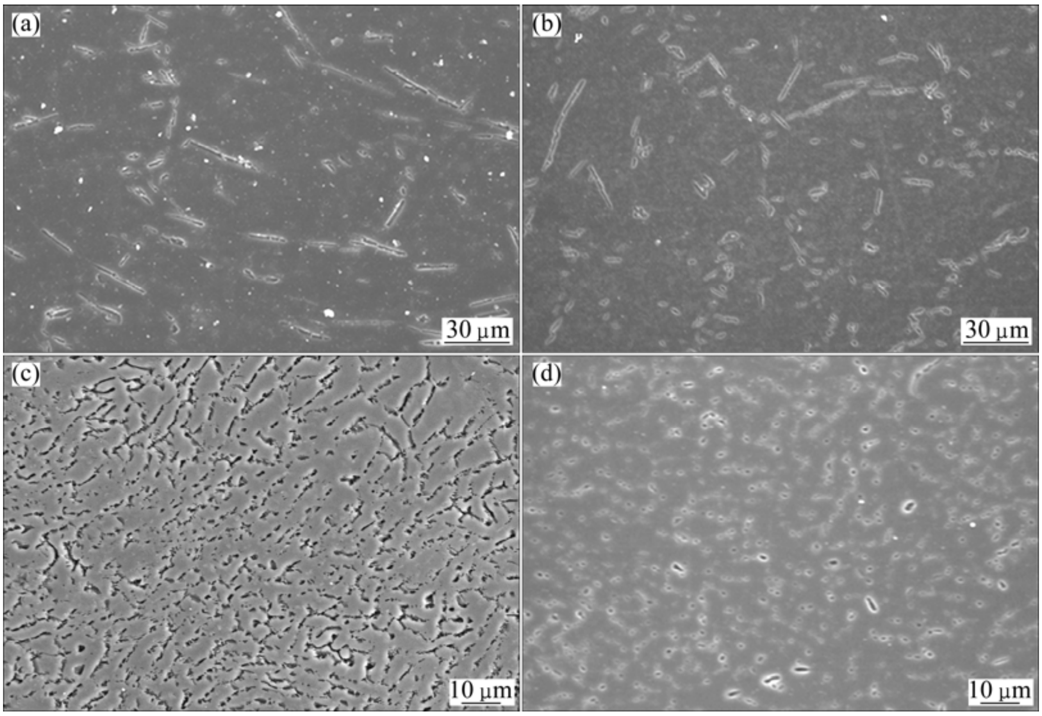

Fig. 3 SEM images of DC and TRC processed A8006 alloys with and without homogenization: (a) DC; (b) DC and homogenization; (c) TRC; (d) TRC and homogenization

dendrite arm spacing (SDAS) in the as TRC processed alloy is (4.63±0.04) μm while the as-DC processed alloy has a SDAS of (18.89±0.08) μm. After the homogenization, SDASs in the TRC and DC processed alloys are rarely decreased. The short rodlike eutectic phase is dispersed homogeneously in Al matrix of homogenized TRC processed alloy. The morphology of the eutectic phase of homogenized DC processed alloy is similar to that of eutectic phase of as-TRC processed alloy.

The EDS results show that contents of Fe and Mn elements in the eutectic phase of DC and TRC processed alloys are decreased after the homogenization, as shown in Table 2. However, the contents of elements Fe and Mn in the eutectic phases of as-TRC processed alloy, which are close to those in eutectic phase of homogenized DC processed alloy, are more further decreased compared with eutectic phase of as-DC processed alloy. Table 3 lists the results of Vickers hardness. It can be seen that the microhardness values of DC or TRC processed alloys are decreased after homogenization.

Figure 4 shows the XRD patterns of DC and TRC processed A8006 alloys. From the X-ray diffraction patterns, neither AlFe nor equilibrium phases present after the homogenization. Nevertheless, the interplane spacing is decreased, as shown in Table 4. Initially, in as-cast condition, {111} interplane spacings of DC and TRC processed A8006 alloys are 2.3523 Å and 2.3306 Å, respectively. The interplane spacings are decreased after the homogenization at 580 °C for 240 min, and they are about 2.3328 Å for DC processed A8006 alloy and 2.3293 Å for TRC processed A8006 alloy. Similar behaviors are also observed for the {200}, {210} and {220} interplane spacings.

Table 2 Chemical microanalysis of eutectic phase in A8006 alloy samples

Alloy	w(Fe)/%	w(Mn)/%
DC processed A8006	57.14	6.12
DC processed A8006 after homogenization	2.25	1.12
TRC processed A8006	8.62	1.72
TRC processed A8006 after homogenization	1.63	0.82

Table 3 Hardness of A8006 alloy samples

Alloy	Vickers hardness
DC processed A8006	47.1
DC processed A8006 after homogenization	36.1
TRC processed A8006	52.2
TRC processed A8006 after homogenization	37.4

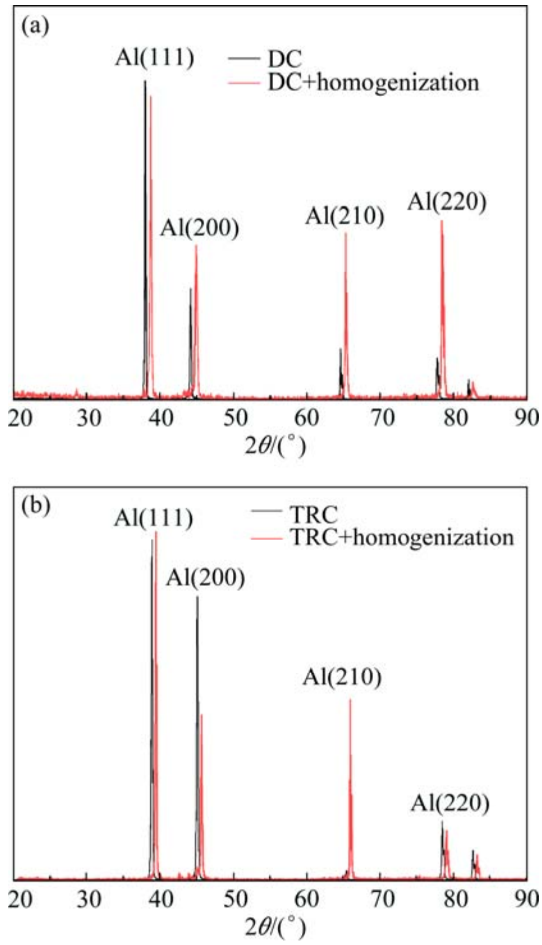

Fig. 4 XRD patterns of samples from DC (a) and TRC processed A8006 alloys (b)

Table 4 Interplane spacings of A8006 alloy samples

Alloy	Interplane spacing/Å	
	{111}	{200}
DC processed A8006	2.3523	2.0372
DC processed A8006 after homogenization	2.3328	2.0202
TRC processed A8006	2.3306	2.0184
TRC processed A8006 after homogenization	2.3293	2.0173

4 Discussion

A dynamic diffusion process is brought during the homogenization, as source of microsegregation on the interdendritic zones. It can produce a short-range order in the aluminium matrix, which has high contents of iron and manganese.

The justification for this metastable phase can not be detected by X-ray diffraction, so it must be associated to the low volume fraction. The decrease of the interplane spacings and the atomic relationship between Al and Fe suggest that a short-range order is necessary for the formation of the Fe-rich or AlFe phase. Based on the X-ray measurements and the other results, the unique configuration possible for that phase is shown in Fig. 5. A Fe-rich or an AlFe phase depends on the following point of view. The lattice of this metastable phase can either be considered face-centered cubic (Fe-rich), with two atoms each of iron and aluminum per unit cell, or body-centered tetragonal (AlFe) with one atom each of iron and aluminum per unit cell. The short-range order can be explained as follows: during decomposition, the aluminum matrix diminishes its lattice parameter up to a_{Al}=3.9785 Å to shelter inside it a body-centered tetragonal lattice where the lattice parameters must be a_{AlFe}=2.8132 Å and c_{AlFe}=3.9785 Å. These results are in agreement with those reported by MORRIS et al [17], who found a tetragonal AlFe structure in a similar aluminum alloy system. Considering the superlattice proposed, the orientation relationships are $[110]_{Al}//[100]_{AlFe}$ and $\{111\}_{Al}//\{110\}_{AlFe}$ represented in Fig. 5. This is the main reason to improve the formability of A8006 alloys. In addition, the fine grain size and fine eutectic phase of A8006 alloys are also contributed to the improvement on the formability and decrease in the hardness after homogenization.

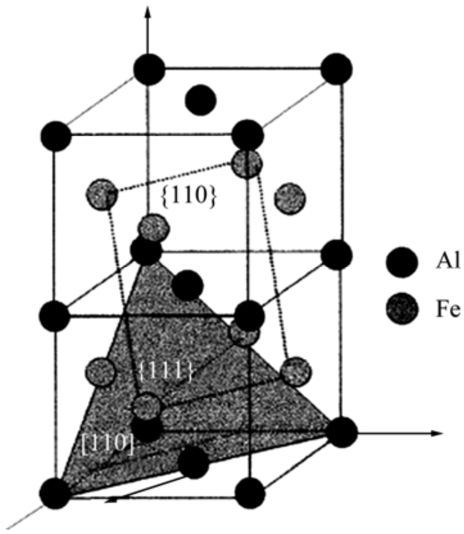

Fig. 5 Lattice of Fe-rich or AlFe phase showing an Al/Fe atomic relationship

In comparison with microstructures and interplane spacings of as TRC processed and homogenized DC processed A8006 alloys, TRC process is beneficial for the less microsegregation, the improvement on the microstructure of as TRC processed A8006 alloy and the formability of the aluminium sheet as well. Hence, the homogenizing cycle can be removed from the process for TRC processed A8006 alloy.

Considering a diffusion path equal to the dendrite arm (λ), the time (t) for homogenizing can be expressed as [18]:

$$\lambda^2=Dt \tag{1}$$

where D is the diffusivity of the element to be homogenized in the Al matrix. As Fe element is the major alloying element in the present alloy, D can be considered the diffusivity of Fe in Al. Consequently, the ratio of homogenizing time for TRC (t_{TRC}) to DC structures (t_{DC}) is as follows:

$$\frac{t_{\mathrm{TRC}}}{t_{\mathrm{DC}}}=\frac{\lambda_{\mathrm{TRC}}^2}{\lambda_{\mathrm{DC}}^2} \tag{2}$$

where λ_{TRC} and λ_{DC} are SDASs for TRC and DC processed alloys, respectively. Substituting the values of λ_{TRC} and λ_{DC}, the ratio of $t_{\mathrm{TRC}}/t_{\mathrm{DC}}$ is about 0.06, which suggests that the time for homogenizing a TRC microstructure is about one sixteen that for homogenizing a DC microstructure. So, the homogenizing treatment is not necessary for TRC A8006 alloy.

5 Conclusions

1) After homogenization, the eutectic phase of DC processed A8006 alloy is refined, and eutectic phase of TRC processed A8006 alloy is further refined as the microstructure of as TRC processed alloy is refined. The short rodlike eutectic phase of as TRC processed alloy is dispersed homogeneously, which is similar to the morphology of eutectic phase of homogenized DC processed alloy.

2) EDS results show that after homogenization the composition of alloys is diffused homogeneously from eutectic to Al matrix, such as Fe and Mn elements

3) The decrease of microhardness for DC or TRC processed alloy is due to the homogeneous composition after homogenization.

4) As TRC processed alloy has better formability than the homogenized DC processed alloy. For TRC processed A8006 alloy, it is possible to remove the homogenizing cycle from the process.

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双辊激冷铸造 A8006 合金的均匀化

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摘 要：通过 SEM、XRD 与硬度测定研究均匀化过程对双辊激冷铸造(TRC)与直接冷却铸造(DC)A8006 合金的微观组织和性能的影响。结果表明，随着 TRC 合金微观组织的细化，均匀化后合金中的共晶相进一步细化。DC 合金均匀化后其共晶相形态相似于 TRC 合金中的共晶相形态。均匀化后，合金共晶相中的 Fe、Mn 元素均匀地扩散到铝基体中，引起合金硬度的降低。TRC 合金的成形性能优于均匀化的 DC 合金，所以，对于 TRC A8006 合金的后续加工过程可省去均匀化过程。

关键词：A8006 合金；双辊激冷铸造；均匀化；微观组织

(Edited by YANG Hua)