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The improvement of boron treatment efficiency and electrical conductivity of AA1070Al achieved by trace Ti assistant

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A B S T R A C T

Generally, Ti in solution damages the electrical conductivity of aluminum, so the less the better. However, during boron treatment process trace Ti can promote the precipitation of transition metal elements in forms of doped borides, thus improving the electrical conductivity of aluminum. With conventional boron treatment, the efficiency is 77.7% and electrical conductivity of AA1070Al is 64.6%IACS. However, with Ti assistant, owing to the compositional evolution of borides, the efficiency can reach 93.3% and electrical conductivity of AA1070Al is increased to 65.3%IACS, which is much higher than that with conventional boron treatment. Based on this, a novel composite boron treatment technology is proposed and a schematic diagram is built to analyze the complex reaction mechanism of boron treatment.

1. Introduction

Nowadays, aluminum is one of the most important industrial conductive materials. In order to satisfy the requirements of industrial applications, good electrical conductivity should be improved [1–3]. As we all know, the electrical conductivity of aluminum is affected by its purity obviously and especially transition metal (abbreviated to TM) elements (V, Ti, Zr, Cr, *etc.*) in solid solution tends to cause lattice distortion, increasing the electron scattering which is harmful to electrical conductivity [4]. Thus the content of TM elements should be controlled within a certain range. For conductive Al materials, boron treatment is an effective method to improve the electrical conductivity [5–7]. Nowadays, Al–B master alloys are widely used in the production of electrical conductive grade aluminum to improve the electrical conductivity [8–10]. Fig. 1 shows the process of boron treatment in detail. The addition of boron makes TM impurities from solid solution into precipitation state, leading to the formation of TM borides that subsequently settle down at the bottom of Al melts. Thus it can maximum limit their damage to electrical conductivity. Wang et al. [11] reported the influence of boron on electrical conductivity of Al alloys, but the forms of borides involved in the reaction is unclear. Most of scholars [1–7] think that during boron treatment process, the products are TiB_2, VB_2, ZrB_2, CrB_2 respectively [11–13], however, according to our study, the products of boron treatment tend to be $(Al,V,Ti,Zr)B_2$ doped particles. Boron treatment has been widely used for the removal of TM impurities from molten aluminum [13–15], but the detailed formation mechanism and existence forms of borides are still being debated in the literature. Most of them are focus on the change of electrical conductivity with boron treatment, but rare of them are focus on boron treatment efficiency and detailed reaction mechanism.

As mentioned above, TM elements in solid solution damage the electrical conductivity of Al seriously, so the less the better for conductive aluminum [16–18]. However, Ref [19,20] reported that the combination between boron treatment and grain refinement can improve the electrical conductivity and mechanical properties of Al alloy simultaneously. Excess Ti contained in the grain refiners may damage the electrical conductivity but combined with boron treatment, the damage of Ti to electrical conductivity can be reduced [19,20], which is interesting. Excess Ti in master alloys is

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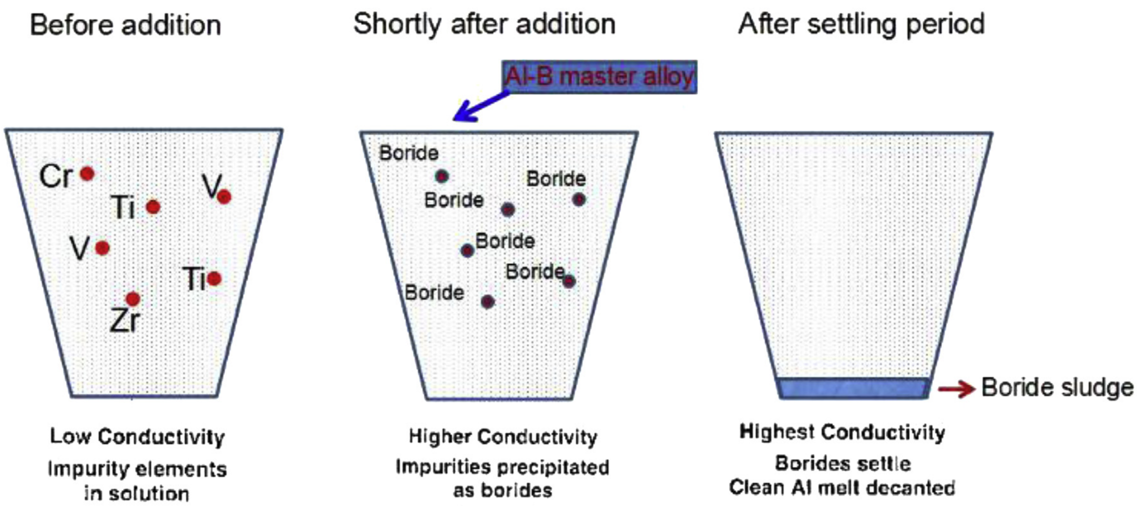

Fig. 1. Schematic representation of the removal of impurities by boron treatment.

beneficial for grain refinement and according to our study, excess Ti can also make contribution to boron treatment, thus the effect of trace Ti on boron treatment efficiency is studied in our work. At the same time, the effect of trace Ti on boron treatment efficiency and the existence form of borides will be studied in detail. At last, a complex reaction mechanism of boron treatment can be proposed and a schematic diagram for boron treatment will be drawn which is important for the optimization of boron treatment process.

2. Experimental process

In this study, AA1070Al (all compositions quoted in this work are in wt.% unless otherwise stated) has been chosen for the research. For boron treatment experiments, firstly, AA1070Al was melted in a medium frequency furnace at 750 ± 10 °C. Then the Al melts was moved to electric resistance furnace holding at 750 °C. Secondly, Al—3B master alloy was added into the melts keeping for 60 min and then furnace cooling to room temperature (marked as conventional boron treatment, CBT). In order to study the effect of Ti element on boron treatment efficiency, trace Ti immediately after Al—B master addition, was added to the melts during boron treatment process (marked as boron treatment with Ti assistant, TBT). In our experiment, in order to analyze boron treatment mechanism and the effect of trace Ti on boron treatment efficiency, AA1070Al melts at 750 °C with CBT or TBT were keeping for 60 min and then furnace cooling to room temperature and the specimens at upper and bottom were analyzed respectively. But after boron treatment mechanism and the effect of Ti on boron treatment efficiency were analyzed clearly, we make use of CBT and TBT to modify AA1070Al and keep the melts at 750 °C for about 30 min and then poured AA1070Al melts on the upper into a mould with size of 10 mm in diameter and 150 mm in length to fabricate rod type specimens for electrical conductivity test.

Specimens for metallographic micro-structure observations were cut from the AA1070Al with different treatments. Metallographic samples were mechanically grounded and polished through standard routines. The microstructures were observed by using field emission scanning electron microscope (FESEM, SU-70, Japan), equipped with an energy dispersion spectrum (EDS) detector, high resolution transmission electron microscopy (HRTEM). The electrical conductivity properties test bars were machined to rod type specimens (10 mm in diameter and 150 mm in length), and examined by a RS.03-DX200H electrical resistivity meter according to the ASTM B193 standard. In this paper, the unit of electrical conductivity is %IACS and IACS means International Annealed Copper Standard. The electrical conductivity of international annealed copper is 100%IACS. Each performance test data is an average of three specimens for accuracy. The contents of elements were tested by SPECTROMAX spectro analysis instrument.

3. Results and discussion

3.1. Study about the effect of trace Ti on boron treatment efficiency

During boron treatment process, the state of TM elements changed from solid solution state into precipitation state in forms of borides. Owing to the change of existence state of TM elements, it can reduce the crystal lattice distortion of Al matrix and the electron diffraction has been significantly reduced, thus the corresponding electrical conductivity of AA1070Al can be improved. Besides, with boron treatment, Ca element in Al melts can react with boron forming CaB_6 easily, thus reducing the damage of Ca to electrical conductivity of Al, so we listed the change of TM and Ca elements in Table 1, Table 1 shows the change of main TM and Ca elements in AA1070Al with CBT and TBT. In this paper, through the analysis about the change of impurity elements with different boron treatments, it can be found that by CBT, the elements of V, Ti, Cr, Zr, Ca in AA1070Al can be reduced to 10 ppm, 22 ppm, 11 ppm, 4 ppm and 8 ppm respectively. While boron treatment with Ti assistant, the elements of V, Ti, Cr, Zr, Ca in AA1070Al can be further reduced to 5 ppm, 4 ppm, 3.5 ppm, 3 ppm and 1 ppm respectively. With CBT, the main impurities of (V + Ti + Cr + Zr + Ca) elements

Table 1
Spectral analysis of main TM and Ca elements in pure Al with boron treatment (unit: ppm).

Elements/Alloys	V	Ti	Cr	Zr	Ca	B
AA1090Al	3	5	6	3	16	4
AA1070Al	139	48	15	19	26	8
CBT (upper)	10	22	11	4	8	145
CBT (bottom)	>1600	922	94	306	15	451
TBT (upper)	5	4	3.5	3	1	120
TBT (bottom)	>1600	>1690	145	498	17	489

Explanation: CBT (add 600 ppm B); TBT (add 100 ppm Ti and 600 ppm B).