[Article ID] 1003- 6326(2002)02- 0277- 03

Composite purification technology and mechanism of recycled aluminum alloys ①

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[Abstract] Iron-rich inclusions in aluminum alloys can be effectively removed by composite purification of sedimentation and filtration technology. The results show that the purposed method has no negative effects on aluminum alloys and obviously improve their mechanical properties.

[Key words] aluminum alloy; composite purification; mechanism
[CLC number] TF803.25 **[Document code]** A

1 INTRODUCTION

With increasing importance of aluminum alloys in industry, the iron-rich inclusions in waste aluminum alloys have caused many problems of recycling. These iron-rich inclusions from furnace charge, smelting tools and molding process are coarse acicular and quite brittle. They largely affect the alloys' physical, chemical and mechanic properties, which are shown respectively as follows: 1) coefficients of thermal conductivity and linear expansion become smaller; 2) resistance to corrosion decreases because of large potential difference between Al and Fe; plasticity and tensile strength decline due to coarse acicular iron passing through α(Al) crystal.

In order to better recycle and develop Al alloys, de-iron purification treatment must be taken on them. Experiments show that the core of sedimentation technology is to add elements which can combine with liquid Fe as low-melting particles (compounds) and deposit to the bottom of crucibles. Keep the sediments when running then iron can be removed. After that, Al obtained by the method mentioned above can be filtered purification by the filtration in gating system[1~4].

2 EXPERIMENTAL

2.1 Experimental materials

An Al-Si alloy with 1% Fe was prepared and its chemical composition is listed in Table 1.

Table 1 Chemical compositions of Al-Si alloys with 1% Fe

Element	Si	Mn	Fe	Mg	Cu	Zn	Al
w / %	8.0~ 10.5	0.46	1.0	0.3	0.3	0.3	Bal.

In the Al-Si alloy, Fe usually exists as $Fe_2Si_2Al_9$ (β) phase and additional small amount of AlSiMnFe phase. Its composition (in mass fraction) analyzed by electron microprobe is 72.89% Al, 8.823% Si and 18.096% Fe, by which the iron-rich phase can be calculated to be $Fe_2Si_2Al_9$ which is long acicular and distributed in the inner and boundary of (αAl) crystals as observed by optical microscopy.

2.2 Preparation of intermediate alloys in sedimentation technology

Intermediate alloys, adding Mn, Cr, Ni, etc. to Al-Si base alloys, were prepared by the results of orthogonal experiments to prevent liquid Al from excess melting loss, oxidation and gettering.

Such intermadiate alloys were processed by melting and over-heating 3/4 of Al-Si alloy ingots in graphite crucibles, adding respectively preheated elements (such as Mn, Cr, Ni of 1cm), stirring completely and then adding remaining Al-Si alloys. After that, melted elements were degasified with C_2Cl_6 at about 850 ℃, stewing for 5 min then pouring quickly, ingots could be obtained (best with thickness ≤254 mm).

2.3 Procedure of de-iron purification in sedimentation technology

Alloys were melted in No. 5 crucible (1.5 kg per melt) and the intermediate alloys were added at 850 ℃. Degasification and skim refining was taken at 750 ℃ after they were completely melted and mixed. In sedimentation process, iron-rich compounds can not be formed or their growth will be restrained at high temperature; however, the iron-rich compounds

① [Foundation item] Project (98- 107) supported by Youth Foundation of Harbin Institute of Technology
[Received date] 2001- 08- 30; [Accepted date] 2001- 11- 05

are easy to form, the viscosity of liquid Al will increase and the deposition of these compounds is slowed down at low temperature. Therefore, it was concluded that the sedimentation process is kept at 690 ℃ and three examples (each less than 6 g to reduce experimental errors) are taken at definite time intervals after complete mixing. Their iron contents were measured to test the sedimentation effects at a certain moment. When the content no longer increases with time, the interval can be regarded as sedimentation time and corresponding iron content can be used as a de-iron index.

2.4 Treatment of filtered liquid alloys after sedimentation

The foam ceramic filtration was taken to purify liquid alloys after sedimentation. Due to mechanical interception and deep absorption, solid iron-rich compounds were kept in the gating system so that the alloys were composite purified.

3 EXPERIMENTAL DATA

The mechanical properties of Al alloys, which were obtained from the orthogonal results before and after de-iron sedimentation, are listed in Table 2. It is found that the mechanical properties of de-iron Al alloys are obviously improved.

The chemical composition of Al alloys before and after de-iron are listed in Table 3. It is found that the contents of major elements in de-iron Al alloys are in an admissible range. Additionally, the trace elements (such as Ni, Zr) can facilitate refining grain and enhance alloy's tenacity, which indicate that the remains of de-iron additions will not pollute Al alloys.

After de-iron treatment, iron-rich compounds of Al alloys decrease and more widely disperse, which result in the decline of stress concentration effects in Al alloys, depletion of rarefaction and pore content, and removal of crack source caused by iron-rich compounds. Suspending particles in purified liquid can be non-spontaneous nucleating center to refine grains as well. Meanwhile, composite purification reduces the viscosity of liquid Al alloys, improves their fluidity and effectively restrains the supercooling between solid and liquid phase, which leads to a smaller crystallizing region, i. e. smaller distance of secondary arborescent crystals, and effectively checks the formation of dispersed rarefaction. Therefore, the mechanic properties of composite purified Al alloys (especially plasticity and tenacity) are apparently improved[5].

4 ANALYSES OF COMPOSITE PURIFICATION MECHANISM

4.1 Sedimentation mechanism

Mn is a good addition[6] to remove Fe by forming high melting iron-rich compounds and depositing. Cr has preferable properties of inoxidizable melting loss though it is not so useful as a de-iron addition as Mn. Ni is added to reduce brittleness caused by remaining Mn and Cr. Otherwise, the residual compounds of Mn, Cr, Ni will exist as large acicular particles. Therefore, the elements above are selected to intermodulate and improve de-iron ability. As the result shows, the purification effects of multiple additions are better than that of single element.

These additions will interact with coarse acicular iron-rich compounds in liquid Al alloys and form multiple iron-rich compounds, which will grow with decreasing temperature and deposit when they are big enough to overcome sedimentation force. As for

Table 2 Mechanical properties before and after de-iron

Property technology	σ_b/MPa		δ/%	
	Dispersion value	Mean value	Dispersion value	Mean value
Before de-iron	197 172 173 173	174	4.6 5.0 3.3 4.3	4.3
After de-iron	198 225 202 246	218	5.8 6.5 6.3 6.7	6.3
Add and subtract/%	25		47	

Table 3 Chemical compositions of Al alloys before and after de-iron

Element	Si	Mn	Mg	Cu	Zn	Cr	Ni	Zr	Fe	Al
Before de-iron	80~10.5	0.46	0.3	0.3	0.3	–	–	–	1.0	Bal.
After de-iron	9.64	0.48	0.3	0.3	0.3	0.10	0.16	0.12	0.20	Bal.

smaller one, they will suspend in the liquid and can be removed through the filter.

4.2 Mechanical interception mechanism

The complex structure of foam ceramic has strong efficiency in mechanical interception, which results from the sedimentation of filtered inclusions whose sizes are bigger than the surface pore of the filter. Such inclusions pile up at the inlet of the filter and act as "a filtered plate" to make running channels smaller so that new filter medium surface can intercept finer inclusions. Meanwhile, deep filtration processes in the inner of media. Among the many pores of ceramic body, some are minute slits, some are dead angles and these different regions are all possible positions to intercept inclusions as the mechanical interception is named[6,7]. Fig. 1 shows the water simulation experiment results of mechanical interception with a horizontal setting filter.

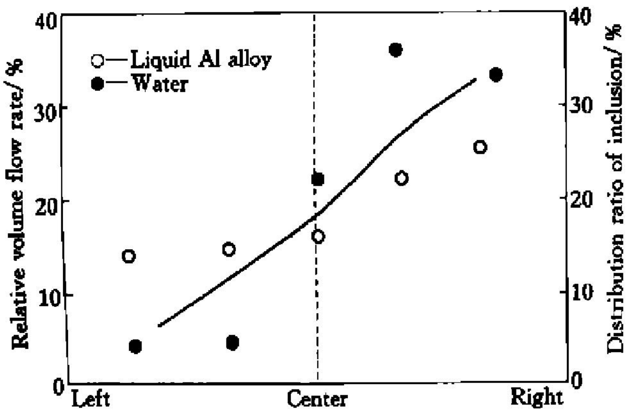

Fig. 1 Results of mechanical interception based on water simulation experiment

4.3 Surface effect

Liquid metals will be greatly divided through complex ceramic, which increase the contact areas and possibilities of their inclusions and filer media since the filter surface is minute roughness together with static absorption and adhesion interception effects on inclusions[8]. Of high surface energy, inclusions have poor wettability on metals and can easily be separated from liquid, and liquid metals of high energy can "sinter" inclusions on the surface of the filter ceramic body.

4.4 Rectification effects

As liquid metals are divided into many smaller plumes through the foam ceramic filter, their Reynolds number ($Re = vd/r$) decreases and the metals have a tendency of laminar motion. When they are in laminar state, the density of liquid metals is far above that of inclusions, so inclusions can completely rise and be removed, i. e. the foam ceramic filter is helpful for skimming of cross gates. The filter settled in the gating system can increase flow resistance force of liquid metals and overflow in cross gates can be easily formed to slow down flow velocity, which favors the rising of inclusions and their stagnation on top of cross gates, i. e. skimming effects of cross gates can be represented to the largest extent with the subsidiary foam ceramic filter.

In gating system, three filtration mechanisms are used to remove inclusions. At the inlet of the filter, mechanic interception is the major mechanism; at the inner, absorption and adhesion interception are major ones. Under such conditions, many inclusions can be intercepted, and the assistant skim effects of cross gates can be obviously presented due to the rectification of the filter.

5 CONCLUSIONS

1) Multiple additions interact with coarse acicular iron-rich compounds in liquid Al alloys, and the multiple iron-rich compounds obtained will grow and deposit with decreasing temperature, while smaller ones which are not big enough to resist sedimentation force and suspend in liquid can be filtered removed.

2) With composite purification, the iron-rich alloys can completely meet the requirement of production with their strength σ_b improved by 25% and elongation percentage δ by 47%.

3) Composite purification combines sedimentation process with filtration technology and can effectively remove iron impurity of Al alloys.

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(Edited by HE Xue-feng)