

The Influence of Fe on Grain Refinement of Recycled A 356 Alloy Initially Refined by Al-5Ti-1B Master Alloy

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Abstract

This research investigated the effect of Fe on the grain refinement of the recycled A 356 alloy refined by Al-5Ti-1B master alloy using macrostructure examination and chemical composition analysis. Results showed that as recycling number increased, the grain refining performance of Al-5Ti-1B master alloy decreased, particularly in the subsequent recycling process. The decreased concentration of titanium and boron were responsible for the degraded grain refining effect in the recycled A356 alloy. Appropriate concentration of the residual iron in recycled A356 provided the grain refining effect which can compensate the degraded grain refining performance of Al-5Ti-1B master alloy. It is suggested that adding the additional Al-5Ti-1B grain refiner and an intentionally added iron of 0.3 wt. % should be a practical alternative to maintain the grain refining efficiency of recycled A356 alloy.

Keywords: A356 alloy, Al-5Ti-1B master alloy, Grain refinement, Macrostructure examination, Recycling, Residual iron

Introduction

Among the various kinds of aluminum alloys, A 356 alloy is extensively used in industries like the automobile and marine applications [1,2]. To reply with the purpose of improving casting quality and mechanical properties of A 356 alloy, fine-grained structures of this alloy are evidently required [2,3]. The commonly used technique in the aluminum foundry industry is adding the master alloy into the melt A356 alloy so that the fine equiaxed grain structure can be obtained [3,4]. Al-5Ti-1B master alloy is known as a useful grain refiner, which can effectively provide the grain refining effect to A356 alloy. The addition of this grain refiner promotes the formation of nucleant particles. These particles then become the nucleation sites of primary α -Al, enhancing the production of grain-refined A356 alloy [4,5].

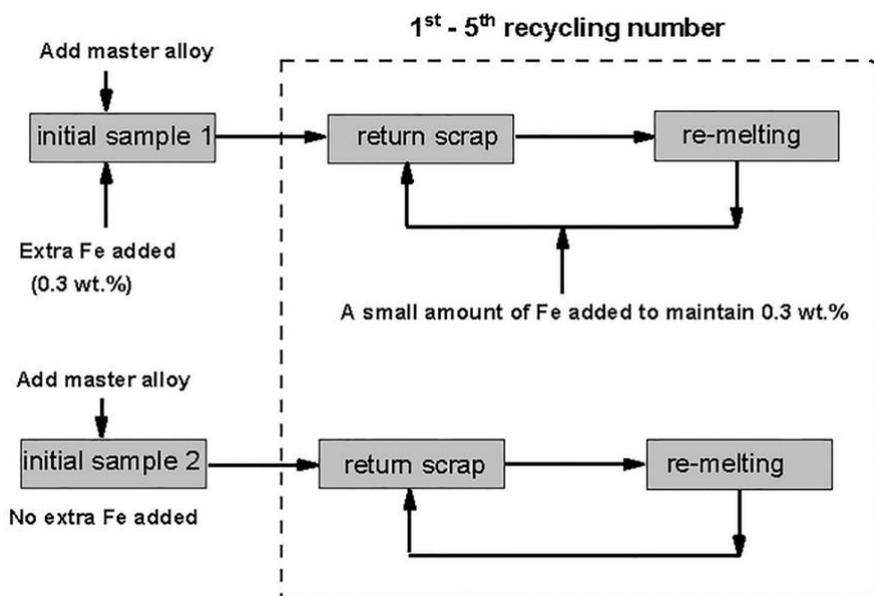
Nowadays, the recycling process of A356 alloy plays an essential role in the aluminum foundry industry. This process remarkably decreases energy usage and the adverse effect to the environment for aluminum casting industries. Interestingly, this process possesses 1-third of aluminum casting products produced from industries [6,7]. However, the significant concern of this process is the alternation of the fine-grained structure of recycled A 356 refined by Al-5Ti-1B master alloy. Besides, in die casting process, the contamination of Fe in the melt recycled A356 alloy is unavoidable. Thus, the imperative question emerged from casting industries whether or not the grain refining performance of Al-5Ti-1B master alloy is still sufficient for the whole recycling process, particularly for the melt recycled A 356 contaminated with Fe from the casting process. In addition, the role of Fe on the grain refinement is still far from clear, especially in the recycling process. Therefore, this paper aims to elucidate such doubtful questions by examining the grain refining performance of Al-5Ti-1B master alloy on the recycled A356 alloy containing a residual Fe. Besides, the practical alternative for maintaining the fine grain structure of the recycled A356 alloy was also suggested.

Experimental procedures

The present studies were carried out by using ASTM 356 aluminum alloy as exhibited in **Table 1**.

Table 1 Chemical composition of A356 alloy used in this study (wt. %).

Sample	Si	Cu	Mg	Zn	Fe	Mn	Ti	Al
A356	7.330	0.040	0.313	0.115	0.150	0.007	0.132	Bal.
A356 with an extra Fe	7.310	0.037	0.303	0.095	0.3	0.010	0.125	Bal.

**Figure 1** Schematic diagram of the experimental procedure in this investigation.

A 356 alloy was melted in a graphite crucible at the controlled temperature of 780 °C by an induction furnace. The zircon-coated mold was used in this study and it was preheated at 300 °C in a closed electric heat-treating furnace. The whole weight of A 356 ingot used in the initial period of each experiment was 2 kg. A covering flux was prepared at the ratio of 45 wt. % sodium chloride, 45 wt. % potassium chloride, and 10 wt. % sodium fluoride and it was then added at the beginning melting period. Upon completion of melting, Al-5Ti-1B master alloy was introduced into the melt at 0.2 wt. % of titanium. Argon was then purged into the melt to degas hydrogen. The time for degassing was 3 min with a flow rate of 5 Liters/ min. A 25-min contact time was employed. Previous to pouring at 720 °C into molds, argon gas was used to agitate the melt for preventing the settlement of both $TiAl_3$ and TiB_2 . The casting from the mold then became the return scarp for recycling process. In the recycling process, the return scarp was recycled for 5 times in the same conditions without the addition of Al-5Ti-1B master alloy. In the interest of studying the role of the residual Fe contaminated in the recycled A356 refined by Al-5Ti-1B master alloy, another set of investigation was carried out using A356 with an extra Fe (0.3 wt. %). To maintain the constant residual Fe content for the whole recycling process, a small amount of Fe was added to the recycled melt. To understand the investigation, the experimental procedure of this present investigation is schematically provided in **Figure 1**. Samples from the entire recycling conditions of both A356 alloys were polished and etched by the Tucker's reagent for the macrographic analysis. The linear intercept method (ASTM standard E112-88) was conducted for the grain size evaluation. The concentration of titanium and boron of both sets of A356 were examined by using an emission spectrometer.

Results

Figures 2(a) - 2(g) exhibits the macrographs of A356 alloy refined by Al-5Ti-1B master alloy with various recycling conditions. The macrograph in **Figure 2(a)** shows the coarse grain structure of the unrefined A356 alloy. **Figure 2(b)** displays the macrostructure of A356 alloy with the addition of Al-5Ti-1B master alloy and a finest equiaxed grain structure is clearly observed in this sample. No additional Al-5Ti-1B master alloy was added into the melt for the entire recycling process. The macrographs of A356

alloy recycled in the early recycling process (1st - 2nd recycling number) show that the recycled A356 structure remained fine and equiaxed as displayed in **Figures 2(c) - 2(e)**. Nevertheless, the macrographs of A356 alloy recycled in the subsequent recycling process (3rd - 5th recycling number) display that the grain structure of recycled A356 alloy was significantly coarser as shown in **Figures 2(e) - 2(g)**. It is obvious from **Figure 2(g)** that the grain size of the sample subjected to the 5th recycling number possessed the largest grain structure.

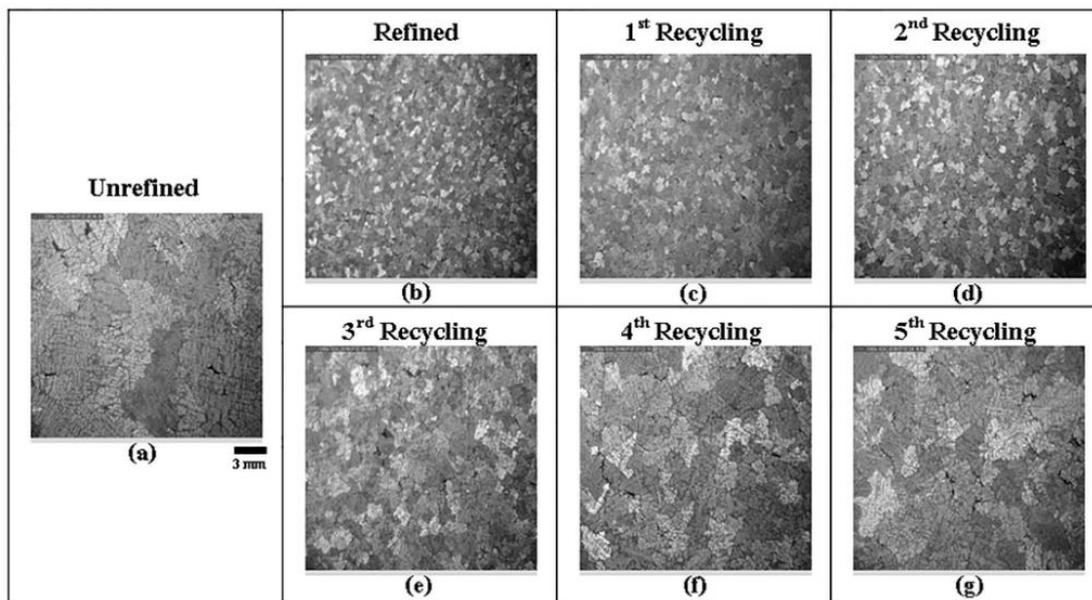


Figure 2 Macrographs of A356 (a) Non-grain refined sample, (b) Grain refined sample, (c) Sample from 1st recycling, (d) Sample from 2nd recycling (e) Sample from 3rd recycling, (f) Sample from 4th recycling, and (g) Sample from 5th recycling.

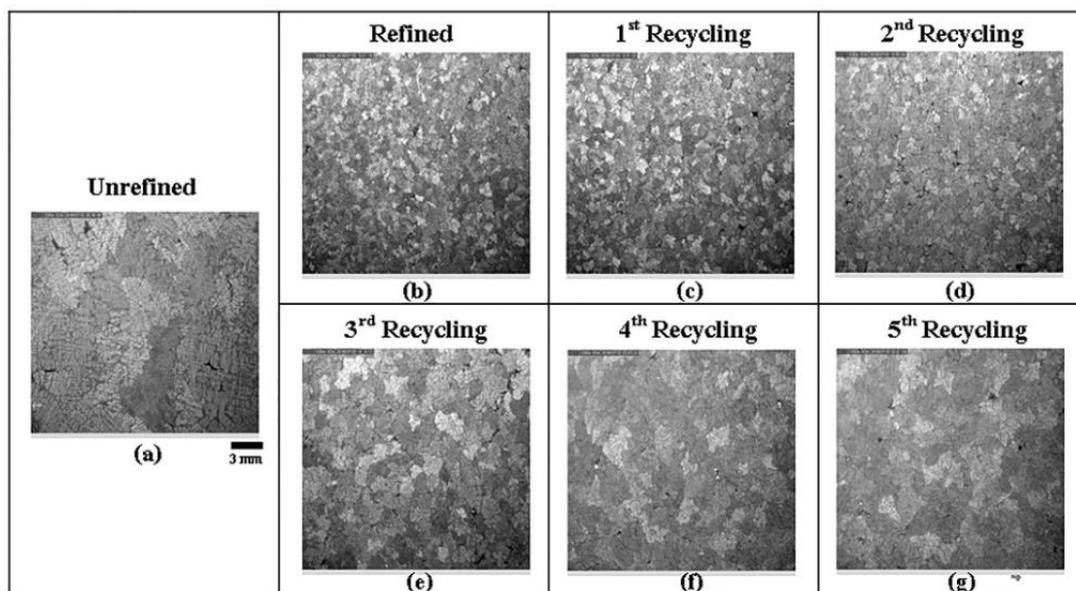


Figure 3 Macrographs of A356 with an extra Fe (a) Non-grain refined sample, (b) Grain refined sample, (c) Sample from 1st recycling, (d) Sample from 2nd recycling (e) Sample from 3rd recycling, (f) Sample from 4th recycling, and (g) Sample from 5th recycling.

Identical investigation, performed at A356 with the extra Fe (0.5 wt. %), displays a similar tendency but even smaller grain size in the subsequent recycling process, as revealed in **Figures 3(d) - 3(g)**. The analysis of the grain size of A356 and A356 with an extra Fe from all recycling conditions is given in **Figure 4**. It is clear from **Figure 4** that the average grain size of A356 and A356 with an extra Fe showed almost no change in the beginning recycling process, but it significantly increased with the recycling number in the subsequent recycling process.

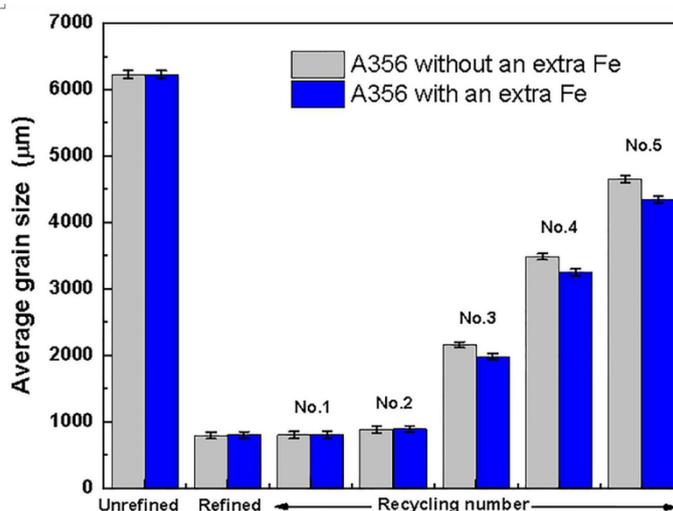


Figure 4 Average grain size of A356 and A356 with an extra Fe during the whole recycling process.

It is also clear from **Figure 4** that the average grain size of recycled A356 with an extra Fe content is smaller than that of recycled A356 for the whole period of subsequent recycling process. The largest increased grain size of both recycled A356 occurred at the 3rd recycling number. Usually, the recycling number where the largest increased grain size occurs reveals the transition from the small to large grain structure and the occurrence of this transition indicates the degraded grain refining performance of grain refiners [8]. Thus, the degradation of the grain refining effectiveness of Al-5Ti-1B master alloy in both recycled A356 takes place in the subsequence recycling process. After grain refining effect was faded, the grain size of both A356 alloys became significantly larger, as seen from **Figure 4**. Concentration of titanium and boron of the recycled A356 alloy and A356 alloy with a residual Fe during the recycling process are shown in **Figures 5(a) - 5(b)**. It was found from **Figures 5(a) - 5(b)** that the concentration of titanium and boron of the recycled A356 alloy and A356 alloy with an extra Fe decreased with the number of recycling and becomes remarkably low in their subsequent recycling process.

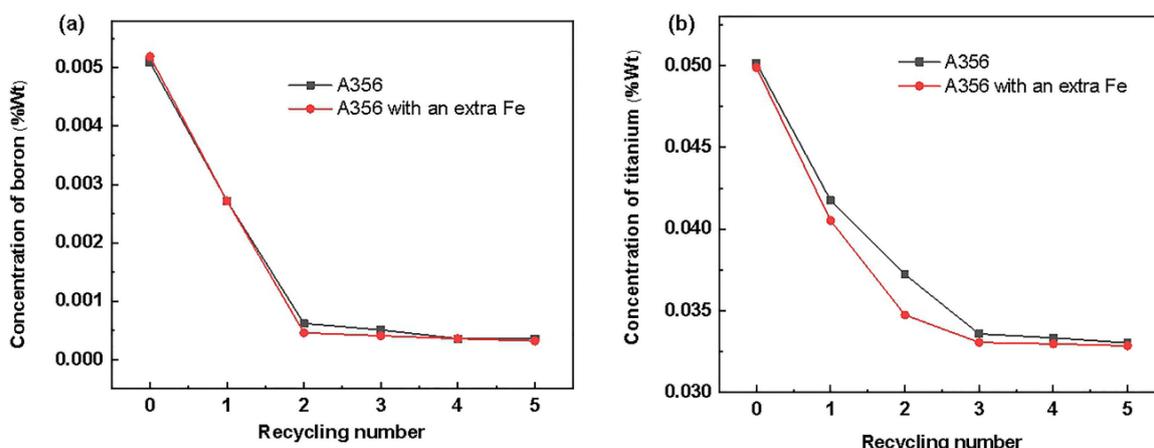


Figure 5 Chemical analysis of A356 and A356 with an extra Fe (a) concentration of boron (B) and, (b) concentration of titanium (Ti).

Discussion

To elucidate the grain refining effect of both A356 alloys refined by Al-5Ti-1B mater alloy during the whole recycling process and the effect of the residual Fe on the recycled A 356, the concentration reduction of titanium and boron (%) and the variation of the average grain size of both recycled A356 alloys are provided in Figure 6. It is obvious that Al-5Ti-1B mater alloy can refine both of A 356 alloys. It is well known that this grain refiner can provide $TiAl_3$ and TiB_2 particles to the melt and both particles later act as the nucleation sites for the primary α -Al [8,9]. TiB_2 is known to be the primary nucleus which contributes its surface for the evolution of $TiAl_3$ [8-10], resulting in the generation of the grain refinement of A356 and A356 with an extra Fe. As the initial recycling process proceeded, the concentration of titanium and boron decreased, particularly in refined A356 with an extra Fe subjected to the 2nd recycling. At the 2nd recycling number, concentration of titanium and boron containing in refined A356 with an extra Fe were significantly lower than those in refined A356, but its grain size was still small and showed almost the same size as that of refined A356. For refined A356, although concentration of titanium and boron decreased, the number of the nucleation sites was still sufficient to refine the structure. In contrast, for refined A356 with an extra Fe, the concentration reduction of titanium and boron were more obvious than that of refined A356, but its grain structure was still fine. Thus, the residual Fe contaminated in the recycled A356 would play a role in the grain refining effect in this recycling number. In order to evaluate the role of the residual Fe contaminated in the recycled A356, the concept of the growth restriction factor (GRF) is employed. Technically, the grain size turned a minimum at a critical GRF [11]. So, within the appropriate concentration, a residual Fe as a solute in recycled A356 can promote the nucleation sites for the solidification of the primary α -Al. Besides, the appropriate concentration of Fe can promote the formation of $FeAl_3$ particle which can subsequently limit the growth of the solidified grains [12]. Therefore, the appropriate concentration of the residual Fe can provide the grain refining effect to compensate the degraded grain refining performance due to the concentration reduction of titanium and boron, resulting in the formation of the fined structure in the recycle A356 with an extra Fe as found in the 2nd recycling number. At the 3rd recycling number, the increased grain size of recycled A356 was obvious. At the same time, the concentration of titanium and boron containing in the recycled A356 obviously decreased. This finding indicates the reduction of the nucleation site density, resulting in the occurrence of the transition of the fine to large structure of the recycled A356 alloys. Normally, the disappearance of $TiAl_3$ and TiB_2 particles in the dross and the coarsening of both particles can take place during the casting process. Both could result in the decreased density of the nucleation sites in the recycling process of refined A356 alloys. During the 4th - 5th recycling number, concentration of titanium and boron did not remarkably decrease with reference to those in the 3rd recycling number. However, the grain size of the recycled A356 significantly increased.

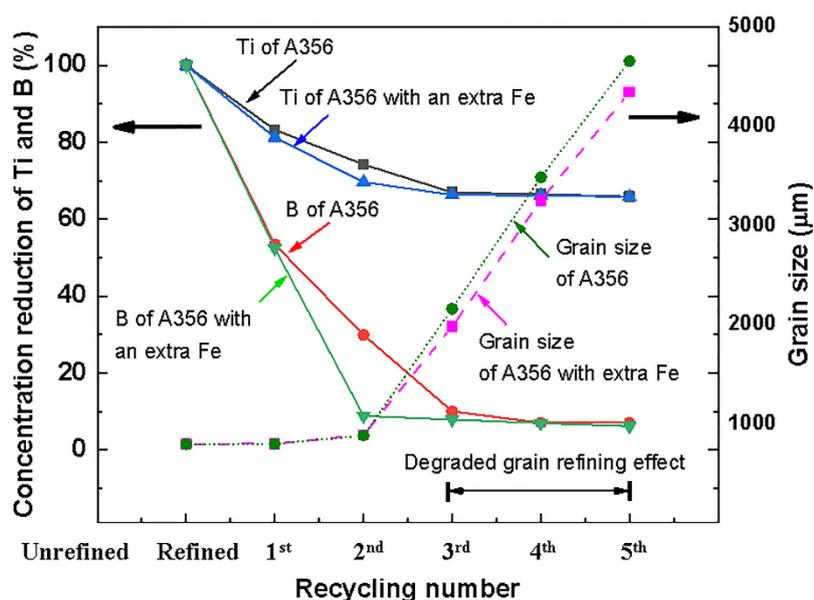


Figure 6 Concentration reduction of titanium and boron (%) and the change of grain size in the continuous recycling process of refined A 356 and A356 with an extra Fe.

This finding is also observed by detailed analysis of the remelting process of the aluminum castings. C Peeratatsuwan [8] studied the residual grain refining efficiency of Al-5Ti-1B in A356 alloy subjected to the remelting process and found that concentration reduction of titanium and boron significantly decreased in the initial period of the remelting process and then did not clearly decrease as the remelting process proceeded, resulting in the increased grain size of the remelted A356 in the subsequent remelting process. Zhao [13] and Alipour [14] observed that the agglomeration of $TiAl_3$ and TiB_2 particles during the casting process caused the lack of the nucleation sites for solidification. Obviously, the finding obtained from this study is in accordance with other recycling process of aluminum castings. Thus, this finding indicates the insufficient density of nucleation sites during the subsequent recycling process, which would be attributed to the adverse effect of the particle disappearance in the recycled melt and the coarsening of the particle taking place in the recycling process. Similar recycling process conducted on recycled A356 with an extra Fe shows the similar trend, but even smaller grain size as displayed in Figure 6. This finding indicates that even though Al-5Ti-1B master alloy lost its grain refining efficiency, the grain refining effect provided by the appropriate concentration of residual Fe still existed and remained useful. Therefore, a residual Fe of 0.3 wt. % is considered to be advantageous for the recycling process of A356 alloy. This also means that the extra Fe of 0.3 wt. % intentionally added to the recycled melt of A356 should be useful to the recycling process of refined A356. From the obtained results, it is suggested that additional Al-5Ti-1B master alloy and an extra Fe of 0.3 wt. % should be added to maintain the grain refining efficiency for the entire recycling process.

Conclusions

In this study, the effect of Fe on the grain refining of recycled A356 alloy refined by Al-5Ti-1B master alloy was investigated. The major conclusions and suggestions drawn from the results of this work are as follows.

- 1) Al-5Ti-1B master alloy loses its grain refining performance in the continuous recycling process, particularly in the subsequent recycling process.
- 2) Appropriate extra Fe of 0.3 wt. % as residual Fe can provide the grain refining effect which can compensate the degraded grain refining performance due to the concentration reduction of titanium and boron.
- 3) Adding additional Al-5Ti-1B together with an intentionally added extra Fe about 0.3 wt. % should be one of a practical alternatives for maintaining the grain-refining structure of recycled A356.

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