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Hereditary effect of Al-based modifiers and grain refiners on structure and properties of A356.2 alloys①

LI Pei-jie(李培杰)[1], ZHANG Yan-fei(张燕飞)[1], V. I. Nikitin[2], E. G. Kandalova[2], K. V. Nikitin[2]
(1. Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China;
2. Physical and Technological Department, Samara State Technical University, Samara 443010, Russia)

[Abstract] The hereditary effect of Al-Ti, Al-Ti-B, Al-Sr master alloys on the structure and properties of A356.2 alloys was investigated, and comparison analysis between the master alloys used in the foundry industry and the fine-crystalline grain refiners produced by technologies of Samara State Technical University was conducted. The results show that less than 0.5% additions of FCR master alloys can promote 8%~ 20% in the elongation of as-cast A356.2 alloys. FCR additives are more efficient in comparison with conventional grain refiners and modifiers. Their effectiveness depends on their genetic effect of their finer structures.

[Key words] master alloys; hereditary effect; grain refinement

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1 INTRODUCTION

Al-Si alloys are the most important aluminum casting alloys. Recent works of improving the Al-Si alloys quality are mainly devoted to modification and grain refinement[1~4]. Studies have presented that the efficiency of Al-Ti and Al-Ti-B grain refiners depends on not only their chemical compositions, but also on the method of their production[5,6]. Now Chinese and Russian scientists are studying using the phenomenon of structural heredity to improve the Al-Si alloys quality. Numerical works to investigate the regularities and applications of this phenomenon has been carried out[7~10]. In practice, the application of structural heredity phenomenon regularities has been called technologies of genetic engineering (TGE).

This article investigates the hereditary effect of various Al-Ti master alloys produced by different processes on the structure and properties of A356.2 alloys.

2 EXPERIMENTAL

The chemical composition of A356.2 alloy (5 kg ingot) is listed in Table 1. Characteristics and compositions of grain refiners and modifiers are presented in Table 2. Microstructural analysis was carried out on the optical microscope Neophot-32. Phase analysis was carried out on the optical microscope (SEM) JSM-6301F. The specimens were etched by 10% NaOH for 1~ 2 min (for optical microscope analysis) or by 0.5% HF for 4~ 5 min (for SEM analysis). 30 min ultrasonic cleaning was additionally put up for specimens examined by SEM.

The crucible was mounted into the empty furnace, and then the furnace was switched on. When furnace air reached 800 ℃, base (ingot alloy) charge was loaded. After melting, the melt was overheated to 720~ 740 ℃, and modifier and grain refiner additions were introduced. After holding for 5~ 20 min, slag was removed out from melt surface, melt was stirred and poured at 720 ℃ into preliminary heated to 200 ℃ metal mold. When as-cast sample was solidified, it was hold in the mold for 5 min, then removed and cooled in the air.

Ultimate tensile strength and relative elongation percentage were tested on WDW-100 device, which is in conjunction with computer. Brinell hardness testing was conducted using HB-3000 device with a 9.8 kN load and 10 mm diameter indenter. The holding time was about 10 s.

3 RESULTS AND ANALYSES

3.1 Optical microscopic analyses of master alloys

Ti-containing master alloys show the most obvious effect of different producing technologies on the parameters of intermetallic particles. Structures of the fine-crystalline modifiers and grain refiners FCR Al-Si (Gr), FCR STB-5/1 (SHS) are shown in Fig. 1. FCR Al-Si (Gr) was made on the base of Al-6Si-2Cu alloy through the method of rapid solidification (10^4 ~ 10^6 ℃/s). FCR STB-5/1 (SHS) was made on the base of Al-6Si-2Cu alloy and rich in Ti and B with the ratio 5:1 using the method of self-propagating high-temperature synthesis (SHS). Typical structures of the other master alloys are shown in Fig. 2. It shows that the morphologies of Al_3Ti particles are changed from large needles to fine blocks.

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Table 1 Chemical compositions of alloy (AA, USA Standard, %)

Si	Mg	Ti	Fe	Cu	Mn	Al
6.5~ 7.5	0.20~ 0.47	0.08~ 0.20	0.1	0.1	0.1	Bal.

Table 2 Characteristics and compositions of grain refiners and modifiers

No.	Modifier and grain refiner composition/label	Characteristic	Note
1	Al-10Si	d 10 mm Holland production	
2	Al-5Ti-B	Ingot (1 kg) Chinese prduction	Used in foundry industry of China for production of Al-Si alloys
3	Al-4.7Ti	Ingot (3 kg) Chinese prduction	
4	FCR Al-4.5Ti (I)	Ingot (3 kg)	
5	FCR Al-4.4Ti (SHS)	Ingot (0.25 kg)	
6	FCR Al-5Ti	Granules	
7	FCR ATM 5/1 (C)	Plates (5 mm thick)	Made by technologies of Samara State Technical University
8	FCR Al-Si (Gr)	Granules (fraction of 1.6~ 1.0 mm)	
9	FCR STB-5/1 (SHS)	Ingot (0.25 kg)	

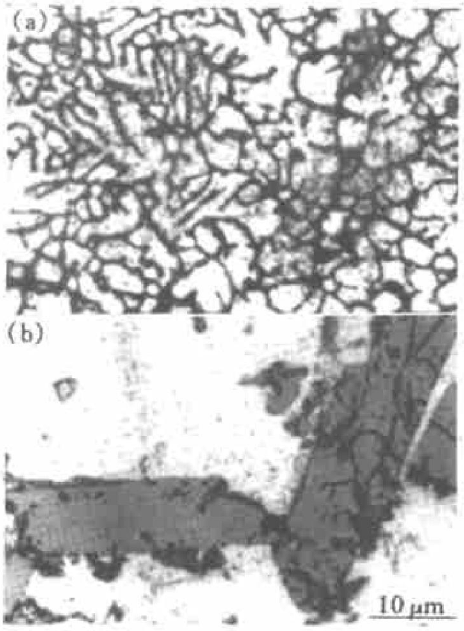

Fig. 1 Microstructures of fine-crystalline modifiers
(a) —FCR Al-Si (Gr); (b) —FCR STB-5/1 (SHS)

Table 3 Phase analyses of master alloys (mole fraction, %)

Master alloy	Al matrix		Titanium aluminide	
	Al	Ti	Al	Ti
Al-4.7Ti	99.95	0.05	75.74	24.26
	99.96	0.04	76.68	23.32
	99.37	0.63	76.28	23.72
	99.63	0.37	78.64	21.36
	99.67	0.33		
Al-4.7Ti (SHS)	99.48	0.52	75.94	24.06
	99.97	0.03	75.93	24.07
	99.93	0.07	76.11	23.89
			76.11	23.89

3.2 Scanning electron microscopic analyses of master alloys

The following master alloys were studied on SEM: Al-4.7Ti of Chinese production and Al-4.4Ti (SHS) of Samara State Technical University production. With a similar Ti concentration, these master alloys have quite different parameters and morphologies of intermetallic particles (Figs. 3 and 4). Phase analysis results are listed in Table 3.

The phase analysis of intermetallic particles has shown that Chinese master alloys differs with higher heterogeneity in Al and Ti distribution within one particle: 21.36% (mole fraction) and 23.72% (mole fraction) in points 1 and 2 respectively (Fig. 3(a)) and 23.32% (mole fraction) and 24.26% (mole fraction) in points 1 and 3 respectively (Fig. 3(b)). The average composition of intermetallic particles is $Al_{3.44}Ti_{0.56}$ and $Al_{3.20}Ti_{0.80}$ respectively. Inermetallic particles in Al-4.4Ti (SHS) are more homogeneous in Ti concentration: 23.89% (mole fraction) in points 1 and 2 (Fig. 4(a)) and 24.06% (mole fraction) and 24.07% (mole fraction) in points 1 and 4 (Fig. 4(b)). The average

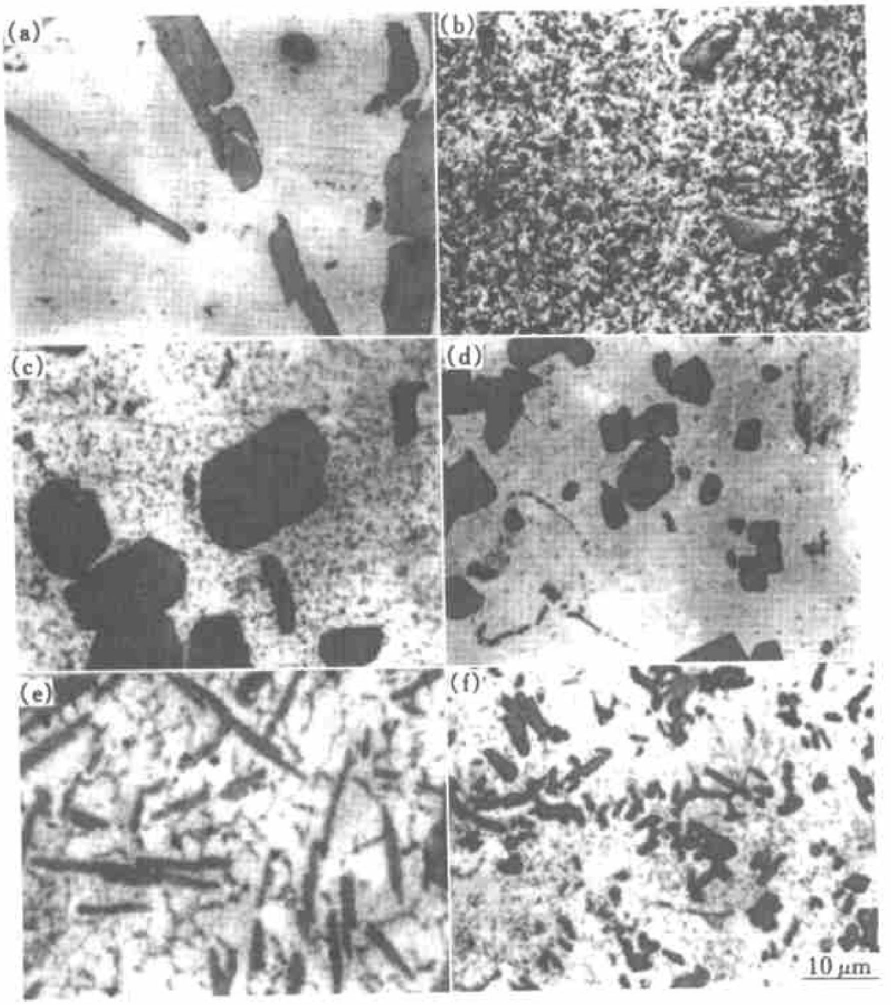

Fig. 2 Microstructures of master alloys
(a) —Al-4. 7Ti; (b) —Al-5Ti-1B; (b) —Al-4. 5Ti (I); (d) —Al-4. 7Ti (SHS); (e) —Al-5Ti, (Gr); (f) —ATM 5/1 (C)

composition is $Al_{3.19}Ti_{0.81}$ and $Al_{3.16}Ti_{0.84}$ respectively, which is much closer to the stoichiometric ratio Al_3Ti. The average Ti content in Al matrix is 0. 28% (mole fraction) in Al-4. 7Ti and 0. 21% (mole fraction) in Al-4. 4Ti (SHS). Thus, in Chinese master alloys Ti content in intermetallic particles is lower, and in Al matrix is higher, than in Al-4. 4Ti (SHS). Therefore, the producing technologies of master alloys make an effect on the parameters and composition of intermetallic particles, and consequently, on their effectiveness.

3. 3 Analyses of as-cast alloys adding different additives

Table 4 gives chemical compositions of the charge of each experimental heats. Using FCR STB-5/1 (SHS), the melt was overheated to 740 ℃ and held for 20 min after introducing additives. In case of combined using other master alloys and FCR Al-Si (Gr), the following procedure was applied: the master alloy was introduced into the melt at 740 ℃ and held for 15 min; during the holding period the melt cooled to 720 ℃. Then FCR addition was introduced into the melt; which was poured into the metal mold in 5 min.

The analysis of mechanical properties (Table 5) has shown that the application of fine crystalline grain refiners and modifiers, made by Samara State Technical University technologies, promote 8% ~ 20% in elongation percentage of A356. 2 alloy (heat 3~ 7). Using Al-10Sr and Al-5Ti-1B, made by Chinese Technology, the rise in ultimate tensile strength and elongation percentage was 4% and 6% (heat 2). The application of Al-Ti (SHS) instead of Al-5Ti-1B brought about the increase in ultimate tensile strength and elongation by 7% and 16% (heat 4). It is necessary to note the significant rise in these features (by 4% and 16% respectively) in the use of fine crystalline addition STB 5/1 (SHS) instead of Al-10Sr and Al-5Ti-1B (heat 6). Combined addition of FCR Al-Ti and RCR Al-Si (Gr), as well as using single FCR Al-Si (Gr) promoted mainly the increase in the elogation by 8% ~ 12% and did not affect on ultimate tensile strength (heat 3, 5, 7). In all cases the hardness insignificantly decreased or remained on the same level.

Comparison of the alloy structures treated by different processes showed almost no difference at magnification of 100. But, evident changes in microstructure can be observed at magnification of 1 000

Table 4 Chemical compositions of charge of each experimental heats (%)

Heat No.	Mass /%	Charge composition	Chemical composition						
			Si	Mg	Ti	Fe	Cu	Mn	Sr
1	635	100% ingot (C)	8.3	0.23	0.052	0.15	0.008	0.014	0.007
2	580	I+ 0.2Al-Sr+ 0.2Al-5Ti-1B	7.7	0.26	0.057	0.12	0.006	0.015	0.017
3	590	I+ 0.2Al-Sr+ 0.3FCR Al-Ti (I)	8.0	0.26	0.069	0.13	0.005	0.016	0.020
4	648	I+ 0.2Al-Sr+ 0.2 FCR Al-Ti (SHS)	8.0	0.26	0.061	0.15	0.006	0.016	0.020
5	640	I+ 0.2 FCR Al-Ti+ 0.5 FCR Al-Si (Gr)	8.1	0.26	0.06	0.13	0.033	0.018	0.009
6	587	I+ 0.4 FCR STB-5/1 (SHS)	8.0	0.26	0.061	0.14	0.018	0.015	0.008
7	618	I+ 0.5 FCR Al-Si (Gr)	7.8	0.28	0.051	0.13	0.014	0.016	0.01

Table 5 Mechanical properties of alloys adding different additives

Heat No.	Mechanical properties			Heredity coefficients*		
	HB	σ_b/MPa	δ/%	K_h^{HB}	$K_h^{\sigma_b}$	K_h
1	60	171	5.0	–	–	–
2	59	177	5.3	0.98	1.04	1.06
3	57	172	5.4	0.95	1.00	1.08
4	58	183	6.0	0.97	1.07	1.20
5	60	171	6.0	1.00	1.00	1.20
6	59	177	5.8	0.98	1.04	1.16
7	60	173	5.6	1.00	1.01	1.12

* K_h is a ratio of property values of after melt treatment (heat 2~7) to without melt treatment (heat 1).

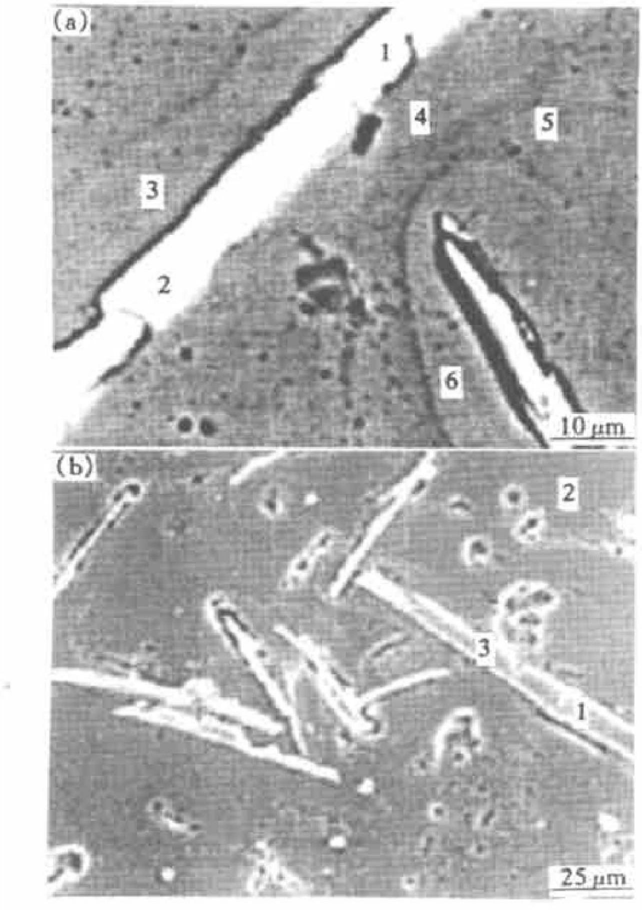

Fig. 3 SEM microstructures of Al-4.7Ti master alloy (Chinese production) with arrows showing phase analysis points
(a) —Higher magnification; (b) —Lower magnification

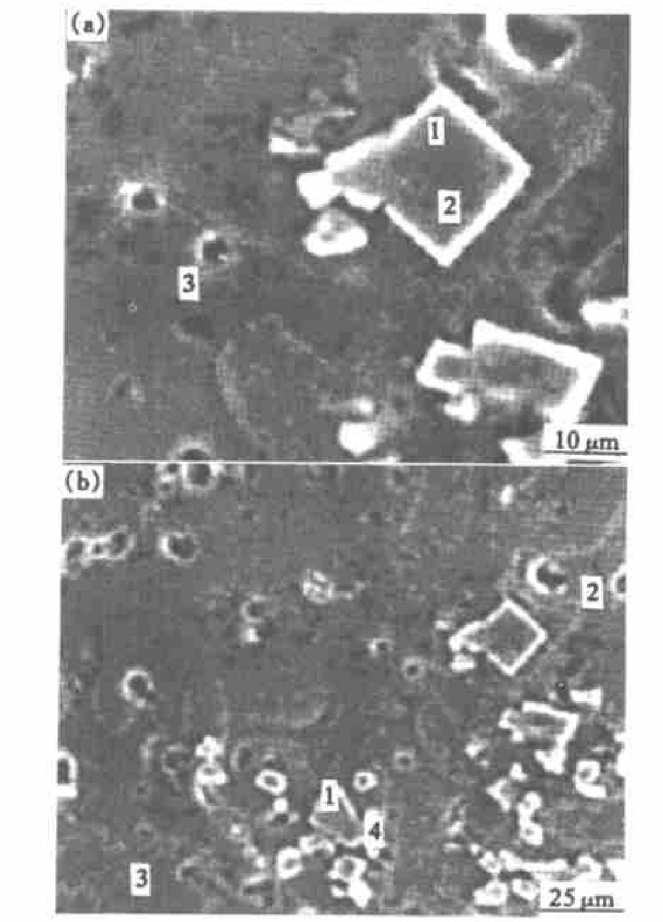

Fig. 4 SEM microstructures of Al-4.7Ti (SHS) master alloy (SamSTU) with arrows showing phase analysis points
(a) —Higher magnification; (b) —Lower magnification

(Fig. 5). In the eutectic of the remelted alloy without any additions there are phase in the shape of Chinese scripts, which is inherited from the initial ingot alloy (Fig. 5(a)). Inducing additives reduced eutectic components in size (Fig. 5(b) ~ (c)). Comparison of these samples has shown that alloys with fine-crystalline additions have finer eutectic than those with Chinese additives. This result could be achieved even when Al-5Ti-1B master alloy was replaced by the cheaper Al-Ti (SHS) (Fig. 5(c)), as well as only one addition (without Al-10Sr), such as STB-5/1 (SHS) or FCR Al-Si (Gr) (Fig. 5(d), (e)), respectively),

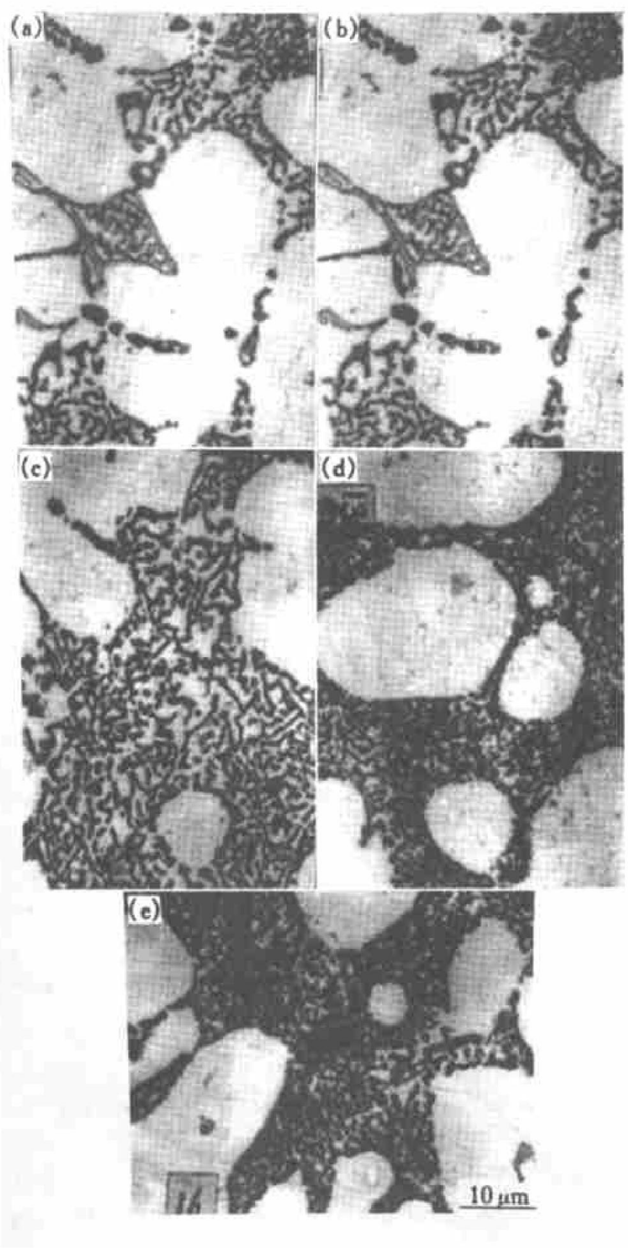

Fig. 5 Microstructures of as-cast A356.2 alloy with and without additives

(a) —Ingot remelt without additives (heat 1);
(b) —With 0.2 Al-Sr+ 0.2 Al-5Ti-1B (heat 2);
(c) —With 0.2 Al-Sr+ 0.2 Al-Ti (SHS, heat 4);
(d) —With 0.4 FCR STB-5/1 (SHS, heat 6);
(e) —With 0.5 FCR STB Al-Si (Gr, heat 7)

was used.

Recently, the structure heredity effect was getting more and more recognition. In theory, the heredity effect was defined as "the comparability of structural and properties transfers from original object to subsequence". During the melting process, the atom groups gradually split into small parts, but when the outside conditions caused the splitting to pause, some minute remnant can be left, so the structural information can be transferred down. This experiment gives a good demonstration of this phenomenon. The fine-crystalline additives (FCR) and our conventional master alloys have similar chemical compositions, but they were produced by different technologies, consequently their effectivenesses are different too. This shows that the structural parameters of intermetallic particles controlling is very important to improve the quality of Al-Si alloys.

4 CONCLUSIONS

1) Technologies of making fine-crystalline additive, developed in Samara State Technical University, allow the given structural parameters (such as size, morphology, quantity) of nuclei to be obtained.

2) The modifying and grain refining effect of FCR is based on the genetic effect of their fine structural components.

3) Small additions of fine-crystalline modifiers and grain refiners (less than 0.5%) make a combined effect on the mechanical properties of alloys. It has better results in comparison with the conventional technology.

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