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EFFECT OF Sr ADDITION ON THE MICROSTRUCTURE AND PROPERTIES OF THE A356 Al ALLOY

VPLIV DODATKA STRONCIJA NA MIKROSTRUKTURO IN LASTNOSTI ALUMINIJEVE ZLITINE VRSTE A356

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An effective way of integrating purification and modification is used for casting the A356 Al alloy. Self-generated inclusion-eliminating flux exhibits excellent purification in the alloy with an inclusion-removal rate of 74 %. The grains of eutectic silicon are fine or vermicular, and diffusely distributed in the A356 Al alloy at a 0.012 *w*/% Sr addition. The mechanical properties of the alloy are significantly improved, including a tensile strength of 208.5 MPa and an elongation of 17.5 %. As the Sr addition is increased, the comprehensive properties of the material are not improved. The Sr addition can be reduced to a certain degree during the modification of the melt after high purification. The addition of 0.012 *w*/% Sr is most preferable in the alloy.

Key words: A356 Al alloy, Sr content, modification, purification, eutectic silicon

Avtorji v pričujočem članku opisujejo učinkovit način integracije čiščenja (rafinacije) in modifikacijo lite Al zlitine tipa A356. Spontano nastalo talilo, za odstranitev vključkov iz taline zlitine, je imelo odlične oz. učinkovite (74 %) rafinacijske lastnosti. V mikrostrukturi nastala kristalna zrna evtektskega Si so bila drobna ali v obliki črvičkov in difuzno porazdeljena v Al zlitini A356 z 0,012 *w*/% stroncija. Na ta način so avtorji v raziskavi izboljšali njene mehanske lastnosti. Natezna trdnost zlitine je narasla na 208,5 MPa in raztezek na 17,5 %. Z nadaljnjim povečevanjem dodatka Sr se lastnosti zlitine niso izboljšale. Dodatek Sr so lahko zmanjšali za določeno stopnjo, ne da bi pri tem zmanjšali učinkovitost očiščenja taline. Najprimernejša ugotovljena količina dodatka Sr je bila 0,012 *w*/%.

Ključne besede: Al zlitina A356, vsebnost Sr, modifikacija, čiščenje, evtektski silicij

1 INTRODUCTION

Cast aluminum A356 alloy has been widely used in the automobile industry and aviation because of its excellent casting performance, good corrosion resistance, high strength-to-weight ratio and low casting cost, and has become one of the most important Al-Si series cast alloys.[1–5] The mechanical properties of the A356 Al alloy relate closely to its microstructure. In an Al-Si alloy, the microstructure is mainly composed of α-Al dendrite and a eutectic region. Therefore, the dendrite arm spacing (DAS) and morphology of a eutectic silicon particle affect the mechanical properties of the alloy. In order to obtain high-quality A356 alloy castings, it is necessary to use the most effective ways of integrating the melting process, purification and modification.[6–10] Generally, the finer, rounder and more isolated the silicon particles, the better is their plasticity. The resistance to crack formation and diffusion becomes larger with the tensile load. An addition of Sr to aluminum melt has a metamorphic effect, which can effectively refine the eutectic silicon and primary silicon in the alloy, improving the mechanical properties of the alloy. A metamorphic alloy exhibits a good long-term performance, remelting stability and corrosion resistance.[11–16]

Over all, an effective way of integrating purification and modification of the A356 Al alloy is studied. The effect of the Sr content on the microstructure and mechanical properties of the alloy is also studied closely. It is of theoretical significance and practical value, when improving the metallurgical quality of automobile wheel hubs and other components in related industries.

2 EXPERIMENTS

The chemical composition (in mass fractions, *w*/%) of the A356 Al alloy is shown in **Table 1**.

A cast A356 aluminum alloy melt was purified using the traditional purity-flux addition and self-generated purity-flux addition,[17,18] and the addition amount was 2 %, separately. The self-generated purity-flux addition was to adjust the amount of NaCl, KaCl and other chemical reagents through an orthogonal experiment under certain melting conditions so as to achieve the optimal purification effect and obtain the best chemical-reagent ratio of the addition. Intermediate Al10Sr alloy was used in the modification. The addition of the Sr content was 0.006 *w*/%, 0.012 *w*/% and 0.018 *w*/% respectively. A melting tem-

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Table 1: Chemical composition of the A356 Al alloy

Element	Si	Mg	Fe	Ti	Cu	Mn	Zn	Al
Composition (*w*/%)	6.8–7.5	0.2–0.35	≤0.20	≤0.20	≤0.20	≤0.005	≤0.005	Balance

Table 2: Purification effect on the A356 Al alloy

Purification	Inclusion content (*w*/%)	Hydrogen content [mL/(100 g A1)]	Density of DS specimen [g/cm^3]
N/A	1.24	0.22	2.24
Conventional	0.37	0.13	2.37
Self-generated	0.32	0.11	2.41

perature of 720 °C and a dwell time of 30 min were adopted for the casting.[18,19]

During melting, the temperature was measured by a NiCr-NiAI thermocouple and controlled by a DRZ-4 furnace-temperature controller. An ELH-IV instrument was used for measuring the hydrogen content of the melt, and the measuring range was 0–0.99 mL/(100 g Al). Samples were prepared with a CQY-01db decompression-solidification (DS) instrument, and the density was measured. The inclusion content was determined with the flux-washing method.[17,18] The microstructure was observed and the second dendrite arm spacing (SDAS) was determined with the transverse-line method using light microscopy. Tensile testing was done with an INSTRON-1185 tester. Three samples from each alloy with a Sr content were selected for the tensile testing, and the average values of tensile strength σ_b and elongation δ were taken. The standard deviation of the tensile strength was within the allowable range of 5 MPa. The metallographic structure and tensile fracture were observed with the XL30ESEM scanning electron microscopy, and the size of eutectic silicon grains was also determined with the transverse-line method.

3 RESULTS AND DISCUSSION

3.1 Purification effect of the A356 Al alloy

Figure 1 shows the microstructure of the A356 Al alloy treated with different flux-purification and modifica-

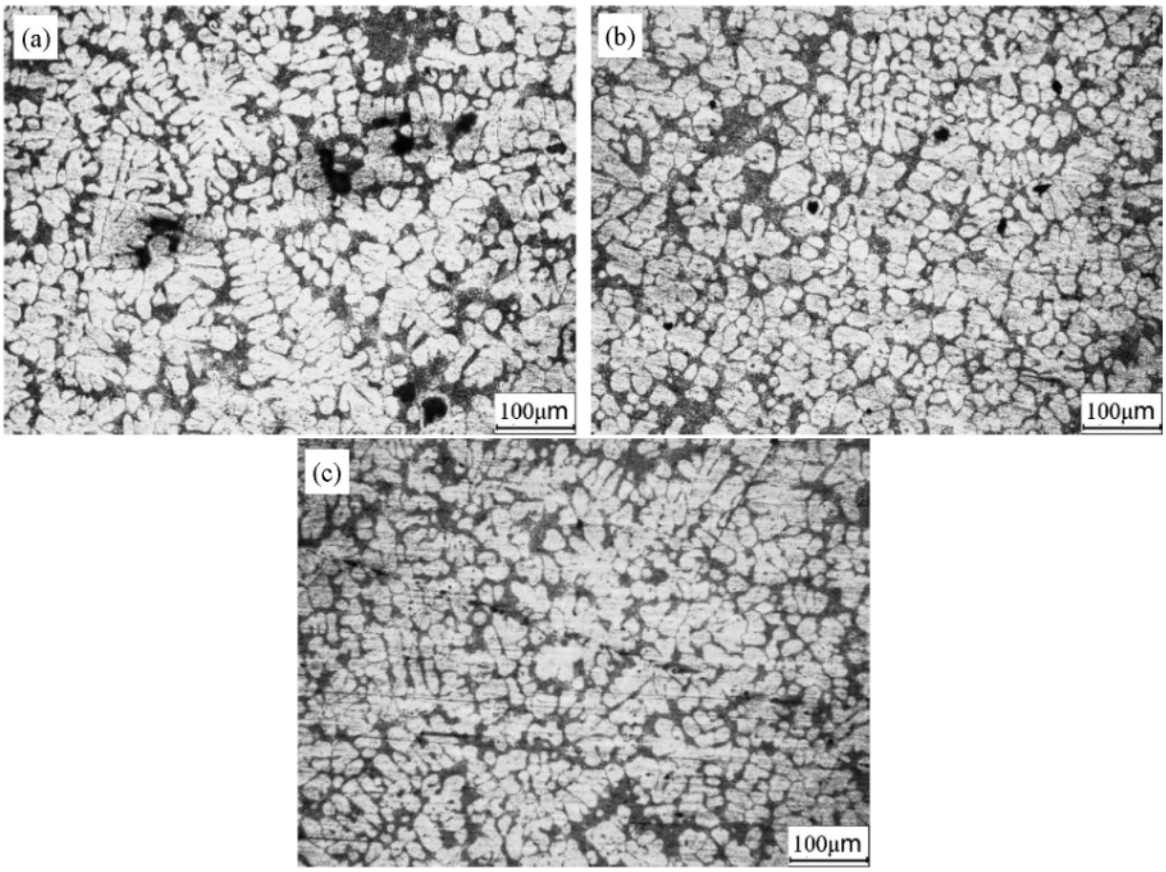

Figure 1: Microstructure images of A356 Al alloy treated by: a) no purification, b) conventional flux purification, c) self-generated flux purification

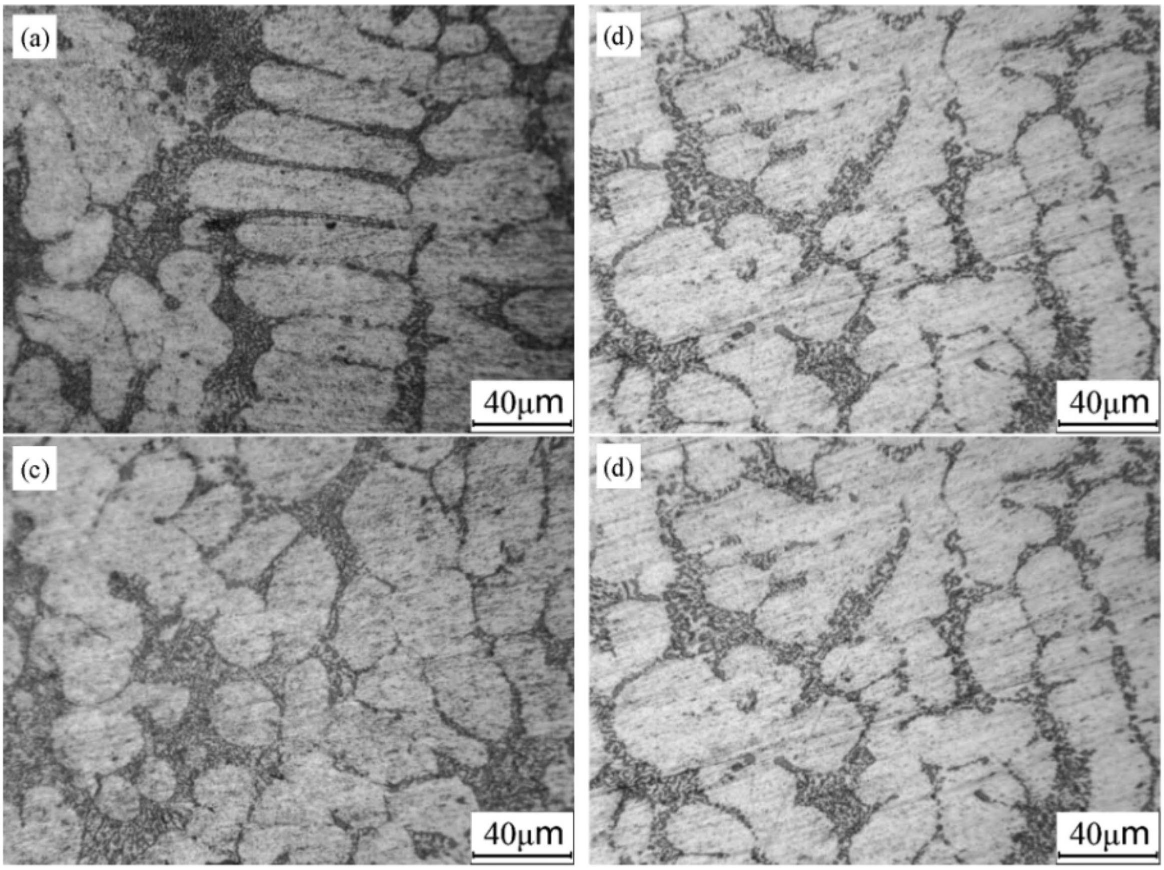

Figure 2: Dendrites of A356 Al alloy with: a) no modification, b) 0.006 *w*/% Sr, c) 0.012 *w*/% Sr, d) 0.018 *w*/% Sr

tion treatments. **Table 2** shows the purification effect corresponding to **Figure 1**.

From **Figure 1**, some large block inclusions and thick rod dendrites can be seen in the A356 Al alloy without any melt purification. In the alloy with conventional inclusion-eliminating flux purification, a number of inclusions of a small size are observed. In the alloy with self-generated inclusion-eliminating flux purification, the inclusions are reduced significantly, and no obvious block inclusions can be seen in the image. The inclusions are fine and dispersed uniformly.

The resolution of the hydrogen-content testing is 0.01 mL/(100 g Al) in **Table 2**. According to this table, the inclusion content decreases to the lowest amount of 0.32 w/% in the alloy with self-generated flux purification, and the impurity removal rate is as high as 74 %. Besides, the lowest hydrogen content of the alloy is 0.11 mL/(100 g A1), and the highest density of the decompression-solidification (DS) specimen is 2.41 g/cm^3. Self-generated-flux purification has a better effect on the hydrogen removal.

From the above, the self-generated inclusion-eliminating flux is more effective for the purification of cast A356 Al alloy melt than the traditional one.

3.2 Mechanical properties of the A356 Al alloy with different Sr contents

The A356 Al alloy melt purified with the self-generated inclusion-eliminating flux is modified due to different Sr contents. **Figure 2** shows dendrites of the A356 Al alloy with different Sr contents.

On **Figure 2**, the metallographic structure is characterized by large rod-like dendrites in the A356 Al alloy without any modification. In the Al alloy with 0.006 *w*/% Sr, rod dendrites and isoaxial dendrites are abundant and clustered together. In the alloy with 0.012 *w*/% Sr or alloy with 0.018 *w*/% Sr, the dendrites are isoaxial and evenly distributed.

Table 3 shows modification effects on the A356 Al alloy with different Sr contents. **Figure 3** shows the relationship between the Sr contents and mechanical properties.

Table 3: Modification effects on the A356 Al alloy with different Sr contents

Sr content (*w*/%)	SDAS (μm)	σ_b (MPa)	Std Dev of σ_b (MPa)	δ (%)
N/A	39.8	177.5	4.5	6.8
0.006	35.5	194.6	4.6	9.3
0.012	30.7	208.5	3.9	17.5
0.018	31.6	208.1	4.1	13.8

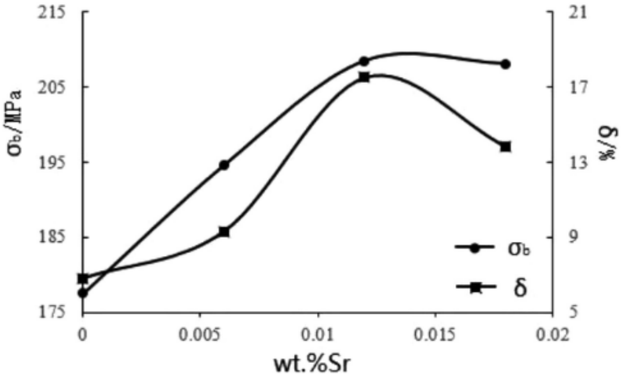

Figure 3: Relationship between Sr contents and mechanical properties

On **Table 3** and **Figure 3**, mechanical properties of the A356 alloy are improved effectively with the increasing Sr content. As the Sr content is bigger than 0.012 *w*/% the comprehensive performance is not improved. At 0.018 *w*/% Sr, conversely, the second dendrite arm spacing (SDAS) goes up from 30.7 µm to 31.6 µm. The increase in the SDAS is modest and the strength remains unchanged. There is a significant reduction in the plasticity, by 13.8 %, which is lower than that caused by 0.018 *w*/% Sr, i.e., by 17.5 %.

The tensile-fracture morphology of the A356 Al alloy with different Sr contents is shown in **Figure 4**. The morphology of the alloy without modification includes dimple and cleavage fractures with a river pattern (**Figure 4a**). There is a certain degree of brittle fracture. After modification with the Sr element, more dimples are observed. In the fractures of the alloy with 0.012 w/% Sr and 0.018 w/% Sr, dimples are deep and round. The toughness of the fracture is remarkable (**Figures 4c** and **4d**).

3.3 Eutectic silicon morphology of the A356 Al alloy with different Sr contents

Eutectic silicon morphology of the A356 Al alloy with different Sr contents is shown in **Figure 5**. **Table 4** shows the average size of eutectic silicon grains in the alloys.

Table 4: Average size of eutectic silicon grains in A356 Al alloy with different Sr contents

Sr content (*w*/%)	N/A	0.006	0.012	0.018
Average size of eutectic grains (µm)	8.1	5.2	3.8	4.9

In the alloys with a low Sr content (**Figure 5a** and **5b**), eutectic silicon is granular or bar-shaped. In **Figures 5c** and **5d**, the eutectic silicon grains are granular, fine and evenly dispersed. The average size of eutectic grains

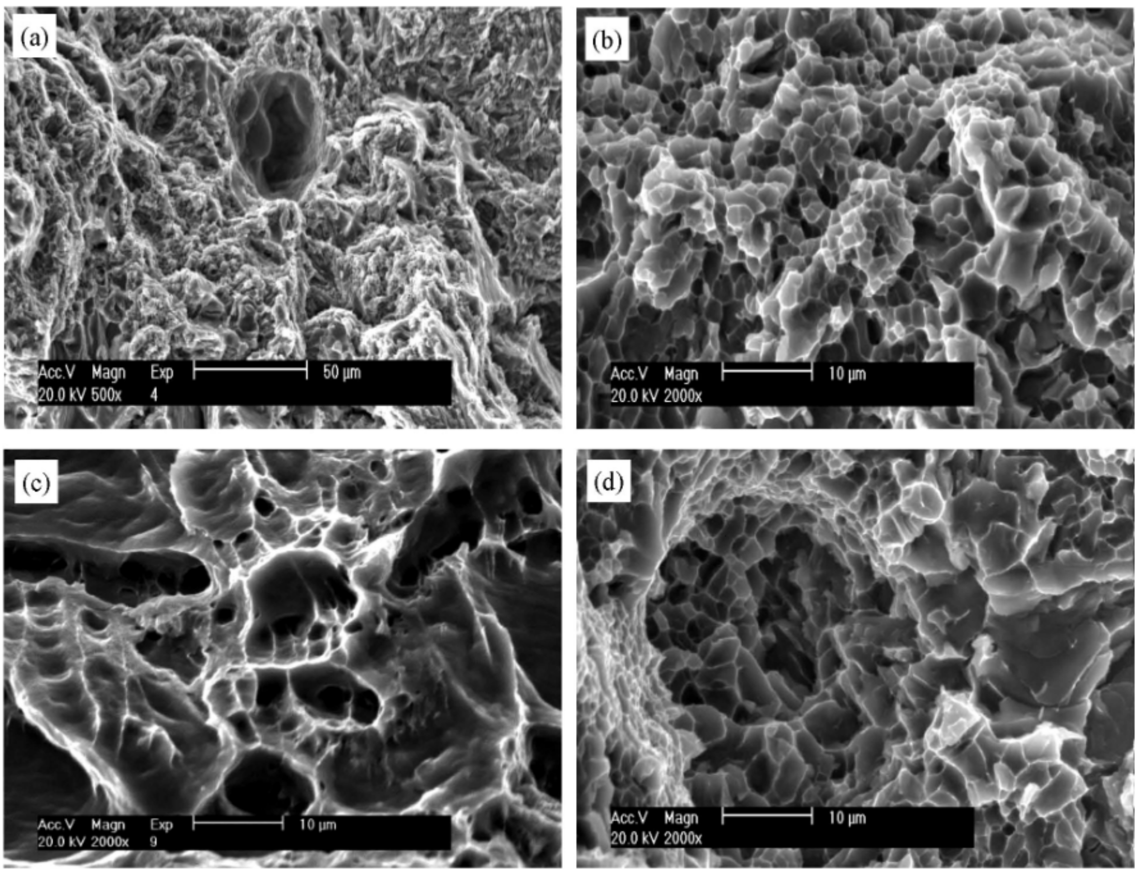

Figure 4: Tensile-fracture morphology of A356 Al alloy with: a) no modification, b) 0.006 *w*/% Sr, c) 0.012 *w*/% Sr, d) 0.018 *w*/% Sr

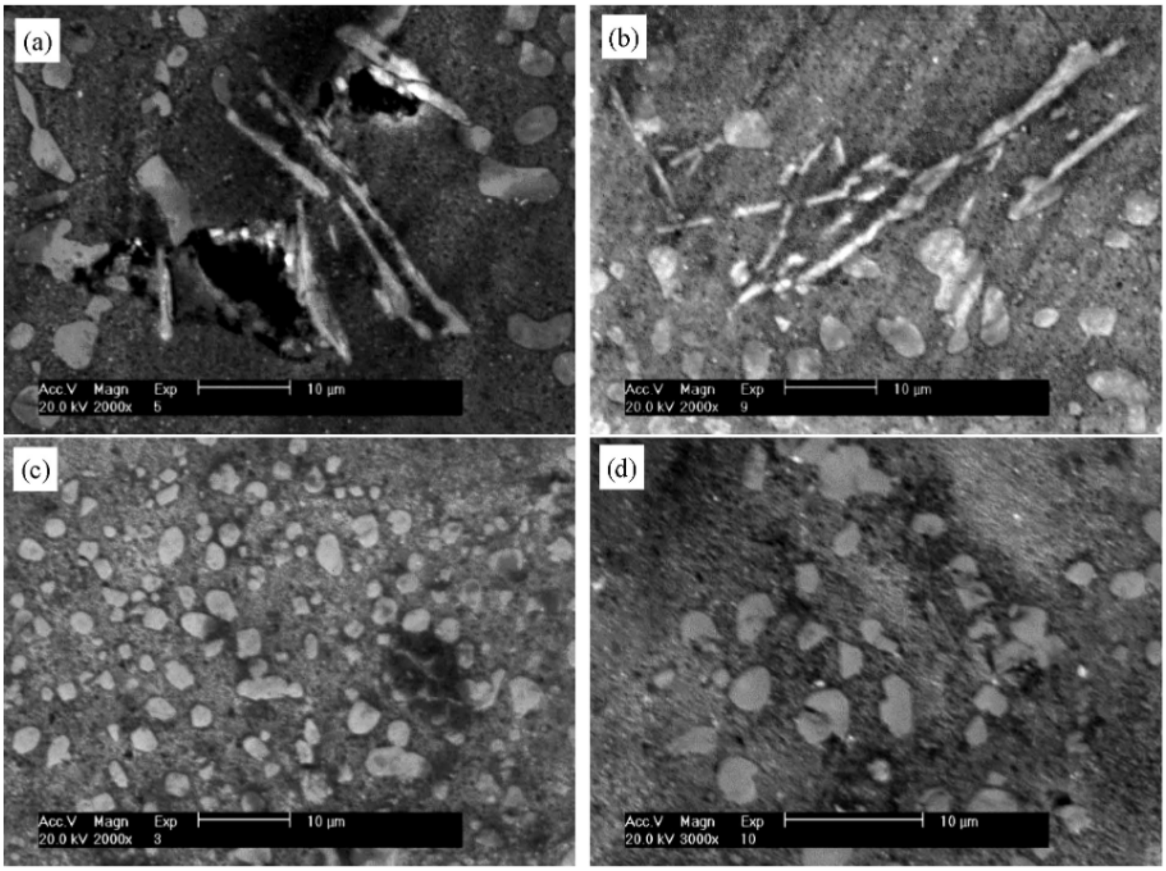

Figure 5: Eutectic silicon morphology of A356 Al alloy with: a) no modification, b) 0.006 w/% Sr, c) 0.012 w/% Sr, d) 0.018 w/% Sr

in the A356 Al alloy with 0.012 *w/%* Sr decreases to its minimum, i.e., 3.8 µm, as shown in **Table 4**.

The Sr addition can be reduced to a certain degree in the modification of a high-purity A356 Al alloy melt. The main reason for this is that the chemical activity of element Sr is very strong, and it will react with Al_2O_3 in the melt to produce a Sr-rich compound. Because of the high purity, less Sr is needed. A larger Sr addition will cause excessive Sr, which will produce a compound of Al_2Si_2Sr and finally degrade the performance of the material.[19–21] The higher the purity of the melt, the less Sr is needed for the modification of the A356 Al alloy melt.

4 CONCLUSIONS

1) The self-generated purity flux shows an excellent purification effect on the A356 Al alloy, with an inclusion-removal rate of 74 %, while the hydrogen content of the alloy is low, i.e., 0.11 mL/(100 g A1).

2) The Sr content has an obvious influence on the microstructure and properties of the A356 Al alloy. The grains of eutectic silicon are fine or vermicular and diffusely distributed in the alloy with 0.012 *w/%* Sr. The mechanical properties are excellent including a tensile strength of 208.5 MPa and elongation of 17.5 %. The performance of the alloy does not improve with the increased Sr content.

3) The higher the purity of the melt, the less Sr is needed for the modification of the A356 Al alloy melt. The addition of 0.012 *w/%* Sr is most effective for improving the performance of the alloy.

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