Refinement the Microstructure of Al–7Si Alloy by the Addition of Cadmium

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Abstract

Cadmium (Cd) modified aluminium–silicon cast alloys are well known for their outstanding mechanical properties as they combine excellent strength with good ductility that is due to a modification of brittle Si in the eutectic with traces of Cd (0.2–1.0 wt%). The results showed that the Cd leads to the refinement of eutectic silicon from ~95 to 10µm. The alloys which used in this work were Al-7Si alloy with additions of 0.2, 0.6 and 1 wt% Cd as well as Al-7%Si with out Cd addition. The effect of keeping time also studied and the results indicate that the addition of 1%Cd with keeping time 3min was the best (about 10 µm).

Keywords:
Casting, Solidification, Microstructure, Al alloys, Modification.

الخلاصة

تكون مصبوبات سبائك الألمنيوم–سليكون، المعدلة بنيتها البلورية بإضافة كميات محسوبة من الكادميوم، ذات خواص ميكانيكية عالية. وهذه الخواص ناتجة عن الجمع بين المتانة العالية والمطيلية الجيدة والناتجة عن تعديل البنية البلورية لطور السليكون الايوتكتيكي من شكل رقائق أو صفائح هشة إلى شكل خيطي منتظم وذلك بفعل إضافة الكادميوم لغاية 1% كمعدل للبنية البلورية. تشير نتائج فحص البنية المجهرية لطور السليكون الايوتكتيكي إلى أن المصبوبة المضاف إليها كادميوم بنسبة 1% قد يصل تحول هذا الطور من شكل ابري أو رقائقي ذو طول حوالي 95 مايكرون إلى خيطي بطول حوالي 10 مايكرون . إن السبائك التي تم دراستها في هذا البحث هي ألمنيوم–7%سليكون بإضافة الكادميوم بنسب(0.2، 0.6 و 1.0%) إضافة إلى السبيكة الأصلية بدون إضافات. كذلك تم دراسة تأثير وقت الحفظ عند درجة حراة إضافة الكادميوم وقد أظهرت النتائج إن المصبوبة التي أضيف لها الكادميوم بنسبة 1.0% ووقت حفظ 3 دقائق كانت هي الأفضل (طول السليكون الايوتكتيكي الخيطي10 مايكرون).

1. Introduction

The Al–Si alloys have been used in the automotive industry on the basis of his relatively high relationship resistance/weight [Khalifa , Samuel , Gruzleski, 2005]. The stress–strain curves of Al-7SI cast aluminum alloy exhibit an unusual size effect on flow properties: the finer the microstructure, the lower the tensile flow strength. Tensile tests were carried out on specimens made of an alloy with 7% Si as the main alloying element [Benzerga , Hong , Kim , Vander Giessen Needleman, 2001].

Over the last several decades, there has been a growing trend to replace steel and cast iron in automotive industries with aluminium castings with the intention of making use of the reduction in weight to lessen energy consumption; the enhanced mechanical performance also makes these castings of great interest in the field of design engineering. Also use of cast Al–Si alloys as a tribological component in recent years has been expanding widely in military, automobile and general engineering industry. Aluminium–silicon eutectic, near-eutectic and hypereutectic alloys are cast to produce majority of pistons and are known as piston alloys [Chanrashkharaiah , Kori, 2009, Prof. Rundman, 2001]

Hypoeutectic Al–Si alloys are of tremendous importance for the aluminium casting industry. Cast alloys like A356 (AlSi7Mg0.3), A357 (AlSi7Mg0.6) or AlSi9Cu4 are some of the most important aluminium cast alloys with excellent mechanical properties. Hence those alloys are more and more used in the automobile industry. The critical property for many safety components, however, is the ductility, which is highly influenced by the morphology of the brittle Si crystals in the eutectic phase. It is well reported that some elements of the alkali, alkaline earth and rare earths group like Na, Sr or La can change the Al–Si eutectic from a coarse flake (Fig. 1) to a fine fibrous morphology (Fig. 2) [Elliott,1983, Zhou , Zhom,1983].

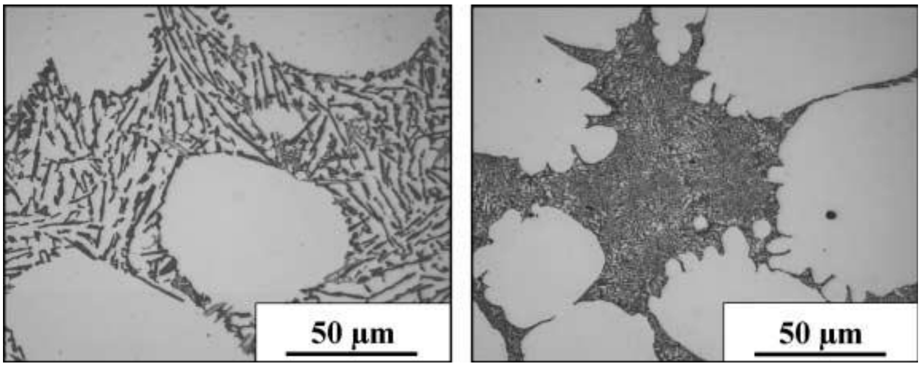

Fig. 1. Light microscopy image of the globulitic α_{Al}-phase and the surrounding eutectic in unmodified (normal flake) (left) and Sr modified AlSi7Mg0.3 (right) [Zhang ,Zheng , Han, 1981]

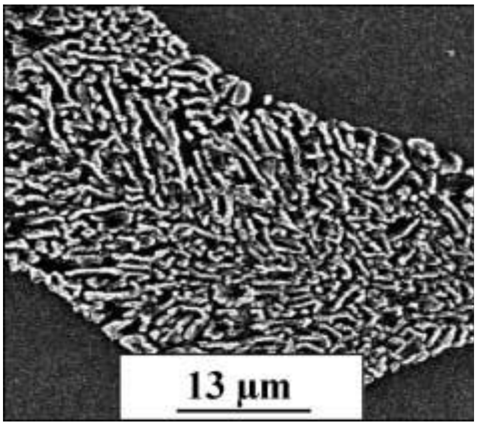

Fig. 2. SEM picture of the fine fibrous eutectic silicon in Srmodified AlSi7Mg0.3 [Zhang ,Zheng , Han, 1981]

Modification has been a well-known foundry practice employed for refining the large size eutectic silicon needles to fine fibrous or lamellar in morphology [Benzerga , Hong , Kim Vander Giessen , Needleman, 2001, Makhlouf, Guthy, 2001], Later on many researchers [Makhlouf, Guthy, 2001, Kim , Heine, 1964 , Smith , 1967, Lu, Hellawell, 1987 , Mondolfo, 1976] have attempted to refine the size of silicon using various elements.

Several researches have also [Makhlouf, Guthy, 2001, Smith, 1967, Lu, Hellawell, 1987] tried to explain the mechanism of modification in Al–Si alloys. According to Kim and Heine [Kim, Heine, 1964] , cadmium leads to little modification of the eutectic silicon, but they did not explain the exacted mechanism of modification. Mondolfo [Mondolfo, 1976] reported that Cd additions may or may not modify the eutectic silicon in Al–Si alloys. However, there is no clear explanation of the modification behavior of Cd present in Al–Si alloys. Present work is tried to investigate the role of Cd in the modification of eutectic silicon in Al–7Si alloy.

2. Experimental details

Al–7Si alloy was melted in silicon carbide crucible (preheated at 200 ◦C) under a cover flux (50 wt %NaCl + 50 wt %KCl) gas furnace. The melt was brought to a temperature of 750 ◦C and then degassed (to remove H2) using commercial degasser, hexachloroethane (C_2Cl_6). After degassing, a part of untreated melt was poured into a cylindrical cast iron mould (18mm diameter and 150mm height) with its top open for pouring. Later, a calculated amount (0.2, 0.6 and 1.0 wt %) of modifier (Cd) was duly wrapped in an aluminum foil and plunged in to the melt in the form of chips. The melt was stirred for 3 minutes with graphite rod, after which no further stirring was carried out. A part of the melt was poured into cast iron mould (18mm diameter and 150mm height) after holding time of 3 and 30 min. Specimens were cut across the diameter in transverse axis at a height of 25mm from the bottom of the casting for microstructural characterization under light optical microscope (LOM). The chemical composition analysis was performed by using XRF spectroscopy (X-Met 3000 TX, horizon 600 series, model 2004) as shown in table 1**.**

Table1. Chemical composition

Element	Si %	Fe%	Cu%	Mn %	Ti %	Cd	Al
A1	7.937	0.137	0.05	0.004	0.0001	....	Bal.
A2	7.937	0.137	0.05	0.004	0.0001	0.2	Bal.
A3	7.937	0.137	0.05	0.004	0.0001	0.6	Bal.
A4	7.937	0.137	0.05	0.004	0.0001	1.0	Bal.

3. Results and discussion

Effect of cadmium on the shape and size of eutectic silicon is studied by adding Cd in elemental form to the melt of Al–7Si alloy at 750 ◦C. Fig. (3a) shows the light optical microscope micrograph of as-cast Al–7Si alloy without Cd [Makhlouf ,Guthy, 2001, Prasada Rao, Das, Murty, Chakraborty, 2008], which reveal coarse platelet and needle-like of eutectic silicon in the α-Al matrix. On the other hand Fig.3(b – d) represent the microstructures of Al–7Si alloy inoculated with 0.2, 0.6 and 1.0 wt% Cd and cast after holding times of 3 min, respectively. The micrographs in fig.3 (e-g) represent the microstructures of Al-7Si alloy inoculated with 0.2, 0.6 and 1.0 wt% Cd and cast after holding times of 30 min, respectively. Microstructures of Cd treated Al–7Si alloy (Fig.3 (b-d) show finer Si particles compared to the alloy without Cd addition (Fig. 3a). It has also been found that the modification of eutectic silicon improves with the increase in the addition level of Cd from 0.2 to 1.0 wt%. However, the results indicate that, the structure obtained from 1.0wt% Cd addition level and keeping time 3 min. was finer. The shorter keeping time was better because the Cd oxidizes at high temperature and lost its effect with the time.

b

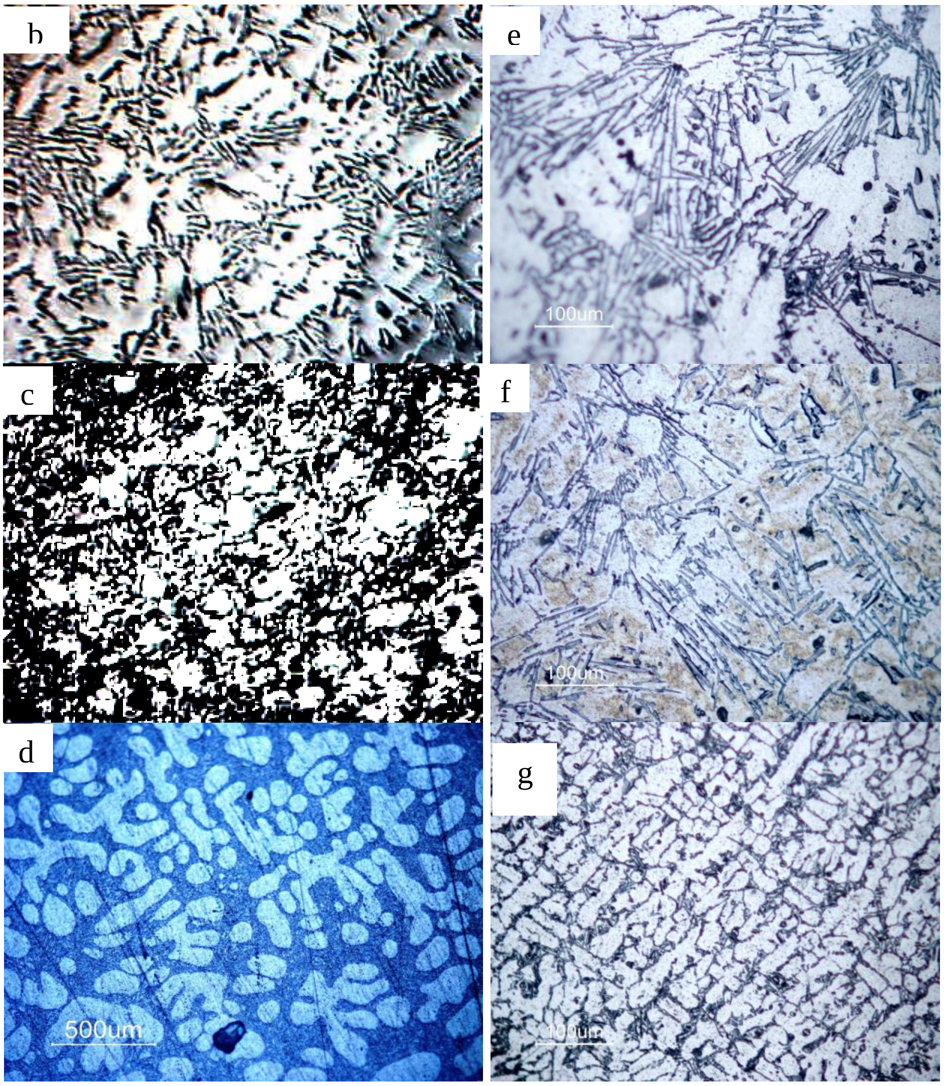

Fig.3 LOM photomicrograph of as-cast Al–7Si alloy (a) without inoculation Si-eutectic length~95µm, (b) inoculated with 0.2.0%Cd and 3 min keeping time (length 42 µm), (c) inoculated with 0.6% Cd and 3 min keeping time (length 30 µm, (d) inoculated with 1.0% Cd and 3 min keeping time (length 10 µm, (e) inoculated with 0.2% Cd and 30 min keeping time (length 88 µm, (f) inoculated with 0.6% Cd and 30 min keeping time(length 60 µm and (g) inoculated with 1.0% Cd and 30 min keeping time (length 45 µm), all at magnification x200.

Cadmium has very little solubility either in Al or Si at room temperature. It does not form any compound either with Al or Si, up on solidification of Al–7Si alloy. Hence, there is less possibility of Cd acting as a good modifier unlike other elements like (Na, Sr, Sb, etc.). However in the present work, refinement of the eutectic silicon needles is observed in Cd containing Al–7Si alloy. The possible mechanism involved in the refinement of eutectic silicon needles is discussed below. When Al–7Si melt containing Cd at 750 ◦C is cooled slowly, α-Al nucleates first, and the dendrites start growing. During this process, the liquid rich in Si and Cd will be rejected by the growing α-Al solid front. And then the concentration of the melt at solid-liquid interface increased and at eutectic temperature (577 ◦C), a mixture of α-Al and silicon will be formed in the inter-dendritic regions.

Earlier study of Popel etal. [Popel, Kushnir, Domashnikov, 1981] has reported that presence of Cd in molten aluminum increases the viscosity and density of the melt (at 700 ◦C). As the melt temperature drops further, viscosity of the solute rich liquid increases due to the presence of cadmium (compared to the one with without Cd). Hence, during eutectic reaction (Al–Si) at 577 ◦C there exists a growth restriction of eutectic silicon due to viscous friction between the growing eutectic and the cadmium rich liquid. The last liquid to solidify is liquid cadmium (since melting point of Cd is very low, 321 ◦C), and this will be pushed to the inter-dendritic regions by the solid front, which eventually leads to the modification of the eutectic silicon.

There is change in the aspect ratio; this is evident from the light optical micrographs shown in Fig. 3b -d.

4. Conclusion

1. A new technique of modification of eutectic silicon using Cd has been proposed.
2. The result indicates that Cd modifies the eutectic silicon in hypoeutectic Al–Si alloys.
3. The modification effect increases with the increase in the addition content of Cd up to 1% Cd.
4. Further, cadmium shows better modification effect at shorter holding time than at longer holding of the Cd containing melt of Al–7Si alloy.

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