Microstructure and Mechanical Properties of Micro-Alloying Modified Al-Mg Alloys

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***Abstract*—Er and Sr were added to 5052 Al alloy to investigate their possible effects on the microstructure and mechanical properties of the alloy. The results show that while Sr addition has a moderate grain refinement effect and has no positive effect on alloy plasticity, Er addition refines both the grain size and Al6Fe intermetallics and obviously improves the tensile elongation from 12% for 5052 alloy to 20% for Er-containing alloy. It is also revealed that Er either dissolves in the matrix or combines with Fe and Si and that Er can purify the alloy by eliminating impurity elements Fe and Si from the melt and Al-matrix.**

Keywords-5052 Al alloy; micro-alloying; microstructure; mechanical properties

I. INTRODUCTION

With the increased demand of energy saving and pollution reduction, Al-Mg series (5XXX) alloys is increasingly used in automotive and transportation industry due to their high specific strength, wieldable, good workability and corrosion resistance [1]. Al-Mg alloys are non-heat treat hardening but derive their strength from solid solution strengthening and strain hardening. It has been shown that micro-alloying is an effective way to further strength the alloys. Alloying elements such as Sc, La, Ce, Y, Nd, Zr, Er, Sr have been added to high-Mg-containing Al-Mg alloys, especially 5083 aluminium alloy [2-9]. However, the role of alloying addition on low-Mg-containing Al-Mg alloys has not been studied. Comparatively, low-Mg-containing Al-Mg alloys have better formability and are more suitable for large wrought products. Demand in light rail train, coal conveyor, refrigerated truck, etc., requires larger width Al sheets, which in turn, raises higher formability requirement in order to ensure a homogenous deformation along width direction. In consideration that rare earth addition is beneficial to both microstructure and properties [10], micro-alloying elements Er and Sr have been added to 5052 Al alloy, a typical low-Mg-containing alloy, and their modification role on the as-cast microstructure and mechanical properties are investigated.

II. EXPERIMENTAL PROCEDURES

Commercial 5052 Al alloy was used as base alloy. Minor Er and Sr were added. The chemical composition was analyzed by inductively coupled plasma emission spectrometer (ICP) and is shown in Table 1. The alloys were prepared by mold casting. Samples sectioned from the center of the ingots were polished and etched for microstructure observation, by optical microscope and TESCAN VEGA II scanning electron microscope (SEM) equipped with INCA Energy 350 energy dispersive X-ray spectrometer (EDX). The grain size was measured by the mean liner intercept method. The phase transformations during the solidification of these alloys were characterized by employing a NETZSCH STA449C simultaneous thermal analyzer. In the DSC testing, samples of 30 mg were heated to 700 ºC for 5 min and then cooled at a controlled speed of 15 K/min under flowing argon. Microhardness was measured using a Vickers micro-hardness tester with a load of 50g and duration of 10s. Cylindrical samples of 56 mm gauge length and 13 mm diameter were cut from the ingots for tensile mechanical testing.

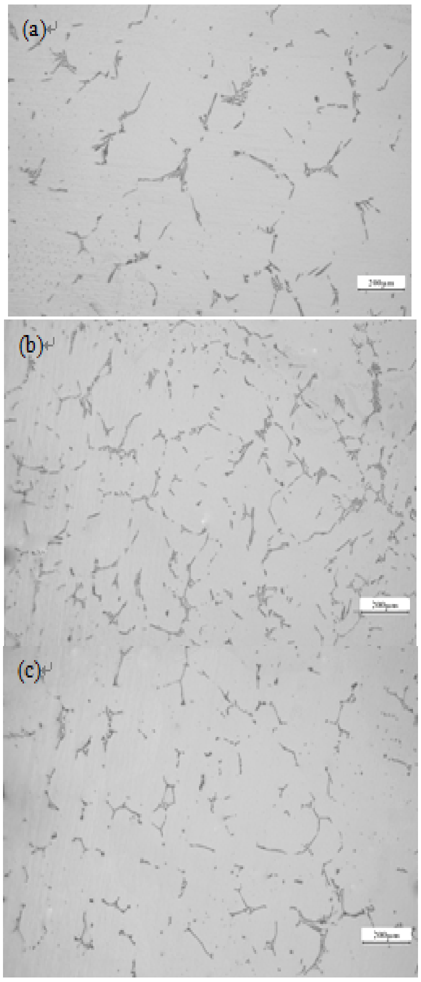
TABLEI. CHEMICAL COMPOSITIONS OF THE EXPERIMENTAL MATERIALS(WT%)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ti	Er/Sr	Al
5052	0.070	0.417	<0.1	<0.1	2.25	0.14	0.006	/	Balanced
5052+Er	0.081	0.665	<0.1	<0.1	2.27	0.10	0.020	0.30	Balanced
5052+Sr	0.070	0.460	<0.1	<0.1	2.41	0.14	0.006	0.028	Balanced

III. Results and Discussion

A. Microstructure

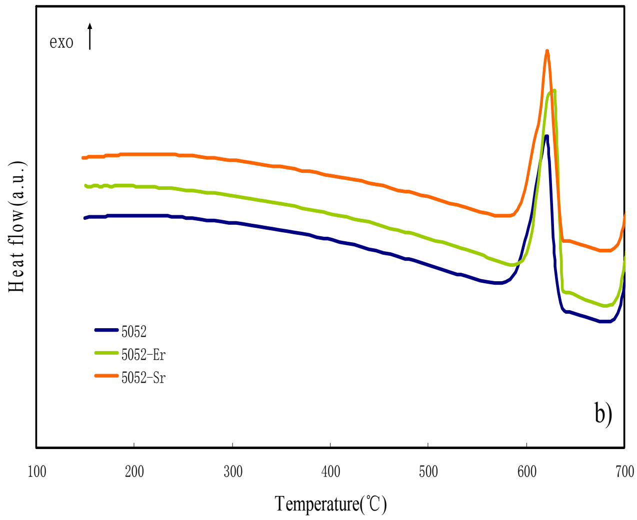
The as-cast microstructures of 5052 base alloy and Er/Sr modified alloys were shown in Figure1. The microstructures manifest dendritic morphology with the second phase distributed along grain boundaries. The grain size of 5052 alloy is within 200~300 μm. With Er/Sr addition, the grain sizes are much reduced. As the same time, the amount of the secondary phases is obviously increased with Er addition while Sr addition does not influence the amount of the particles. The volume fraction of the particles was measured to be ~2%, 3% and 2% for the base alloy, the alloy with Er and Sr additions, respectively.



FIGUREI. AS-CAST MICROSTRUCTURES OF 5052 ALLOYS: (A) BASE ALLOY, (B) WITH ER ADDITION, (C) WITH SR ADDITION

Thermal Analysis

DSC curves of the as-cast alloys are shown in Figure 2. The addition of Er and Sr does not change the phase transformation characteristics. The exothermal peak on the cooling curves corresponds to the crystallization of the α-Al matrix. However, it is noted that the addition of Er and Sr does change the characteristic temperatures. The initial temperature TN, the peak temperature TM and the end temperature TR of the exothermal peaks are listed in Table 2. The solidification temperature range ΔT（ΔT=TN-TR）is also given in Table 2. It can be seen that ΔT decreases by micro-alloying and it decreases the most with Er addition. The smaller the solidification temperature range, the better the fluidity and filling performance of the alloy. Therefore, the addition of alloying elements, especially Er, is beneficial to improve the casting performance of the alloy, which is important for large billet production. Furthermore, it is noted that the initial temperature increases incrementally with Sr and Er addition. This means that nucleation can occur at a relatively low undercooling temperature, a phenomenon which is normally associated with lower nucleation energy. From this point of view, the grain size of Er-containing alloy should be the finest, which accords with the microstructure observation results.



FIGUREII. DSC COOLING CURVES OF THE AS-CAST ALLOYS

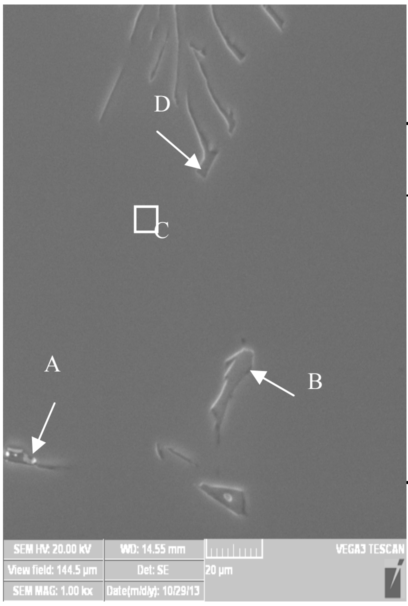
TABLEII. THE CHARACTERISTIC TEMPERATURES (INITIAL TEMPERATURE TN, PEAK TEMPERATURE TM AND END TEMPERATURE TR) OF THE EXOTHERMAL PEAKS ON THE COOLING CURVES (°C)

Alloy	T_N	T_M	T_R	ΔT
5052	630.6	619.7	590.4	40.2
5052+Er	635.0	625.9	606.2	28.8
5052+Sr	631.8	622.3	595.7	36.1

B. Phase Constitution

To determine the effect of micro-alloying addition on the phase constitution, SEM and EDS analysis were performed. In 5052 alloy, Mg is almost dissolved in α-Al matrix. Impurity elements Fe and Si exist in the form of intermetallic Al6Fe and Mg2Si phases. With Sr addition, the phase constitution does not show detectable change. After adding Er, no Mg2Si particles were detected, instead, Si combined with Er, as illustrated by arrow A in Figure3 whose composition is also inserted in the figure. Al6Fe phase still exist, however, the size is much reduced, being ~100 μm in 5052 alloy and ~20 μm with Er addition, respectively. Moreover, it is interesting to note that there is always minor Er detected in the Al6Fe phase. The results suggest that Er can purify the alloy by eliminating impurity elements Fe and Si from the melt and Al-matrix, thus diminishing their harmful effects. Furthermore, Er segregates in the front of the advancing solid/liquid (S/L) interface during the solidification and inhibits the growth of the secondary phase [11], resulting in a size reduction of the Al6Fe phase.

EDS results also reveal that there is certain amount of Er dissolved in the α-Al matrix. Besides, it is found [12] that Al and Er have a stronger tendency than Mg-Er and Mn-Er to combine together, therefore there might be some Al3Er particles which can act as effective nuclei for the Er-containing alloy.

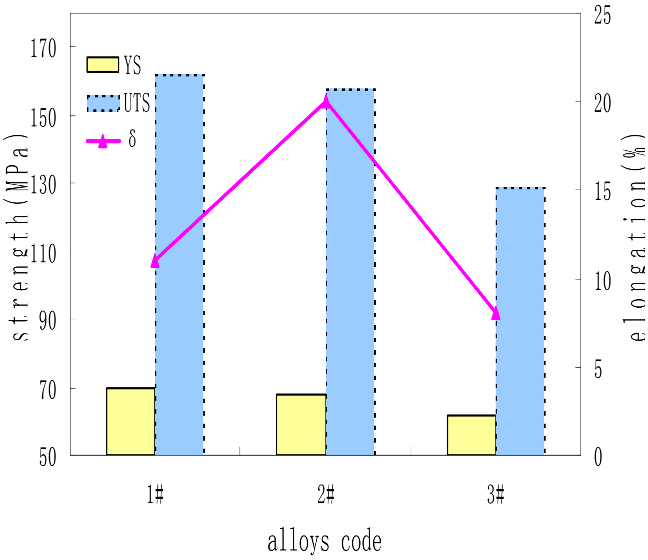


Elements (wt.%)			
Al	Er	Fe	Si
91.02	1.78		7.20
67.32	0.86	31.83	
99.60	0.40		
73.62	1.10	25.28	

FIGUREIII. SEM MORPHOLOGY AND EDS ANALYSIS RESULTS OF THE ER-CONTAINING ALLOY

C. *Mechanical Testing*

Hardness testing shows that HV value remains almost unchanged with alloying element addition, being in the range of 47~50. Mechanical testing shows (Figure4) that tensile strength decreases a bit with alloying element addition, while the elongation is obviously improved with Er addition, increasing from 12% for 5052 alloy to 20% for Er-containing alloy. The improvement of elongation is beneficial to subsequent plastic deformation processing.



FIGUREIV. TENSILE MECHANICAL PROPERTIES OF THE ALLOYS. 1#:5052 ALLOY #2:5052+ER; 3#:5052+SR

IV. CONCLUSIONS

1) The as-cast microstructure of 5052 alloy has a typical dendritic morphology. The main phases are α-Al matrix, intermetallic compounds Al6Fe and Mg2Si.

2) Er addition refines both the grain size and the Al6Fe phase. Er either dissolves in the matrix or combines with Fe and Si; Er can purify the alloy by eliminating impurity elements Fe and Si from the melt and Al-matrix.

3) Tensile elongation is obviously improved by Er, increasing from 12% for 5052 alloy to 20% for Er-containing alloy. The improvement of elongation is beneficial to subsequent plastic deformation processing.

4) Sr has a moderate grain refinement effect. Moreover, it does not change the phase constitution and has no positive effect on alloy plasticity.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support of the International Technical Cooperation Project (2011DFR50950) by the Ministry of Science and Technology of China and sharing fund of Chongqing University's large scale equipment.

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