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Microstructure and Mechanical Properties of As-cast 5182 Aluminum alloy Modified with Al-RE and Al-5Ti-1B Master Alloys

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Abstract. The modification effects of Al-RE (rare earth) and Al-5Ti-1B master alloys on the microstructure and mechanical properties of as-cast 5182 aluminum alloys were studied. Experimental results show that both of the modifications refine the α-Al grains and the Mg_2Si and $(FeMn)Al_6$ eutectics. The Mg_2Al_3 phases exist in the forms of thin flake (β′-Mg_2Al_3) and small granule (β-Mg_2Al_3) for the unmodified 5182 aluminum alloy. Modifications with 0.1 wt% Al-5Ti-1B and 0.2 wt% Al-RE yield longer flakes of β′-Mg_2Al_3 and small amounts of β-Mg_2Al_3 granules. The other contents of the modifiers reduce the longer flakes of β′-Mg_2Al_3 but facilitate formation of the particles and islands of β-Mg_2Al_3. The 0.2 wt% of Al-RE modification yields the finest microstructure and the largest ductility; the 0.2 wt% of Al-5Ti-1B modification has better microstructure and the highest tensile strength.

1. Introduction

5182 aluminum alloy is widely used to fabricate vehicle bodies, steering wheels, stiffeners and brackets because of its good combination of strength and plasticity, formability and welding ability. Optimization of the microstructure and mechanical properties is necessary to enhance reliability of the aluminum alloy.

The microstructure and properties of the 5182 aluminum alloy can be improved by controlling its solidification, plastic processing and heat treatment procedures. Thompson et al [1] studied the effect of cooling rate on the solidification characteristics of AA 5182 alloy. They found that increasing the cooling rate slightly increases the solid fraction of the eutectic precipitation and results in a decrease in the solidus temperature and an increase in the solidification interval. Whitehead et al [2] compared the effect of Al–3 wt% Ti–0.15 wt% C and Al–3 wt% Ti–1 wt% B modifiers on the grain structure of 5182 aluminum ingots. Both of the modifiers distinctly refine the Al matrix because of the existence of nucleating particles such as TiC and TiB_2; the effect of the Al-Ti-C is stronger than that of theAl-Ti-B

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does. Ratchev [3] observed that the addition of Cu produces a large number of small dispersoids and so retards the recrystallization; adding 0.5 wt% Cu reduces the hot formability. Flood et al [4] studied the effects of casting speed, grain refinement and the variations in iron and silicon contents on the microstructure and macrosegregation of 5182 alloys. They found that the cell structure and macrosegregation are insensitive to the casting speed. Grain refinement prevents plumose grains and produces fewer but larger iron-bearing particles. The type of the iron intermetallics is determined by the Fe/Si ratio but is insensitive to the casting parameters. The mechanical properties are deteriorated when the iron and silicon contents increase. Cao et al [5] compared the microstructure and properties of 5182 alloys prepared by an electromagnetic casting (EMC) and direct chill casting (DCC). The EMC ingot has a better microstructure and properties than those of the DCC; the hardness, wear resistance and fatigue life of the EMC sample are increased because of the presence of the homogeneous microstructure.

Rare earth (RE) and Al-Ti-B master alloys have been used in the aluminum alloy modification to obtain fine granularity and excellent mechanical properties. However, few researches have introduced the RE–modification technique to optimize the microstructure for the 5182 aluminum alloy. Therefore the present work is to compare the modification effects of Al-RE and Al-5Ti-B master alloys on the microstructure and the mechanical properties of the as-cast 5182 alloy ingots.

2. Materials and Methods

Materials. Industrial pure aluminum ingot and intermediate alloys of Al–10 wt% Me (Me=Mg, Si, Cu, Ti, Cr, Zn, Mn, Fe) were used as row materials. Commercial Al-5Ti-1B alloy and Ce-rich mixed rare earth-aluminum alloy (Al-RE) were used as the modifiers. The composition of the Al-RE alloy is listed in Table 1.

TABLE 1 CHEMICAL COMPOSITION OF AL-RE INTERMEDIATE ALLOY, WT%

Element	Ce	La	Pr	Nd	Sm	RE total	Al
Content	6.95	1.54	0.32	0.58	0.10	9.49	Bal.

Methods. The aluminum ingot was put into an electric furnace at 730 °C to melt. Specific amounts of intermediate alloys were added into the melts. After stirred for 15 min, A N_2 gas purification was adopted to eliminate gases and inclusions in the melts. The chemical composition of the melts is listed in Table 2. Then different amounts (0, 0.1, 0.2 and 0.3 wt%) of modifiers were respectively added and held at the constant temperature for 10 min. the melts were poured into a preheated (200 °C) steel mold to form ingots with a size of 30 (thickness)×80 (width)×150 (height) mm and cooled to room temperature in the mold. The ingots were transversely cut and machined into tensile bars with a diameter of 8 mm.

TABLE 2 MAIN CHEMICAL COMPOSITION OF 5182 INGOT, WT%

Mg	Si	Fe	Mn	Cr	Cu	Zn	Ti	Al
4.58	0.18	0.31	0.34	0.08	0.15	0.12	0.09	Bal.

The microstructure was observed by a metallurgical microscope (OLYMPUS-GX51). The surface of the samples was polished and etched by an HF (5 wt%)-alcohol solution. The mechanical property was measured using a material test machine (Jinan SHT4605) with a loading speed of 0.2 mm/min.

3. Results

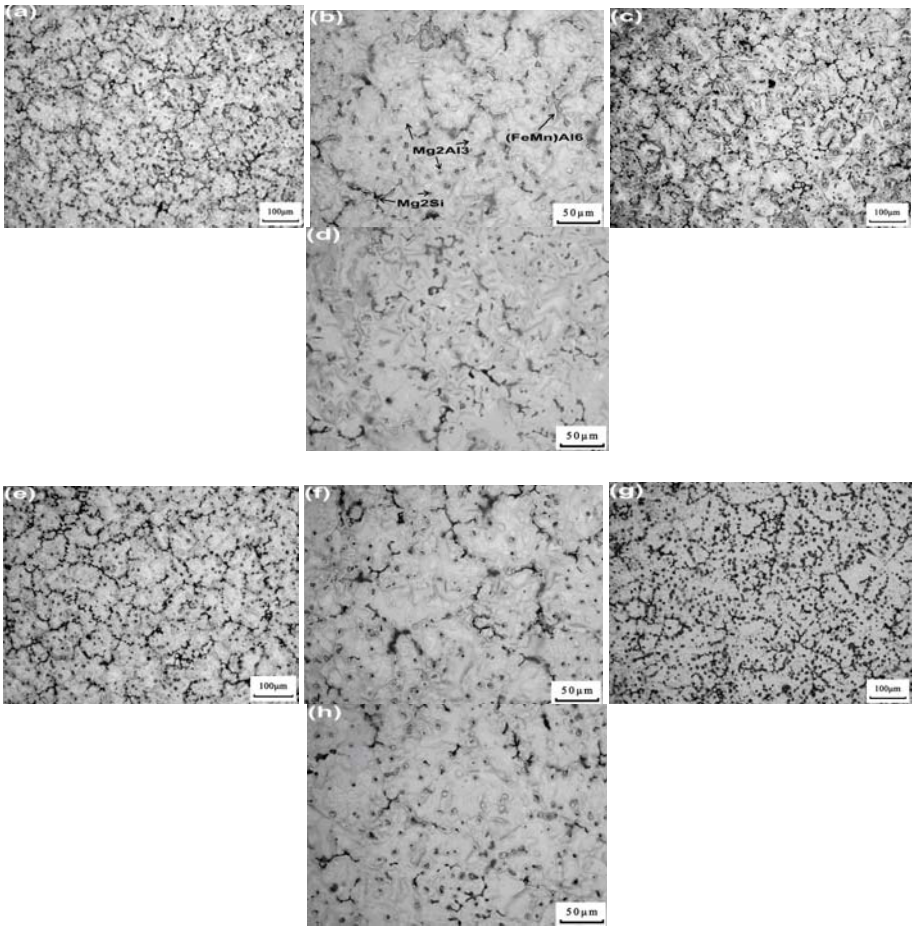

Fig. 1 Microstructure of 5182 alloy modified with different amounts of Al-5Ti-1B master alloy, (a, b) Unmodified; (c, d) 0.1wt%; (e, f) 0.2wt%; (g, h) 0.3wt%

The Microstructure of Al-5Ti-1B Modified Alloys. Fig. 1 shows the microstructure of as-cast 5182 alloys modified with different amounts of Al-5Ti-1B master alloy. For the unmodified sample, the Mg_2Al_3 phase precipitate in three forms—thin flake, island and small annuli (Fig. 1b). With 0.1 wt% Al-5Ti-1B modification, the Mg_2Al_3 phase is completely transformed into longer and thicker flake (Fig. 1d); further, Al-5Ti-1B addition in turn makes the Mg_2Al_3 phase appear as the short flake and island and small annuli (Figs. 1f, 1h). Moreover, the α-Al grain and the Mg_2Si and $(FeMn)Al_6$ phases are gradually refined with the addition of Al-5Ti-1B (Figs. 1a, 1c, 1e, 1g).

The Microstructure of Al-RE Modified Alloys. Fig. 2 shows the microstructure of the alloys modified with different amounts of Al-RE master alloy. Modification with 0.1 wt% Al-RE causes the Mg_2Al_3 phase to precipitate as thick flake, annuli and island (Fig. 2b), similar to the results obtained in the 0.2 wt% Al-5Ti-1B modification (Fig. 1f). The 0.2 wt% Al-RE modification increases the proportion of the thick flake of Mg_2Al_3, and further increasing the content of Al-RE (0.3 wt%) results in an aggregation of fine Mg_2Al_3 particles (Fig. 2f). Modification with 0.2 wt% Al-RE has the best effect on the microstructure because of the greatly refined α-Al grains, as well as the Mg_2Si and $(FeMn)Al_6$ interphases. However, 0.3 wt% Al-RE modification yields some coarse α-Al grains (Fig. 2e), indicating a worsened modification effect.

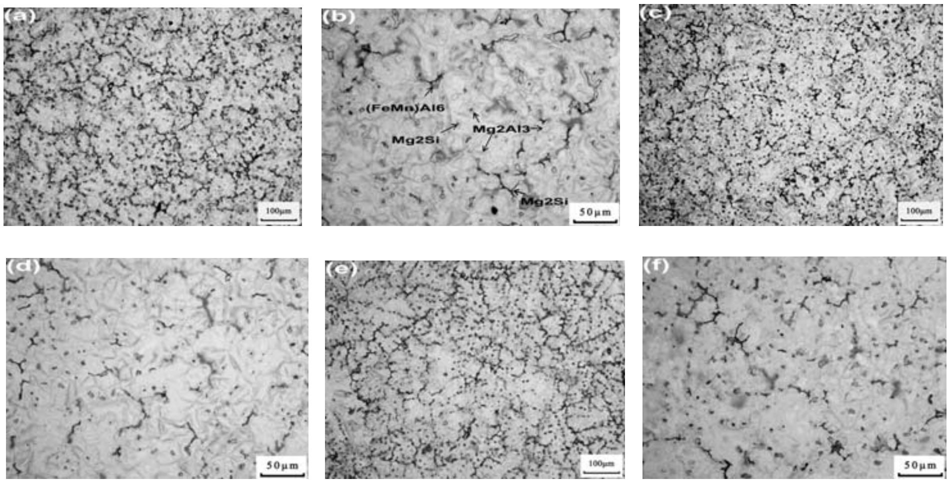

Fig. 2 Microstructure of as-cast 5182 alloy modified by different amounts of Al-RE master alloys (a, b) 0.1wt%, (c, d) 0.2wt%, (e, f) 0.3wt%

The Mechanical Properties of Samples. Table 3 shows the mechanical properties of the as-cast alloys modified with Al-5Ti-1B and Al-RE master alloys. Both of the modifications enhance the elongation and tensile strength in some extent, but have little influence in the yield strength and hardness, The 0.2 wt% Al-5Ti-1B modification yields the highest temsile strength (288.6 MPa) and better elongation of 27.4%, while the 0.2 wt% Al-RE modification produces the highest elongation (32.3%) and higher temsile strength of 276.7 MPa. This result can be related to changs in the microstructure (Fig.1 and Fig. 2).

TABLE 3. MECHANICAL PROPERTIES OF AS-CAST ALLOYS MODIFIED BY AL-5TI-1B AND AL-RE MASTER ALLOYS

Modifier and content wt%	Yield strength MPa	Tensile strength MPa	Elongation %	Hardness HB
-	141.7	245.8	19.5	66.5
Al-5Ti-1B, 0.1	142.3	264.6	25.9	66.7
Al-5Ti-1B, 0.2	143.5	288.6	27.4	67.2
Al-5Ti-1B, 0.3	143.1	267.8	24.2	67.8
Al-RE, 0.1	142.3	258.8	27.9	66.2
Al-RE, 0.2	141.5	276.7	32.3	65.8
Al-RE, 0.3	142.8	271.8	27.4	65.8

4. Discussion

In the Al-Mg binary phase diagram [6], the α-Al dendrites roughly crystallize in the temperature range of 640-600 °C. The Mg_2Al_3 phase starts to precipitate below 250 °C approximately for the Al–(4.0–4.5) wt% Mg system. In the present polynary system, the interphases of Mg_2Si and (FeMn)Al_6 form prior to the crystallization of α-Al dendrites and are distributed in boundaries between them.

The Effect of Modifiers on the Refinement of α-Al Grains and Mg_2Si and (FeMn)Al_6 Interphases. The refining mechanism of Al-Ti-B in aluminum alloys has been reported [7-9]. $TiAl_3$ and TiB_2 particles separated from the master alloy form heterogeneous nuclei for the α-Al dendrites; so the α-Al dendrites can be refined in the crystallization process. In this case, the Mg_2Si and $(FeMn)Al_6$ phases do not have enough space to grow up among the refined α-Al dendrites. In particular, the continuously distributed Mg_2Si phases can be greatly isolated by them. The RE modification has a different refining mechanism than the Al-5Ti-1B master alloy does. Because rare earth metals have larger radii (La: 1.877 Å; Ce: 1.825 Å: Pr: 1.828 Å, Nd:1.822 Å) [10], they hardly dissolve into α-Al crystals. With the crystallization of α-Al dendrites, they are discharged out of the crystals and enrich around them, resulting in a local composition overcooling in melts, which stimulates the formation of the α-Al dendrites [11-13]. Moreover, the RE elements adsorbed on the surface of α-Al grains and Mg_2Si and $(FeMn)Al_6$ phases likewise inhibit their growth by influencing the diffusion of Al, Si, Mg, Mn, Fe, etc. and by deteriorating the crystal planes for growth. Thus, the RE modification results in the refined α-Al grains, as well as Mg_2Si and $(FeMn)Al_6$ crystals. Extra addition (0.3 wt%) in turn yields abnormal α-Al grains, as reported in the literature [12, 14], because of the inhomogeneous adsorption on the interface.

The Effect of Modifiers on Precipitation of Mg_2Al_3 Phases. The Mg_2Al_3 has three structures: noncoherent stable phase β (FCC), semicoherent intermediate β′ (hexagonal) and completely coherent β″ (GP zone) [15]. The β″- and β′-Mg_2Al_3 nucleate at defects such as dislocations and vacancies and are easy to stretch into thin flakes [16, 17]. The crystallization of α-Al dendrites is easy to introduce such defects in the Al matrix due to the rapid solidification. Thus, the Mg_2Al_3 phases preferentially precipitate into thin flakes, and the subsequent β-phase will randomly precipitate into fine particles, resulting in an inhomogeneous distribution of the Mg_2Al_3 phases (Fig. 1b).

With the Al-5Ti-1B addition, the heterogeneous crystallization of α-Al dendrites appears and the α-Al crystals are refined. In subsequent cooling process, the Si, Mn and Fe atoms can easily precipitate out of the α-Al crystals, decrease the oversaturation and lattice distortion and make the coherency more suitable to the preferred orientation growth of the β′-Mg_2Al_3 phases, thus resulting in longer flakes distributed uniformly in the Al matrix (Fig. 1d). Further increasing the Al-5Ti-1B (0.2 wt% and 0.3 wt%) makes the precipitation of the atoms easier, the oversaturation and lattice distortion (defects) in α-Al crystals will be decreased. Thus, the orientation growth is weakened again; the noncoherent β-Mg_2Al_3 phases precipitate and grow into large particles or islands (Figs. 1f, 1h).

In case of the RE modification, the precipitation form of the Mg_2Al_3 phases occurr as the short flakes (Fig. 2b), longer flakes (Fig. 2d) and a mixture of short flakes and fine-particle aggregation (Fig. 2f) with an increase in the amount of RE added. This is because the RE adsorption layer around the α-Al grains depresses the decrease in oversaturation by inhibiting the discharge of Si, Mn and Fe atoms out of the grains. In contrast, the refinement of α-Al crystals is favorable to discharge the atoms. Therefore, the orientation growth of β′-Mg_2Al_3 will depend on the competitive result on both sides. For the 0.1 wt% and 0.3 wt% Al-RE modifications, the stimulating effect of the refinement may be weaker than the inhibiting effect of the rare earth adsorption layer; therefore, the orientation growth of β′-Mg_2Al_3 is depressed, and the precipitation of β-Mg_2Al_3 phases is improved. In contrast, the 0.2 wt% Al-RE modification just produces an inverse competitive result, and the orientation growth of β′-Mg_2Al_3 is improved.

5. Conclusions

Modifications with Al-5Ti-1B and Al-RE master alloys can refine the α-Al grains and the Mg_2Si and $(FeMn)Al_6$ phases. Modifications with 0.1 wt% Al-5Ti-1B and 0.2 wt% Al-RE yield longer flakes of β′-Mg_2Al_3 and small amounts of β-Mg_2Al_3 granules. The other contents

of the modifiers reduce the longer flakes of β′-Mg_2Al_3 but facilitate the formation of particles and islands of β-Mg_2Al_3.
The 5182 alloy modified with 0.2 wt% of Al-5Ti-1B has finer microstructure and the highest tensile strength; the 0.2 wt% of Al-RE modification has the finest microstructure and the largest ductility.

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