Effects of different Al contents on as-cast microstructure and properties of Mg-Al-Si-Sr alloy

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Abstract. Effects of different Al additions (3wt.%, 5wt.%, 7wt.%, 9wt.% Al) on as-cast microstructure and properties of Mg-Al-1Si-0.5Sr alloy were studied. The average grain size decreases and then increases with the increasing of Al additions. There are polyhedral shape, fine fibers shape, a few Chinese script Mg_2Si particles and β-$Mg_{17}Al_{12}$ divorced eutectic phase appeared in the interdendritic area in Mg-3Al-1Si-0.5Sr alloys. With the increase of Al content, more and more β-$Mg_{17}Al_{12}$ divorced eutectic phase appear in semi-continuous distribution. The lamellar-like shape β-$Mg_{17}Al_{12}$ secondary-precipitated phase emerge with Al addition of 5wt.%, 7wt.% and 9wt.%. The optimum tensile properties of Mg-7Al-1Si-0.5Sr alloy can be obtained, where the ultimate strength, yield strength and elongation are 201.1MPa, 160.7MPa, 4.8% at ambient temperature and 164.5MPa, 128.0MPa, 7.4% at 150°C respectively. The hardness increased with the increasing of Al content.

Introduction

Magnesium alloys, as well known for their low density, high strength to weight ratio and high stiffness to density ratio, have drawn wide attention in the application in the aerospace, automotive and electronic industries[1,2].

Mg-Al-Si alloys have high potential as heat-resistant light metals due to the Mg_2Si particles in the alloys that exhibit a high melting temperature of 1085°C, low density of 1.99×10^3 kg·m^{-3}, high hardness of 4.5×10^9 Nm^{-2}, a low thermal expansion coefficient of 7.5×10^{-6} K^{-1} and a reasonably high elastic modulus of 120 GPa[3]. However, the course grain and Chinese script Mg_2Si particles were detrimental to tensile properties of the alloy. It had been found that Sr was effective on the refinement of grains and modification of Mg_2Si[4-6]. The common alloys in this series are AS21, AS31 and AS41. Aluminium, as an important element in magnesium, exists in the form of β-$Mg_{17}Al_{12}$ phase. With increasing Al content in Mg-3.5Ca alloy, the grain size, the distribution and the morphology of phases changed[7]. The susceptibility of stress corrosion cracking increases as the Al content increases from 1% to 8%[8].

The Al content has important influences on microstructure and mechanical properties of casting products due to the solid solution strengthening and aging precipitation strengthening. Therefore, The present paper studies the effects of Al content on as cast microstructure and properties (at ambient temperature and 150°C) of Mg-Al-Si-Sr alloy.

Experimental Procedure

AS31 magnesium alloy (the chemical composition of the alloy is illustrated in Table 1), aluminum, magnesium and Strontium were used as raw materials in this study. The AS31 alloy was remelted to 720°C in an electrical resistance furnace under a protective atmosphere (0.5% SF_6 + 99.5%CO_2,

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volume fraction), and then aluminum, magnesium and 0.5 wt.% Sr were added to the AS31 alloy melt. Then the melt was stirred for 5 minutes and held at 700°C for 30 min to make sure the Sr could have the best refining effect[9,10]. After that, the metal crucible was placed in a depth of 10 mm. Microstructure was investigated by an optical microscopy and SEM . The grain size was measured by SISCIAS8.0 software.

The tensile tests were performed at ambient temperature and 150°C with a crosshead speed of 2 mm/min. The 0.2% yield strength (YS), ultimate tensile strength (UTS) and elongation to rupture (EL.) were averaged over three specimens. The hardness was measured using Brinell hardness tester (HBRV-187.5).

Element	Al	Si	Mn	Be	Cu	Fe	Ni	Mg
Content	3.10	0.91	0.17	0.0014	0.0049	0.0011	0.0003	Balance

Table 1 Chemical composition of AS31 ingot (wt.%)

Results and Discussion

Average grain size. The Macrographs of Mg-xAl-1Si-0.5Sr alloys with 3 wt%, 5 wt.%, 7 wt.%, and 9 wt.% Al are compared in Fig. 1. The variation of the average grain size is showed in Fig. 2. The average grain size decreases and then increases with the increasing of increasing of Al contents. The minimum average grain size can be obtained with 7wt.% of Al content. The average grain size reduces from about 635μm of Mg-3Al-1Si-0.5Sr alloy to about 253μmof Mg-7Al-1Si-0.5Sr.

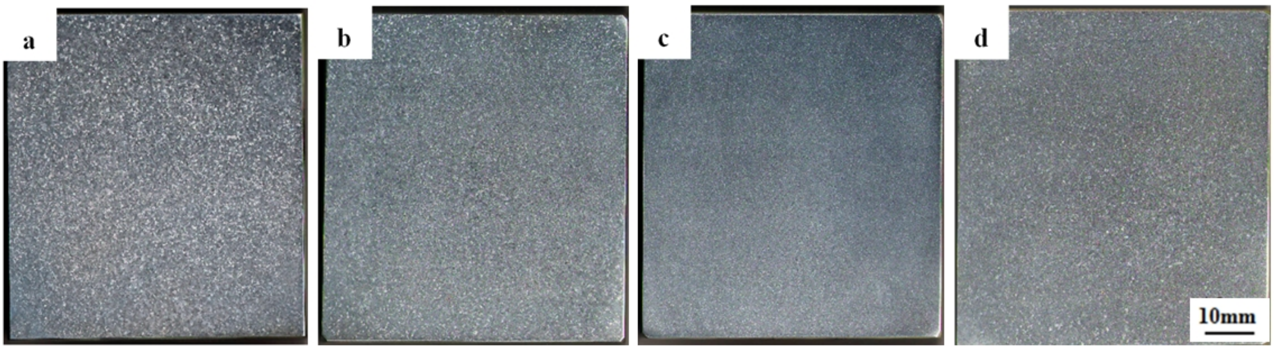

Fig. 1 Macrographs of Mg-xAl-1Si-0.5Sr alloys with 3 wt%(a), 5 wt.%(b), 7 wt.%(c), and 9 wt.%(d) Al

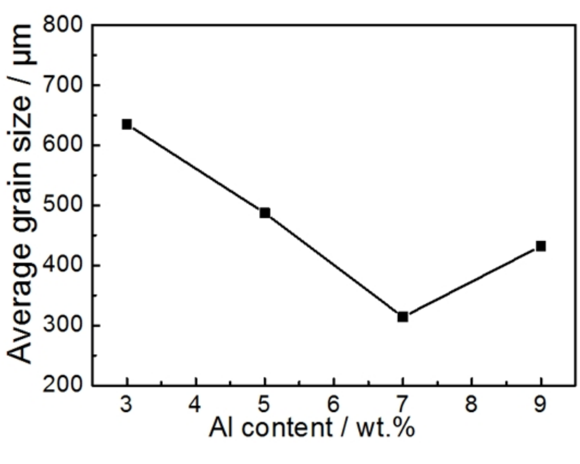

Fig. 2 Average grain size of as-cast Mg-xAl-1Si-0.5Sr alloys with different Al content

Microstruture. The microstruture of Mg-xAl-1Si-0.5Sr alloys with 3 wt%, 5 wt.%, 7 wt.%, and 9 wt.% Al are showed in Fig. 3. There are polyhedral shape, fine fibers shape, a few Chinese script Mg_2Si particles and island β-$Mg_{17}Al_{12}$ phase in Mg-3Al-1Si-0.5Sr alloys. With the increase of Al content, the Chinese script Mg_2Si become fewer and the size become smaller, more and more β-$Mg_{17}Al_{12}$ divorced eutectic phases appear in semi-continuous distribution in Mg-7Al-1Si-0.5Sr alloys and network distribution in Mg-9Al-1Si-0.5Sr alloys. The lamellar-like shape β-$Mg_{17}Al_{12}$ secondary-precipitated phase emerge with Al addition of 5wt.% and increase with the increasing of Al content.

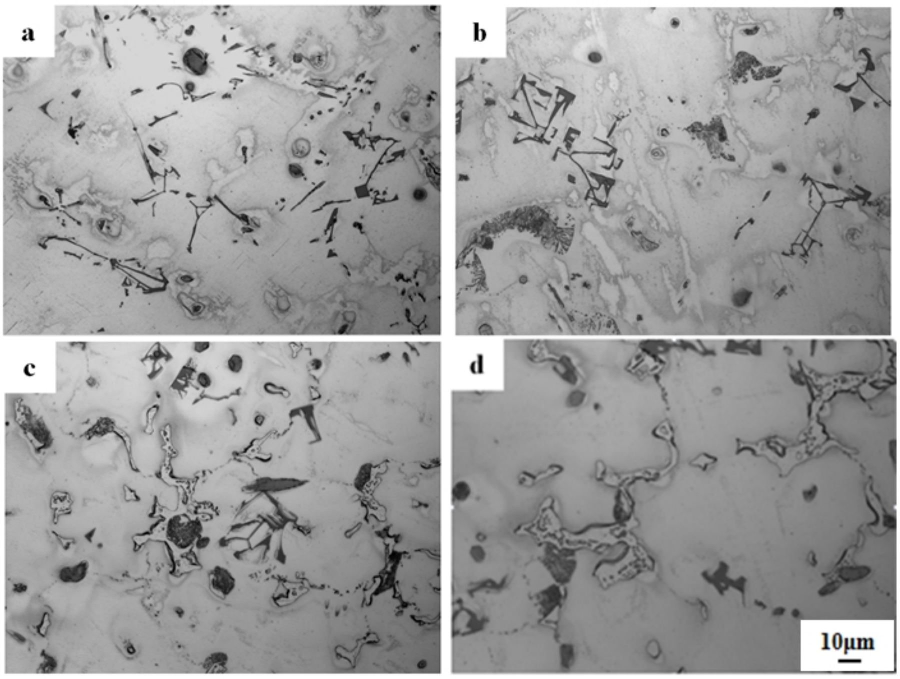

Fig. 3 Microstructure of Mg-xAl-1Si-0.5Sr alloys with 3 wt%(a), 5 wt.%(b), 7 wt.%(c), and 9 wt.%(d) Al

Tensile properties. The variation of tensile properties of as-cast Mg-xAl-1Si-0.5Sr alloys with 3 wt%, 5 wt.%, 7 wt.%, and 9 wt.% Al at ambient temperature and 150°C was showed in Fig .4. The ultimate strength, yield strength at both ambient temperature and 150°C decrease due to the grain refinement and phases modification as the Al content arises from 3wt.% to 7wt.%. Mg-5Al-1Si-0.5Sr have the maximum elongation.The optimum tensile properties of Mg-7Al-1Si-0.5Sr alloy can be obtained, where the ultimate strength, yield strength and elongation are 201.1MPa, 160.7MPa, 4.8% at ambient temperature and 164.5MPa, 128.0MPa, 7.4% at 150°C respectively. The solid solution strengthening and aging precipitation strengthening improve as the increasing of Al additions. The β-$Mg_{17}Al_{12}$ phase becomes coarse when the Al content arises to 9wt.%, which reduce the tensile properties of alloy.

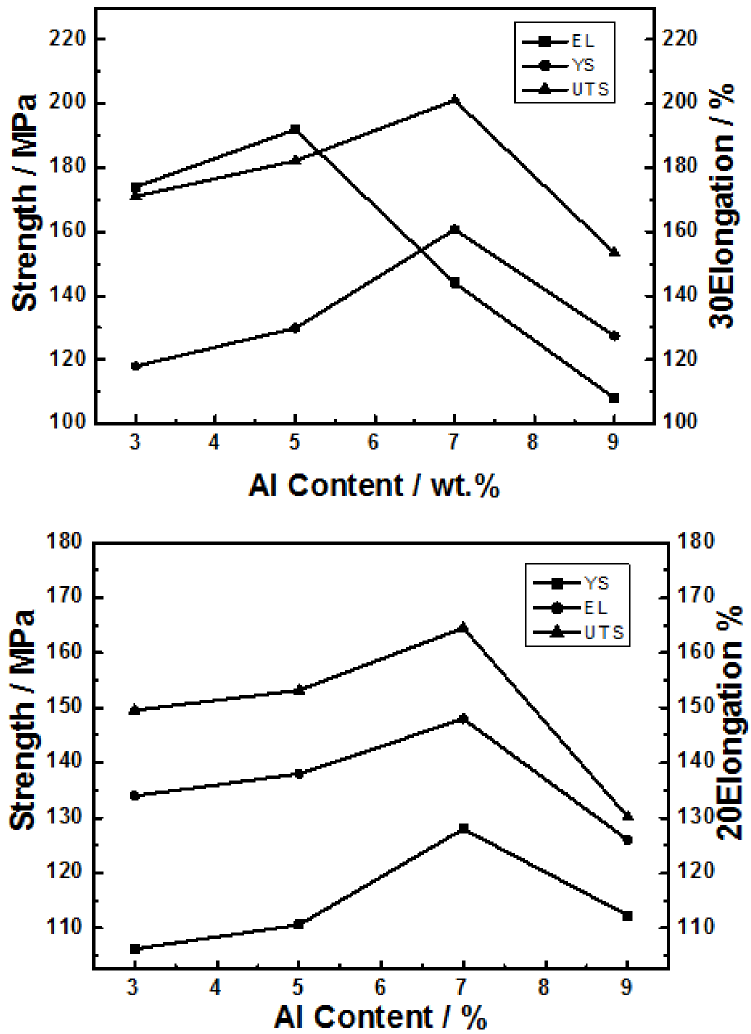

Fig. 4 The variation rule of tensile properties of Mg-Al-1Si-0.5Sr alloys with different Al contents at ambient temperature and 150°C

Hardness. The variation of Vickers hardness of as-cast Mg-xAl-1Si-0.5Sr alloys with 3 wt%, 5 wt.%, 7 wt.%, and 9 wt.% Al was showed in Fig .5. Five places of every alloy were selected to carry out the average value. It could be observed that the Vickers hardness increase with the increasing the Al content. The Vickers hardness arised from 56.4 HV of Mg-3Al-1Si-0.5Sr to 75.0 HV of Mg-9Al-1Si-0.5Sr due to the β-$Mg_{17}Al_{12}$ phase increased and become coarse.

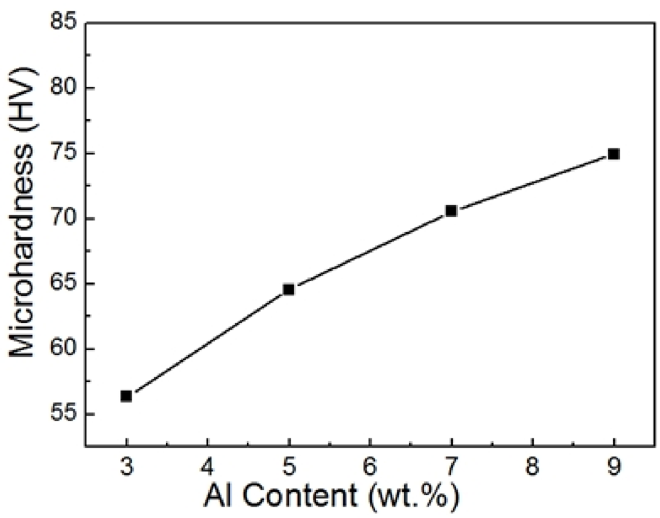

Fig. 5 Microhardness of as-cast Mg-xAl-1Si-0.5Sr alloys

Conclusions

The average grain size decreases with the Al content from 3wt.% to 7wt.% and then increases from 7wt.% to 9wt.%. There were island β-$Mg_{17}Al_{12}$ phase in Mg-3Al-1Si-0.5Sr alloys and the lamellar-like shape β-$Mg_{17}Al_{12}$ secondary-precipitated phase emerge in Mg-5Al-1Si-0.5Sr alloys. With the increasing of Al content, more and more β-$Mg_{17}Al_{12}$ divorced eutectic phase appear in semi-continuous distribution in Mg-7Al-1Si-0.5Sr alloys and network distribution in Mg-9Al-1Si-0.5Sr alloys. The optimum tensile properties of Mg-7Al-1Si-0.5Sr alloy can be obtained, where the ultimate strength and yield strength are 201.1MPa, 160.7MPa at ambient temperature and 164.5MPa, 128.0MPa at 150°C respectively. The hardness increased with Al addition.

Acknowledgements

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References

[1] Z, Yang, J.P. Li,et al: Acta Metallurgica Sinica Vol.21 No.5, 313-328 (2008)

[2] Y.C. Pan, X.F. Liu and H. Yang: Mater Charact Vol. 55 , 241 (2005)

[3] J. X. Zhou, Y.S. Yang, S.Q. Tang and C.W. Tian: Materials Science Forum Vol. 686 , 125 (2011)

[4] S. Q. Tang, J. X. Zhou, C. W. Tian and Y. S. Yang, Trans. Nonferrous Met. Soc. China Vol. 21, 1932-1936 (2011)

[5] J.X. Zhou, D.Q. Zhao,J.W. Wang, S,Q. Tang and W.H. Li, Materials Science Forum. Vol. 788 , 110-114(2014)

[6] J. X. Zhou, J.W. Wang. Y. Zhang. S. Q. Tang, W.H. Li, and Y. S. Yang, Advanced Materials Research. Vol. 816, 465-469 (2015)

[7] Z. T. Jiang, B. Jiang, Y. Xiao, Y. Xiao, Y. Tian, G. Y. Zhou and F. S. Pan, Materials Research Innovations. 137-141(2014)

[8] R. C. Zeng, J. Zhang, W. J. Huang, W. Dietzel and K. U. Kainer, Trans. Nonferr. Met. Soc. China. 763-771(2006)

[9] J.W. Wang. J. X. Zhou, S. Q. Tang, F.M. Chu and Y. S. Yang, Advanced Materials Research. Vol. 915-916 , 583-587 (2014)

[10] J.W. Wang. J. X. Zhou, B. C. Ma. S. Q. Tang, F.M. Chu and Y. S. Yang, Advanced Materials Research. Vol. 697, 71-71 (2015)