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ARTICLE

Effects of Sn on the Microstructure and Mechanical Properties of As-cast AZ80 Alloys

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Abstract: The effects of Sn addition on the microstructure and mechanical properties of as-cast AZ80 alloy were investigated by OM, XRD, SEM and tensile property test. The results show that the microstructure of as-cast AZ80-xSn (x=1, 3, 5, wt%) alloys exhibits typical equiaxed dendrites morphology, which consists of α-Mg primary, Mg_2Sn and $Mg_{17}Al_{12}$ divorced eutectic and secondary precipitation laminar $Mg_{17}Al_{12}$. It is indicated that the addition of Sn can refine the grain size obviously when the Sn content is less than 3 wt% and effectively suppressed the laminar $Mg_{17}Al_{12}$ phase precipitating. When the Sn content is 5 wt%, the laminar $Mg_{17}Al_{12}$ phase nearly disappears. The addition of Sn to AZ80 alloy improves the tensile property at room temperature with the Sn addition increasing from 1 wt% to 3 wt%.

Key words: AZ80; Sn; microstructure; mechanical property

AZ80 magnesium alloy, which is one of the most widely used magnesium alloy in the AZ series, has some attractive properties including low density, high strength to mass ratio and good machinability. However, the coarse β-$Mg_{17}Al_{12}$ phase that exists on the grain boundaries seriously affects the strength and ductility, which is unfavorable to its application in industry[1-4]. AZ80 alloy is based on the Mg-8 wt%Al, with the addition of Zn and Mn less than 1 wt%. The β-$Mg_{17}Al_{12}$ phase of AZ80 includes two types: dis-continuous precipitation (DP) and continuous precipitation (CP)[5]. DP is a cellular growth of alternative layers mainly distributing in the high angle grain boundaries and CP forms as fine and plate shaped precipitates[6]. Some researches report that the volume and distribution of second phase have a significant impact on the corrosion resistance and creep behavior of AZ91 alloy[7,8].

Alloying is the most fundamental and effective method to form different precipitates and to modify the mechanical properties of alloys. Many researches found that Sn as an additional element had great potential to enhance the mechanical properties in Mg-Al systems[9-11]. The intermetallic phase Mg_2Sn of Mg-Sn binary alloy has better hot mechanical properties because of a higher melting point (770 ºC) than $Mg_{17}Al_{12}$ phase (463 ºC). Jung et al[12]. found that Sn could effectively suppress the DP and enhance the density of CP on the aging behavior. Kim et al[13]. investigated the effect of 3 wt%~5 wt% Sn into squeeze cast AZ51 alloy and found that the tensile and fracture properties were improved by introducing twins in α-Mg grain and the crack initiation and propagation were suppressed.

AZ80 alloy could be used as cast magnesium alloy as well as wrought magnesium alloy. However, a few studies pay their attention to the AZ80 alloy and the influence of Sn addition on the structure and mechanical properties of AZ80 casting alloy is still unclear. Therefore, it is worth investigating the addition amount of Sn element to AZ80 alloy.

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The microstructure and mechanical properties of the cast AZ80 alloy were studied with different Sn contents.

1 Experiment

The AZ80-*x*Sn (*x*=0, 1, 3, 5wt%) alloys were prepared by resistance furnace with mixing the pure Mg (99.9wt%), Al (99.9wt%), Zn (99.9wt%), Sn (99.9wt%) and Mg-10Mn intermediate alloys in a protective atmosphere (mixed gas of SF_6 and CO_2) in a resistance furnace. The ingot diameter is 100 mm and the chemical composition of the studied alloys are shown in Table 1.

The metallographic, X-ray diffraction and tensile samples (GB/T228.1-2010) were obtained on the middle of the center and edge of the cast rod to carry out the microstructure observation, phase analysis and tensile test, respectively. The cast samples were etched with a mixture of 99 mL water and 2 mL acetic acid for microstructure observations by ZEISS2000-C optical microscope (OM) and SX2-12-10Y scanning electron microscope (SEM). The phase analysis was performed by the X-ray diffraction Philips PW170 (XRD), Mo kα1 radiation and the selected parameters were 40 kV, 40 mA with the angle range of 2θ=20°~80° at a scanning rate of 0.03°/s. The PDF card of the MDI Jade5.0 software was used to determine the phase of the alloy. The tensile test was performed on the model DW-200E microcomputer controlled electronic universal testing machine at a strain rate of 2 mm/min at room temperature and the values of the ultimate tensile strength (UTS), the yield strength (YS) and elongation (EL) were the average of at least three specimens.

2 Results and Discussion

The XRD analysis (Fig.1) indicates that AZ80 alloy mainly consists of α-Mg and $Mg_{17}Al_{12}$ phases. However, Mg_2Sn is present in the AZT801, AZT803, AZT805 alloys.

The microstructures of the as-cast AZ80, AZT801, AZT803, AZT805 alloys are shown in Fig.2. The as-cast microstructure consists of typical equiaxed dendrites morphology with some secondary phases mainly located in the interdendritic region. The addition of Sn element effectively suppresses the laminar structure precipitating during solidification. When the content of Sn is more than 3 wt%, the Sn element reveals excellent effect on prohibiting laminar structure from forming in interdendritic. By studying the effect of cooling conditions during casting on fraction of β-$Mg_{17}Al_{12}$ in Mg-9Al-1Zn cast alloy, Zhu[14] found that β-eut phase formed during eutectic solidification and the fraction of discontinuous precipitates formed during subsequent solid state cooling. Depending on solidification conditions, partially divorced eutectic or lamellar morphologies can be formed in magnesium alloys. Duly[15,16] inferred that the formation of fine Mg_2Sn phase in the grain boundary restricts the formation of the $Mg_{17}Al_{12}$ nuclei. When the addition of Sn is 5wt%, almost no lamellar $Mg_{17}Al_{12}$ is observed.

Table 1 Nominal composition of the AZ80-*x*Sn (*x*=0, 1, 3, 5, wt%) alloys (wt%)

Alloy	Al	Zn	Sn	Mn	Mg
AZ80	8.1	0.5	0	0.4	Bal.
AZT801	8.0	0.4	1.1	0.4	Bal.
AZT803	8.1	0.4	3.1	0.5	Bal.
AZT805	8.1	0.5	4.9	0.4	Bal.

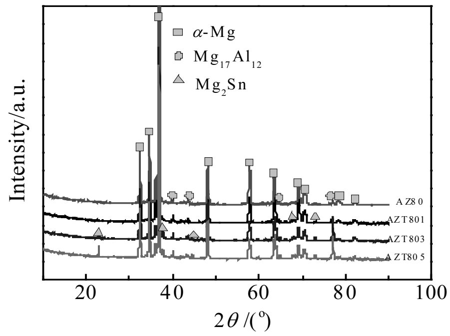

Fig.1 XRD patterns of AZ80, AZT801, AZT803 and AZT805 alloys

To confirm the refining effect of Sn addition to AZ80 alloy, the grain size was measured with a line transect method according to the microstructure of alloys in Fig.2. It is found that the grains of the as-cast AZ80 alloys are refined from 93.5 μm to 78 μm of AZT801 and 63.7 μm of AZT803, and then to 97 μm of AZT805 alloy, which is shown in Fig.3.

During non-equilibrium solidification of alloy, the segregation of Al and Sn elements lead to refinement of grains. With the increase of Sn content, the undercooling degree is increased and the refining effect is better. Because lamellar $Mg_{17}Al_{12}$ precipitates mainly within grain boundaries or dendrites, their decrease indicates that the solubility of Al within grain boundaries or dendrites decreases, Since the increase of Sn content inhibits the segregation of Al element. When the content of Sn increases to 3wt%, the degree of the grain refinement trends to weaken because the decrease of Al segregation becomes stronger than that of the grain refinement trend enhancing due to the decrease of Sn segregation, and the grain size begins to increase. Therefore, when the content of Sn is 3wt%, there is the best refinement effect.

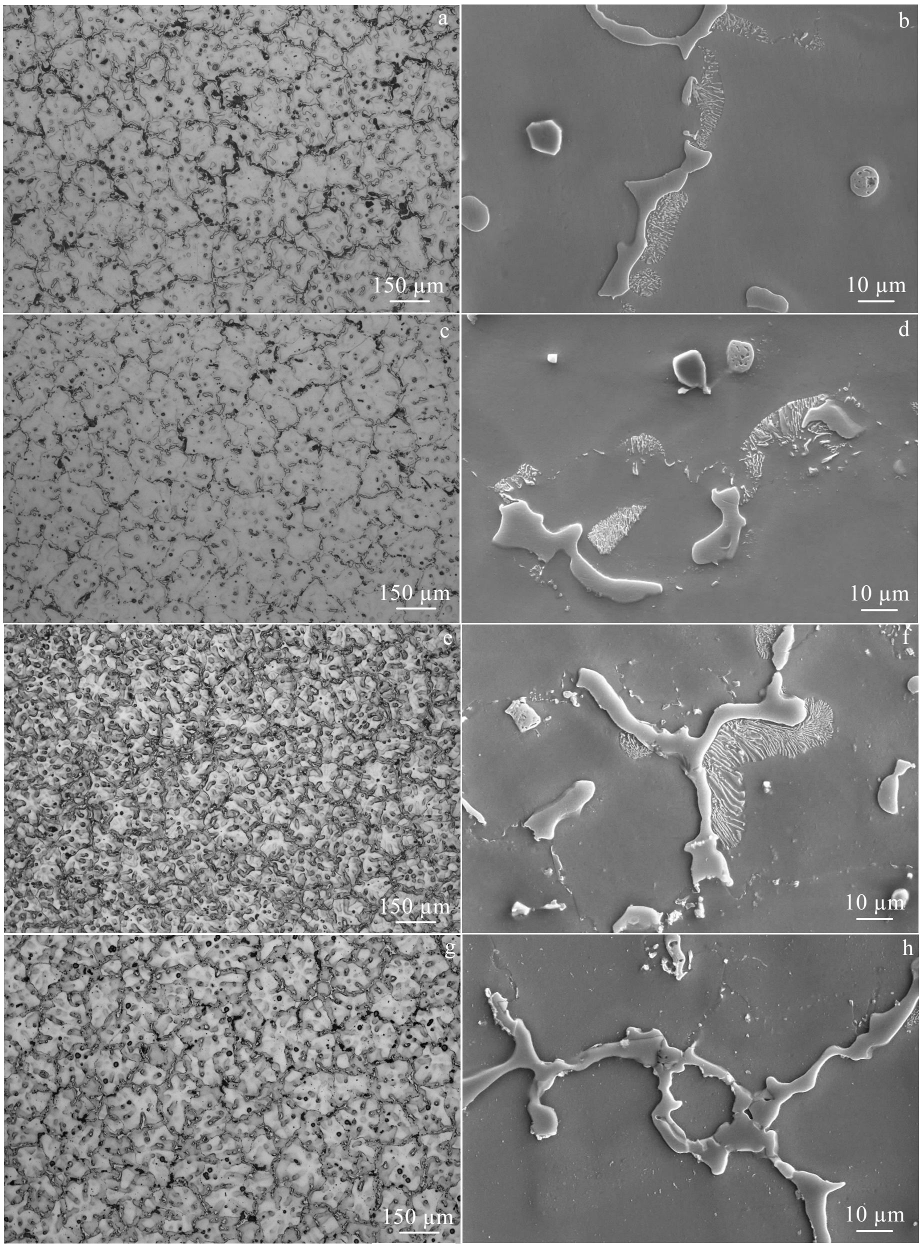

Fig.2 Optical microstructures (a, c, e, g) and SEM images (b, d, f, h) of the as-cast AZ80 (a, b), AZT801 (c, d), AZT803 (e, f), and AZT805 (g, h)

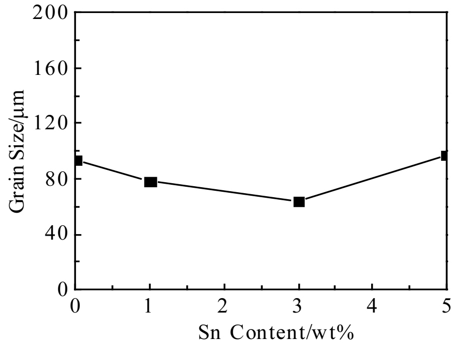

Fig.3 Average grain size of the as-cast AZ80, AZT801, AZT803, AZT805 alloys

Fig.4 shows the BSE images of the as-cast AZ80, AZT801, AZT803, AZT805 alloys. Combined with the XRD analysis (Fig.1) and the EDS analysis of phases in Table 2, the area A is the divorced eutectic (α-Mg+$Mg_{17}Al_{12}$), where the interdendritics are mainly distributed. The area B with lamellar structure mainly containing Mg and Al elements is secondary precipitation laminar $Mg_{17}Al_{12}$, where the interdendritics are mainly distributed. the area C is the divorced eutectic Mg_2Sn which attaches to the divorced eutectic $Mg_{17}Al_{12}$ phase distributing the interdendritic.

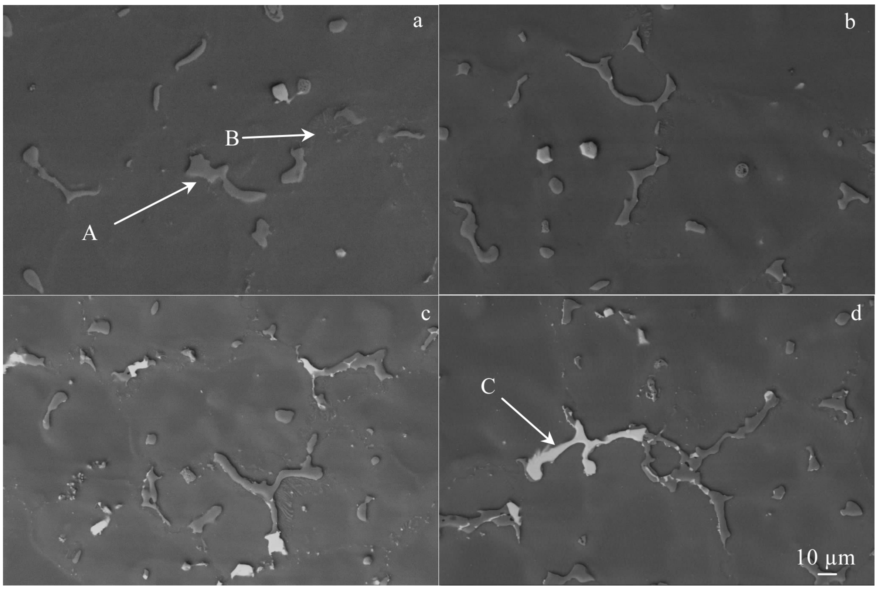

Fig.4 BSE images of the as-cast AZ80 (a), AZT801 (b), AZT803 (c), and AZT805 (d) alloys

The volume fractions of second-phases in AZ80, AZT801, AZT803, and AZT805 alloys were measured, which is shown in Fig.5. The volume fractions of lamellar $Mg_{17}Al_{12}$ phase in AZ80, AZT801, AZT803, AZT805 alloys were measured to be 12.4%, 7.19%, 0.85%, 0.2%, respectively. The volume fractions of divorced eutectic $Mg_{17}Al_{12}$ phase in AZ80, AZ801, AZT803, AZT805 alloys were measured to be 6.9%, 5.5%, 4.93%, 4.5%, respectively. The volume fractions of Mg_2Sn phase in AZ80, AZT801, AZT803, AZT805 alloys increase with the Sn content increasing. With the increase of Sn content, the divorced eutectic $Mg_{17}Al_{12}$ phase is not significantly affected and the laminar structure decreases obviously, which also affords with the microstructure observed in Fig.2.

Fig.6 shows the tensile properties of AZ80, AZT801, AZT803, AZT805 alloys. It indicates that the mechanical properties increase with the Sn content increasing from 1 wt% to 3wt% and the ultimate tensile strength, yield strength and elongation of AZ80 alloy increase from 200.3 MPa, 150.9 MPa, 10% to 245.6 MPa, 192.5 MPa, 14.7% of AZT803 alloy, respectively. When the Sn content is 5wt%, the comprehensive mechanical properties decrease.

Table 2 EDS analysis of marked area in Fig.4 (at%)

Area	Mg	Al	Zn	Sn	Mn
A	63.76	34.52	1.73	0	0
B	80.63	18.47	0.89	0	0
C	67.96	0	0	32.04	0

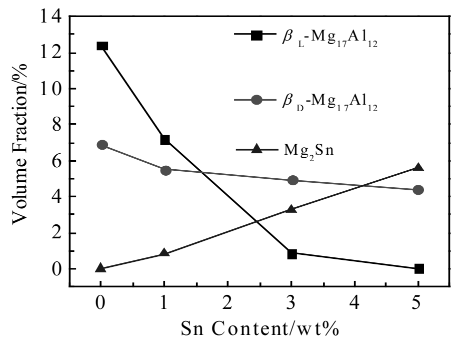

Fig.5 Volume fraction of second-phases in AZ80, AZT801, AZT803 and AZT805 alloys

From the above conclusions, the improvement in mechanical properties are attributed to the following aspects. With the addition of Sn, the laminar $Mg_{17}Al_{12}$ phase, which is harmful for improving mechanical properties[13], is reduced obviously or even disappears. When the addition of Sn is 3 wt%, the phase distribution of Mg_2Sn is the most uniform and the β_L-$Mg_{17}Al_{12}$ nearly disappears at grain boundaries, which has the best refinement effect on the grain size (Fig.3). As the content of Sn addition in the alloy becomes higher to more than 3wt%, Mg_2Sn phases become coarser, which can be the crack source, reducing the strength. Additionally, according to the Hall-Petch relation: $\sigma_s \propto 1/d^2$, grain size has an important role in the tensile strength and the finer the grain size, the higher the mechanical properties. The refined grains prevent the motion of dislocation to improve the strength. The best strengthening effect is concordant with the best microstructures refinement with 3wt% Sn content.

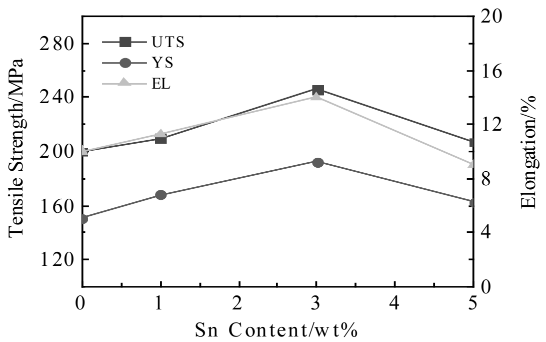

Fig.6 Tensile properties of AZ80, AZT801, AZT803 and AZT805 alloys

3 Conclusions

1) The phases of as-cast AZ80-*x*Sn (*x*=1, 3, 5, wt%) alloys consist of *α*-Mg primary, Mg_2Sn and $Mg_{17}Al_{12}$ divorced eutectic and secondary precipitations laminar $Mg_{17}Al_{12}$.

2) The Sn element has excellent effect on prohibiting laminar $Mg_{17}Al_{12}$ phase and the grain size decreases from 93.5 μm to 63.7 μm with the Sn content increasing from 0wt% to 3 wt%.

3) The AZT803 alloy has the best mechanical properties and the tensile strength, yield strength and elongation are 245.6 MPa, 192.5 MPa, and 14.7%, respectively.

References

1 Kim J K, Oh S H, Kim K C *et al*. *Materials Science and Engineering A*[J], 2017, 23(2): 308

2 Polmear I J. *Materials Science & Technology*[J], 1994, 10(1) : 1

3 Wang L, Qiao Q, Liu Y *et al. Journal of Magnesium and Alloys*[J], 2013(1): 312

4 Nie J F. *Metallurgical and Materials Transactions A*[J], 2012, 43(11) : 3891

5 Kubota K, Mabuchi M, Mater K. *Journal of Materials Science*[J], 1999, 34(10): 2255

6 Duly D, Simon J P, Brechet Y. *Acta Metall Mater*[J], 1995, 43: 101

7 Mahmudi R, Moeendarbari S. *Materials Science and Engineering A*[J], 2013, 566: 30

8 Zhang M X, Kelly P M. *Scripta Materialia*[J], 2003, 48(5): 647

9 Zhu T, Fu P, Peng L *et al*. *Journal of Magnesium & Alloys*[J], 2014, 2(1): 27

10 Elsayed F R, Sasaki T T, Mendis C L *et al. Materials Science and Engineering A*[J], 2013, 566: 22

11 Elsayed F R, Sasaki T T, Ohkubo T *et al*. *Materials Science and Engineering A*[J], 2013, 588(24): 318

12 Jung I C, Kim Y K, Cho T H *et al*. *Metals & Materials International*[J], 2014, 20(1): 99

13 Kim B, Do J, Lee S *et al. Materials Science and Engineering A*[J], 2010, 527(24-25): 6745

14 Zhu T P, Chen Z W, Gao W. *Journal of Alloys and Compounds*[J], 2010, 501: 291

15 Duly D, Cheynet MC, Brechet Y. *Acta Metallurgica et Materialia*[J], 1994, 42(11): 3843

16 Duly D, Simon J P, Brechet Y. *Acta Metallurgica et Materialia*[J], 1995, 43(1): 101

Sn 对 AZ80 组织和力学性能的影响

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摘 要：通过 OM、XRD、SEM 和拉伸性能测试研究了添加 Sn 元素对 AZ80 组织和拉伸性能的影响。AZ80-*x*Sn（*x*=1, 3, 5 质量分数, %）合金呈现出典型等轴树枝晶形貌，主要有初生相 *α*-Mg，离异共晶相 Mg_2Sn 和 $Mg_{17}Al_{12}$，层片状的二次析出相 $Mg_{17}Al_{12}$。结果表明，添加 Sn（≤3%）元素能够明显的细化晶粒尺寸以及有效的抑制了层片状 $Mg_{17}Al_{12}$ 相得析出；当 Sn 含量为 5%时，层片状的 $Mg_{17}Al_{12}$ 基本消失。添加 Sn 元素（1% ≤Sn 含量≤3%）能够提高 AZ80 合金室温拉伸性能。

关键词：AZ80；Sn；组织；力学性能

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