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Effect of Mn content on microstructure and mechanical properties of modified ZA-27 alloy ①

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[Abstract] ZA-27 alloys reinforced by Mn-containing intermetallic compounds were prepared and the effect of Mn content on their mechanical properties were examined. By adding Mn, rare earth elements(RE) and Ti into ZA-27, experimental alloys were fabricated by sand casting. The volume fraction, grain size and morphology of the Mn-containing intermetallic compound phases vary with the changing of Mn content. Mechanical properties of the reinforced ZA-27 alloys at elevated temperatures were measured. The results show that the hardness, compressive strength and compressibility of experimental alloys increase with increasing Mn content until they reach a maximum at 0.5% Mn. Excessive and coarse hard phases would act as crack origins instead of dispersion strengthening particles. Best tensile properties of these alloys at elevated temperature can be achieved at a Mn content of 0.18 %.

[Key words] ZA-27; intermetallic compounds; mechanical properties
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1 INTRODUCTION

ZA alloys have a strength comparable to aluminum casting alloys, wear-resisting properties comparable to bearing bronzes while have lower cost and properties similar to many cast irons but are easier to machine. They have been applied to many high performance parts as substitutes for cast irons and aluminum alloys, or applied to bearings and bushings as substitutes for bronzes. For bearings working under heavy load, high mechanical properties as well as good tribological properties at room and elevated temperatures are required. By means of changes in processing techniques[1~4] and using modifying elements such as rare earth elements(RE), Mn, Ti, B[5~8], the mechanical properties of ZA alloys can be improved. It was reported that an appropriate addition of Mn into ZA-27 could improve the tensile strength of the alloy, especially at 150 to 180 ℃[5]. On the other hand, ZA-27 components subjected to compressive stress on many applying occasions, however, its compressive properties were seldom investigated in detail.

Based on the chemical composition of ZA-27 and by adding Mn, RE and Ti as modifying elements, a novel wear-resisting zinc alloy has been developed in our previous investigation[9~12]. The effects of Mn content on the friction and wear behavior of modified ZA-27 alloys has been reported[11]. The effect of Mn content on mechanical properties of this alloy, including its tensile strength and compressive strength were studied in this paper. The relationship between mechanical properties and microstructural characteristics of the reinforced alloy was also discussed.

2 EXPERIMENTAL

The chemical compositions of experimental alloys in mass percent were based on the ZA-27 alloy with a slightly higher Mg content. Ti, Mn and RE(Ce ≥45 %, La 23%~ 28 %, Nd 17 % and Pr 5%~ 6 %, all in mass percent) were used as modifying elements. A series of alloys with different Mn contents were prepared by sand casting. Chemical compositions of the experimental alloys are listed in Table 1. High melting point elements were introduced in the form of master alloys with aluminum. Raw materials were melted in a graphite crucible. After degassing and removal of covering slag, the molten alloy was poured into a sand mold, which was preheated to approximately 150 ℃ in open air.

The microstructure and fracture surface were examined by optical microscopy and scanning electronic microscopy, respectively. Micro-constituents were measured by an EPM-810Q electron microprobe with wavelength dispersive spectroscopy (WDS) and an S-550 scanning electron microscope with energy dispersive spectroscopy(EDS). The micro-hardness was measured on a model 71 micro-hardness tester. Brinell hardness was measured by an HDI-1875 hardness tester. Tensile properties at room and elevated temperatures were tested

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on a WD-10A electronic tensile testing machine and a WJ-10A mechanical tensile testing machine, respectively. The compression test was conducted using a model WE-30 hydraulic compression testing machine.

Table 1 Chemical compositions of experimental alloys (in mass percent, by wet chemical analysis)

Sample	Al	Cu	Mg	Mn	Ti	RE	Fe	Zn
ZA-27	27.64	2.16	0.018	-	-	-	< 0.029	Bal.
M1	27.39	2.08	0.039	0.18	Tiny	Tiny	< 0.041	Bal.
M2	28.38	2.06	0.039	0.50	Tiny	Tiny	< 0.045	Bal.
M3	27.99	2.07	0.039	0.90	Tiny	Tiny	< 0.050	Bal.
M4	26.33	2.05	0.038	1.22	Tiny	Tiny	< 0.060	Bal.

3 RESULTS AND DISCUSSION

3.1 Microstructure

Microstructures of the experimental alloys are shown in Fig. 1 in comparison with that of ZA-27. Fig. 1(a) shows the microstructure of ZA-27 alloy, which consists of α dendrites and (α+ β) + (α+ β+ ε) inter-dendrite eutectics, where α, β, ε are Al based solid solution, Zn based solid solution and $CuZn_3$ phase, respectively. For the M series alloys shown in Figs. 1(b), (c) and(d), some white phases were formed in both α dendrites and the eutectics region. These white phases are found to be Mn-containing intermetallic compounds such as $Al_5(MnZn)$, $Al_9(MnZn)_2$ and $Al_{65}Mn(RE)_6Ti_4Zn_{36}$ (approximate chemical formula)[10]. It can be seen in Fig. 1 that the size and volume fraction of the intermetallic compounds increase with increasing Mn content from M1 to M4. The morphology of these Mn-containing intermetallic compounds changes gradually from fine particulates to coarse rod shape. In M4 shown in Fig. 1 (d), some rod shaped Mn-containing intermetallic compounds grow across the α dendrite.

From Fig. 1, it is also found that the α dendrites in M4 alloy are refined compared to that of ZA-27. Previous investigations discovered that RE, Mn, Ti and B have the refining effects on the microstructure of ZA-27[13, 14]. These modifying elements could form high melting-point compounds with the alloy elements which acted as heteronuclei to nucleate the α-Al phase. Moreover, aggregation of these elements and their compounds on the solidification front of α dendrite would hinder the grain growth of dendrite. Thus the α grains of M4 alloys are refined compared with that of ZA-27.

As the solubility of Mn, RE and Ti in α-Al phase is very limited, most of them form intermetallic compounds in the eutectics and dendrites region. Most of Mn content would form $Al_9(MnZn)_2$ and Al_5 (MnZn) while RE and Ti would form $Al_{65}Mn(RE)_6Ti_4Zn_{36}$ in experimental alloys. Phase

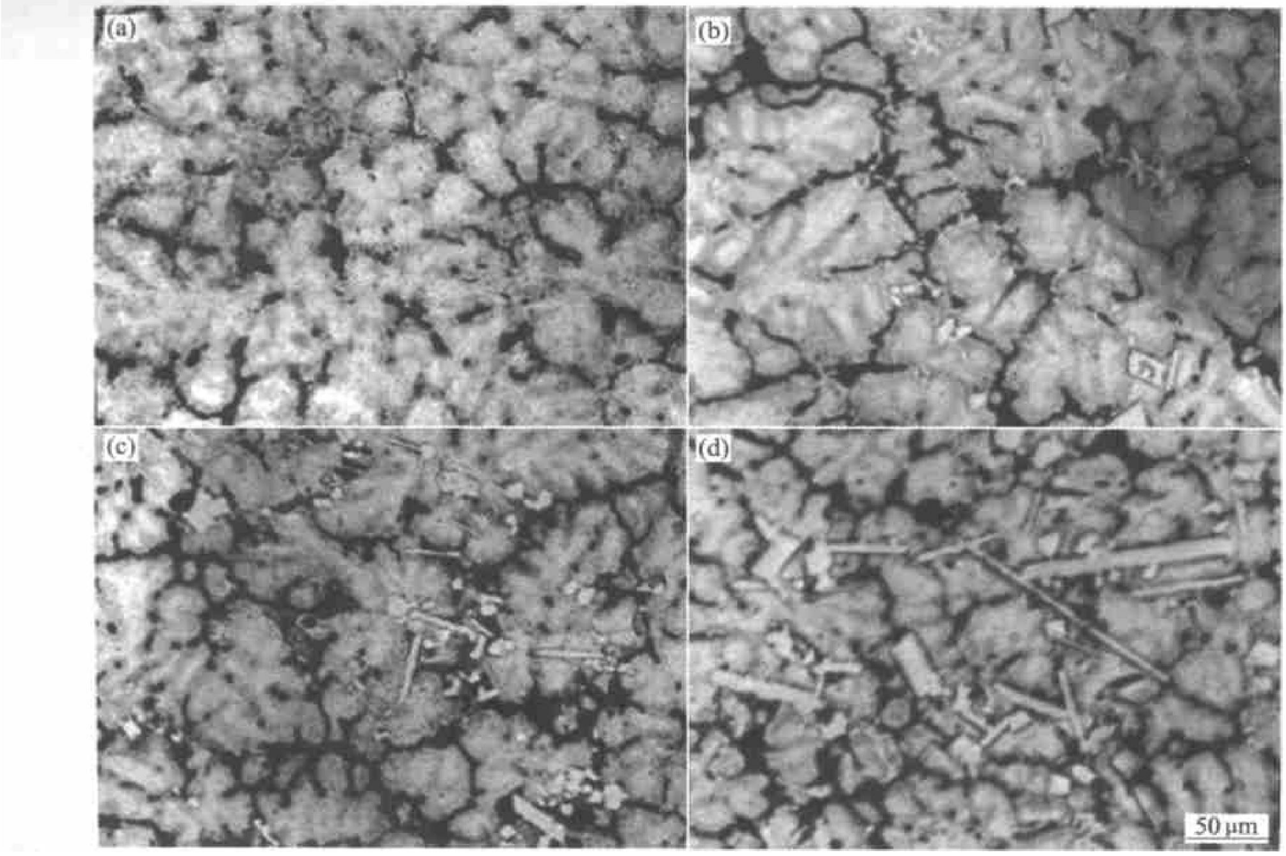

Fig. 1 Microstructures of experimental alloys and ZA-27
(a) —ZA-27; (b) —M1; (c) —M2; (d) —M4

analysis indicates that the morphology of the Al_5-(MnZn) phase is generally rod-shaped, while the other intermetallic compounds such as ε, Al_9-$(MnZn)_2$ and $Al_{65}Mn(RE)_6Ti_4Zn_{36}$ phases show polygonal or irregular particulate shape.

The micro-hardness of phases in zinc alloys are presented in Table 2. The results show that the hardness of these Mn-containing intermetallic compounds are much higher than that of the metal matrix. It is also indicated in Table 2 that the hardness of the eutectics region and rim region of α dendrites is lower than other regions in ZA-27. While in M2 alloy, hardness of the eutectics region and the rim region of α dendrites have been increased by the modification. The development of micro-hardness in these regions may be caused by the solution strengthening of modifying elements and dispersion strengthening of the fine intermetallic compounds phases.

Table 2 Microhardness of phases in tested alloys(HV/0.01)

Alloy	α (center)	α (rim)	Eutectics	ε	Al_9-$(MnZn)_2$	Al_5-(MnZn)	$Al_{65}Mn(RE)_6$-Ti_4Zn_{36}
ZA-27	90.7*	41.1*	27.5	235.5	–	–	–
M2	82.2*	55.7*	49.1	230.1	560.9	616.8	380.8

*: HV/0.05

3.2 Mechanical properties at room and elevated temperatures

Results on the compressive strength σ_d, compressibility ε and hardness HB are shown in Fig. 2.

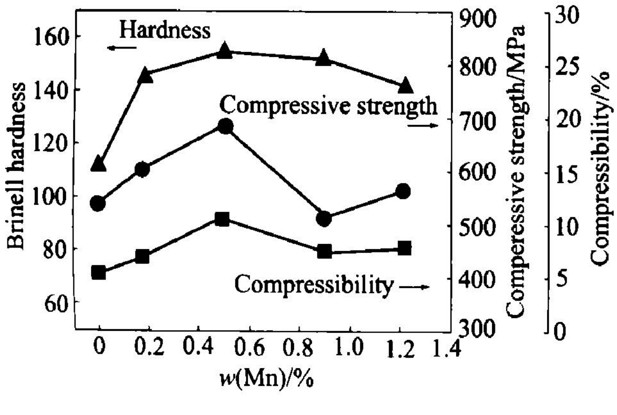

Fig. 2 Compressive properties and hardness of experimental alloys

In Fig. 2, the compressive strength, compressibility and hardness increase gradually with increasing Mn content until the Mn content reaches 0.5% in M2 alloy. When the Mn content is higher than 0.5 %, the compressive properties and hardness of alloys become lower. The highest compressive strength, compressibility and hardness are 684.0 MPa, 10.7% and HB155, respectively, which are 27%, 94% and 38% higher than those of ZA-27, respectively.

The tensile strength σ_b and elongation δ_{10} at room and elevated temperatures are shown in Fig. 3.

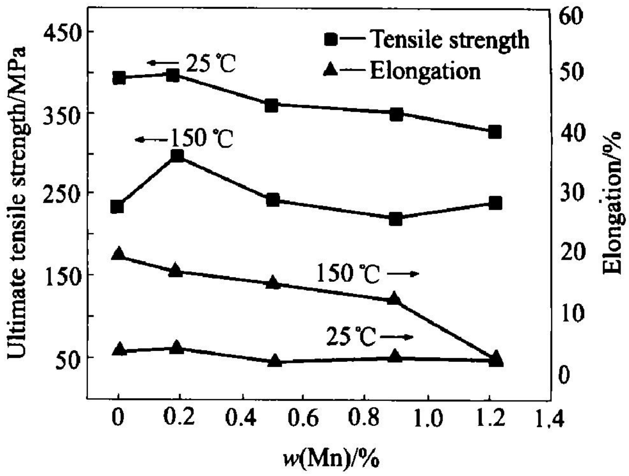

Fig. 3 Tensile strength and elongation of experimental alloys at room and elevated temperatures

It can be found in Fig. 3 that the tensile strength and elongation of the experimental alloys at room temperature are comparable with those of ZA-27 when the Mn content is 0.18%, then basically decrease with further increasing Mn content. The tensile strength at elevated temperature shows an obvious increase at the Mn content of 0.18%, then basically falls with increasing Mn content. The maximum of elevated-temperature tensile strength is 298.9 MPa, which is 29% higher than that of ZA-27. The elongation at 150 ℃ decreases with increasing Mn content.

It is noticed that the compressive strength of alloy first increases with increasing Mn content when the Mn content is low. This can be attributed to the following reasons. It can be found in Fig. 1 that the volume fraction and size of the hard phases in the experimental alloys increase with increasing Mn content. Therefore the hardness and compressive strength of the alloy first increase with increasing volume fraction of hard phases then drop with the coarsening of the hard phases.

From Figs. 2 and 3, it is found that in M1 and M2, the compressive strength of experimental alloys increases with the volume fraction of intermetallic compounds while the tensile strength of them is similar or even lower than ZA-27. The reason is that the microcracks are much easier to initiate and propagate near the intermetallic compounds under tensile stress than under compressive stress.

Since the mechanical properties of ZA-27 decrease quickly as the temperature increases, the working temperature of zinc alloys is suggested to be limited to lower than 150 ℃. It is important to enhance the elevated-temperature strength of zinc alloy to expand its application. The tensile strength of M1 at 150 ℃ is 29% higher than that of ZA-27. It is indicated that the zinc alloy reinforced with certain volume fraction of fine hard phases (approximately 10%) has much higher elevated-temperature tensile strength. This could be caused by the fact that the high-melting-point hard phases dispersed in the near-eutectic region retard the phase boundary movement at elevated temperatures. However, further increase of Mn content would generate excessive and coarse intermetallic particles, which conglomerated in the near-eutectic region and may increase the tendency of intergranular fracture, thus the elevated-temperature tensile strength of the alloy M2 to M4 is lower than that of M1.

As ZA-27 is always applied to parts working under friction and heavy-load condition, the enhancement on its compressive properties and elevated-temperature strength is desirable.

4 CONCLUSIONS

1) After modification by Mn, RE and Ti, the α grains of experimental alloys could be refined compared to that of ZA-27 and some Mn-containing intermetallic compounds were formed. The volume fraction and size of these intermetallic compounds increase with increasing Mn content, while their morphology changes gradually from fine particulates to coarse rod shapes.

2) Moderate addition of Mn into ZA-27 could improve the compressive properties, hardness and elevated-temperature tensile strength. The experimental alloy with an Mn content of approximately 0.18 % has the best tensile strength at elevated temperature, addition of Mn content from 0.18 % to 0.50 % would decrease its tensile strength and elongation, but is beneficial to the hardness, compressive strength and compressibility.

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