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Mechanical properties and creep resistance of Mg-Li composites reinforced by MgO/ Mg_2Si particles①

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[Abstract] The mechanical properties at room temperature and the creep resistance at room and elevated temperatures of Mg-Li alloy and composites reinforced by MgO/ Mg_2Si particles were studied. The (Mg-8Li) eutectic binary alloy is of better mechanical properties than those of the others. The strength, elastic modulus and hardness of composites are much higher than those of matrix alloys. The elongation of the composites is lower than that of the matrix, but it keeps a high level(> 4%) and is much higher than that of the Mg-Li base composites reinforced with Al_2O_3 and SiC fibres. The creep resistance of the composites is significantly increased in comparison with the matrix, such as the creep rate of the composite is respectively 10% and 2% of that of matrix at room temperature and at 160 ℃. The creep mechanism is also discussed.

[Key words] Mg-Li alloys; composites; mechanical properties; creep resistance
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1 INTRODUCTION

Mg-Li alloy is a new and super-light structural material. It is widely used in space and weapon industry because of higher specific strength and rigidity. Some research[1~ 8] indicated that: 1) the strength of binary alloy is lower and the creep resistance is very poor; 2) the strength can be increased by adding Al, Zn, Cd and so on, but the stability of structure and property is poor because of overage taking place at room and elevated temperature; 3) the properties at high temperature can be improved by adding rare-earth elements, but the properties at room temperature are poorer; 4) C, SiC and Al_2O_3 short fibres and B, B_4C particles can increase the strength at room and elevated temperatures, but decrease the elongation because of interface reaction easily taking place. Therefore, a new processing for the preparation of Mg-Li composites was studied, in which reinforced particles were formed by reaction synthesis in Mg-Li melts[9~ 12].

This paper mainly reports that the mechanical properties and creep resistance of the composites at room and elevated temperature.

2 EXPERIMENTAL

High pure Li piece, pure Mg ingot and analytic pure SiO_2 powders were the main raw materials used.

The Mg-Li alloys and composites were prepared in vacuum electric resistance furnace under Ar atmosphere and the processing was as follows: firstly, pure Mg was melted and heated to proper temperature; secondly, the pure Li piece was added by means of an inverted cup, overheated to certain temperature and kept at that temperature for about 10 min; thirdly, the melt was poured into a graphite mould. The preparation processing of the composites was similar to that of the matrix alloys, but the difference between them was adding SiO_2 power(50 ~ 100 μm) packed in aluminum foil by means of an inverted cup after Mg-Li alloys were melted and overheated, mixing round properly and pouring after keeping 10 min.

The experiments of tensile stretch property and creep resistance at room temperature were performed by using a Schenel RSA-250 Electronic Universal Machine and on specimens 2 mm thick. The creep resistance at elevated temperature was tested with a TMA-50 test equipment and specimens with 0.2 mm thick. The hardness was tested with a HV1-10A test machine under the condition of 15 g load.

3 RESULTS AND ANALYSIS

3.1 Microstructures of Mg-Li alloys and composites

Two types of phases(Fig. 1(a)) are observed in the microstructure of Mg-6.5Li alloy, the one with flower form is α phase, the other in alternative lamellae is (α + β) eutectic. here α is a solid solution of Li in Mg (hcp) and β is the solid solution of Mg in Li(bcc).

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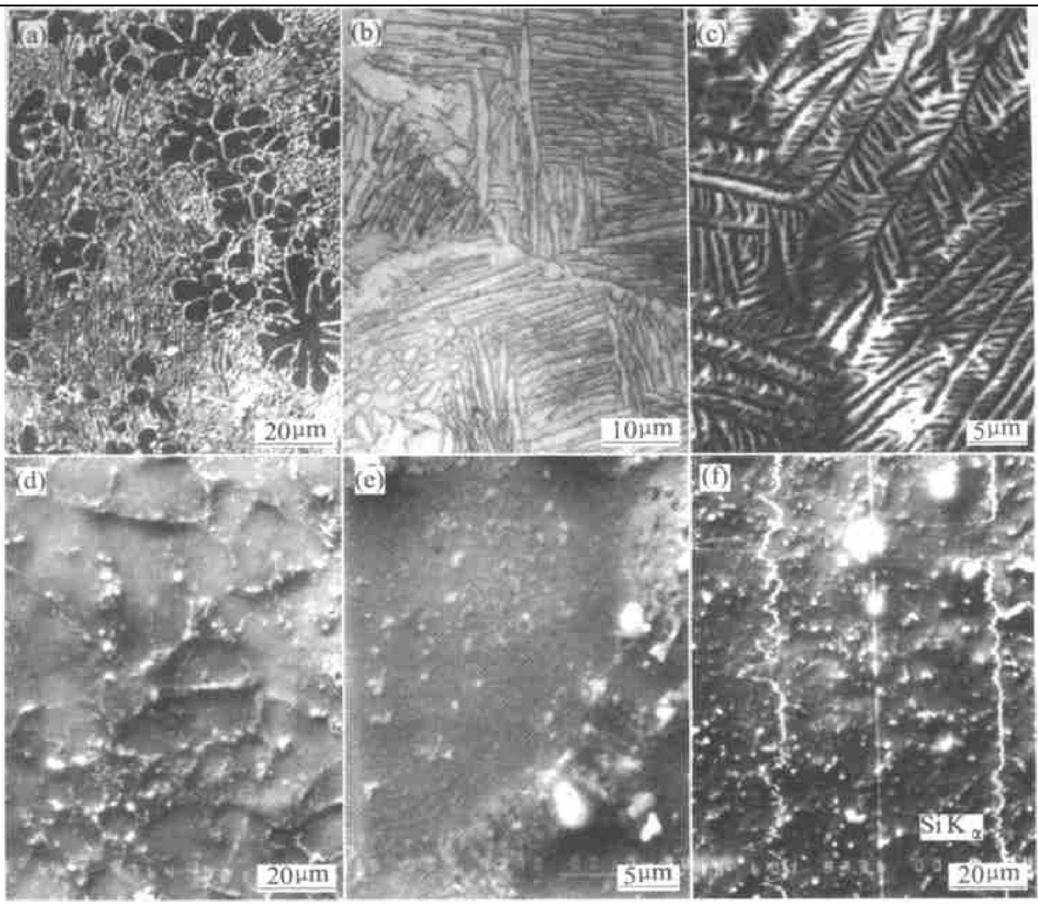

Fig. 1 Microstructures of Mg-Li alloys and composites reinforced by MgO/Mg_2Si particles

(a) —Mg-6.5Li alloy; (b) —Mg-8Li alloy; (c) —Mg-11Li alloy;
(d) and (e) —Mg-11Li-5% MgO/Mg_2Si; (f) —Mg-11Li-10% MgO/Mg_2Si

There is only eutectic in the microstructure of Mg-8Li alloy (Fig. 1(b)) and only β phase in Mg-11Li alloy (Fig. 1(c)).

Figs. 1(c) ~ (e) show the microstructure of some Mg-Li composites prepared by adding SiO_2 powders into Mg-Li alloy melt. There are many particles about 2~5 μm in diameter at the grain boundaries (Figs. 1(d) and 1(f)), and many fine particles (less than 0.5 μm) in grains (Fig. 1(e)). EP analysis indicates that some of them contain O, but no Si, and others contain Si, but no O. XRD curve verifies the existence of MgO and Mg_2Si phases.

3.2 Mechanical properties at room temperature

Mechanical properties of several Mg-Li alloys and Mg-Li composites reinforced by MgO/Mg_2Si particles are shown in Table 1.

Mg-8Li alloy is of better tensile strength, yield strength, elongation and elastic modulus than the other binary Mg-Li alloys, which may be the result of interface strengthening and structure fining. The hardness decreases when the Li content is increased.

The strength, elastic modulus and hardness of the composites reinforced by MgO/Mg_2Si particles are obviously higher than those of the matrix alloys. Good reinforcing effects are obtained at high Li content, e.g. as 5% MgO/Mg_2Si (mass fraction) particles are added, the tensile strength of Mg-11Li increased about 73%, yield strength about 148%, elastic modulus about 35%, hardness about 50%, but the elongation reduced about 48%.

The elastic modulus and hardness increase with the content of particle, but the elongation decreases with the content of particle. The change of strength is non-linear with the content of particles. The strength reaches an optimum value at certain content, and will decrease when more particles are added beyond that point. This is related to the formation of larger size Mg_2Si if more SiO_2 powder is added (Fig. 1(e)).

The elongation of the composites is obviously lower than that of matrix, but is also obviously higher than that of the composites reinforced by SiC and Al_2O_3 fibres[3]. This may be related to fine particle size, clean particle surface, high heat stability, little interface reaction taking place and good interface connection[8~12].

3.3 Creep resistance at room and high temperature

The results of creep tests of several Mg-Li alloys and composites reinforced by MgO/Mg_2Si particles are shown in Table 2. The creep resistance of binary Mg-Li alloys is very poor even at room temperature. Such as the stationary creep rate of binary Mg-11Li alloy is $10.2 \times 10^{-6}\ s^{-1}$ and $6.25 \times 10^{-6}\ s^{-1}$ at the stress of 56.3 MPa and 40 MPa respectively, and the stationary lasting time is less than 1 h and 5 h respectively. When 5% MgO/Mg_2Si particles exist in the alloy, the stationary creep rate is $2.91 \times 10^{-6}\ s^{-1}$ and $1.03 \times 10^{-6}\ s^{-1}$ at the stress of 85.8 MPa and 66.3 MPa respectively, which is only 10% of the matrix alloy.

The stationary creep rate of binary Mg-Li alloys raises rapidly with temperature. For instance, the creep rate is $2.35 \times 10^{-6}\ s^{-1}$ at 120 ℃, and up to $133 \times 10^{-6}\ s^{-1}$ at 160 ℃ under the same stress (7.64 MPa). However, the creep rate of the composites decreases clearly, especially at higher temperature. For example, the creep rate of composites containing 5% MgO/Mg_2Si is 35% of that of matrix alloys at 120 ℃, 13% at 140 ℃, 2.1% at 160 ℃ under the stress of 10.9 MPa.

Moreover, the creep rates of the composites at room and elevated temperatures are reduced with the increase of the particle content, especially at elevated temperature.

3.4 Discussion

The melting point of Mg-Li alloys containing more than 5.5% Li is about 590~600 ℃, at room temperature (20~25 ℃) is more than $0.25\ T_m$, so the creep at room temperature belongs to moderate temperature creep, and the creep at 160 ℃ belongs to high temperature creep[13]. The diffusion coefficient of Li in Mg is greater because of the smaller atomic radius of Li, and the diffusion coefficient of the atoms increases with the raising of temperature. It may be the main cause of bad creep resistance of Mg-Li binary alloys at room temperature, especially at elevated temperature. The very high creep rate of Mg-11Li alloy at 160 ℃ may be the results of higher rate of atom and vacancy diffusion, easier doing dislocation climb and taking place of grain boundary slipping.

The introduction of MgO/Mg_2Si particles to Mg-Li matrix alloys can increase the elastic modulus, yield strength and stability of structure and mechanical properties at room and elevated temperatures, so the creep rate has been distinctly reduced based on the equation[14] as

$$\varepsilon = B[(\sigma - \sigma_0)/E(T)]^n \cdot \exp(-Q_c/RT)$$

where B and n are constant, Q_c is creep activation energy, T and $E(T)$ are temperature and elastic modulus, R is the gas constant, σ_0 is creep internal

Table 1 Mechanical properties of several Mg-Li alloys and composites (as-cast)

Material	σ_b/MPa	σ_s/MPa	ε/%	E/GPa	HV
Mg-6.5Li	112.5	57.9	10	33.3	54.5
Mg-8Li	127.2	77.6	21	42.8	52.5
Mg-11Li	104.6	66.3	16.4	35.4	46.2
Mg-6.5Li-5MgO/Mg_2Si	137.4	82.5	5.6	44.6	68.9
Mg-11Li-5MgO/Mg_2Si	180.9	164.6	8.5	47.9	69.5
Mg-6.5Li-10MgO/Mg_2Si	127.3	91.5	4.3	49.6	72.3
Mg-8Li-10MgO/Mg_2Si	157.4	97.8	9.5	49.5	63.6
Mg-11Li-10MgO/Mg_2Si	162.1	142.6	5.3	62.0	77.1

Table 2 Creep rate of several Mg-Li alloys and composites at different temperatures

Material	σ/MPa	Creep rate/($10^{-6}\ s^{-1}$)								
		20 ℃	120 ℃	140 ℃	150 ℃	160 ℃	170 ℃	180 ℃	190 ℃	210 ℃
Mg-11Li	56.3	10.2	–	–	–	–	–	–	–	–
	40.0	6.25	–	–	–	–	–	–	–	–
	7.64	–	2.35	13.2	3/	1.33	–	–	–	–
Mg-11Li-5MgO/Mg_2Si	85.8	2.91	–	–	–	–	–	–	–	–
	66.3	1.03	–	–	–	–	–	–	–	–
	10.9	–	0.81	1.77	–	2.85	–	6.36	–	–
Mg-11Li-10MgO/Mg_2Si	85.3	0.85	–	–	–	–	–	–	–	–
	5.10	–	–	0.009	–	0.24	–	0.43	0.72	
Mg-8Li	40.3	1.86	–	–	–	–	–	–	–	–
	6.3	2.51	3.77	–	12.3	–	42.9	–	–	
Mg-8Li-10MgO/Mg_2Si	71.7	0.19	–	–	–	–	–	–	–	–
	9.73	2.35	4.24	–	12.0	–	–	–	–	
	7.21	–	0.91	–	–	–	–	2.77	–	3.18

stress, namely lattice internal friction or dislocation reactive stress.

The micro-mechanism of the effect of reinforced particles on creep behavior may be as: restricting the movement of dislocation, and blocking relative sliding of grain boundary.

4 CONCLUSIONS

1) The strength, elongation and elastic modulus of eutectic binary alloy (Mg-8Li) are better than those of the other binary Mg-Li alloys, but the hardness reduces with the increase of content of Li.

2) The strength, elastic modulus and hardness of the composites are obviously improved because of reinforcing particles. The elastic modulus and hardness increase with the particle content, but the strength reaches an optimum value at a certain particle content. The elongation of the composites is obviously lower than that of matrix.

3) The creep resistance of composites is obviously higher than that of matrix, and it raises with the particle content, especially at elevated temperature. The creep rates at room temperature and 160 ℃ are respectively 10% and 2% of those of matrix. This may be related to the reinforcing particles improving the yield strength and elastic modulus of composites, restricting the movement of dislocation, and blocking relative sliding of grain boundary.

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