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Present Development Status of Anti-creep Magnesium Rare-Earth Alloys

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Abstract. The research status of creep resistance of rare earth magnesium alloy at home and abroad is reviewed, and the mechanism of high temperature creep resistance and the way of improving the creep resistance of magnesium alloy were also discussed. The problems of high temperature resistance and creep resistance of cast magnesium alloy are pointed out, and its future development direction is forecasted. The purpose of this paper is to provide the idea and basis for the development of creep resistant and heat resistant magnesium alloy.

1. Introduction
Metal magnesium and its alloys are among the lightest metal structural materials currently available. It has a series of advantages such as low density, high specific strength, high specific rigidity, high specific elastic modulus, excellent damping shock absorption performance, good thermal conductivity, good electromagnetic shielding effect, excellent machinability, stable dimension and easy recovery, which has aroused more and more attention[1-4]. Nowadays magnesium alloy has been widely used in aerospace, automotive, communications electronics, computers and other industrial fields. However, the heat resistance of magnesium alloys is poor, when the temperature increases, its strength and creep resistance dramatically reduced, which limits the further application of magnesium alloys. Compared with the general magnesium alloy, rare earth heat-resistant magnesium alloy has a higher high temperature strength and high temperature creep resistance[1-5]. Therefore, how to improve the high temperature creep properties of magnesium alloys has become a hot topic in recent years.

2. Research progress on creep resistance of rare earth magnesium alloys
From the 20th century, 30 years, the addition of rare earth elements in magnesium alloys to improve the creep resistance of magnesium alloys has begun, until the 70's rare earth magnesium alloy began to get practical application. At present, the heat-resistant magnesium alloy systems are mainly Mg-Al alloy, Mg-Zn alloy and Mg-RE alloy[6-9]. The following describes several types of new anti-creep Mg-RE magnesium alloy.

2.1 Binary rare earth magnesium alloy
Suzuki M et al[10] studied the relationship between the creep rate and the stress of the Mg-Y binary alloy and found that the creep mechanism is a dislocation-climbing mechanism when the Y content is between 0.2% and 1.1%. When the Y content is 1.1% -2.4%, the creep mechanism is mainly sticky sliding.B. L. Mordike[11] studied Mg-Gd binary alloys with different Gd contents. Compared with the alloys of WE43 and QE22, the creep resistance of Mg-Gd alloy is better than that of other alloys. With

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the increase of Gd content, the creep resistance of the alloy gradually increased.YAN J L et al[12] studied the microstructure and creep resistance of Mg-2Nd alloy, the results show that the as-cast microstructure of Mg-2Nd alloy is composed of α-Mg matrix and Mg12Nd eutectic phase distributed at grain boundaries. The tensile strength and yield strength of as-cast Mg-2Nd alloy decrease with increasing temperature, however the magnitude of decrease is not big, it has better high temperature stability. Elongation increased with temperature increased significantly. The as-cast Mg-2Nd alloy exhibits good creep resistance. The stress exponent of the alloy in the range of 150 ~ 250 ℃, 30 ~ 110 MPa is 3.3 ~ 8.0, and the creep activation energy is in the range of 108 ~ 142 kJ / mol. The creep mechanism of the alloy is due to the dislocation climbing control and the grain boundary slip play a certain role.ZHU B B et a[l][13] studied microstructure and mechanical properties of Mg-Sm alloy, it is found that the comprehensive mechanical properties of Mg-3Sm alloy are better. The maximum solid solubility of Sm in magnesium was 5.7% (mole fraction), so it has good solid solution strengthening and aging strengthening effect. T6 state of binary Mg-6Sm alloy creep resistance and WE43 is equivalent.Mordike's[11] research shows that the creep resistance of simple binary Mg-Sc alloy is poorer than WE43 alloy, and must be combined with other elements to produce composite strengthening. After addition of Mn, the creep resistance of Mg-Sc-Mn alloy was found to be two orders of magnitude higher than that of alloy WE43 at 350 ℃.XUE S et al[14] studied microstructure and properties of Mg - 2La binary rare earth magnesium alloy. At 175℃ and 70MPa, the stress exponent n and creep activation energy Q of the alloy are 2 and 67 kJ / mol, respectively, the creep mechanism of alloy is grain boundary sliding mechanism. Because the eutectic Mg17La2 phase does not have a high melting point (about 600 ℃), the thermal stability is poor, so the creep resistance of the alloy is low.

2.2 Multiple rare earth magnesium alloy

FU S L et al[15] studied high temperature creep behavior of Mg-12Gd-2Y-0.5Zr alloy, the results show that the creep resistance of the alloy is generally better than that of the WE54 alloy. In the stress range of 50-70MPa, the stress index n is between 2.5-3.8 at 200℃, n is between 4.2-6.1 at 300℃, the creep of this series of alloys is mainly controlled by dislocation climbing control to dislocation cross slip control mechanism. The creep activation energy Qc is 66kJ/mol at 50MPa and 87.2kJ/mol at 70MPa under the temperature range of 200-300℃. With the increase of temperature and stress, the grain boundary diffusion activation energy (80kJ/mol) of pure magnesium is getting closer and closer.ZHANG Q et al[16] studied creep behavior of Mg-5Y-3Sm-0.8Ca-0.5Sb alloy, the results show that Mg-5Y-3Sm-0.8Ca-0.5Sb alloy has similar creep properties to the commercial heat-resistant magnesium alloy WE43 at 200 ℃. With the increase of creep stress, the grain size of the alloy changed little and the grain boundary became not obvious. The calculated values of the stress index show that the creep is controlled by both diffusion and grain boundary sliding mechanisms.FU S L et al[17] studied high temperature creep behavior of Mg-12Gd-2Y-2Sm-0.5Zr magnesium alloy, the results show that the aged Mg-12Gd-2Y-2Sm-0.5Zr alloy has excellent creep resistance at 200 ℃, 300 ℃ / 50MPa and 70MPa. Under the stress of 50 MPa and 70 MPa, the stress exponent n=3.8 at 200℃ and n=5.6 at 300℃. The creep activation energy Qc = 50.8kJ / mol at 50MPa and the creep activation energy Qc = 64.8kJ / mol at 70MPa under 200 ℃ and 300 ℃.TONG Y et al[18] studied microstructure and properties of Mg-13Gd-3Y-0.4Zr alloy, the steady-state creep rate of the T6 alloy is 3.61×10-9s-1, and the creep strain rate is 1.18% under the condition of 250℃ and 80MPa.At 300℃ and 50MPa, the fracture time of alloy specimen is 30h, the strain rate is 12.47%, and the steady state creep rate is 2.41×10-8s-1.The precipitation phase of high melting point alloy effectively prevents the slip and climbing of the dislocation, and improves the creep resistance of the alloy.SHA G Y et al[19] studied compressive creep behavior and micro - mechanism of Mg-4Y-2Nd alloy , at 300 ℃, 100 MPa conditions, the alloy still has extremely excellent creep properties, the steady-state creep rate is 1.505×10-6s-1. Sliding and twinning are the basic ways of creep deformation of alloys, precipitation strengthening and grain boundary strengthening are the main ways to improve the creep resistance of this alloy.

3. Creep mechanism of magnesium alloys

Creep refers to the material in the sustained force, with the time of the slow and sustained non-elastic deformation. For creep theory research, a large number of scholars[20,21], the formation of a variety of creep theory, the more commonly used theory dislocation creep, diffusion creep, Nabarro-Herring creep, Coble creep, Harper -Dom creep, the third power viscous sliding creep and low temperature creep and so on. It is pointed out that magnesium alloys have many creep deformation mechanisms under different creep conditions, in which dislocation slip and grain boundary slip are the main deformation mechanisms of magnesium alloys. Dislocation slip creep is the deformation of material under the action of stress, slip through the dislocation to achieve the deformation, and slip of the essence of intraocular dislocation movement[20-22]. In the process of creep, the dislocations slide on the sliding surface. When the dislocation slip is blocked, dislocations accumulate to form dislocation agglomerates. At low temperatures, dislocations accumulate to form strain hardening. At high temperatures, dislocations Dislocations can be dislocated and crossed[20-22]. Diffusion creep generally occurs at high temperature and low stress creep conditions, where low creep stresses do not permit a large number of dislocations to slip, and creep deformation occurs through the diffusion of matter[21, 22]. The grain boundary sliding is mainly due to the diffusion of the atoms at the grain boundaries at high temperature. The grain boundaries are moved and the creep deformation occurs under the action of stress. As the temperature increases and the creep stress decreases, The more the contribution of creep deformation, and the finer the grain size, the more grain boundaries provide the channel for diffusion, and the contribution of grain boundary slip to creep deformation increases. The Raj and Ashby studies have shown that if there is enough slip in the creep process to meet the deformed Von Mises condition, grain boundary slip is not needed to coordinate grain deformation, but in diffusion creep, Is indispensable coordination mechanism of grain deformation[20-22].

4. The way to improve the creep property of magnesium alloy

For the creep mechanism of magnesium alloy, creep strengthening of magnesium alloy should be to limit dislocation movement, to prevent the grain boundary sliding principle, so far to improve the creep resistance of magnesium alloy is mainly solid solution strengthening, precipitation strengthening, dispersion strengthening and grain boundary.

4.1 Solid solution strengthening

Solid solution strengthening refers to adding solute elements in the alloy to improve its homogenization temperature and elastic modulus, slow down the diffusion and self-diffusion process, reduce the rate of dislocation climbing, so as to improve the high temperature creep properties of the alloy. Solid solution strengthening is the result of the interaction between solute atoms and dislocations. In terms of their properties, they can be divided into elastic, chemical, electrical and geometric types. Solute atoms can be segregated around the dislocation to form a variety of air mass, can also be irregularly distributed in the matrix Therefore, adding alloy elements with high solid solubility to the magnesium alloy can improve the aging hardening ability, and can obviously improve the creep resistance of the alloy. In the process of high temperature creep, the role of solid solution strengthening mainly in the recovery process, can delay the recovery process, thereby reducing the creep rate of magnesium alloy. In the process of high temperature creep, the role of solid solution strengthening mainly in the recovery process, can delay the recovery process, thereby reducing the creep rate of magnesium alloy[20-24].

4.2 Precipitation strengthening

Precipitation aging strengthening is the precipitation phase in which the solid solubility of alloying elements decreases with the decrease of temperature during the aging process. The interaction between precipitates and dislocations leads to the increase of the yield strength of the alloy. As the magnesium atoms larger, usually with the magnesium matrix formation of non-co-precipitated complex phase, the interface energy is high, easy to coarsen at high temperatures, it is difficult to effective grain boundary pinning role Therefore, the key to improve the creep resistance of magnesium alloy is to improve the crystal structure of the precipitation phase with the appropriate alloying elements to reduce the mismatch of the lattice constant with the magnesium matrix, to improve the precipitation mode and

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morphology of precipitated phase, Phase to reduce its diffusivity, so as to improve the creep properties of magnesium alloy[20-24].

4.3 Dispersion strengthening

Dispersion strengthening is much less affected by temperature changes than precipitation strengthening. It has high melting point, good thermal stability, little solubility in the matrix and dispersed in the grain boundaries and grains. It can effectively control the grain deformation, grain boundary sliding and dislocation movement, so it can be produced in the alloy Diffusion strengthening phase to improve the alloy in different temperature range of the ability to adapt to the alloy and the mechanical properties, especially magnesium alloy creep resistance[20-23].

4.4 Grain boundary strengthening

The grain size has great influence on the high temperature properties of the metal materials. The grain size of the magnesium alloy can be controlled by controlling the preparation way, solidification process and adding appropriate alloying elements In general, the creep at low temperature and high stress is mainly due to the dislocation of intracrystalline dislocation climbing, grain boundary will become barriers to dislocation climbing, so the smaller grain size of magnesium alloy creep beneficial; But at the same temperature and above, the grain boundary sliding increased, appropriately reduce the number of grain boundaries, increasing the grain size, you can improve the creep resistance of magnesium alloy.Grain boundary strengthening is mainly achieved through purification and microalloying methods. The purpose of purification is to reduce the harmful impurities in the grain boundary of the segregation. Microalloying improves the thermal strength of the alloy by improving the shape and distribution of the second phase of the grain boundary and the organization of the region near the grain boundary by segregation of the microalloying element at the grain boundary[20-24].

5. Conclusions

In recent years, the main industrial countries put a huge financial and human resources for the development of anti-creep heat-resistant magnesium alloy,which achieved initial results. Mg-Al and Mg-Zn systems are inexpensive at present, but the heat resistance is not satisfactory and the space for improvement is small .The Mg-RE system has high heat resistance, but it is expensive and difficult to be commercialized and marketized..It Should be further optimized by alloying elements, effective alloy design and casting magnesium alloy to solve high temperature, creep resistance and other problems.

It is the good choice to have a depth study of magnesium alloy creep behavior and creep mechanism, and the use of rare earth elements developed to meet the various requirements of the new high-performance, low cost creep resistant magnesium alloy .And it will be an important research direction in Magnesium alloy.

6. References

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