Effects of Nd on Microstructure Mechanical Properties of Mg-10Gd-3Y-0.5Zr Alloy

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The optical microscope, XRD diffraction, scanning electron microscope and electron tensile testing machine equipment, through observing microstructure, tensile test and fracture analysis, study the effects of Nd on Microstructure and properties of the alloy Mg-Gd-Y-Nd-Zr, and results show that casting alloy organization are the α-Mg matrix and eutectic phase (Mg5Gd, Mg24Y5 and Mg41Nd5) composition. With the increase of Nd content, the eutectic phase of as cast alloy increases gradually, the tensile strength at room temperature increases first and then decreases, while the content of 2wt.% Nd is 216Mpa. After solution treatment and aging, there is no change in the composition of the alloy, but the content is changed. The room temperature and high temperature mechanical properties of the test alloys are obviously improved. When the content of Nd is more than 1wt.%, the tensile strength of the same composition of the alloy at room temperature is lower than 300°C, and the temperature anomaly effect occurs.

Keywords: Magnesium Alloy; Nd; Microstructure; Mechanical Properties.

1. Guidelines

Magnesium alloy have a series of unique advantages, such as high specific strength, stiffness, electromagnetic shielding and thermal conductivity, easy machining and easy recovery, etc. Therefore it is known as the "The 21 Century's Green Engineering Material ". It is widely used in the aerospace, automotive, electronics and other fields [1-3]. But the mechanical property and creep resistance of the common magnesium alloy at high temperature are severely hampered its wide application. Magnesium rare earth (Mg-RE) system has become a hot research topic in recent years because of its excellent high temperature properties [4, 5].

The rare earth elements in the magnesium alloy mainly by fine grain strengthening, solid solution strengthening and precipitation strengthening, improve the alloy structure greatly improve the high temperature mechanical properties of the alloy. Gd, Y rare earth elements in magnesium has greater solubility, which can formed Mg5Gd and Mg34Y5 compounds with good solid
solution aging strengthening and precipitation strengthening effect [6-9]. Nd, Sm and other light rare earth elements can obviously refine the grain of magnesium alloy, the purification of magnesium alloy melt. Multi-component light and heavy rare earth composite can achieve better strengthening effect, in which Mg-10Gd-3Y-0.5Zr has excellent mechanical properties at range of from room temperature to 250°C [10]. As Gd higher prices, in order to reduced Gd addition amount and improve the properties of the alloy at the same time, this research based on multi alloying heat resistant magnesium alloy design concept, combined with the effect of light rare earth elements, heavy rare earth and other alloy elements, developed the heat resistant magnesium alloy, study the effect of rare earth elements Nd content on the microstructure and the mechanical properties of Mg-Gd-Y-Nd-Zr.

2. Experimental Method

The design composition of the test alloy is Mg-10Gd-3Y-(0,1,2,3,4)Nd-0.5Zr (wt.%). The test alloy selection mainly raw materials are intermediate alloy Mg-30wt.%Gd, Mg-30wt.%Y, Mg-25wt.%Nd, Mg-30wt.%Zr, pure magnesium ingot (purity 99.99%). All the raw materials were dried before melting, and the oxide scales were removed. Alloy melting using high purity corundum crucible in induction furnace, using 99%CO2 + 1% SF6 (volume fraction) mixed gas for protection. After melting, the alloy is heated to 750°C, and heat preservation for 5min, then poured it into the preheating metal mould.

Heat treatment the sample with MgO powder covers: first 535°C ×6h solid solution treatment, hot water quenching (80°C); then 225°C×14h aging treatment, air cooling. Tensile test at room temperature and high temperature using the SHIMADZU AG-1250kN electronic tensile testing machine, the sample with Ф6mm×33mm metal rod. Using Olympus optical microscope to observe the metallographic structure. Using Advance D8 type of diffraction analysis of phase analysis.

3. Results and Analysis

3.1. Microstructure and phase analysis

As can be seen from the fig.1, the cast alloy Mg-10Gd-3Y-0Nd-0.5Zr only α-Mg matrix and Mg5Gd, Mg24Y5 phase, after add different amounts of rare earth elements Nd, the three phases are basically same. In addition to the α-Mg matrix, a new phase Mg541Nd5 phase is produced. With the increase of Nd
content, the characteristic diffraction peaks of Mg$_{24}$Y$_5$ and Mg$_5$Gd are gradually increased.

The aging alloys are all composed by $\alpha$-Mg matrix and Mg$_5$Gd phase, Mg$_{24}$Y$_5$ phase and Mg$_{41}$Nd$_5$ phase. Compared with the Figure 1 (a), the intensity of the diffraction peak of the $\alpha$-Mg in the aging alloy is decreased, and the diffraction peak intensity of the rare earth phase is increased. The results showed that there is no change in the composition of the alloy after solid solution and aging treatment, only the phase content has changed.

Figure 1. XRD patterns: (a) as-cast (b) aging state.

The optical microstructure of as-cast Mg-Gd-Y-Nd-Zr alloy with different Nd content is shown in Figure 2. It can be seen from the figure that the change of Nd content significantly affects the microstructure of as-cast alloy. The as-cast microstructure of alloy is mainly composed of white matrix ($\alpha$-Mg over saturated solid solution) and black dendritic phases distributed along grain boundaries. With the increase of the content of Nd, the average grain size of the alloy is also decreasing, and the number of the second phase at grain boundaries increased significantly, and the grain size of the alloy is larger. It is obvious that earth element Nd can refine the grain size of the alloy effectively, and increase
the number of eutectic phase. These second phase is mainly for mixed phase of Mg5Gd phase and Mg24Y5 phase.

3.2. Mechanical properties analysis

Test results of tensile properties of as cast Mg-Gd-Y-Nd-Zr alloy at room temperature are shown in Figure 3 (a). With the increase of Nd content, the tensile strength elongation of the alloy increases first and then decreases with the increase of Nd content, the elongation rate is slow, and the change is not very large. When the content of Nd is 2wt.%, the tensile strength of the alloy reaches the maximum value (216Mpa), and the elongation is 2.6%. When the content of Nd is more than 2wt.%, the tensile strength and yield strength decrease. This is because the Nd content is too high, the second phase number increases, resulting in partial poly, resulting in alloy as cast microstructure is not uniform, easy to cause stress concentration.

Figure 3 (b) is aging state Mg-Gd-Y-Nd-Zr tensile test results at room temperature and high temperature(300°C). Compared with the room temperature mechanical properties of as-cast alloy, the tensile strength of the Mg-Gd-Y-Nd-Zr system was increased at room temperature after the solid solution aging treatment, and the maximum value was 290MPa. Room temperature tensile strength of the alloy decreases with the increase of the content of Nd; 300°C, with the increase in content of Nd, tensile strength first increases and then decreases, but the peak is not obvious, the maximum value is 283Mpa(2wt.% Nd). When the Nd content is greater than 1wt.%, tensile strength is almost as same, and the tensile strength of the alloy at high temperature is higher than that of the tensile strength at room temperature. This kind of situation is different from the normal temperature increase strength, and has the abnormal behavior of mechanical behavior. The elongation of the alloy decreases with the increase of Nd content, and increases with the increase of the test temperature.

Figure 3. Mechanical properties of the alloy : (a) as-cast state (b) aging state.
At high temperature, the atomic activity is enhanced, the new slip system begin to move, the element distribution becomes more uniform, the phenomenon of stress concentration is delayed or weakened, so the tensile strength of the alloy can be improved. Another research shows that Mg-Gd-Y, Mg-Gd-Nd, Mg-Y-Nd and ternary alloy precipitation sequence S.S.S.S (cph) → \( \beta''(D019) \) → \( \beta'(Cc) \) → \( \beta_1(fcc) \) → \( \beta(fcc) \), where \( \beta' \) phase distribution is dispersed, large volume fraction, perpendicular to the surface of Mg, can obstruct the dislocation movement strongly, and has good thermal stability under a certain temperature range, the size does not change much before and after tension, through appropriate adjustment of its phase relationship between the alloy strengthening and heat resistant effect [11, 12].

4. Conclusions

(1) The addition of proper amount of rare earth element Nd can improve the microstructure of Mg-10Gd-3Y-0.5Zr alloy, and generate the Mg\(_{41}\)Nd\(_{5}\) phase.

(2) The addition of Nd can greatly improve the mechanical properties of Mg-10Gd-3Y-0.5Zr alloy, especially the high temperature resistance, 300°C, the tensile strength of Mg-10Gd-3Y-2Nd-0.5Zr is 283MPa.

(3) The mechanical properties of Mg-10Gd-3Y-xNd-0.5Zr alloy were improved by solid solution strengthening and precipitation strengthening and dispersion strengthening after the addition of Nd alloy.

Acknowledgments

The project is supported by the National Natural Science Foundation of China (No. 51171059, No. 51571084), Henan Province Key Science and Technology Project (No. 152102210072).

References


