Effects of Nd and Homogenizing on As-cast Phase of ZM21 Alloy

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Abstract. In this paper, by adding different amounts of magnesium in ZM21 alloy we look into the influence that Trace Nd has on the microstructure and mechanical properties of magnesium alloy cast ZM21 and how homogenizing effects the mechanism of its organization and performance. The results showed Mg-Zn-Nd ternary phase forms in ZM21 and the reducing of solute concentration in the solid-liquid interface Zn atomic frontier. As a result, the component avoids being too cold and the nucleation rate declines. That is why the grains become larger.

1. Introduction
In the research of magnesium alloy, Nd is mainly added as the primary element to improve the mechanical properties of alloy at room and high temperature [1-2] by generating Mg-Nd dual strengthening phase. There are also some research to add Nd as micro alloy elements to magnesium alloy. For example, we add Nd to Mg-Zn alloy, which mainly generates the Mg-Zn-Nd ternary alloy phase, to strengthen the effect to the alloy. However, there are just a few research about the effect on the plasticity of magnesium alloy. It is necessary to do more research on it so as to extend the application of Nd in the magnesium alloy and provide basic research for developing high plastic deformation of magnesium alloys on the basis [3-5]. In this paper, by adding different amounts of magnesium in ZM21 alloy we look into the influence that Trace Nd has on the microstructure and mechanical properties of magnesium alloy cast ZM21 and how homogenizing effects the mechanism of its organization and performance.

2. Experiments
Raw materials used in the experiment of alloy for pure Mg (mass fraction 99.98%), Zn (mass fraction 99.7%), Mg-34%Mn and Mg-20%Nd alloy, with low carbon steel crucible in 60 kw resistance furnace refining, 5 flux as refining agent and coating agent, by water-cooled semi continuous casting system of Ф92 mm ingot casting, melting and pouring process with CO2 and SF6 gas mixture for their own protection. By adding ZM21 magnesium alloy to the successive Nd intermediate alloy, we get Mg-20%Nd for ZM21 magnesium alloy as substrate. The alloy has different contents of Nd, whose components through laser spectrometer detecting are as shown in table 1.
| Alloy Number | Zn  | Mn  | Nd  | Mg  |
|--------------|-----|-----|-----|-----|
| 1#           | 1.93| 0.86| —   | other|
| 2#           | 1.97| 0.88| 0.07| other|
| 3#           | 1.97| 0.87| 0.22| other|
| 4#           | 1.99| 0.87| 0.35| other|
| 5#           | 1.94| 0.88| 0.47| other|

Give the sample 420℃×10 h homogenization annealing treatment in 12 kw wind circulation box and put it in the corrosion of picric acid. Then observe it with the OPTEC MDS organization metallographic microscope. Analyse the phase by Rigaku D/Max-1200-X ray diffractometer (alpha) Cu target, Ka. Scan the tissue morphology and analyse its compound elements with TESCAN VEGA company II LMU variable vacuum SEM and EDS.

3. Test results and analysis
Analyze the effect that Nd and homogenizing annealing have on ZM21 magnesium alloy as-cast alloy phase by using scanning electron back scattering spectroscopy. The BSE scanning and ED’s analysis are shown in figure 1 and EDS energy spectrum analysis is shown in table 2. As is shown in the picture, there is a small amount of Zn and Mn in the alpha 1# alloy solid solution, which is as shown in point A. As is shown in point B, there are a small number of dark irregular shaped particles in the alloy. We can know from the Mg-Mn binary phase diagram, Mg and Mn do not form chemical compounds when there are a lot of Mn, so this kind of particle phase is for alpha Mn phase. At the same time, from point C we can see many light particles that exist in the alloy and short strips of the second phase. We can conclude that when the number of atom zinc is much larger than the matrix, it is for Mg-Zn phase, which should be the last solidification alloy parts. Due to the non-equilibrium solidification segregation, there are more Zn in the last solidification alloy parts than the first set of alpha Mg.

![Fig 1 BSE and EDS of as-cast alloy.](image)

(a):1# alloy ;(b): 2# alloy; (c): 3# alloy; (d): 4# alloy; (e): 5# alloy; (f): 3# alloy, 420℃×10h homogenized;
After adding a small number of trace rare earth Nd, there are not only a small amount of Zn and Mn atoms but also a few Nd atoms in the 2# in the alpha Mg alloy, which is shown in figure D point. Because of the different ingredients, through the BSE scanning, there are three different contrasts of the second phase in 2# alloy, which are respectively shown in figures E, F, G points. Point E is the darkest and point F is brighter while point G is the brightest. It can be seen from the spectrum result that the Nd content is gradually increasing in E, F, G point, so the second phase contrast of the image is mainly caused by the amount of Nd content. Point E contains much Mn, so it is α-Mn phase, whose Nd content is more than matrix mostly due to the attachment for the bright second phase with Nd. F point is Mg-Zn-Nd ternary phase. Because there are a variety of the Mg-Zn-Nd ternary phases, so we mark it as I phase. There are much more Nd in G point than that in point F, and Zn/Nd atomic ratio is less than 1, Nd content is higher than that of Zn content. Based on the available results of Mg-Zn-Nd ternary phase research, there is no such Mg-Zn-Nd ternary phase whose Nd content is higher than the Zn content, so the G point should be Mg-Nd binary phase, as Mg_{12}Nd phase. There are many Zn and Mn because the bright Mg_{12}Nd phase is usually attached to the Mg-Zn-Nd ternary phase or light α-Mn particles shown in F and E point, which contain much Zn. There is no evidence of Mg-Zn alloy binary alloy phase. All the second phases containing Zn are Mg-Zn-Nd ternary phases.

| Position | Mg (at. %) | Zn (at. %) | Nd(at.%) | Zn/Nd | Mn(at.%) | phases   |
|----------|------------|------------|---------|-------|---------|---------|
| A        | 99.26      | 0.37       | —       | —     | 0.37    | α-Mg    |
| B        | 56.82      | —          | —       | —     | 43.18   | α-Mn    |
| C        | 74.85      | 25.15      | —       | —     | —       | MgZn    |
| D        | 99.03      | 0.46       | 0.04    | —     | 0.47    | α-Mg    |
| E        | 96.71      | 0.40       | 0.90    | —     | 1.99    | α-Mn    |
| F        | 57.01      | 40.49      | 2.51    | 16.1  | —       | I       |
| G        | 77.05      | 8.13       | 9.78    | 0.8   | 5.03    | Mg_{12}Nd |
| H        | 98.94      | 0.57       | 0.06    | —     | 0.43    | α-Mg    |
| I        | 73.55      | 12.76      | 13.69   | 0.9   | —       | Mg_{12}Nd |
| J        | 71.89      | 25.47      | 2.64    | 9.6   | —       | I       |
| K        | 68.20      | 27.82      | 3.98    | 7.0   | —       | I       |
| L        | 98.43      | 1.08       | 0.05    | —     | 0.44    | α-Mg    |
| M        | 88.85      | 2.03       | 9.12    | 0.2   | —       | Mg_{12}Nd |
| N        | 83.45      | 13.56      | 2.99    | 4.5   | —       | I       |
| O        | 98.78      | 0.66       | 0.05    | —     | 0.51    | α-Mg    |
| P        | 74.31      | 18.01      | 7.68    | 2.3   | —       | II      |
| Q        | 86.62      | 10.73      | 2.66    | 4.0   | —       | I       |
| R        | 98.92      | 0.64       | —       | —     | 0.43    | α-Mg    |
| S        | 99.21      | 0.35       | —       | —     | 0.44    | MgZn    |
| T        | 79.96      | 12.42      | 4.18    | 2.9   | 3.43    | T_3     |

We found that the alloy phase of 3# alloy includes bright Mg_{12}Nd phase with much Nd content, which is shown in point I. It also contains bright granules, stripes and flake of Mg-Zn-Nd ternary phase (I class), which is shown in point J and K. Besides, it also contains some dark α-Mn phase. Compared to the 2# alloy, there are more I class phase content and a small amount of flake (J) I class in the 3# alloy, and the Mg_{12}Nd phase content also has a small amount of increase. There are more I class phase contents in the 4# alloy (shown in N point), and they are coarsening, which is obviously more than that in 3# alloy. In the 5# alloy, there formed many continuous fine meshes in the second phase, which is actually Mg-Zn-Nd ternary phase rich in Zn and Nd. In addition to the Zn, Nd contents and the Zn/Nd atoms, which is similar to the I class (shown in point Q), there is another Mg-Zn-Nd...
ternary phase (as II class), which has more Nd and Zn/Nd is higher (about 2) and it is mainly attached to the I class. To sum up, after adding trace rare earth Nd, the Mg-Zn phase disappears, mostly replaced by Mg-Zn-Nd phase. Moreover, with the increase of the Nd, the Mg-Zn-Nd phase is also increasing and coarsening. In 5# alloy, there are many continuous fine mesh, and a new Mg-Zn-Nd ternary phase containing a high percentage of Nd appears. From the analysis of the 3# alloy homogenization annealing spectroscopy, we can see that there appears more Mg-Zn-Nd ternary phases, whose Zn/Nd atomic ratio is close to T3 phase ((Mg, Zn)3 Nd) (shown in the T point) and it has never appeared in the 3# alloy as-cast organization before. So we can conclude that in the 420°C×10 h homogenizing annealing process, 3# alloy phase change can occur, and it formed the new T3 phase. To verify our speculation, and further determine the phase of ZM21 magnesium alloy after adding rare earth Nd, we do the XRD pattern (see figure 2) analysis before and after the homogenization.

![XRD spectrums of as-cast alloys and 420°C×10h homogenized;](image)

**Fig2** XRD spectrums of as-cast alloys and 420°C×10h homogenized;

(a) 1# alloys, (b) 2# alloys, (c) 3# alloys, (d) 4# alloys, (e) 5# alloys

4. Conclusions
After adding different contents of Nd in ZM21 alloy, along with the increase of the content of Nd, the Mg-Zn alloy phase gradually disappears and there form the Mg-Zn-Nd ternary phase T2 phase ((Mg, Zn)11.5Nd) and a small amount of T3 ((Mg, Zn)3 Nd), and the number of the second phase increases in the interdendritic segregation, which becomes thicker and more and more continuous.

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