

As-cast Microstructures and Mechanical Properties of Mg-5Y-2Nd-xSm-0.5Zr (x= 0, 1, 3, 5) Magnesium Alloys

Gui Yunwei¹, Li Quanan^{1,2}, Chen Xiaoya¹, Li Zhitao¹

¹School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang, China

²Collaborative Innovation Center of Nonferrous Metals, Luoyang, China

Email address:

guiyunwei1@163.com (Gui Yunwei), liquanan2016@163.com (Li Quanan), chenxiaoya2010@163.com (Chen Xiaoya), csx199595@163.com (Li Zhitao)

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Abstract: The microstructures and mechanical properties of the as-cast Mg-5Y-2Nd-xSm-0.5Zr (x= 0, 1, 3, 5) alloys have been investigated by optical microscope (OM), scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) analysis, transmission electron microscopy (TEM), X-ray diffraction (XRD) and mechanical tensile test. The results show that all the as-cast alloys are mainly composed of α -Mg, Mg₂₄Y₅ and Mg₄₁Nd₅. After adding Sm, the alloy has a new phase of Mg₄₁Sm₅. Furthermore, grain gets refinement, the second phases gradually increase and the morphology of second phases transforms to continuous network distribution. In addition, the mechanical properties of the as-cast alloys vary with Sm content. With the increase of Sm, the ultimate tensile strength, yield strength and hardness of the alloy increase firstly and then decrease, and the elongation decreases. When the amount of Sm is 3%, the alloy has the best mechanical properties, and the ultimate tensile strength, yield strength, hardness and elongation are 245.9 MPa, 207.6 MPa, HV85.9 and 5.88%, respectively. The Mg-5Y-2Nd-0.5Zr alloy to which Sm is not added has a mixed fracture characteristic of ductile fracture and local cleavage fracture. In comparison, when the Sm is 3%, the tear surface of the fracture surface is fine and uniform, and there is no obvious secondary crack and a large dissociation surface, indicating that the fracture energy absorbs more energy, so it shows a high fracture. Strength and high elongation.

Keywords: Mg-Y-Nd Alloy, Sm, Microstructures, Mechanical Properties

1. Introduction

Magnesium and its alloys have low density, high specific strength, specific rigidity, good recyclability, good casting properties, good welding performance, etc., and are increasingly used in aerospace, automotive, 3C products and medical equipment, etc. In many fields [1-4], known as "the 21st century green engineering materials." However, the disadvantage of relatively poor heat resistance of ordinary magnesium alloys greatly limits the development and application of magnesium alloys [3-6]. Therefore, the development of heat-resistant magnesium alloys with better performance has become an important research direction in the application of magnesium alloys [1-7].

The common magnesium alloy strengthening method is mainly to strengthen the alloy by adding alloying elements

such as Sr, Si, Ca, and RE, among which the rare earth element has a more prominent strengthening effect in magnesium alloys due to its similar crystal structure to that of magnesium. It has been found that adding two or more rare earth elements of different light and heavy rare earth components to a magnesium alloy can increase the content of the second phase, thereby exerting a better strengthening effect. According to this principle, a series of rare earth heat-resistant magnesium alloys have been developed at home and abroad [4-8]. Among them, WE-based (Mg-Y-Nd) magnesium alloys have been widely used as the most successful commercial heat-resistant magnesium alloys. Studies have shown that the main strengthening mechanism of this series of alloys is the second phase strengthening of Y and Nd elements [7-11]. Compared with Nd, Sm shows higher maximum solubility and second phase strengthening effect in magnesium alloys, and the price is cheaper [6-12].

Li Quanan et al. studied the microstructure and properties of Mg-10Y-0.5Sm alloy [13]. The results show that the addition of 0.5wt% Sm can not only promote the fine dispersion of $Mg_{24}Y_5$ phase, but also improve their morphology and distribution. The thermal stability of the $Mg_{24}Y_5$ phase is increased; at the same time, the addition of Sm significantly increases the tensile strength of the Mg-10Y alloy. Based on this, the research and development of the more mature commercial WE series magnesium alloy as the base alloy, the use of Sm elements with higher solid solubility to replace part of the Nd elements in the Mg-Y-Nd alloy, aimed at reducing costs while developing A more excellent heat-resistant magnesium alloy, and systematically explore the strengthening effect and mechanism of Sm element in multi-component rare earth magnesium alloy [5-16]. In this

paper, Mg-5Y-2Nd-xSm-0.5Zr ($x = 0, 1, 3, 5$) series alloys were prepared by mixed gas protection, and Mg-5Y-2Nd- was studied by microscopic analysis, mechanical properties testing and analysis. The microstructure and mechanical properties of Mg-5Y-2Nd-xSm-0.5Zr series alloys.

2. Experimental Procedures

The raw materials used to prepare the experimental alloys were: intermediates of pure magnesium ($\geq 99.98\%$), Mg-Y (30%), Mg-Nd (30%), Mg-Sm (30%), and Mg-Zr (30%). alloy. The actual composition of the alloy obtained by the full spectrum direct reading inductively coupled plasma emission spectrometer (ICP) was as shown in Table 1.

Table 1. Chemical composition of the tested alloys (mass%).

Alloys	Y	Nd	Sm	Zr	Mg
Mg-5Y-2Nd-0.5Zr	5.17	1.94	0	0.45	Bal.
Mg-5Y-2Nd-1Sm-0.5Zr	5.15	1.96	1.10	0.61	Bal.
Mg-5Y-2Nd-3Sm-0.5Zr	5.24	2.01	3.04	0.49	Bal.
Mg-5Y-2Nd-5Sm-0.5Zr	5.31	2.10	4.67	0.41	Bal.

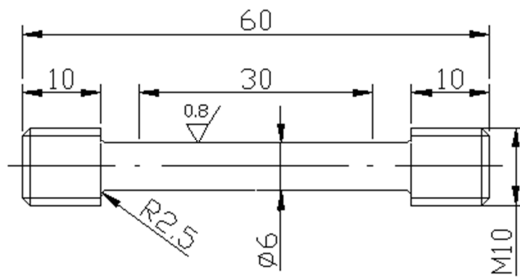


Figure 1. Shape and size of cylindrical tensile specimen (unit: mm).

Before smelting, it is necessary to put all the prepared raw materials into a drying oven and dry it for about 1 h. The molds and the sprue cups are preheated to 200°C. in the furnace. The smelting of the alloy is carried out in an electromagnetic induction furnace. During the smelting process, a mixture of CO_2 and SF_6 having a volume ratio of 99:1 continues to act as a protective atmosphere. When the temperature was heated to 700°C, the pure magnesium ingot was placed first, and after completely melting, the Mg-Y, Mg-Nd, Mg-Sm, and Mg-Zr master alloys were sequentially added. After the alloy is melted, it is left to stand by stirring and kept at a temperature of 730°C. for 10 minutes. When the molten metal is cooled down to 700°C-710°C, it is cast into a preheated metal mold.

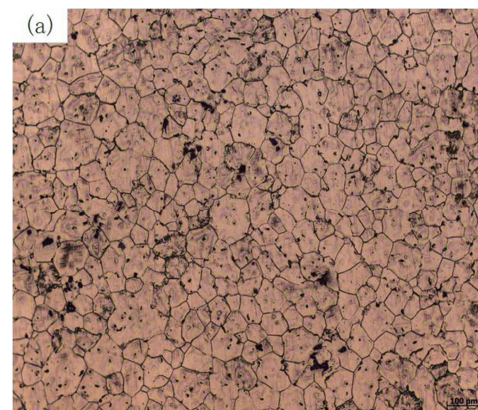
The microstructure of the alloy was analyzed using an Olympus optical microscope, an X'pertmpdpro type X-ray diffractometer, a JSM-5610 LV scanning electron microscope (SEM) and a transmission electron microscope (TEM) with an energy spectrum device (EDS). Phase and composition were observed and analyzed. The hardness value of the alloy was measured by an Akashi (MVK-E) hardness tester with a load of 250 g and a holding time of 10 s. Tensile tests were performed on a Shimadzu AG-I 250 KN precision universal testing machine with a tensile rate of 1 mm/min. The tensile test

specimens were shaped and dimensioned as shown in Figure 1.

3. Results and Discussion

3.1. Microstructure

The metallographic microstructures of the four alloys in the as-cast state are shown in Figure 2. From Figure 2 (a), it can be seen that the Mg-5Y-2Nd-0.5Zr alloy is mainly composed of an α -Mg matrix and a small amount of black second phases distributed inside the grains. After observing Figure 2 (b)-(d), after the addition of Sm element, a long second phase begins to appear in the alloy, which is formed first at the trigeminal boundary and grows along the grain boundary as the Sm content increases. Obviously increased. When the Sm content is 5%, the second phase in the alloy is substantially continuous in the grain boundary. The grain size of four kinds of alloy samples was measured, and the average grain size gradually decreased. This shows that the addition of appropriate amount of Sm element has a good refining effect on the as-cast alloy grains.



(a) $x=0$

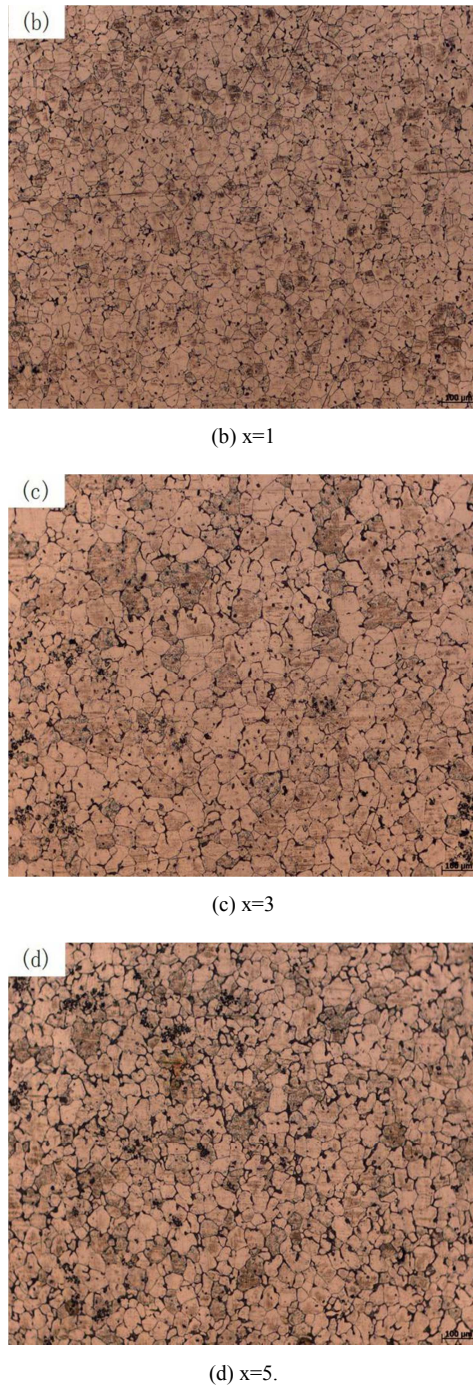


Figure 2. Optical microstructures of as-cast Mg-5Y-2Nd-xSm-0.5Zr alloy.

Further X-ray diffraction analysis was performed on four as-cast alloys, as shown in Figure 3. According to the calibration of the map, the Mg-5Y-2Nd-0.5Zr alloy without Sm is mainly composed of α -Mg, Mg_{24}Y_5 and $\text{Mg}_{41}\text{Nd}_5$ phases. After Sm is added, a new $\text{Mg}_{41}\text{Sm}_5$ phase is formed in the alloy and the Sm content is increased with the addition of Sm. With the increase, the number of diffraction peaks of $\text{Mg}_{41}\text{Nd}_5$ and $\text{Mg}_{41}\text{Sm}_5$ phases increased, and the Mg_{24}Y_5 phase remained basically unchanged. This may be due to the fact that rare earth elements Sm and Nd have similar atomic radii and electronegativity is not much different, but Sm has a higher solid solubility than Nd, and Sm atoms replace Nd

atoms in part of α -Mg matrix, with Sm The increase of the content of $\text{Mg}_{41}\text{Nd}_5$ and $\text{Mg}_{41}\text{Sm}_5$ phase increased.

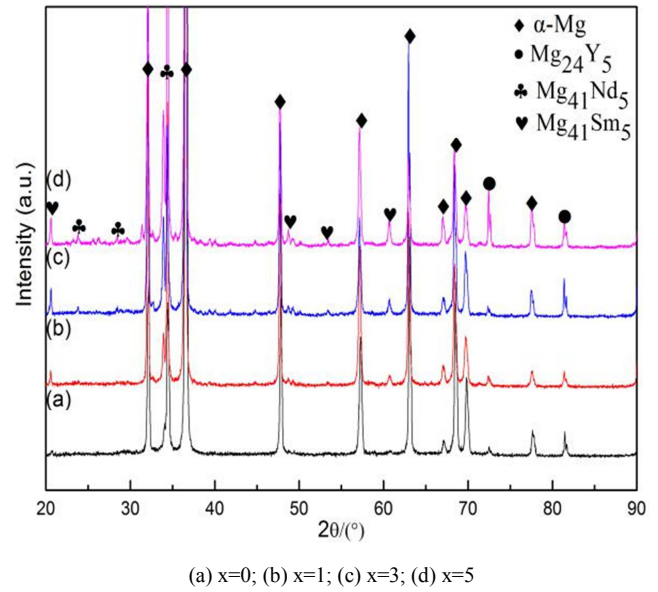


Figure 3. X-ray diffraction patterns of as-cast Mg-5Y-2Nd-xSm-0.5Zr alloy.

3.2. Mechanical Properties

Table 2 and Figure 4 show the mechanical properties of the alloy samples subjected to standard tensile tests and hardness tests. According to the variation pattern of the graph in Figure 4 and the numerical results in Table 2, we can see that at room temperature, the tensile strength, yield strength, and hardness of the alloy appear to increase first and then decrease as the Sm content increases. The trend reached a maximum at a Sm content of 3%, but the elongation decreased. Therefore, within the scope of this study, by adding 3% Sm content to Mg-5Y-2Nd-0.5Zr alloy, the alloy has the best mechanical properties of tensile strength 245.9 MPa, yield strength 207.6 MPa, and elongation. The rate is 5.88% and the Vickers hardness value is HV85.9. This is mainly due to the greater solid solubility of the rare earth element Sm in magnesium alloys. With the increase of Sm content, the Sm elements dissolved in the alloy matrix are also increased. After Sm is dissolved in the matrix, it can be in the magnesium matrix. Causes strong lattice distortions, hinders the movement of dislocations, and strengthens the alloy [14-17]. In addition, the second phase of the alloy without Sm is mainly Mg_{24}Y_5 and $\text{Mg}_{41}\text{Nd}_5$ phases. Although the second phase is small and evenly distributed, the content is too small (as shown in Figure 2 (a)), and the strengthening effect is not obvious. With the addition of Sm, on the one hand, the Sm atom can replace the Nd atoms in the solid solution and promote the formation of more $\text{Mg}_{41}\text{Nd}_5$ phases in the alloy. On the other hand, it also increases a large number of new $\text{Mg}_{41}\text{Sm}_5$ phases. These Mg_{24}Y_5 and $\text{Mg}_{41}\text{Nd}_5$ phases in grain boundaries can effectively pin dislocations, hinder slip, and effectively improve the mechanical properties of the alloy [15-17]. However, when further increasing the Sm content to reach 5%, due to the

excessive number of second phases, a continuous network distribution on the grain boundary will form a severe splitting effect on the matrix, which will deteriorate the structure and

reduce the strength and plasticity of the alloy. [18-21]. Therefore, Mg-5Y-2Nd-3Sm-0.5Zr alloy has the highest mechanical properties and the best overall performance.

Table 2. Mechanical properties of as-cast alloys at room temperature.

Alloys	UTS/MPa	YS/MPa	EL/%	HV
Mg-5Y-2Nd-0.5Zr	203.1	151.2	7.35	53.5
Mg-5Y-2Nd-1Sm-0.5Zr	214.5	178.7	6.14	65.8
Mg-5Y-2Nd-3Sm-0.5Zr	245.9	207.6	5.88	85.9
Mg-5Y-2Nd-5Sm-0.5Zr	229.2	198.5	3.79	83.6

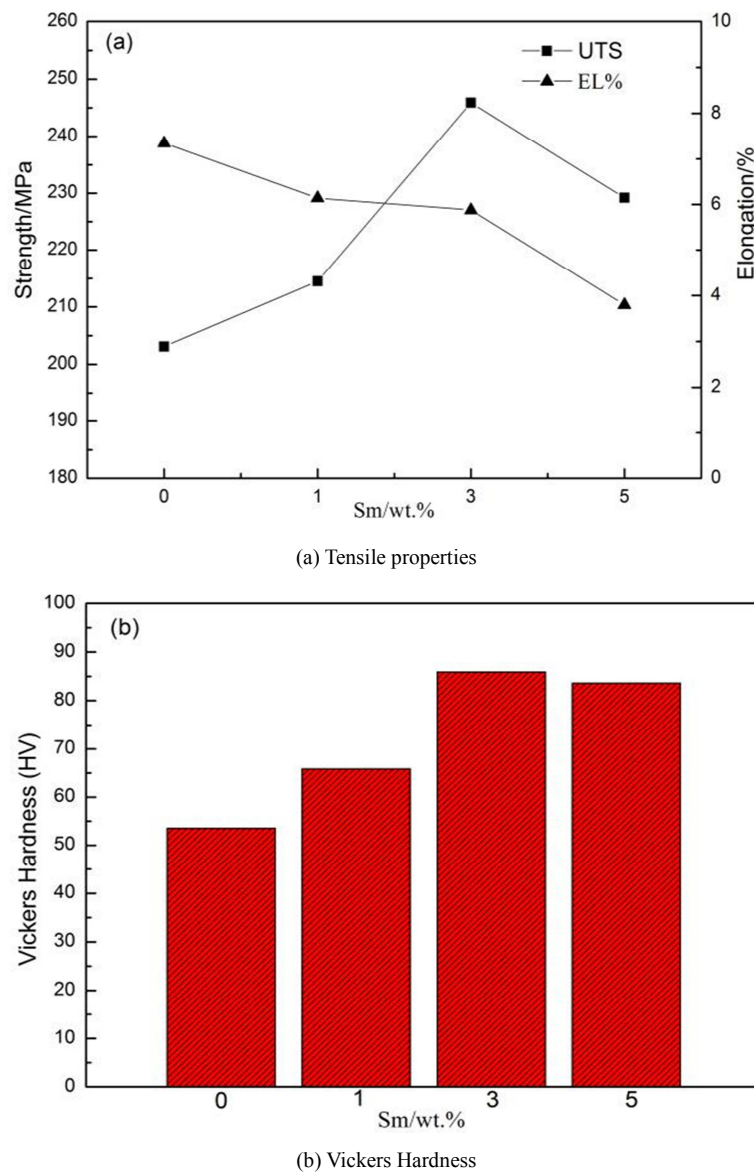


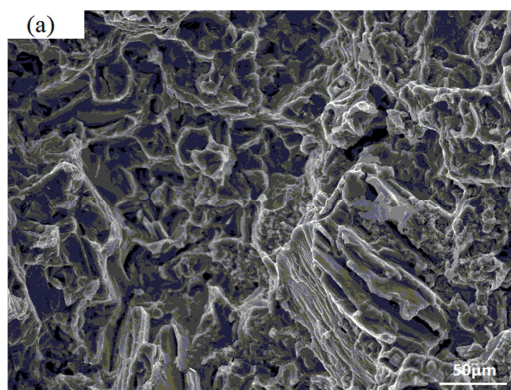
Figure 4. The variation diagram on mechanical properties of as-cast Mg-5Y-2Nd-xSm-0.5Zr (x=0, 1, 3, 5) alloy.

3.3. Fracture Behavior

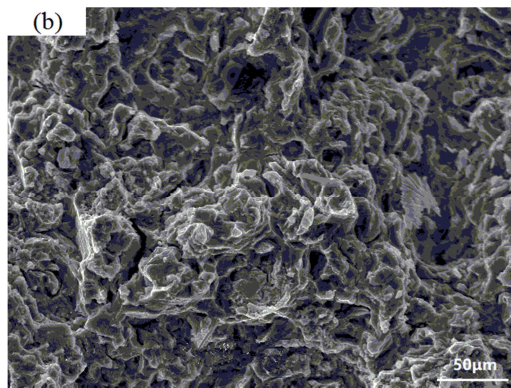
The fracture morphology of four cast alloys at room temperature is shown in Figure 5. It can be seen from the figure that the Mg-5Y-2Nd-0.5Zr alloy without Sm has the characteristics of mixed fractures of ductile fracture and local cleavage fracture. The fracture of the alloy is mainly composed of cleavage planes and torn edges. There are river

patterns and small steps, and the torn edges are more developed (Figure 5 (a)). With the addition of Sm and increasing content, the morphology of the fracture changes significantly. When Sm is 1%, the fracture becomes a mixed fracture composed of cleavage facets and torn edges, the dimples are significantly reduced, and the intergranular fracture characteristics (Figure 5 (b)), indicating that the grain boundary is the weak link of strength.. When Sm is 5%, a small amount of cleavage facets can be observed in the

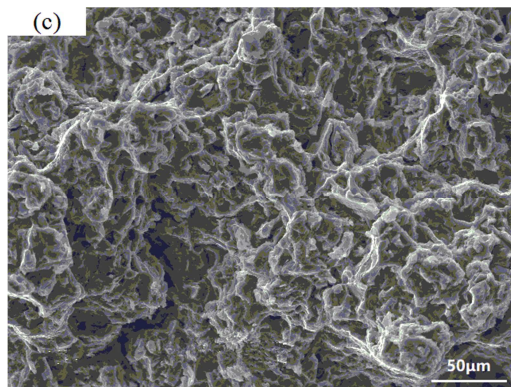
fracture, and there is a significant increase in secondary cracks on the fracture. The intergranular fracture characteristics are obvious (Figure 5 (d)) due to the coarse second phase along the grain boundary. The intermittent network distribution not only does not play the role of strengthening the alloy, but on the contrary, the formation of large stress concentration at the grain boundary causes crack initiation and expansion, manifesting as obvious brittle fracture, thus reducing the strength and plasticity of the alloy simultaneously. In comparison, when the Sm is 3%, the tear surface on the fracture surface is small and uniform, there is no obvious secondary crack and a large dissociation surface (Figure 5 (c)), which indicates that more energy is absorbed during the fracture process. Therefore, it shows high breaking strength and high elongation.



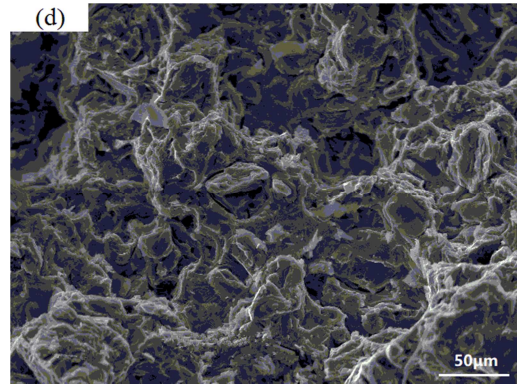
(a) x=0



(b) x=1



(c) x=3



(d) x=5.

Figure 5. The tensile fracture SEM photographs of as-cast Mg-5Y-2Nd-xSm-0.5Zr alloy at 25°C.

4. Conclusion

- (1) The microstructure of Mg-5Y-2Nd-0.5Zr as-cast alloy is mainly composed of α -Mg, Mg_{24}Y_5 and $\text{Mg}_{41}\text{Nd}_5$ phases. With the addition of Sm, the alloy grains are refined and the second phase $\text{Mg}_{41}\text{Sm}_5$ mainly distributed along the grain boundary is generated. The $\text{Mg}_{41}\text{Nd}_5$ phase inside the grains also increased slightly.
- (2) With the addition of Sm, the tensile strength, yield strength and hardness of the as-cast alloys increase first and then decrease, and the elongation decreases. When 3% content of Sm is added, the alloy has the highest strength and hardness, high elongation, and the best comprehensive mechanical properties.
- (3) The addition of appropriate amount of Sm can effectively improve the mechanical properties of Mg-5Y-2Nd-0.5Zr as-cast alloys. The strengthening method is mainly for the second phase strengthening, fine grain strengthening and solid solution strengthening also play a role.

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