The Influence of Mg/Cu on Tensile Properties of ZA27 Alloy

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Abstract. In this paper, the addition of magnesium and copper was changed to investigate the effect of magnesium and copper on the tensile properties of ZA27(Zn-27Al) alloy. The experimental results showed that Zn-27Al-0.8Mg has the largest tensile strength of 294.61 MPa. The fracture of Zn-27Al-xMg alloy was mainly related to the newly precipitated magnesium phases (β + β’). For the Zn-27Al-xCu alloy, when the amount of copper added was 0.4wt.%, the tensile strength reached 292.58 MPa, and when the amount of copper added was 2.0wt.%, the elongation even reached 80%, indicating that the alloy has good plasticity. The fracture of the Zn-27Al-xCu alloy was mainly related to defects in the structure and the second phase particles.

Keywords: Zinc-aluminum alloy; Tensile properties; Elongation; Second phases

1. Introduction
As a new light material, zinc-aluminum alloy had many excellent properties, such as higher hardness, better wear resistance and good damping performance. The material was used in the industrial field, which can effectively solve the problems of noise and vibration, and it can also be beneficial to achieve the goal of lightweight vehicles to a certain extent. So it has great prospects in industrial applications such as ships, aerospace, and automobiles.

In the past, people were mainly devoted to studying the properties of zinc-aluminum binary alloys[1–5] and the effect of rare earth elements on the properties of zinc-aluminum alloys. Ren et al. proved that Y increased the yield strength and hardness of Mg-Al-Zn alloys[6][7]. Jia Wenxu et al. studied the characteristics of Gd on Cu-Zn-Al shape memory alloys (SMAs). It was found that the shape memory effect of Cu-Zn-Al alloys was the best when the content of Gd was between 0.08wt.% and 0.12wt.%. Luo Bing-hui found that 0.21wt.% Sc and 0.15wt.% Zr can improve the
damping stability of Zn-22%Al[9]. Regarding magnesium and copper, the combined effects of two elements on zinc-aluminum alloys were often considered, Zn-Al-Cu-Mg alloys with medium Mg content (0.21wt.%) exhibited the highest yield strength at room and high temperatures, and ZnAl4Cu1-based alloys with less Mg showed excellent ductility at high temperatures[10]. However, there are few literatures on the effects of Mg/Cu alone, and their influence on the fracture mechanism of ZA27 alloy is not clear.

2. Experimental procedure

In this paper, the influence of Mg/Cu on the tensile properties of ZA27 alloy is explored by analyzing the microstructure of alloys with different compositions.

Zn-27Al-xMg and Zn-27Al-xCu alloys were prepared by the casting process. The copper and magnesium contents were designed to be 0.4wt.%, 0.8wt.%, 1.2wt.%, 1.6wt.%, and 2.0wt.%, respectively. Due to the poor performance of the as-cast alloy, the test as-cast alloy was annealed and solution treated. After consulting the literature[11 ̂13], the specific heat treatment process was shown in Table 1.

Table 1. Heat treatment process of experimental sample

| Number | ab | a1 | a2 | a3 | a4 | a5 | b1 | b2 | b3 | b4 | b5 |
|--------|----|----|----|----|----|----|----|----|----|----|----|
| Alloy composition | Zn-27Al | Zn-27Al-xMg | Zn-27Al-xCu |
| Heat treatment process | 400 ºC /h+125ºC/24h | 360 ºC /h+120 ºC /24h | 460 ºC /h+130 ºC /24h |

ZEISS200MAT digital metallographic microscope, FEI QUANTA200F scanning electron microscope and X, Perth pro multi-functional X-ray diffractometer (XRD) were used to analyze the microstructure of materials. And Instron 4505 electronic universal testing machine was adopted to test tensile properties of materials.

The material was cut into 10 mm×10 mm×5 mm with a metallographic sample cutter, and the samples were polished in the order of 150, 400, 800, 1200, 1500, and 2000 mesh sandpapers, then polished, and Cr2O3 was used as the polishing powder. The polished samples were etched with 4% nitric acid, and immediately rinsed with water after the appearance of grayish white corrosion produced on the surface, then wiped with alcohol and blew dry.

The tensile specimens are designed and processed according to the national standard GB/T6397-1986. The samples size processing standard was shown in Fig.1.

![Fig.1. Size show of the testing samples](image)
3 Microstructure analysis

3.1 Effect of Magnesium and Copper on Microstructure of ZA27 Alloy

According to the XRD test results of these alloys (Fig. 2), when magnesium was added to the ZA27 matrix alloy, Zn-27Al-xMg not only contained Al-rich phases η-Zn and eutectoid phases(α´+η), but also magnesium phases(MgₓZny). However, copper and magnesium atomic radii were similar, indicating that copper remained in the matrix in the form of a replacement solid solution in Zn-27Al-xCu.

![Fig.2. XRD test results of alloys](image)

3.2 Effect of Magnesium Content on Tensile Properties of ZA27

![Fig.3. (a) SEM images of Zn-27Al-xMg alloys; (b) EDS spectrum of spot A; (c) EDS spectrum of spot B](image)

According to the microstructure of Zn-27Al-xMg(x=0, 0.4, 0.8...2.0wt.%) after heat treatment, The microstructure was mainly composed of black η-Zn, gray black eutectoid phases(α´+η) and Mg phases(MgₓZny). The bright white β (MgₓZny) phase was
distributed in a network from Fig.3, and the gray β´ (MgZn₂) was continuously
distributed in the gap of the β, and was coordinated with the β. With the increase of
magnesium content, we can see that the amount of Mg phase was gradually increased
and became more uniform from Fig.4. When the magnesium content reached 0.8wt.%,
the Mg phases (β and β´) constituted a stable and uniform network structure. However,
when the magnesium content continued to increase, the precipitation and growth of the
Mg phases were inhibited, as η-Zn and (α´+η) continued to grow, they would be
extruded into the surrounding Mg phases. And the network structure formed by the Mg
phases became sparse.

Fig.4. Zn-27Al-xMg alloys microstructure (a) ZA27; (b) ZA27~0.4wt.%Mg; (c)
ZA27~0.8wt.%Mg; (d) ZA27~1.2wt.%Mg; (e) ZA27~1.6wt.%Mg; (f)
ZA27~2.0wt.%Mg

Compared with the ZA27 binary alloy, the elongation of Zn-27Al-xMg(x=0.4,
0.8…2.0wt.%) was lower from the Table 2, and the general trend decreased with the
increase of magnesium content, and the maximum was Zn-27Al-0.4Mg, which did not
reach 15%. In the same series, the tensile strength of Zn-27Al-0.8Mg was the largest,
which is 294.61MPa.

| Alloy composition | Percentage of magnesium in Zn-27Al-xMg(wt.%) |
|-------------------|---------------------------------------------|
| Tensile Strength(Mp) | 175.96 188.22 294.61 240.97 190.59 180.96 |
| Elongation(%)     | 14    11.6 10.55 9 5.6 6.4               |

Table.2 Tensile properties of Zn-27Al-xMg(x=0, 0.4, 0.8…2.0wt.%)
As can be seen from Fig.5(a), there was no significant macroscopic plastic deformation near the crack, the surface had a relatively flush particle shape. Therefore, the fracture form of the Zn-27Al-xMg(x=0.4, 0.8...2.0wt.%) alloy was mainly brittle fracture.

Fig.5(b) showed the morphology of the Zn-27Al-xMg(x=0.4, 0.8...2.0wt.%) ductile fracture zone. Fig.4(c) showed the fracture surface morphology of the brittle dendrites in the final fracture zone. It can be seen from Fig.5(d) that the significant brittleness along the crystal plane fracture characteristics appeared at the interface between β and β', indicating that the material did have intergranular brittleness. There was also a small amount of casting dimples between the magnesium phases, a fishbone pattern appeared from Fig.5(e), and the river pattern appeared on the fracture from Fig.5(f), which showed that this is a hybrid fracture mode dominated by brittle fracture.

According to the Cottrell dislocation reaction theory and the Smith theory, the fracture of the sample was related to the Mg phases(β and β') precipitated in the eutectoid phases and the internal defects. On the one hand, since the Mg phases were hard phases and had a small angle sharp angle, It can be inferred from Fig.5 when the Mg content was less than 0.8wt.%, the Mg phases precipitate very little, which contained only dendrites, and were uniformly distributed at the grains boundary. When the Mg content was 0.8wt.%, the irregularly shaped Mg phases precipitated in a large amount, the size became larger, the brittleness increased, and the matrix was split. At the same time, the tensile deformation of the test alloy first occurred on the intergranular eutectoid phases or the crystal defects, resulting in local stress concentration at the tip of
the polygonal and irregularly shaped $\beta'$ during the stretching process, so that the $\beta'$ cracked or produced microcracks. However, since the Mg phases were arranged in a regular and stable network structure, the tensile strength of Zn-27Al-0.8Mg was large. On the other hand, the Mg phases were brittle phases, and as showed in Fig.5(d), there was a clear marked trace of brittle fracture on the Mg phases. Due to the presence of the gray Mg-rich phase $\beta'$ in the test alloy structure, lattice distortion easily occurred when an external force was applied, resulting in the material to be brittle fracture. Moreover, since the alloy was formed by casting, it was obvious that there were many crystal defects such as shrinkage holes in the fracture surface of Zn-27Al-xMg in Fig.5(b), which was also the main reason for the limited tensile strength of materials. The origins of the quasi-cleavage crack were the shrinkage cavity and other defects in the grain caused by casting and the crack source of the cleavage fracture is the grain boundary or the magnesium phase ($\beta$ and $\beta'$) interface.

3.3 Effect of Copper Content Tensile Properties of ZA27 Alloy

It can be seen from Fig.6 that the microstructure of Zn-27Al-xCu is composed of black Zn-rich phase $\eta$-Zn and gray-black eutectoid phases ($\alpha' + \eta$) from the SEM results. And black $\eta$ distribution was relatively regular. When the copper content was 0.4wt.%, it was uniformly distributed in the form of needle or strip, and the eutectoid phases ($\alpha' + \eta$) existed at the center of the $\eta$. As the copper content increased, black $\eta$ phase became significantly smaller, gradually aggregated, and was distributed in the eutectoid structure in the form of dendrites or snowflakes (Fig.7). Even the number of grains had also increased and regional segregation occurred.

![Fig.6](image_url)

**Fig.6.** (a) SEM images of Zn-27Al-xCu alloy; (b) EDS spectrum of spot A; (c) EDS spectrum of spot B

It can be seen from Table 3 that the addition of copper can significantly improve the tensile properties and elongation of ZA27 alloy. The tensile strength of the alloy decreases and the elongation increases with the increase of copper content. In particular, the tensile strength of Zn-27Al-0.4Cu can reach 292.58MPa, and the elongation of Zn-27Al-2.0Cu reached 80%.
Fig. 7. Zn-27Al-xCu alloys microstructure (a) ZA27; (b) ZA27–0.4wt.% Cu; (c) ZA27–0.8wt.% Cu; (d) ZA27–1.2wt.% Cu; (e) ZA27–1.6wt.% Cu; (f) ZA27–2.0wt.% Cu

Table 3. Tensile properties of Zn-27Al-xCu (x=0, 0.4, 0.8...2.0wt.%)

| Alloy composition | Percentage of magnesium in Zn-27Al-xCu (wt.%) |
|-------------------|-------------------------------------------------|
|                   | 0      | 0.4   | 0.8   | 1.2   | 1.6   | 2     |
| Tensile Strength (Mpa) | 175.96 | 292.58 | 267.79 | 264.08 | 264.55 | 242.8 |
| Elongation (%)      | 14     | 20    | 40    | 40    | 65    | 80    |

As shown in Fig. 8(a), the alloy had a large necking, and the appearance of the fracture was cup-shaped, and the bottom of the cup was perpendicular to the direction of the tensile stress. The surface of the fracture was goose-like, the color was gray, and it had obvious topographic characteristics of pure shear fracture. So the fracture form of the Zn-27Al-xCu alloy was ductile fracture.
Fig. 8. Schematic diagram of Zn-27Al-xCu tensile fracture

From Fig.8, the dimple morphology of the final fracture zone of the tensile fracture was observed, and second-phase particles appeared at the bottom of dimples. It can be seen from Fig.8 (a) that there were relatively porous holes in the material, and the holes were mainly divided into two parts. The first part is the casting defect and the second part is formed by the movement of the second phase particles (α' + η). The pores nucleated, grew up, and accumulated. Under the action of slip, the cavity gradually grew and was connected with other voids. The (α' + η) and the matrix η interface aggregated strength weaken. Therefore, with the increase of copper, more and more pores were formed by the sliding movement of the second phase particles, and the tensile strength of Zn-27Al-xCu is getting smaller and smaller.

4 Conclusions

In this paper, the effect of magnesium or copper and its content on the tensile properties of ZA27 alloy was studied. Through experiments and analysis, the following conclusions were obtained:

1. Magnesium was added to the ZA27 alloy, and magnesium phases (β and β') was formed; and the copper atom was present in the matrix as a replacement solid solution.

2. The tensile test results of Zn-27Al-xMg alloy showed that the fracture form was a mixed fracture mode dominated by brittle fracture. The magnesium phases (β and β') are the main reason for the brittle fracture of Zn-27Al-xMg alloy. With the increase of magnesium content, the tensile strength of Zn-27Al-xMg increased first and then decreased. The value of Zn-27Al-0.8Mg was the largest, which is 294.61MPa. However, due to the presence of brittle magnesium phase, the elongation of Zn-27Al-xMg was
smaller than the elongation of ZA27.
3. The fracture form of Zn-27Al-xCu alloy was ductile fracture, and the cause of the
fracture was divided into two parts, one was related to the defects such as holes or
inclusions generated during the casting process, and the other was related to the
distribution, morphology and size of the eutectoid phase (α′+η). Therefore, with the
increase of copper content, the tensile strength of Zn-27Al-xCu decreased. The tensile
strength of Zn-27Al-0.4Cu was the largest, which was 292.58MPa.

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