Effects of Alloying Element Cu and Rare Earth La on Properties of Aluminum Alloys

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ABSTRACT

The effects of alloying element Cu and rare earth La on the performance of aluminum alloy die castings were mainly studied. Through comparative analysis of the experimental hardness, tensile strength, elongation data and fracture morphology of each group, it was found that aluminum alloys with 1.98% Cu and 0.32% La elements added at the same time had the best mechanical properties compared to the original base materials. Hardness, tensile strength and elongation increased by 61.2%, 51.5% and 63.9%, respectively, and the quality of aluminum alloys increased significantly.

KEY WORDS

Aluminum Alloy; Die Casting; Alloy Element; Mechanical Properties

INTRODUCTION

In the course of nearly two hundred years of development, the aluminum industry has developed rapidly due to a series of unique and excellent properties of aluminum and aluminum alloys. It has been widely used in transportation, architectural decoration, packaging containers, mechanical and electrical, aerospace, electronic communications and other fields. Aluminum has become an important basic material for national development[1]. Pure aluminum has low tensile strength, high plasticity, high elongation, about 35%, 80% reduction in area, poor casting
properties, and it is difficult to meet practical use requirements. Therefore, it is necessary to add other alloy elements to improve performance.

EXPERIMENTAL CONDITIONS AND SOLUTIONS

Experimental Conditions

The LK DCC500 cold chamber horizontal die casting machine was used to prepare experimental samples. MR2000 metallographic microscope was used to observe microstructure. Tensile properties measured in an electronic universal testing machine model CMT5105. Macroscopic hardness measured in a Brinell hardness tester model HB-3000B. Direct reading spectrometer Model ARL3460 was used to analysis quantitative of sample elements. Scan photos photographed in a Tungsten Filament Scanning Electron Microscope Model JSM-6490LV.

Experimental Program

Seven groups of experiments were designed. The composition of the alloy measured in each group was as shown in Table 1 and Table 2. Through comparative analysis of the microstructure and properties of different constituents of Cu and La elements, the effects of the resulting conclusions were studied.

EXPERIMENTAL RESULTS AND ANALYSIS

Effect of Cu Element on Properties of Aluminum Alloys

| groups | Si  | Fe  | Mg  | Mn  | Zn  | Ni  | Cu  | La  | Al  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1      | 10.75 | 0.72 | 0.18 | 0.34 | 0.52 | 0.35 | 0   | 0   | remainder |
| 2      | 10.68 | 0.75 | 0.19 | 0.32 | 0.50 | 0.29 | 1.51 | 0   | remainder |
| 3      | 10.74 | 0.64 | 0.21 | 0.30 | 0.51 | 0.38 | 1.98 | 0   | remainder |
| 4      | 10.70 | 0.69 | 0.17 | 0.36 | 0.49 | 0.34 | 2.52 | 0   | remainder |
TABLE II. CHEMICAL COMPOSITION OF DIFFERENT LA CONTENT ALLOYS.

| groups | Si\% | Fe\% | Mg\% | Mn\% | Zn\% | Ni\% | Cu\% | La\% | Al\% |
|--------|------|------|------|------|------|------|------|------|------|
| 1      | 10.75\% | 0.72\% | 0.18\% | 0.34\% | 0.52\% | 0.35\% | -\% | -\% | remainder\% |
| 5      | 10.78\% | 0.70\% | 0.16\% | 0.36\% | 0.51\% | 0.31\% | 1.98\% | 0.14\% | remainder\% |
| 6      | 10.64\% | 0.65\% | 0.20\% | 0.31\% | 0.56\% | 0.35\% | 1.98\% | 0.32\% | remainder\% |
| 7      | 10.71\% | 0.68\% | 0.19\% | 0.33\% | 0.47\% | 0.30\% | 1.98\% | 0.51\% | remainder\% |

Figure 1. Microstructure of sample with different Cu content: 
(1) 0% Cu; (2) 1.51% Cu; (3) 1.98% Cu; (4) 2.52% Cu (wt.%).

MICROSTRUCTURE ANALYSIS

The microstructure of different Cu content is shown in Figure 1. It can be seen from Fig. 1 that the sample organization without Cu added has large plate-like primary silicon. The eutectic silicon distribution is relatively concentrated and the crystal grains are coarse. The secondary dendritic spacing of the grains is relatively large. With the increase of Cu content in the alloy, it can be found that the distribution of eutectic silicon tends to be uniform and fine, and the secondary dendrite spacing of the grains also tends to decrease significantly. However, when the Cu content continues to increase, it can be found that eutectic silicon has accumulated.
MECHANICAL PROPERTIES ANALYSIS

![Figure 2](image.png)

(a) hardness; (b) tensile strength; (c) elongation.

From Figure 2, it can be seen that as the content of Cu increases, both the hardness and the tensile strength of the die casting increase, while the elongation of the product gradually decreases. When the use requirements of the elongation cannot be less than 3%, under the premise of meeting the performance requirements, choose a percentage of 1.98% Cu content, its hardness, tensile strength and elongation were 95.1HB, 240.82MPa and 3.84%, respectively.

Effect of Rare Earth Elements on Properties of Aluminum Alloys

MICROSTRUCTURE ANALYSIS

The microstructure of different La content is shown in Figure 3. It can be seen from the figure that as the La content of the rare earth element in the alloy increases, the microstructure becomes more uniform and fine, and the secondary dendrite spacing of the grains decreases significantly. When the La content reaches 0.32%, the eutectic silicon is distributed along the grain boundaries as extremely fine fibers (Fig. 3(6)). However, increasing the content of rare earth can be found that the degree of refinement of rare earth is reduced, and the phenomenon of specific gravity segregation occurs due to the large content of rare earth in the structure.

MECHANICAL PROPERTIES ANALYSIS

From Figure 4, it can be seen that as the content of rare earth increases, the Brinell hardness, tensile strength and elongation of the shell all show a tendency of increasing first and then decreasing. The content of rare earth La is best at 0.32%, its hardness, tensile strength and elongation reach 108.8HB, 311.55MPa and 8.75%.
Comparative Analysis of Effect of Cu and Rare Earth Elements on Properties of Aluminum Alloys

Through the above analysis, it can be found that the hardness and tensile strength of No. 3 experimental die castings are increased by 46.2% and 30.5% respectively, and the elongation is reduced by 47.4%. The hardness, tensile strength and elongation of the 6# experimental diecastings with 0.32% La content were 108.8HB, 311.55MPa and 8.75%, respectively, which were 61.2%, 51.5% and 63.9% higher than those of the 1# experiment respectively. By comparing the data, it can be found that the Al-Si aluminum alloy added 1.98% Cu and 0.32% La at the same time.

SEM scanning of tensile fractures of 1#, 3# and 6# experimental samples. By observing the macroscopic morphology of the fractures of the three groups of
specimens, it can be found that the fracture of 1# test specimen is perpendicular to the direction of tensile load, and it is a grayish, amorphous, rough surface with a small amount of reflective facets, which can be initially judged as brittle fracture. The fractured specimen 3# is grainy and relatively flush and perpendicular to the tensile direction. There are many strongly reflective facets on the fracture surface, that is, the fracture surface of the specimen is fractured. It can also be initially judged as a brittle fracture. The fracture angle of the 6# test specimen was approximately 45° to the tensile direction, and the fracture surface was gray in color. A slight necking phenomenon was observed at the fracture surface. Therefore, the 6# experiment was judged to be plastic fracture[3-4]. Through the comparative analysis of the three fracture surface topographies, it can be found that the microscopic morphology of the fracture specimens of experiment 1 is characterized by river-like patterns, "fishbone shape" and "tongue" patterns, and almost no dimples can be seen. The fracture morphology is typical of cleavage fractures. The fracture morphology of the specimen of Experiment 3 showed a small amount of small dimples compared to Experiment 1, and the material plasticity slightly improved. The fractures show different degrees of crystal polyhedrons and have a strong three-dimensional appearance, which is typical of the characteristics of intergranular fractures. In experiment 6, the dimples were distributed on the fracture surface of the sample, but the dimples were shallow. Therefore, the plasticity of the experimental alloys was better than that of the former two groups. There is a dense tear line on the fracture, which is a typical quasi-cleavage fracture. The analysis of the three experimental fractures also verified the reliability of the foregoing analysis.

CONCLUSIONS

This paper mainly studies the effect of alloying elements Cu and rare earth La on the properties of aluminum alloys. Firstly, the materials were prepared and tested by die-casting. After that, metallographic specimens, hardness specimens and tensile specimens were prepared for mechanical properties testing. Through comparative analysis of the experimental hardness, tensile strength, elongation data and fracture morphology characteristics of each group, it can be found that aluminum alloys with 1.98% Cu and 0.32% La elements added at the same time have the best performance.
Compared to the original base material, the hardness, tensile strength, and elongation were increased by 61.2%, 51.5%, and 63.9%, respectively, and the quality of aluminum alloys was greatly improved.

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REFERENCES

1. Duan Huizhen.2013. Research and Application of Aluminum Alloy Die Casting Process and Virtual Process Optimization [D]. Xiamen: Jimei University.
2. Yang G.Y, Liu S.J, Jie W.Q.2013. Effects of Minor Sc Addition on the Microstructures and Mechanical Properties of Al-Zn-Mg-Cu Casting Aluminum Alloy[J]. Light Metals, 463-467.
3. Liu Jingan, Xie Shuisheng.2012. Aluminum processing defects and countermeasures [M]. Beijing: Chemical Industry Press.
4. TANG Anmin, Liu Zeming.2003. Experimental Analysis of the Variation of Fracture Forms of Aluminum Alloys[J]. Journal of Xi’an University of Technology, 19(3): 226-229.
5. Huang Zhixin. 2016. ANSYS Workbench 16.0 Super Study Handbook [M]. Beijing: People's Posts and Telecommunications Press.