# Microstructure and Properties of Copper Mold Casting Mg-5Al-3Sn-0.2Sc Alloy

Jiong Zhang[1], Shaofei Chen[2], Lihua Liu[3]

*1 School of Vocational and Technical Education*
Guangxi University of Science and Technology
Liuzhou Guangxi 545006 China
2 Engineering Training Center
Guangxi University of Science and Technology
Liuzhou Guangxi 545006 China
3 College of Science
Guangxi University of Science and Technology
Liuzhou Guangxi 545006 China

***Abstract* — Mg-Al-Sn alloy is a novel magnesium alloy with extremely high application values; however, it also has defects in high temperature properties and corrosion resistance. Alloying and preparation technology are two effective approaches used to improve alloy properties. In this study, specimens of Mg-5Al-3Sn-0.2Sc alloy were prepared using the copper mold spray casting method. A series of experiments, including XRD, SEM, and mechanical and corrosion resistance property tests were conducted. First, the results indicated that the alloy prepared using the copper mold casting method was an amorphous alloy, and its tensile strength, yield strength, and elongation at ambient temperature were 462MPa, 378MPa, and 21.8%, respectively. Compared to the ambient temperature, when at a higher temperature of 350°C, the tensile strength and yield strength decreased by 5% and 9.8%, respectively, but elongation increased by 35.8%. Second, the corrosion potential increased 509mV, compared to commercial AZ31 magnesium alloy, indicating its corrosion resistance property significantly improved. The results show that using the copper mold casting method is efficient. The experiment results demonstrate that the alloy prepared using the copper mold casting method has important academic significance and application prospects.**

***Keywords - Magnesium alloy; copper mold casting; Mg-5Al-3Sn-0.2Sc alloy; mechanical properties under high temperature; corrosion resistant property***

## I. INTRODUCTION

Magnesium alloy has received an increasing number of industry applications due to its advantages, including low relative density, high specific strength, good damping property, and recyclability. However, magnesium alloy's poor corrosion resistance limited its extensive application. Elsayed et al.[1] investigated the impact of the content and microalloying of Al on the age hardening of Mg-Sn alloy. Luo et al.[2] analyzed the solidification microstructure and mechanical properties of casting alloy Mg-Al-Sn. Mg-Al-Sn alloy is a novel magnesium alloy with extremely high application values; however, it also has defects in high temperature properties and corrosion resistance. It is well known that alloying and preparation technology are two effective approaches used to improve alloy properties. This paper prepared Mg-5Al-3Sn-0.2Sc alloy using the copper mold casting method and conducted microstructure observations, XRD analysis, and tests on mechanical properties (under ambient temperatures and high temperatures) and corrosion resistance properties.

## II. EXPERIMENTAL MATERIAL AND METHODOLOGY

Industrial grade metals Mg, Al, and Sn and the intermediate alloy Mg-5Mn and Mg-10Sc were selected as raw materials to prepare Mg-5Al-3Sn-0.2Sc alloy, using the TXZ-150 variety of medium frequency induction melting furnace. The purpose of adding Mn materials was to eradicate the impure elements in Fe. Figure 1 shows the melting process of the different specimens. A mixed gas consisting of SF6 and CO2 with a volume ratio of 5 to 2 was inflated as a protection gas during the melting process. Mg was first melt at a temperature of 690°C, then the furnace temperature was raised to 700°C and other materials were added; after all materials were melted, the furnace temperature was raised to 720°C and maintained that heat for 15 minutes; finally the furnace was cooled down to room temperature in order to obtain the necessary metal bulk. After that, the Rapid Quench Machine System VF-RQT50 high-speed cooling equipment was used to induct heating to achieve alloy bulks; these alloy bulks were copper mold spray-casted under the condition of argon with a spray casting pressure of 0.02MPa to obtain the necessary Mg-5Al-3Sn-0.2Sc alloy specimens, the dimensions of which were 80mm (length)×10mm (width)×4mm (height). The chemical compositions of the specimens were analyzed using the SEA-1000A type of X-ray fluorescence spectrometer. The corresponding analysis results are presented in Table1.

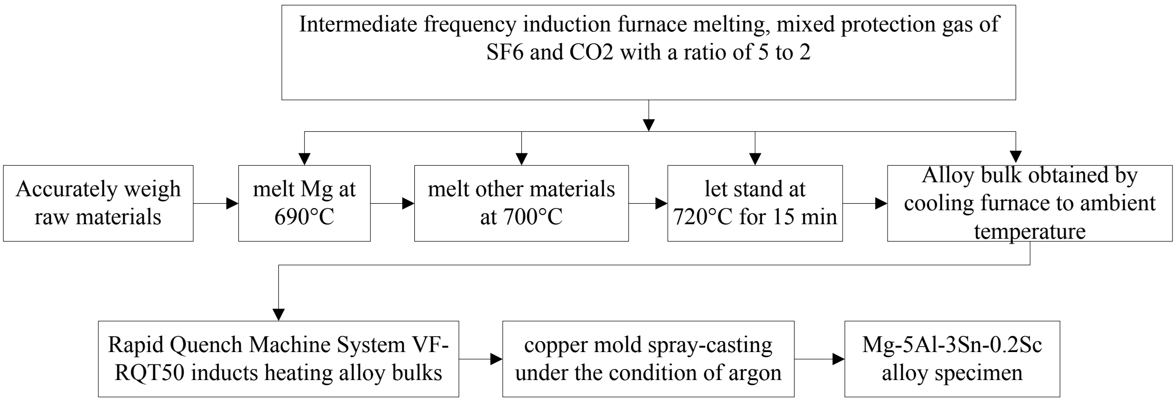


Figure1. Schematic of Melting Unit

TABLE 1 CHEMICAL COMPOSITION OF THE SAMPLE

| Al | Sn | Mn | Sc | Fe | Si | Mg |
|---|---|---|---|---|---|---|
| 4.996 | 3.006 | 0.311 | 0.198 | 0.014 | 0.008 | Allowance |

The XRD analysis of the alloy specimens used a D8 ADVANCE X-Ray diffraction instrument with a diffraction angle of 0-90 degrees. Cu was selected as a target for analysis.

After the specimens were coarse-ground, fine-ground and then polished using metallographic abrasive paper, the specimens were corroded for 15 seconds using a mixed corrodent (liquid mixture consists of 100 ml of ethanol, 100 ml of water, 5 ml of acetic acid, and 5 gram of picric acid), and then dried by an air blower. After that, an EVO18 scanning electron microscope (SEM) was used to observe the microstructure of specimens using the Rutherford Backscattering Spectrum (RBS).

The UH-100GL high temperature tensile testing machine was used to test the mechanical properties of the specimens both at the ambient temperature and at a higher temperature of 350°C. The configuration of the tensile testing specimens was as follows: the total length was 70 mm; the length of the parallel section was 30 mm; the width of the parallel section was 5 mm; the arc radius of was 5 mm; the chuck width was 10 mm; and the chuck length was 15 mm. After testing, an EVO18 scanning electron microscope (SEM) was used to observe the tensile fracture morphology.

The CHI660B electrochemical workstation was used during the specimen's corrosion testing, conducted under ambient temperatures. The electrolyte was 5wt% of a NaCl solution. The scanning velocity was 0.001mV/s with a scanning range of -1.2 V to -0.3 V. A three-electrode system consisting of a working electrode to preparing alloy specimens, a calomel electrode as a reference electrode, and a platinum black electrode as an auxiliary electrode were all used in testing. After testing, a PG25 metallographic microscope was used to observe the surface corrosion in the specimens.

## III. TESTING RESULTS AND OBSERVATION

### A. *XRD analysis*

Figure 2 shows the XRD spectrum for the Mg-5Al-3Sn-0.2Sc alloy specimens prepared using the copper mold spray casting method. It can be observed from Figure 2 that there was a wide diffuse peak only when the Mg-5Al-3Sn-0.2Sc alloy specimens were under the condition of $2\theta=30^{o}\sim50^{o}$; a diffraction peak characterizing the crystal phase of Mg-5Al-3Sn-0.2Sc alloy has not been observed within the range of 0 to 90 degrees. Therefore, the g-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method in this research was an entire non-crystal microstructure, and the alloy was a non-crystal alloy.

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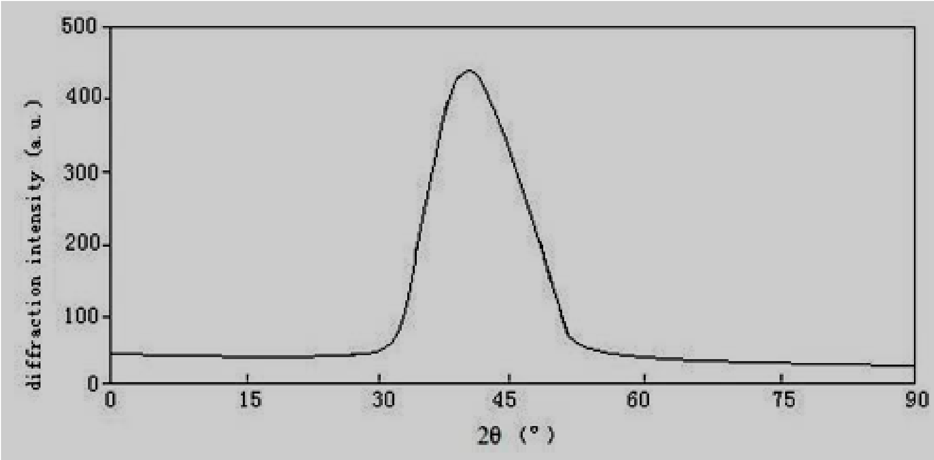


Figure2. XRD Spectrum of specimens

*B. Microstructure*

Figure 3 shows a Rutherford Backscattering Spectrum scanning picture of the Mg-5Al-3Sn-0.2Sc alloy specimens prepared using the copper mold spray casting method. It can be observed from Figure 3 that the alloy prepared using the copper mold spray casting method in this study had no evident metallic impurities or crystal boundary, and exhibited completely non-crystalline morphology. This observation is consistent with the XRD analysis results.


Figure3. Rutherford Backscattering Spectrum scanning picture of alloy specimens

*C. Mechanical properties*

Figure 4 represents the tensile curves for the Mg-5Al-3Sn-0.2Sc alloy specimens prepared using the copper mold spray casting method at room temperature and at a high temperature of 350°C, respectively. It was observed from Figure 4 that the tensile strength, yield strength, and elongation of the alloy specimens were 462MPa, 378MPa, and 21.8% at room temperature, respectively; these measurements were 439MPa, 361MPa, and 29.6% at the higher temperature of 350°C. Compared to room temperature, the tensile strength of the alloy specimens decreased by 23MPa or 5% from 462MPa to 439MPa; the yield strength decreased by 17MPa or 9.8% from 378MPa to 361MPa; however, the elongation increased by 35.8% in percentage from 21.8% to 29.6%. Thus, it can be concluded that the Mg-5Al-3Sn-0.2Sc alloy specimens prepared using the copper mold spray casting method in this research exhibited better mechanical properties, not only at room temperature conditions but also at high temperature conditions. The better properties for the prepared Mg-5Al-3Sn-0.2Sc alloy are largely attributed to the fact that the alloy preparation using the copper mold spray casting method was a non-crystalline material. In this non-crystalline material, the atom arrangement lost its periodicity and symmetry, and the long-range order of the crystal was destroyed. Thus, the atom arrangement maintained a short-range order only through inter-correlation between atoms; the alloy represented a disorder structure featured by a long-range disorder, but a short-range order. This disorder structure explained the high strength, high elongation, and high temperature resistance of the alloy, which exhibited better mechanical properties both at room temperature and at high temperature conditions.

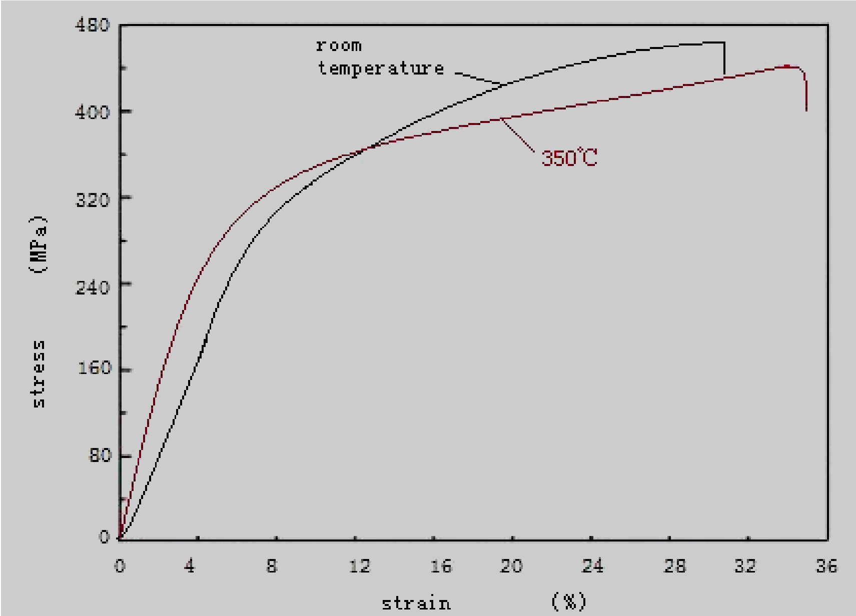

Figure4. Tensile curve of specimens

Figures 5 and 6 represented the tensile fracture morphology of the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method at room temperature and at a higher temperature of 350°C, respectively. It can be observed from Figures 5 and 6 that regardless of whether the temperature was the ambient room temperature or 350°C, there were a large number of equiaxed dimples and few tearing prisms, which represented evident ductile fracture characteristics. This observation was consistent with the results of tensile testing.

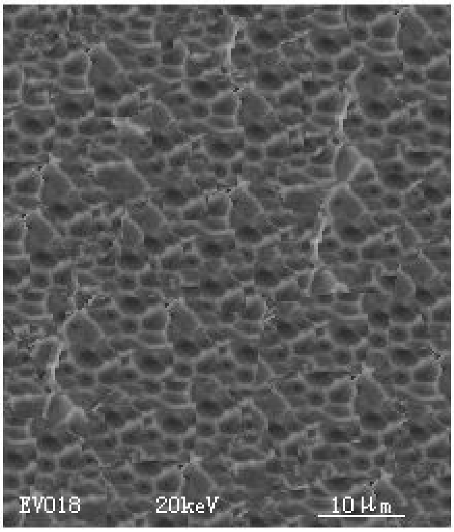

Figure5. Room temperature tensile fracture of specimens SEM picture

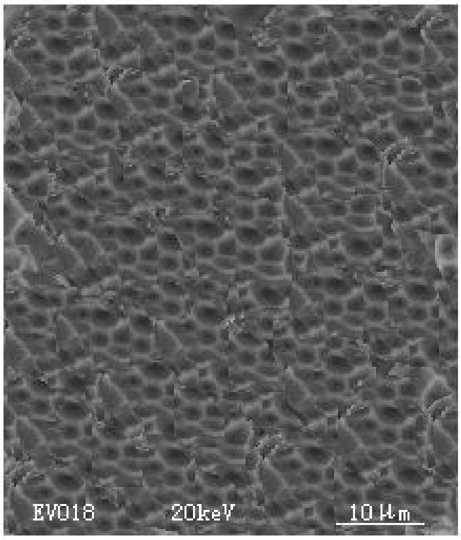

Figure6. 350°C temperature tensile fracture of specimens SEM picture

*D. Corrosion resistant property*

Figure 7 represents the Tafel curves for the Mg-5Al-3Sn-0.2Sc alloy, prepared using the copper mold spray casting method, and a commercial AZ 31 magnesium alloy in a 5wt.% NaCl solution at room temperature and scanned at a velocity of 0.001 mV/s. It can be observed from Figure 7 that when compared with the commercial AZ31 magnesium alloy, the corrosive potential of the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method shifted positively by 509 mV from -0.972V to -0.463V. It is well known that more positive potential represents a stronger corrosion resistance ability, while more negative potential represents poorer corrosion resistant properties. Therefore, it can be concluded that the corrosion resistance property of the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method increased significantly compared to the commercial AZ31 magnesium alloy. The improvement in corrosion resistance for the Mg-5Al-3Sn-0.2Sc alloy was largely contributed to the fact that the copper mold spray casting preparation method produced a non-crystalline alloy. This type of non-crystalline alloy had no crystal boundary, precipitate, or dislocation that could readily result in corrosion. It also had no composition segregation, which often exists in crystal alloys. Therefore, the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method exhibited a more even distribution in structure and ingredients and better corrosion resistant properties compared to the commercial AZ31 magnesium alloy.

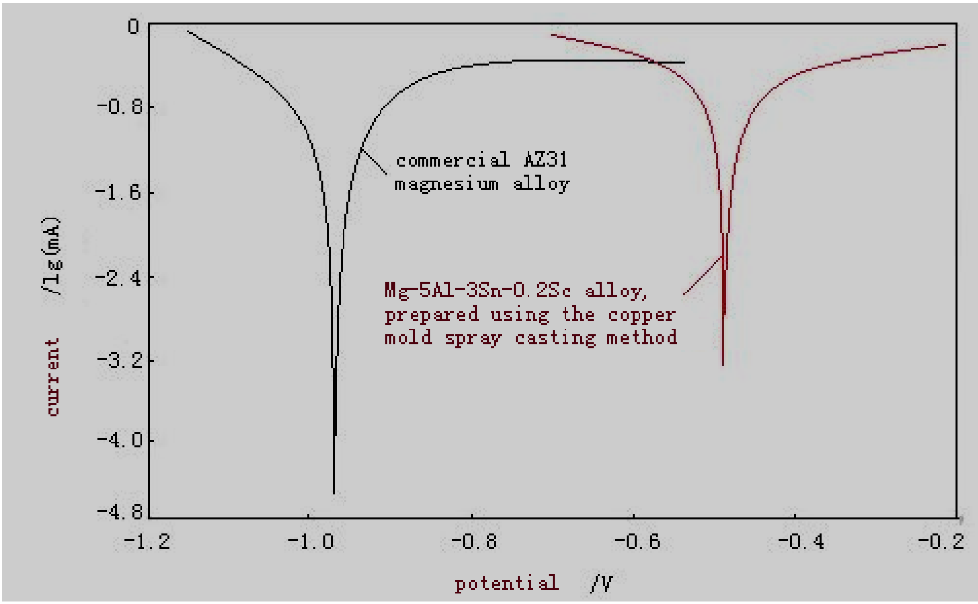

Fig. 7 Polarization curve of specimens

Figures 8 and 9 represent the surface corrosion morphology picture for the commercial AZ31 magnesium alloy and the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method, respectively. It can be observed from Figure 8 that on the commercial AZ31 magnesium alloy's corrosion surface, there were many group-types of etch-pits of various sizes, which indicates severe corrosion. Meanwhile, Figure 9 shows there were only few corrosion spots, and no evident group-types of etch-pits on the surface of the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method. This observation indicates that the corrosion on the Mg-5Al-3Sn-0.2Sc alloy evidently decreased, while the corrosion resistance significantly increased, findings that are consistent with the results of Tafel curves.

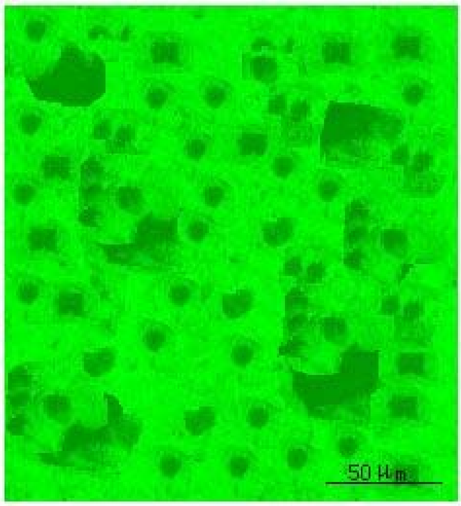

Fig. 8 Surface morphology after the AZ31 magnesium alloy corrosion

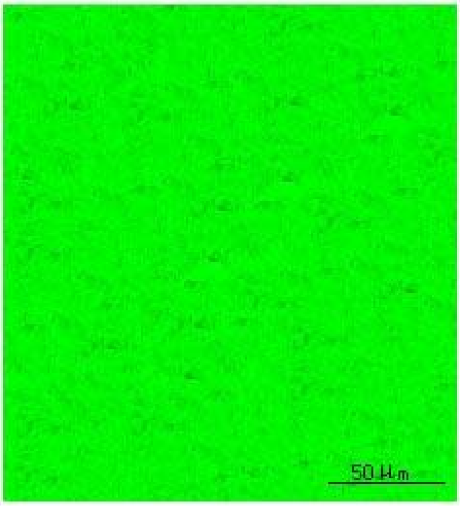


Fig. 9 Surface morphology after the Mg-5Al-3Sn-0.2Sc alloy corrosion

## IV. CONCLUSION

In this paper, the copper mold spray casting method was used to prepare the Mg-5Al-3Sn-0.2Sc alloy specimens. The tests and analyses conducted in this study included: XRD, SEM scanning, a mechanical property test, and a corrosion resistance property test. The following concluded the findings of this work:

1) The Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method was a non-crystal alloy without evident metallic impurities or crystal boundaries. There was a wide diffuse peak only under the condition of $2\theta=30^{o}\sim50^{o}$. The diffraction peak characterizing the crystal phase of the Mg-5Al-3Sn-0.2Sc alloy has not been observed within the range of 0 to 90 degrees; the g-5Al-3Sn-0.2Sc alloy represented a completely non-crystal microstructure.

2) The tensile strength, yield strength and elongation for the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method at room temperature conditions were 462MPa, 378MPa, and 21.8%, respectively; at a higher temperature of 350°C, the tensile strength and yield strength for the alloy decreased only 5% and 9.8%, respectively, but the elongation increased by 35.8%. The tensile fracture of the alloy exhibited ductile fracture characteristics.

3) Compared with the commercial AZ31 magnesium alloy, the corrosion potential for the Mg-5Al-3Sn-0.2Sc alloy prepared using the copper mold spray casting method shifted 509 mV positively from -0.972 V to -0.463 V, which indicates the corrosion resistance of the alloy significantly improved.

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