

Communication

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Communication

Effect of Al or Cu Content on Microstructure and Mechanical Properties of Zn alloys Fabricated Using Continuous Casting and Extrusion

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Abstract: The effect of Al or Cu content on the microstructure and mechanical properties of continuous casting and extrusion Zn alloys has been studied by room temperature tensile test, X-ray diffraction, and scanning electron microscope. With the increase of Al content, the microstructure of continuous casting and extrusion Zn alloys slightly coarsens and the lamellar eutectic structure increases. The changes in the above structural factors result in a slight decrease in strength and a significant increase in elongation of Zn-Al alloys. The strength of Zn alloys increases as the Cu content increases, due to the increased content and size of the second phase in the Zn alloys. This means that the mechanical properties of Zn alloys can be adjusted by continuous casting and extrusion process, and the improvement of equipment capacity can improve the structure and morphology of the alloys.

Keywords: Zn alloy; continuous casting and extrusion; elongation; mechanical property; eutectic structure

1. Introduction

Zinc and its alloys have a low melting point, fine fluidity, easy brazing, plastic processing, and other excellent properties, so they are widely used in thermal spraying, capacitor spraying gold, hardware, electronics, industrial equipment, and automotive industries [1-3]. The current method of manufacturing rods or wires for the preparation of zinc and its alloys is mainly casting followed by extrusion. The low elongation of cast zinc alloy rods or wires makes them more difficult to machine, which greatly limits their application [4-7]. However, the conventional hot extrusion process for the production of zinc alloy rods or wires is long, mainly because most zinc alloys have a hexagonal crystal structure that makes plastic deformation at room temperature quite difficult. The process of continuous or semi-continuous casting of zinc and its alloy ingots, followed by heating of the extrusion barrel and die, has so far been the common process used at home and abroad for zinc alloy rods or wires [8-10]. The strength and plasticity of zinc alloy can be greatly improved after deformation, but the process is long and the production cost is high. Therefore, it has become one of the hot spots for research to reduce the production cost and efficiency of zinc alloys while ensuring the performance of the products.

The continuous casting and extrusion process has been successfully applied to the industrial production of Al alloy and Mg alloy bars and wires. This has successfully demonstrated the feasibility of continuous casting and extrusion in the production of alloys and has achieved great economic benefits [11-13]. Recently, it has been found that continuous casting and extrusion process has been successfully applied to the preparation of zinc alloys. However, the current study focuses on the microstructure and room temperature mechanical properties of the Zn-15Al alloys [14, 15]. The Al and Cu are common alloying elements in zinc alloys [16-19]. Therefore, the effect of different Al or Cu content on the microstructure and room temperature mechanical properties of Zn alloy by

continuous casting and extrusion was discussed. This can provide a new idea for processing Zn alloy with low cost and high efficiency.

2. Materials and Methods

The Zn-2Al and Zn-4Al alloys were conducted using pure Zn and Al with a purity of over 99.9 wt.% (mass fraction). Similarly, The Zn-2Cu and Zn-4Cu alloys were made using pure Zn and Cu with purities exceeding 99.9 wt.%. As shown in Figure 1, the pure zinc was first heated to 600 °C for melting and then pure aluminum or pure copper was added. After all the metal had been melted, a graphite bell was pressed into the alloy with 2 wt.% C_2Cl_6 for degassing. The temperature was lowered to 550 °C and then left to stand for 20 minutes to obtain the Zn alloy melt. The alloy melt was poured into the CASTEX-300 continuous casting and extrusion machine. The rotational speed of the casting and extrusion wheel was 8 r/min, and the cooling water flow rate was 15 L/min.

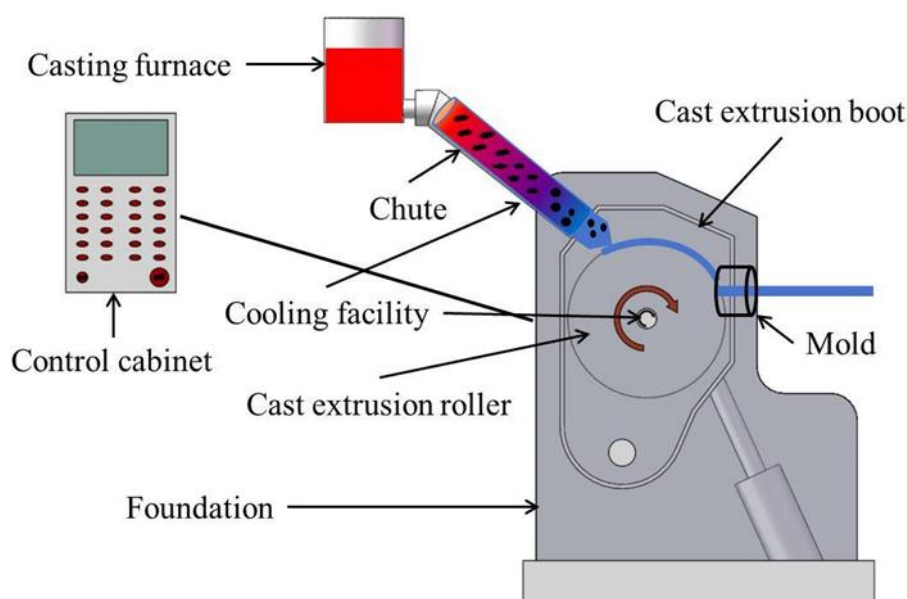


Figure 1. Schematic of continuous casting and extrusion Zn alloys.

After sanding with 200 # to 2000 # sandpaper, the Zn alloy was mechanically polished to a mirror shape. The corrosion solution was a 9% HNO_3 +91% H_2O solution. The metallographic observation of the alloy was examined by the GX71 inverted optical microscope. The microstructure and fracture morphology of the alloy were observed under a JSM-6510 scanning electron microscope. The X-ray diffraction (XRD) was conducted on the PW3040/60 X-ray analyzer with Cu target K_α Line and a scanning speed of 3 °/min. The room temperature tensile specimen was machined from Zn-Al alloy with a gauge length of 25 mm and a diameter of 5 mm. The tensile tests at room temperature were enforced at a strain rate of $10^{-3} s^{-1}$ on a microcomputer- controlled AG-X electronic universal experimental machine. Five specimens were carried out to check the repeatability of the results.

3. Results and Discussion

3.1. X-Ray Diffraction

According to the Zn-Al phase diagram, during the solidification process of Zn-Al alloy with a mass fraction of 1-5%, rich Zn phases first precipitate. As the temperature decreases to 381 °C (eutectic point), a eutectic structure composed of rich Al and rich Zn phases begins to precipitate. The temperature continues to decrease, and the eutectic structure undergoes a dissolution process. Secondary rich Al and rich Zn phases precipitate in the rich Zn and Al phases [20]. From the Zn-Cu phase diagram, it can be seen that the maximum solubility of copper in Zn is 2.75 wt.% at 425 °C. The first intermetallic phase formed by Cu addition in Zn is $CuZn_4$ phase [21]. Figure 2 shows the XRD

patterns of continuous casting and extrusion Zn alloys. It can be seen that the Zn-Al alloys with different Al contents are mainly composed of rich Zn phase and rich Al phase. With the Al content increases, there is no significant change in the phase composition of the alloy, but the diffraction peak intensity of the Al-rich phase slightly increases, which agrees with the observation of the Zn-Al alloys [22]. The Zn-Cu alloys have similar phenomena as Zn-Al alloys.

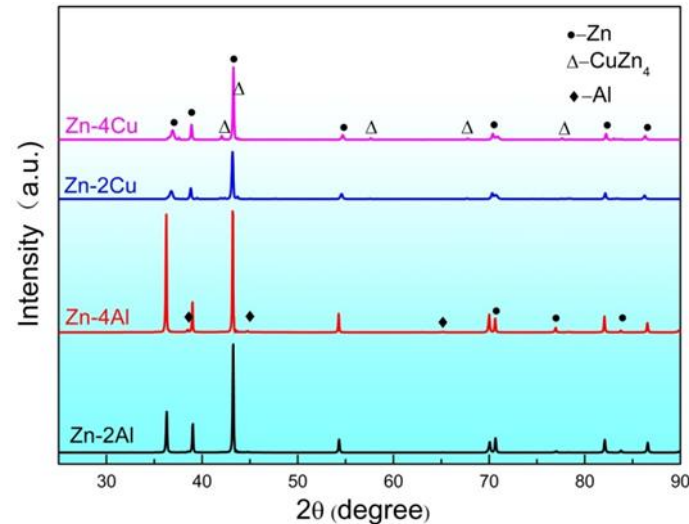


Figure 2. XRD patterns of continuous casting and extrusion Zn alloys.

3.2. Microstructure

The metallographic images of Zn alloys with different Al or Cu contents after continuous casting and extrusion are shown in Figure 3. It is clear from the figure that the Zn-2Al alloy uses Zn-based solid solutions as the matrix, with a certain amount of Al-based solid solutions distributed. Among them, white is the Al-rich phase, and black is the Zn-rich phase. At the same time, it has deformation characteristics and presents fibrous characteristics along the extrusion direction (Figure 3 (a)). The Zn-4Al alloy is composed of Zn-based solid solution and eutectic structure. After continuous casting and extrusion, it undergoes complete recrystallization, and its grain size is relatively uniform (Figure 3 (b)). As the Al or Cu content increases, the deformation degree of Zn alloy weakens and the fibrous structure decreases (Figure 3).

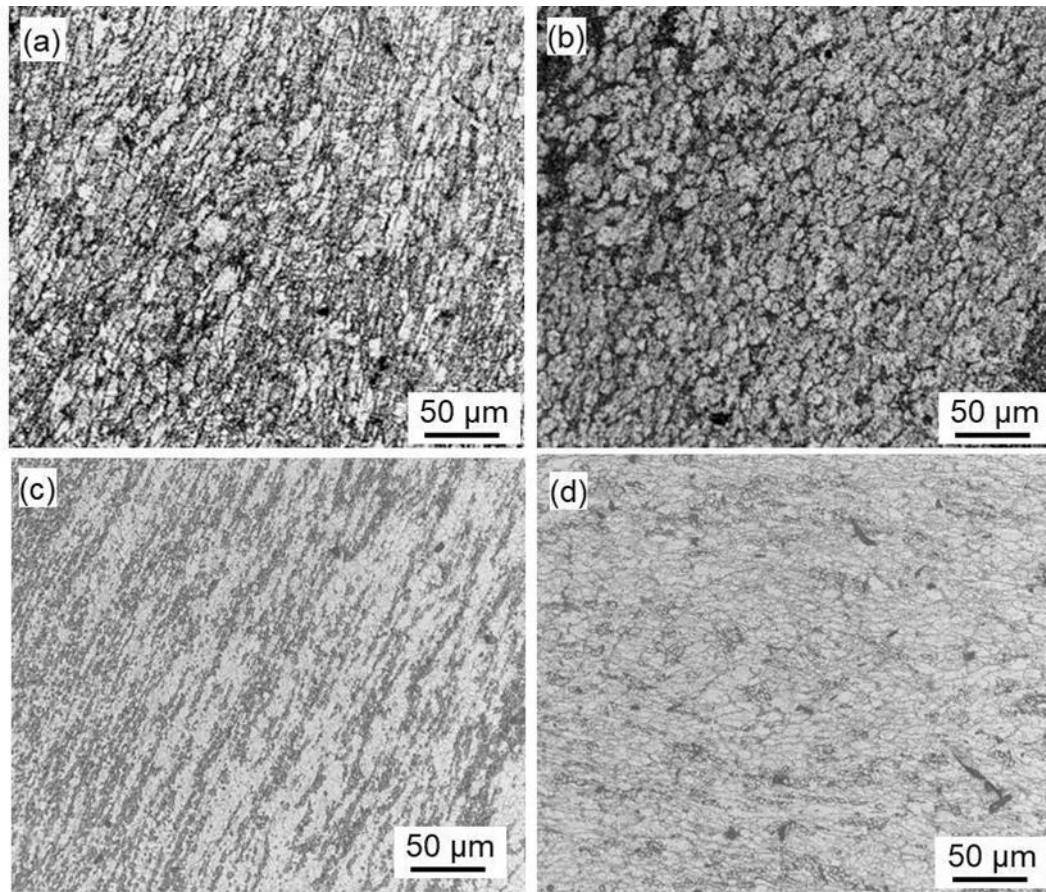


Figure 3. Metallographic microstructure of continuous casting and extrusion Zn alloys with different Al or Cu contents: (a) Zn-2Al; (b) Zn-4Al; (c) Zn-2Cu; (d) Zn-4Cu.

The SEM microstructure of continuous casting and extrusion Zn alloys with different Al or Cu contents is shown in Figure 4. The bright ones are rich Zn phase, while the dark ones are rich Al phase. The microstructure of Zn-2Al alloy by continuous casting and extrusion is composed of Zn-based solid solutions as the matrix, with a certain amount of Al-based solid solutions distributed. At the same time, there is a certain degree of deformation along the extrusion direction (Figure 4 (a)). From Figure 4 (b), it can be seen that the continuous casting and extrusion Zn-4Al alloy is composed of Zn-based solid solution and lamellar eutectic structure, which also produces a certain degree of deformation along the extrusion direction. This microstructure is similar to other preparation methods of Zn-Al alloy [23-25]. With the increasing of Al content, the lamellar eutectic structure in the Zn-Al alloys increases and the microstructure appears slightly coarse, but the degree of structural deformation weakens. The SEM microstructure of the Zn-Cu alloy is presented in Figure 4 (c) and 4 (d). The micrometer-sized second phase (bright phases) gradually increases with increasing Cu content in the Zn-Cu alloys [26].

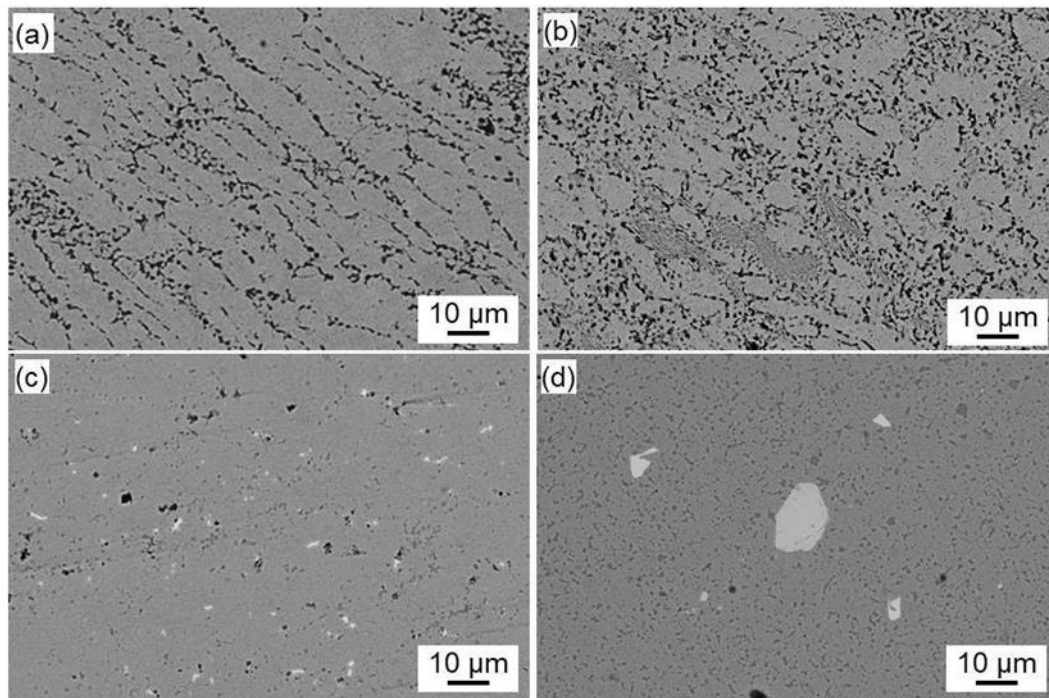


Figure 4. Microstructure of continuous casting and extrusion Zn alloys with different Al or Cu contents: (a) Zn-2Al; (b) Zn-4Al; (c) Zn-2Cu; (d) Zn-4Cu.

3.3. Mechanical Properties

Figure 5 shows the tensile engineering stress-strain curves at room temperature of continuous casting and extrusion Zn alloys with different Al or Cu contents. The strength of the Zn alloy increases significantly with the addition of Cu compared to the addition of Al. With the increase of Cu content, the strength of the alloy gradually increases, but the elongation does not change much, basically around 2%. The tensile strength of continuous casting and extrusion Zn-Al alloy slightly decreases with the increase of Al content, from 199 MPa to 197 MPa. The yield strength decreases with the increase of Al content, from 164 MPa to 148 MPa. The room elongation increases from 1.2% to 20% with the increase of Al content. Generally speaking, with the increase of Al or Cu content, the strength and plasticity of Zn alloy increase simultaneously, because the increase of Al or Cu content refines the microstructure of Zn alloy [26-28]. In this experiment, continuous casting and extrusion is a process that integrates casting and extrusion, so Zn alloy has both casting and extrusion microstructures [29]. This results in an increase in Al content in Zn-Al alloy from 2 wt.% to 4 wt.%, with a slight decrease in strength and a significant increase in plasticity. However, the strength and plasticity of the alloy are slightly enhanced as the Cu content is increased from 2 wt.% to 4 wt.%.

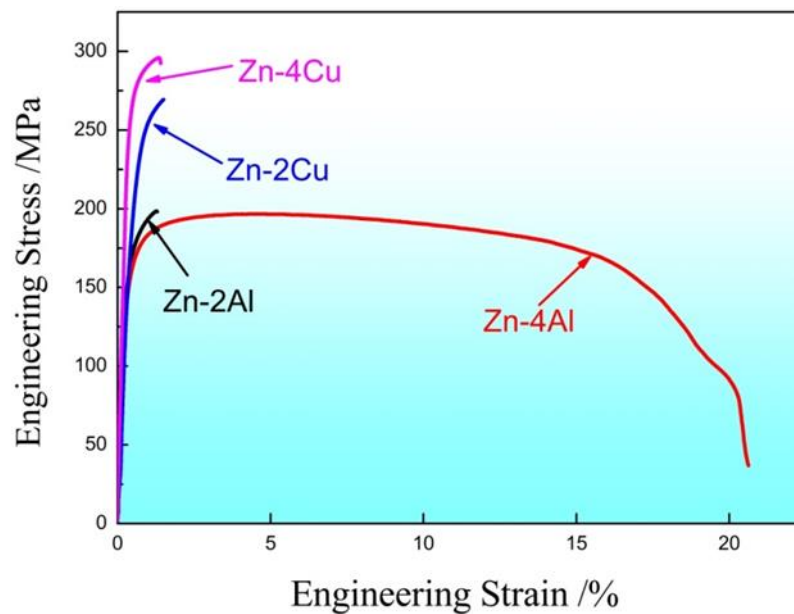


Figure 5. The room temperature tensile engineering stress-strain curves of continuous casting and extrusion Zn alloys with different Al or Cu contents.

In the present experiments the mechanical properties of continuous casting and extrusion Zn alloys were altered due to grain refinement and the combined effect of the second phase content and morphology. With the increase of Al content, the size of Zn-rich phase in the matrix of the Zn-Al alloys increases slightly, and the increase of lamellar eutectic. The combined effect of the above microstructural factors leads to a slight decrease in the strength of the Zn-Al alloys with the increase of Al content and a substantial increase in the elongation. For the Zn-Cu alloys, the second phase plays a decisive role in increasing its strength.

4. Conclusions

Continuous casting and extrusion process is a forming method that combines casting and extrusion. It is a short process and low-cost processing method, which can greatly improve the performance of alloys. Therefore, this article conducted the effect of Al or Cu contents on the microstructure and room temperature tensile properties of continuous casting and extrusion Zn alloys. The following conclusions are obtained:

- (1) The Zn alloy with a lower Al or Cu contents can be prepared by continuous casting and extrusion.
- (2) With the increase of Al content, the strength of the Zn-Al alloy slightly decreases and the elongation of the Zn-Al alloy significantly increases, from 1.2% to 20%, which is due to the combined effect of microstructure refinement, deformation degree, eutectic microstructure morphology, and content.
- (3) The strength and elongation of the Zn-Cu alloy are slightly enhanced as the Cu content is attributed to the size and content of the second phase.

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