Effect of Cu Additions on the Microstructure and Mechanical Properties of Spray Deposited Zn-30Al Alloy

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Abstract. Zn-30Al-xCu (x=0, 1, 2, 4) alloys were prepared by the spray atomization and deposition technique. The microstructures of the spray-deposited alloys were investigated by means of scanning electron microscope, transmission electron microscope, X-ray diffraction. The results indicate that the 1 wt. % Cu addition to spray-deposited Zn-30Al alloy does not make significant change in microstructure. However, with the 2, 4 wt. % Cu additions to the alloy, some ε-CuZn4 compounds with particle or irregular shapes were observed on the grain boundaries in the microstructures. Tensile test results confirmed that the 1 wt. % Cu addition displays superior tensile strengths, whereas the 2, 4 wt. % Cu additions led to the decreasing of the improvement effect of the tensile strengths.

Introduction

Zn-Al alloys have been found to be a promising energy and cost effective substitute to a certain extent plain bearings. Zn-Al alloys exhibit high specific strength, excellent wear resistance, good casting properties and lower coat compared to other nonferrous metals [1]. The addition of Cu to the eutectoid Zn-Al alloys improves its mechanical properties, creep resistance and corrosion behavior [2,3]. In order to improve the mechanical properties of Zn-Al alloys, various metallurgical processes, such as continuous casting, thermal evaporation and spray deposition etc. are developed[4,5]. It has been recognized generally that the spray deposited process is an innovative technique of rapid solidification. In this process, droplets are first atomized from a molten metal stream, quickly cooled by an inert gas, then deposited on a substrate, and finally built up to form a low-porosity deposit with the required shape[6,7].

In this work, one binary Zn-Al and three ternary Zn-Al-Cu alloys were produced by the spray atomization and deposition technique. The objective of this study is to investigate the microstructural evolution and mechanical properties of spray-deposited Zn-30Al-xCu (x=0, 1, 2, 4) alloys, and the effect of Cu addition on the microstructure and mechanical properties of spray-deposited Zn-Al alloy was analyzed.

Experimental Procedures

In Table 1 are listed the chemical compositions of the Zn-Al-Cu alloys. The spray deposition experiments were conducted in an environmental chamber. During spray-deposition process, the molten metal was atomized by N2 at 700 °C, the distance of atomizing deposition was kept constant at 500 mm. The preform, after being cut into cylindrical billets was extruded at a temperature of 250 °C with a reduction ratio of 10:1 and a ram speed of 5 mm/s. After extrusion, the materials were cooled in air. The microstructures of spray-deposited materials were characterized using scanning electron microscopy (SEM) attached with energy dispersive X-ray analyses (EDX), transmission electron microscopy (TEM) and X-ray diffraction. A S360 type scanning electron microscopy working at 15 kV was used to observe the microstructures. The scanning electron microscopy samples were prepared using standard metallographic techniques and were etched using Keller's reagent. The transmission electron microscopy studies were conducted on a H-800 type transmission electron microscope at an acceleration voltage of 200 kV. The X-ray diffraction experiments were performed on a Japan Rigaku diffractormeter using Cu-Kα radiation. The tensile tests were conducted with an Instron tensile testing machine at an initial strain rate of 0.5 s^{-1}.

Table 1 Chemical compositions of the alloys (mass%)

Alloy	Al	Cu	Zn
A0	30	0	Bal.
A1	30	1	Bal.
A2	30	2	Bal.
A4	30	4	Bal.

Results and Discussion

Microstructure

Fig.1 (a) shows the typical SEM microstructure of the spray-deposited A0 alloy, which is composed of the α-Al matrix and the η-Zn phase mostly with a lamellar shapes. The coarse and fine lamellar α-Al + η-Zn eutectoid was primary phase in the microstructure. With the addition of 1 wt. % Cu to the spray-deposited A0 alloy, no obvious change was observed in the micrograph, in Fig.1 (b). Fig.1 (c) and (d) show the SEM micrographs of spray-deposited A2 and A4 alloys, it can be seen that 2, 4 wt. % Cu additions lead to the variation in the microstructures. Some compounds with particle or irregular shapes were observed on the grain boundaries, as labeled by arrows. Quantitative energy-dispersive spectroscopy analysis results indicate that the compounds mainly contain elements of Zn and Cu.

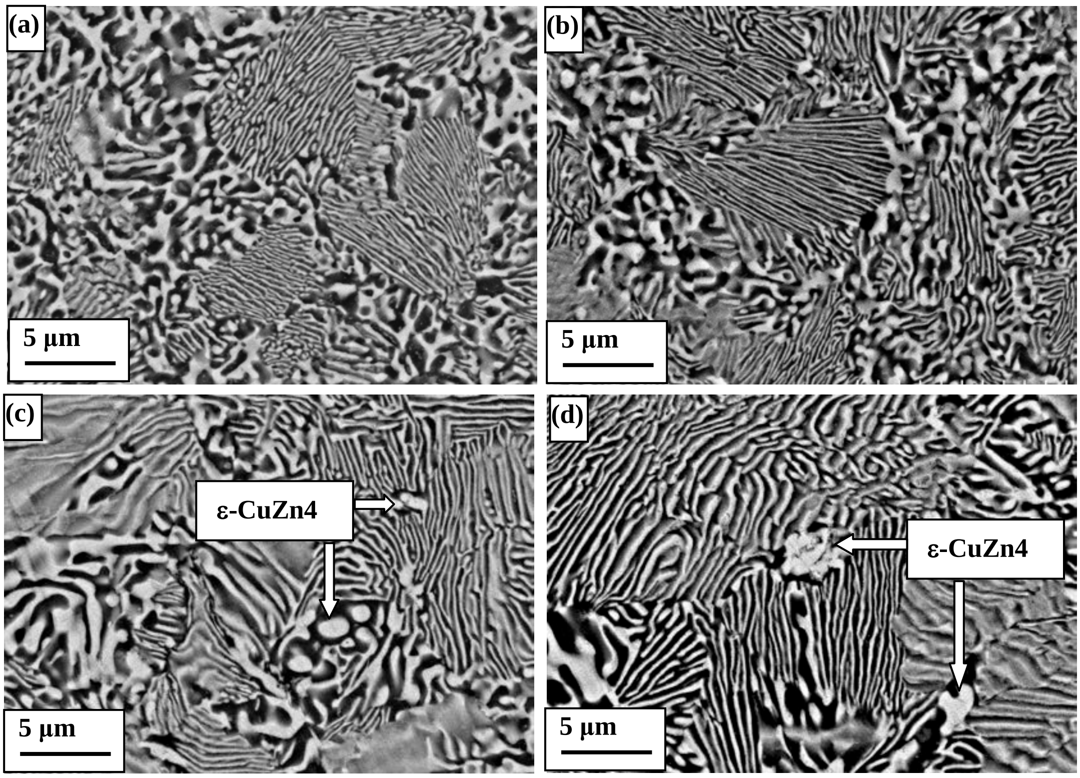

Fig.1 SEM micrographs of the spray-deposited alloys, (a) A_0; (b) A_1; (c) A_2; (d) A_4

Fig. 2 shows the X-ray diffraction (XRD) patterns of the spray-deposited alloys. XRD was performed to identify the phases in the microstructures, and analysis of the diffraction patterns shows that the compound phases mainly are ε-CuZn4 in spray-deposited A2 and A4 alloys. No definitive evidence for the presence of ε-CuZn4 was found in the XRD result of spray-deposited A1 alloy, this suggested that 1 wt. % Cu addition was dissolved entirely into α-Al or η-Zn phases under rapid solidification condition.

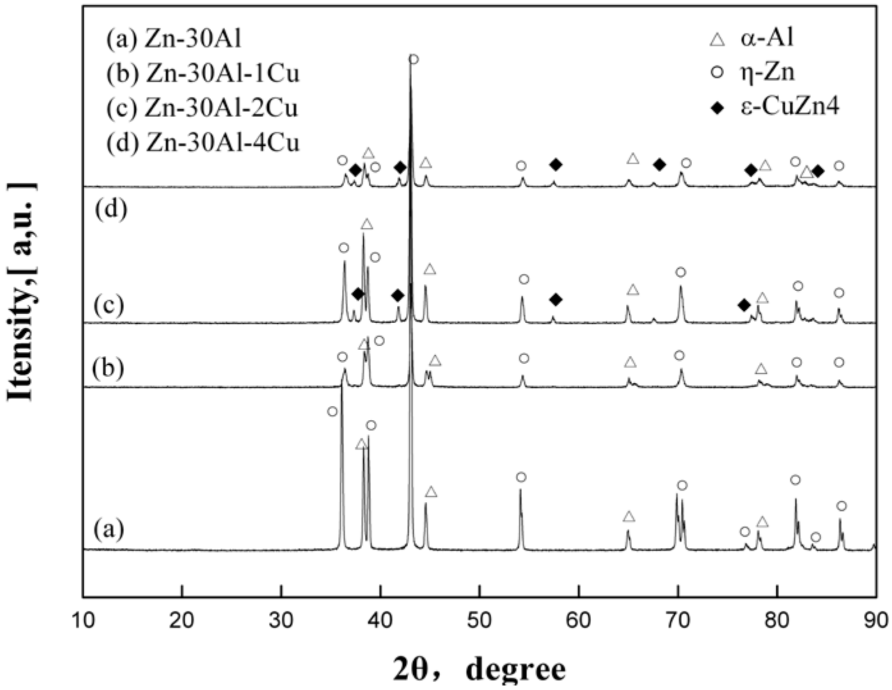

Fig.2 X-ray diffraction patterns of the spray-deposited alloys, (a) A_0; (b) A_1; (c) A_2; (d) A_4.

The lamellar structure eutectoid was primary phase in the microstructure of the spray-deposited alloys. Fig. 3(a) shows the typical TEM micrograph of the lamellar eutectoid, the selected area diffraction patterns of two phases of the eutectoid were indexed to be α-Al and η-Zn, as can be seen in Fig. 3(b) and (c).

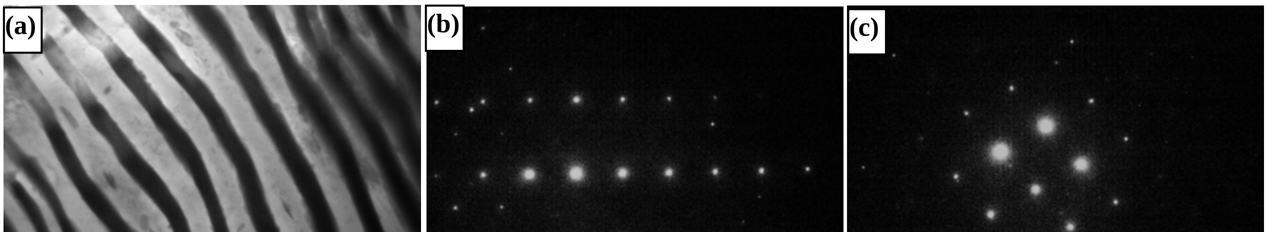

Fig.3 TEM micrographs showing the eutectoid phase (α-Al and η-Zn) in the microstructure. (a) bright-field image; (b) (c) selected area diffraction patterns.

Fig. 4 shows the TEM micrographs of the particle-like compound phases on the grain boundaries in the microstructure of spray deposited Zn-30Al-4Cu alloy. Indexing of the selected area diffraction patterns indicates that the phase is ε-CuZn4 compounds with hexagonal parameters of a=0.274 nm and c = 0.429 nm using electron diffraction, as can be seen in Fig. 4(b). The TEM result is in good agreement with the XRD ones, as shown in Fig. 2.

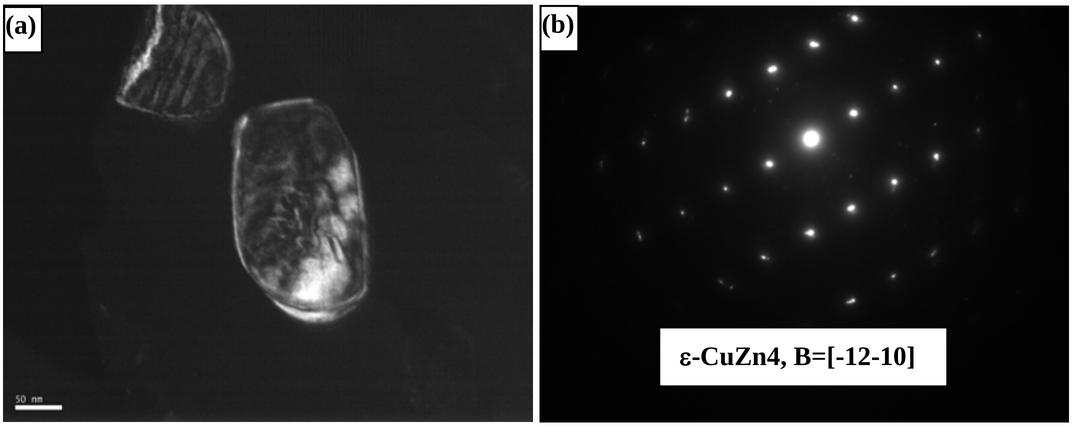

Fig.4 TEM micrographs of spray-deposited Zn-30Al-4Cu alloy, (a) dark-field image; (b) selected area diffraction pattern.

Mechanical Properties

Spray deposited Zn-Al-Cu alloys were subjected to tensile testing after hot extrusion. Table 2 summarized the tensile test results. It is worth noting that the tensile strengths of the A1, A2 and A4 alloys after extrusion are much higher than of the A0 alloy. Obviously, Cu addition leads to improvement of the tensile strengths. However, 1% Cu addition leads to a substantial improvement of the tensile strengths, whereas 2% and 4% Cu additions reduce the improvement effect of the tensile strengths due to the formation of ε-CuZn4 compounds on the grain boundaries in the microstructures. It is worth nothing that the solution strengthening plays important role for the additional strengthening effects of the alloys. With 1% Cu addition to the spray deposited Zn-30Al alloy, and Cu was dissolved entirely into α-Al or -Zn phases due to the use of spray deposition technique, which provide much higher solubilities of the solute atoms. With 2 and 4% Cu addition to the spray deposited Zn-30Al alloy, Cu atoms were dissolved partially into the α-Al or -Zn phases, and residual Cu addition was formed particle or irregular shaped ε-CuZn4 compounds on the grain boundaries. Thus, the solution strengthening effect of the alloys was decreased, and tensile strengths of the A2 and A4 alloys are inferior to A1 alloy.

Table 2 Tensile properties of the spray-deposited Zn-Al-Cu alloys

Alloy	Processing	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
A0		336	298	35.2
A1	Spray deposition +	386	343	18.2
A2	extrusion	369	329	24.1
A4		345	302	30.8

Summary

The addition of 1% Cu to spray deposited Zn-30Al alloy, no obvious change was observed in the microstructure. With additions of 2% and 4% Cu to spray deposited Zn-30Al alloy, ε-CuZn4 compounds with particle or irregular shapes were observed on the grain boundaries in the microstructures. The tensile test results indicate that the 1% Cu addition to the alloy improves its tensile strengths significantly. In contrast, 2% and 4% Cu additions reduce the improvement effect of the tensile strengths of the alloys.

Acknowledgement

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References

[1] Murat Aydin, Temel Savaskan: Mater. Inter. J. Fatigue. Vol. 26 (2004), p. 103

[2] Hector J. Dorantes-Rosales, Victor M. Lopez-Hirata, Jose L. Mendez-Velazquez, Maribel L. Saucedo-Munoz, David Hernandez-Silva: J. Alloy and compounds Vol.313(2000), p.154.

[3] Reza Mojaver, Hamid Reza Shahverdi: Wear Vol. 271(2011), p. 2899.

[4] Y. H. Zhu, W. B. Lee: Mater. Sci. Eng. A. Vol. 293(2000), p. 95.

[5] Yuwei Xun, Farghalli A. Mohamed: Mater. Sci. Eng. A. Vol. 432(2006), p. 261.

[6] P. Bai, X. Hou, X. Zhang, C. Zhao, Y. Xing: Mater. Sci. Eng. A Vol.508 (2009), p. 23.

[7] M.M. Sharma, M.F. Amateau, T.J. Eden, Acta Mater. Vol. 53 (2005), p. 2919.