Effect of Cr Content and Heat Treatment on Microstructures and Mechanical Properties of Cu-Cr-Zr Alloys

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Keywords: Cu-Cr-Zr alloys; Cr content; heat treatment; microstructures; strength

Abstract. The influence of Cr content, hot working, and heat treatment on the performance of Cu-Cr-Zr alloys was investigated. The as-cast microstructure of Cu-Cr-Zr alloys was uneven and micro-segregation. Fluctuations of the solid-phase solute are intensified and the degree of segregation is increased with the Cr content increasing. Cu-Cr-Zr alloys demonstrate combination properties of high strength and high conductivity after solution treatment, aging treatment. Good balance of strength and conductivity, which reach to 431.7 and 79.3% IACS respectively, was obtained in the Cu–0.86Cr–0.1Zr alloy.

Introduction

Copper and its alloys are widely applied in many functional and structural applications because of its exceedingly good thermal conductivity, fine resistance to corrosion, easy work-ability, good strength, good resistance to fatigue as well as excellent electrical conductivity[1-4]. Recently, a hopeful approach for strengthening of Cu-Cr-Zr alloys while keeping their electric conductivity at a sufficiently high level of 80% IACS was developed[5-7]. There are a lot of reports on the Cu-Cr-Zr alloy's phase composition. The phase composition, morphology and structure in alloys impose direct impacts on the comprehensive property of composites after severe deformation. The high strength of Cu-Cr system composites is mainly depend on the Cr fibers, and the Cr fibers are developed by dendritic Cr of as-cast structure through severe deformation. According to Cu-Cr binary phase diagram, Cr generally choose the addition in 0.5 to 1.0 wt %[8].

The research mainly explores the effect on as-cast condition, hot working condition and heat treatment condition and their properties of Cu-Cr-Zr alloys with different chrome content.

Experimental

Chemical compositions of three alloys used in this work are respectively Cu-0.69Cr-0.1Zr, Cu-0.86Cr-0.1Zr and Cu-1.0Cr-0.1Zr. Alloy was melted in a medium-frequency induction furnace under vacuum. The preparation of alloy is mainly high purity electrolytic copper(99.9%), adding Cr and Zr as the intermediate alloys. Alloys were melted at 1200 to 1300℃and keeping the temperature for half an hour. Then cast into round billets with the diameter of 135mm in the iron mold. Then forging billets after heat preservation for 50 to 60 minutes when billets were heating to 900 degrees. The forging size is the diameter of 125mm. The forging billets heated to 850 degrees are processed to the size of 43.5*14.7 mm by hot extrusion (water seal extrusion). Then take a solid solution at 980℃ for 40 minutes, water quenched, aging at 460℃ for 3 hours and then cooling in the air.

In the research, the hardness values of different specimens were measured on a Vickers micro-hardness tester（401MVD）under the condition of 200 N load for 10 s. The tensile test was carried through Instron-8801. The tensile specimens had a gauge length of 15mm and width of 5mm. Conductivity was tested using 7501 electrical conductivity tester. Microstructural characterizations were carried out by OLYMPUS PMG3 metallographic microscope and JSM-5800 scanning electron microscopy equipped with energy dispersive X-ray spectroscopy.

Results and discussion

Effect of Cr content on cast microstructure Fig.1 presents the micrographs cast Cu-Cr-Zr alloys with different Cr content. The results show that the as-cast microstructure of alloys were uneven, some micro-segregation were found. When the Cr content increases, fluctuations of the solid-phase solute are intensified, the degree of segregation is increased. The increasing trend is decreased with increasing Cr content from 0.86% to 1.0% than from 0.69% to 0.86%. When the Cr content is 1.0%wet, the dendrite segregation is the most serious. From Fig.1(c and d), it can be clearly seen that most of Cr element are concentrated along the boundary in network with a few solutioned into Cu matrix. The results indicate that the solid solution extent of Cr solute atoms is low in Cu matrix.

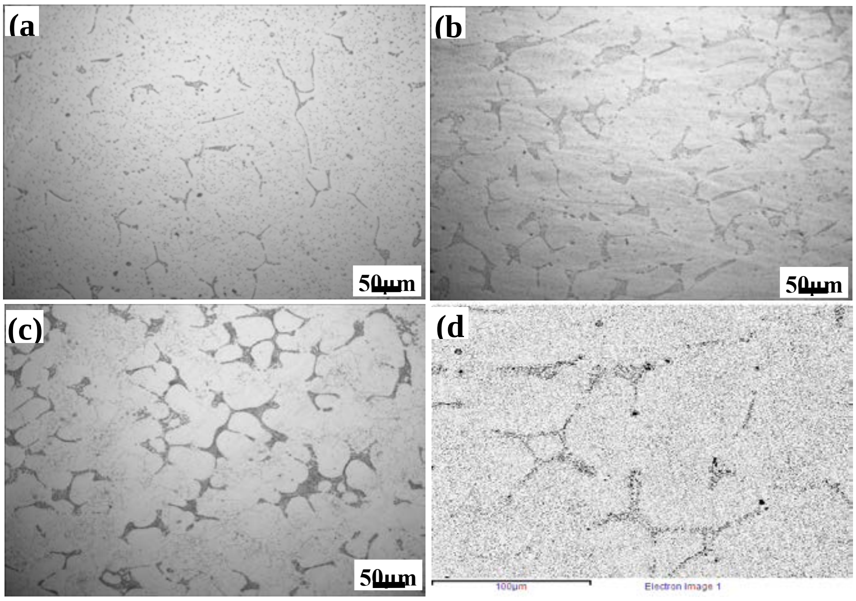

Fig.1 Optical micrographs of cast Cu-0.69Cr-0.1Zr (a) Cu-0.86Cr-0.1Zr (b) Cu-1.0Cr-0.1Zr (c) and SEM micrographs of Cu-1.0Cr-0.1Zr (d).

Fig.2 displays SEM micrographs and the surface scanning of Cr, Zr elements of cast Cu-0.86Cr-0.1Zr alloy. A necklace-like distribution of particles can be observed in the cast Cu–Cr-Zr alloy. It can be seen from Fig. 2(b and c) that spherical solute-rich particles are dispersed in the alloy. The concentrations of Zr are much lower than that of Cr. The Cr concentration at grain boundaries is much higher than that at grain interiors. But Zr distribute uniformly along grain boundaries and grain interiors. The result illustrates that serious segregation of solute elements Cr exists in the Cu–Cr-Zr alloy.

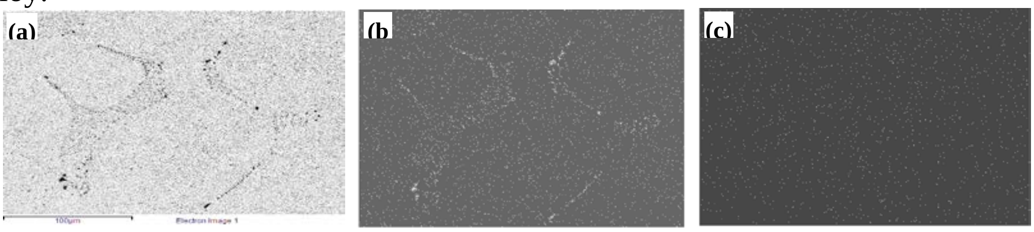

Fig.2 SEM (a) and distribution of Cr elements (b) Zr elements(c) of cast Cu-0.86Cr-0.1Zr

Effect of hot process and heat treatment on microstructure Fig. 3 presents the micrographs of Cu-Cr-Zr alloys after hot extrusion at 850 ℃. The results show that the dendrite segregation of Cr in as-cast is broken down and the grain of Cu-Cr-Zr alloys is uniform and equiaxed after hot extrusion. The size of grain is finer and Cr distribution is more evenly than that in cast Cu-Cr-Zr alloys, which is thought to be caused by the big hot deformation. The size of grain in hot extrusion Cu-Cr-Zr alloys increase with the increase of Cr content. The cause of this phenomenon is that the crystallization temperature decreases and dynamic recrystallization rate increase with the increase of Cr content.

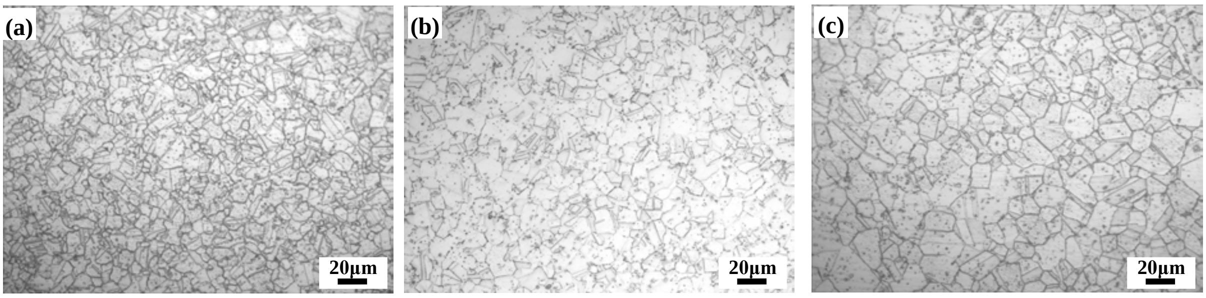

Fig.3 Optical micrographs of hot extrusion Cu-0.69Cr-0.1Zr (a) Cu-0.86Cr-0.1Zr (b) Cu-1.0Cr-0.1Zr (c).

Fig.4 shows the micrographs of Cu-Cr-Zr alloys after solid solution at 980℃ and aged Cu–Cr–Zr alloy at 460℃. The fine near equiaxed grains are changed into coarse grains during solid solution at 980℃. The average grain size is about 100μm and part of Cr was dissolved into the Cu matrix after solid solution treatment. Since the solubility limit of Cr in Cu at the temperature is about 0.65% at 1076.2℃, the ability to get super saturation solid solution by solution treatment is limited[9]. The homogeneous distribution of Cr in matrix is improved after solution treatment. The higher the Cr content, the more the undissolved Cr phase for approaching solid solubility limit. The super saturation solid solution Cr precipitates from alloy matrix during the aging treatment.

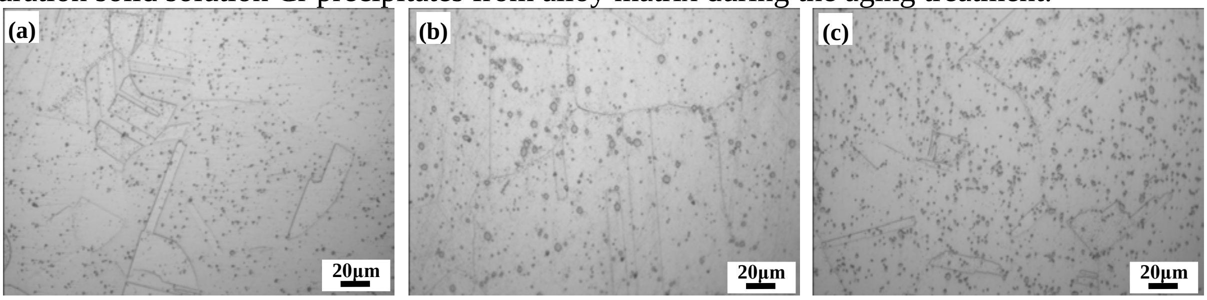

Fig. 4 Micrograph of the solutionized and aged Cu–Cr–Zr alloy Cu-0.69Cr-0.1Zr (a) Cu-0.86Cr-0.1Zr (b) Cu-1.0Cr-0.1Zr (c).

Effect of Cr content on Properties of Heat Treatment Alloys Table1 lists mechanical properties, hardness and conductivity of the original and heat treatment as-cast Cu-Cr-Zr. As shown in Table 2, the hardness and tensile strength of the as-cast and solution alloy increased with the increase of Cr content, while tensile strength of the Cu-Cr-Zr alloys with 0.69% chrome content is the highest after aging treatment. The ductility of the original as-cast alloy decreased with the increase of Cr content. Before aging treatment, the conductivity of the as-cast alloy decreased with the increase of Cr content. But it increased with the increase of Cr content after aging treatment.

Table 1. Properties of the as-cast samples with different Cr content

Treating state	Sample	Hardness/HV	Tensile strength/MPa	Ductility/%	Conductivity/%IACS
The original as-cast	Cu-0.69Cr-0.1Zr	68	183.5	34.4	56.9
	Cu-0.86Cr-0.1Zr	72	191.8	29.9	51.7
	Cu-1.0Cr-0.1Zr	77	198.0	25.0	44.8
Solution	Cu-0.69Cr-0.1Zr	57.5	186.3	44.3	29.3
	Cu-0.86Cr-0.1Zr	59.8	193.1	43.8	33.6
	Cu-1.0Cr-0.1Zr	63.3	198.8	22.2	31.9
Solution +Aging	Cu-0.69Cr-0.1Zr	139.2	301.8	29.1	74.1
	Cu-0.86Cr-0.1Zr	142.9	330.8	22.9	75.9
	Cu-1.0Cr-0.1Zr	131.4	297.6	11.1	81

The properties of the hot extrusion samples with different Cr content are shown in Table 2. It is consistent with as cast alloys that effect of Cr content on the hardness and tensile strength of the hot extrusion alloy. The ductility of the hot extrusion alloy decreased with the increase of Cr content. Before solution treatment, the conductivity of the hot extrusion alloy decreased with the increase of Cr content. But it essentially unchanged after solution treatment.

Table 2. Properties of the hot extrusion samples with different Cr content

Treating state	Sample	Hardness/HV	Tensile strength/MPa	Ductility/%	Conductivity/%IACS
The original hot extrusion	Cu-0.69Cr-0.1Zr	68	183.5	34.4	55.2
	Cu-0.86Cr-0.1Zr	72	191.8	29.9	39.7
	Cu-1.0Cr-0.1Zr	77	198.0	25.0	32.2
Solution	Cu-0.69Cr-0.1Zr	51.6	198.7	45.3	31.9
	Cu-0.86Cr-0.1Zr	53.3	212.9	45.3	30.2
	Cu-1.0Cr-0.1Zr	54.9	225.5	44.6	31.9
Solution +Aging	Cu-0.69Cr-0.1Zr	129.1	396.8	32.8	78.4
	Cu-0.86Cr-0.1Zr	135.5	431.7	28.1	79.3
	Cu-1.0Cr-0.1Zr	131.5	416.3	25	80.2

A comparison of the Properties of Cu-Cr-Zr with different Cr content is given in table1 and table 2. The results show that the conductivity of cast and hot extrusion is usually higher than solution treated Cu-Cr-Zr alloys. Conductivity value of Cu-Cr-Zr alloys usually rises to 74%-81%IACS after aging treatment. Distortion of lattice caused by solid solution is considered as the main reason for the increased resistance of Cu alloys. Precipitation of Cr during the aging treatment restored the distorted lattices, and the conductivity usually increases with the decomposition of supersaturated alloy. The as-cast and hot extrusion Cu-Cr-Zr alloys exhibit large strength during aging process. The peak-strength of hot extrusion Cu-Cr-Zr increase by about 100MPa compared with the as-cast state, which is up to 431.7MPa and 79.3% IACS respectively. Hot extrusion distortion promotes the Cr phases homogeneous precipitated and distributing on the matrix, so strengthen the alloys.

Conclusions

(1)The as-cast microstructure of Cu-Cr-Zr alloys was uneven and micro-segregation. Fluctuations of the solid-phase solute are intensified and the degree of segregation is increased with the Cr content increasing.

(2) Hot deformation accelerates the Strength improvement of the Cu-Cr-Zr alloys during aging treatment. The peak-strength of hot extrusion Cu-Cr-Zr increase by about 100MPa compared with the as-cast state.

(3) Cu-Cr-Zr alloys exhibit high strength and high conductivity after solid solution, aging treatment. Good balance of strength and conductivity, which reach to 431.7 and 79.3% IACS respectively, was obtained in the Cu–0.86Cr–0.1Zr alloy after hot extrusion and solid solution at 980℃ for 40 minutes, aging at 460℃ for 3 hours.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 51104113) and Research Program for Serving Local Funded by Shaanxi Provincial Education Department (Program No. 14JF013).

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