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Influence of Zn content and annealing process on electrical property of CuZn alloy ①

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[Abstract] The relationship among annealing temperature, microstructure and electrical resistivity of Cu-(8% ~ 13%) Zn (mole fraction) alloys was studied. The results show that the relationship between the electrical resistivity of cold deformation CuZn alloy and annealing temperature is related to the recovery and recrystallization of the processes. The increments of electrical resistivity due to strain are restored mainly on the process of recovery and recrystallization. The room temperature resistivity of soft state alloys is linear to the Zn contents. The extended application of Matthissen rule on high concentration solid solution was discussed.

[Key words] CuZn alloy; electrical resistivity; recovery recrystallization

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1 INTRODUCTION

For the commercial use of frequency conversion transducer, the asynchronism electromotor has a increasing application in such fields as underground, city light train and high speed train[1,2]. Therefore, a higher criterion is put forward to the rotator materials, a key materials of asynchronism electromotor. A higher heat resistance, mechanical properties and mezzo electrical resistivity are needed at the same time[3~5]. In high speed train, one set of frequency conversion system is operated to offer power for 4 or 6 electromotor simultaneously, in order to keep loads balance, the tolerance of circuit bar resistivity must be controlled within one percent. Conventional copper alloys can't meet this demand, therefore, a new kind of copper alloy was developed[6~8], which satisfied the need of high speed electromotor through the resistivity regulated effect of Zn and the strengthening effect of trace Zr/Cr addition. In this paper, the effects of Zn content and heat treatment on the resistivity of CuZn alloy are discussed.

2 EXPERIMENTAL

2.1 Materials prepared

The actual compositions of six prepared alloys are listed in Table 1. Alloy ingots of CuZn were prepared by melting nominal amounts of 99.99% copper and zinc together in a middle frequency induction furnace, and casting in a round iron module in air atmosphere. After homogeneous treatment and skinning, ingots were hot extruded to d 8 mm billet. The pre-heat temperature of hot extrusion was 870 ℃ for 2 h with an extrusion ratio $35^2/8^2 = 19$. Followed by cold drawing, the billets were cold deformed with section shrinkage up to 86%, and d 3 mm thin wires were acquired.

Table 1 Content of Zn in CuZn alloys (%)

Alloy	Nominal	Actual	Mole fraction
Cu-8Zn	8	7.69	7.490
Cu-9Zn	9	8.46	8.243
Cu-10Zn	10	9.54	9.298
Cu-11Zn	11	10.59	10.320
Cu-12Zn	12	11.47	11.180
Cu-13Zn	13	12.76	12.450

2.2 Heat treatment and experiment method

Six alloys were isothermally treated for 1 h, the temperatures were as the following: 150 ℃, 250 ℃, 300 ℃, 330 ℃, 350 ℃, 370 ℃, 400 ℃, 450 ℃, 500 ℃, 600 ℃ and 700 ℃, respectively. Double electrical bridge method was applied to measure the resistivity, its precision reaches to 10^{-6} Ω. A light-load hardness instrument was chosen to determine every state hardness and a Germany-made NEOPHOT-21 metallography lens was adopted to observe the microstructure.

3 RESULTS

3.1 Influence of annealing temperature on resistivity of CuZn alloy

Fig. 1 plots the room temperature (16 ℃) resistivity of six kinds of CuZn alloys under different an-

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nealing temperatures. Fig. 2 and Fig. 3 show the light load hardness results and microstructures in part prepared alloys respectively.

It can be concluded from Fig. 1 that the relationships between room temperature resistivity and annealing temperature of all 6 studied alloys are followed by a same rule. Three main steps are represented in this rule. Above 50% of the total restore resistivity is restored under the annealing temperature below 350 ℃, the residual is almost completely restored within the annealing temperature range of 350 ~ 400 ℃, and a stable resistivity is acquired when annealed above 400 ℃.

Comparing Fig. 2 with Fig. 3, it can be conclud-

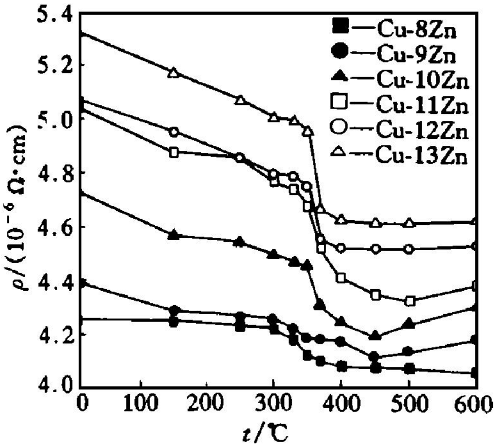

Fig. 1 Room temperature (16 ℃) resistivity under different annealing temperatures

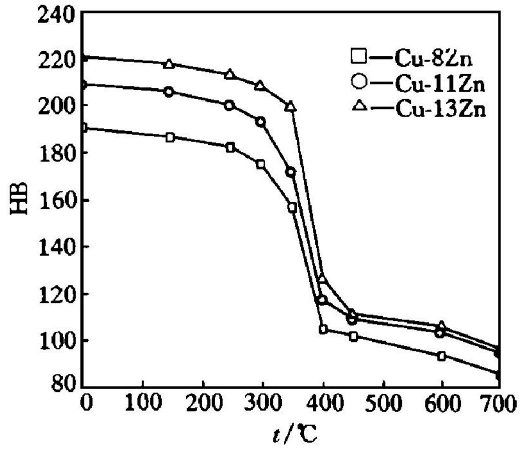

Fig. 2 Hardness under different annealing temperatures

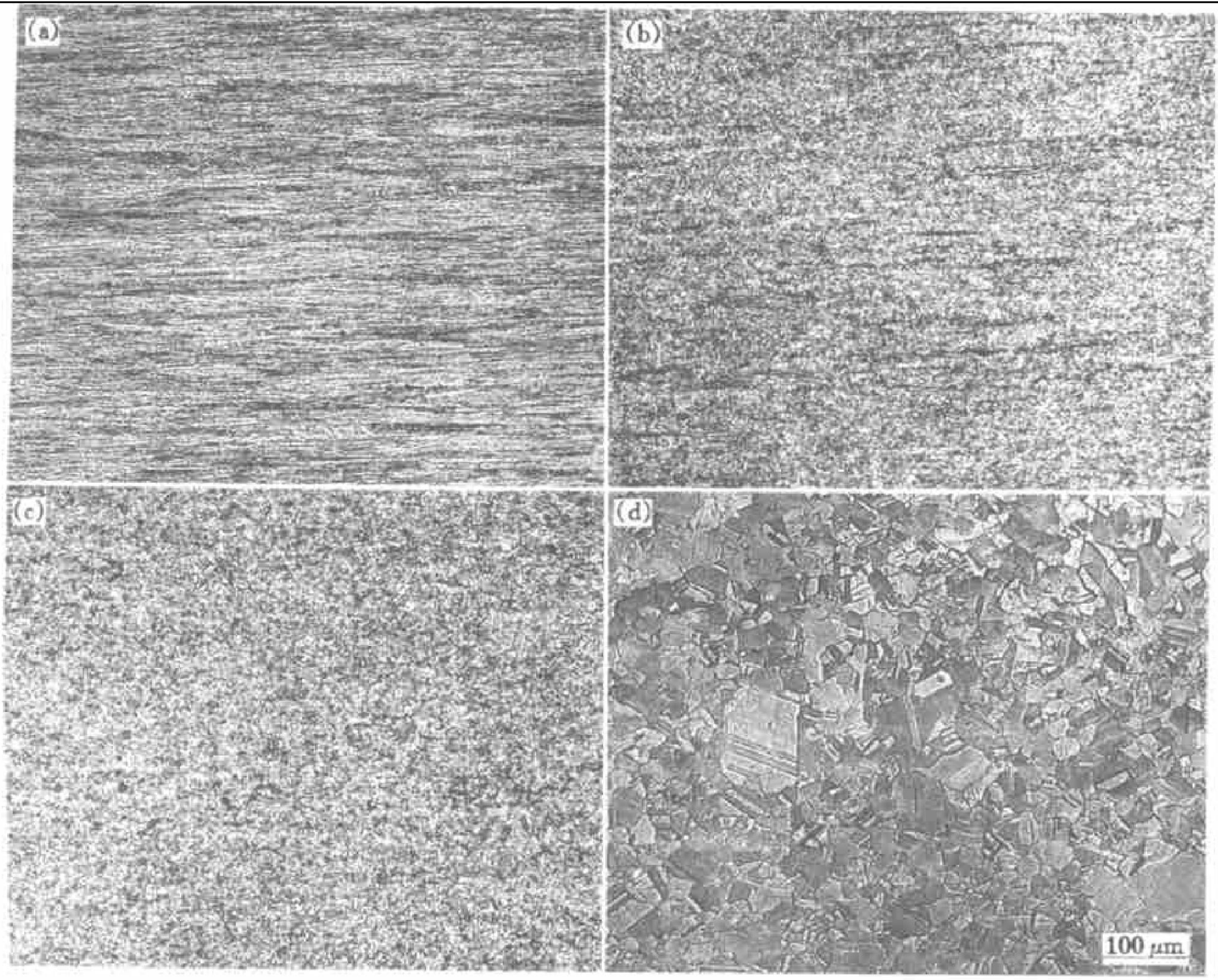

Fig. 3 Microstructures of annealing CuZn alloys

(a) —Cu-13Zn, 250 ℃ for 1 h; (b) —Cu-13Zn, 350 ℃ for 1 h; (c) —Cu-13Zn, 400 ℃ for 1 h; (d) —Cu-13Zn, 600 ℃ for 1 h ed that the room temperature resistivity of CuZn alloys is associated closely to whether there is a recovery or recrystallization annealing process. When the annealing temperature is below 350 ℃, a recovery process has taken place. In this process, the decrease of hardness is not very much, occupied only one fifth of total decreased value, but the decrease of resistivity is up to above 50% of total decreased value. When the annealing temperature is 350~ 400 ℃, a recrystallization process takes place. In this process the effect of cold working is weakened greatly, so the hardness decreases rapidly and the change of resistivity is nearly completed. With increasing annealing temperature, from 400 ℃ to 600 ℃, due to the growth of the first recrystallization grain, the decrease of grain boundary leads to the slowly drop of hardness.

3.2 Influence of Zn content on resistivity of CuZn alloys

Fig. 4 describes the relationship between Zn content and the resistivity of studied CuZn alloys after different temperature annealing treatments.

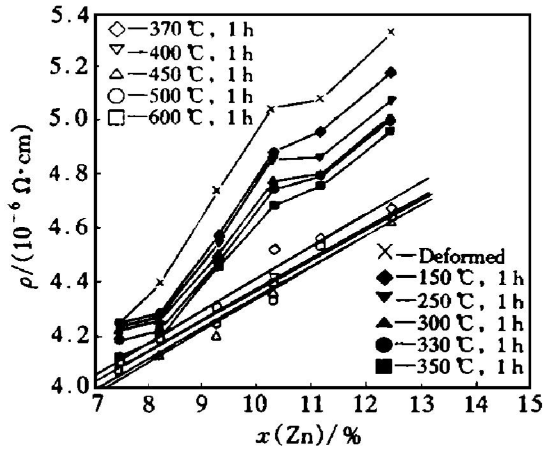

Fig. 4 Relationship between Zn content and resistivity

It can be concluded from Fig. 4 that the relationship between Zn content and resistivity of CuZn alloys after annealed in the temperature range of 400 ~ 600 ℃ conform to a linear regression relation. Table 2 lists the parameters of linear regression relation.

It can be concluded from Table 2 that when the CuZn alloys annealed at temperature range of 400~ 600 ℃, even including 370 ℃, the linear regression results of their resistivity to Zn content are almost equal. From above-mentioned analyses of the resistivity of CuZn alloys to annealing temperature, it is known that the resistivity remains unchangeable at the annealing temperature range of 400 ~ 600 ℃, therefore, the relation between resistivity and Zn content can be represented by a same linear regression relationship, that is to say that this relationship can be calculated statistically. Eqn. (1) gives the relationship between Zn content and the room temperature (16 ℃) resistivity ρ_g (Ω·cm) of soft state Cu-(8% ~ 13%) Zn (mole fraction) alloys.

Table 2 Results of linear regression on electrical resistivity and Zn content

Annealing temperature/ ℃	Interception / (10^{-6} Ω·cm)	Slope / (10^{-6} Ω·cm)
600	3.241 15	0.113 09
500	3.209 68	0.112 97
450	3.170 36	0.116 10
400	3.241 61	0.112 28
370	3.220 36	0.119 00
Average*	3.215 70	0.113 61

* Results of 370 ℃ does not concluded

$$\rho_g = \rho_{g0} + x(\text{Zn})\,\zeta' = 3.2157\times 10^{-6} + 0.11361\times 10^{-6} x(\text{Zn}) \quad (1)$$

where ζ' means the resistivity increment caused by one percent of zinc (mole fraction). From Eqn. (1), it can be deduced that ρ_{g0} equals to the resistivity when the equation extrapolated to zero zinc content, but not the resistivity of real pure copper.

4 DISCUSSION

4.1 Influence of annealing temperature on resistivity

Resistivity reflects the resistance of crystal lattice on the electron that is directional moving under electric field. The crystal structure defect alters the cycle potential field of lattice, becomes the scatter center to moving electron, so leads to the increase of alloy electrical resistivity. For the scatter effect to moving electron, void and interstitial atom are more effective than dislocation, therefore, the change of resistivity is more sensitive to the alteration of point defect[9, 10]. When the alloys annealed below 350 ℃, a recovery process has taken place, point defect concentration decreased mainly in this process, which leads to a large decrease of resistivity occupied above 50% total resistivity decrease value. When the alloys annealed at 350~ 400 ℃, corresponding to the rapid decrease of hardness, a recrystallization process has taken place, crystal defect eliminated greatly, which leads to the rapid decrease of resistivity. However, when the annealing temperature over 400 ℃, a complete recrystallization grain microstructure is formed in the alloys, with the stablizing of point defect, the resistivity is remained unchangeable.

4.2 Influence of Zn content on resistivity

It is a common rule that the conductivity decreasing and the resistivity increasing with the forming of solid solution even if the conductivity of solute atom is larger than that of the solvent atom[11, 12]. The reason why the resistivity of solution is higher than the pure metal relies on the abnormal lattice distortion of solvent due to the solution of solute atom, which increases the scatter effect to electron and enhances the resistivity. At the same time, the chemistry interaction in different composition leads to a decrease of effective electron and results in an increase of resistivity[13].

The resistivity of low concentration solid solution obeys the Matthissen experience rule[13]. The resistance of low concentration solution is divided into two parts. The first part is the resistance brought by solvent atom, this part changes following temperature and equals to zero when the temperature tends to 0K. The second is the additional resistance brought by solute atom and is independent form temperature. If a solid solution is cooled to 0K, the second part of additional resistance will be remained down as the residual resistance. The Matthissen rule can be expressed as the follows:

$$\rho = \rho_0 + \rho' = \rho_0 + x\zeta \qquad (2)$$

where ρ_0 is the resistivity of solvent metal, ρ' is the additional resistivity caused by solute atom, x is mole fraction of solution atom, ζ represents the resistivity increment caused by one percent of the increase of solute atom.

The Matthissen rule is only applicable for low concentration solution. This is because that the resistivity is only considered in the effect of lattice distortion, not involved the interaction effect of different component. But for a high concentration solution this rule is not applicable, the variation of effective electron quantity brought by the interaction effect of different component and the change of band structure cannot be neglected.

Assumed that the solution concentration reaches up to a certain extent, the influence of solute atom on the bonding force and the band structure tends to a stable degree, further increase of solute atom had little influence on the bonding force and band structure, the Matthissen rule could be expandingly applied. That is to say that the additional resistivity brought in only by the effect on lattice distortion of the further increased solute atom and was independent to temperature. Therefore, the resistivity expression of a certain high concentration solid solution could be established on the equation for low concentration solid solution, namely transforming Eqn. (2) as the following one.

$$\rho_g = \rho_{g0} + \rho'' = \rho_0' + x'\zeta' \qquad (3)$$

where x' is the solute mole fraction of further increased. ζ' is the additional resistivity brought by 1% further increased solution. ρ_{g0} is not the same ρ_0 as in Eqn. (2) according to Matthissen rule, which is not only the resistivity of solvent atom but also a physical value including the interaction of different component. Theoretically ρ_{g0} and ζ' are varied with the variation of solute atom concentration in high concentration solid solution. But at a certain concentration value, for the stabilization of the solute atom effect on bonding force and band structure, it can reckoned that the two parameter ρ_{g0} and ζ' are unchangeable. For instance, as the zinc content is 8% ~ 13% (mole fraction) in this paper, the room temperature resistivity of soft state CuZn alloy is followed the Eqn. (1), that implies the applicable of the Matthissen rule.

[REFERENCES]

[1] ZHOU Qi-zhang. Design discuss of high speed cage electromotor [J]. Electrical Machinery Technology, 1987 (1): 5- 7.

[2] Abe M. Traction motors for use in railway [J]. Toyo Denki Review, 1993, 87: 31- 34.

[3] CHEN Zhong-jun. The analysis and improvement on broken bar in H V double cage motor [J]. Large Electric Machine and Hydraulic Turbine, 1990(6): 37- 42.

[4] ZHOU Qi-zhang. Design of frequently start AC asynchronism cage electromotor [J]. Electrical Machinery Technology, 1991(2): 1- 5.

[5] LI Fa-hai. Base of Electric Machine and Fraction [M]. Beijing: Tsinghua University Press, 1994. 170- 260.

[6] LUO Feng-hua and YIN Zhi-min. Influence of trace element Zr on the recrystallization of Cu-Zn alloys [J]. Journal of Central South University of Technology, (in Chinese), 1999, 30(2): 182- 185.

[7] YIN Zhi-min and LUO Feng-hua. Influence of trace Zr on microstructure and mechanical properties of Cu13Zn alloys [J]. The Chinese Journal of Nonferrous Metals, (in Chinese), 1999, 9(4): 705- 708.

[8] LUO Feng-hua. The Copper Alloys Used for the Asynchronous Traction Motor of High Speed Train [D]. Changsha: Central South University of Technology, 1999.

[9] Haessner F. Recrystallization of Metallic Materials [M]. Germany, Druck Printing, 1978.

[10] LIU Guo-xun. Physical Metallurgy Principle [M]. Beijing: Metallurgical Industry Press, 1979.

[11] Suzuki H. Effect of a small addition of transition elements on the heat resistance and electrical properties of cold worked pure copper [J]. Journal of the Japan Institute of Metals, 1984, 48(2): 209- 213.

[12] GE Liang-pu. High strength and high electrical resistivity electrical aluminium alloys [J]. S & M Electric Machines, 1997, 24(5): 28- 30.

[13] XU Jing-juan. Metal Physical Property Analysis [M]. Shanghai: Shanghai Technology Press, 1988. 34- 62.

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