Effect of solid solution and aging treatment on the microstructures and properties of hot-extruded Cu-Te-Li alloys

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The effect of solid solution and aging treatment on mechanical performance, electrical and thermal conductivity of hot-extruded Cu-Te-Li alloys is studied via DDL100 electronic universal machine, MVC-100A1 hardness tester, SB2230 digital electric bridge and DRPL-I coefficient of thermal conductivity instrument. The microstructures of Cu-Te-Li alloys after different processing are observed by CMM-20 metallographic microscope. The results showed that deformed microstructure of Cu-Te-Li alloy sticks disappeared and Te element precipitated as a second phase of Cu_2Te after solid solution and aging treatment. With Te content increasing, the tensile strength and hardness increase, while the electrical and thermal conductivity declines within a small range. When the content of Te reached 0.505%, the tensile strength and hardness of Cu-Te-Li alloy sticks after aging treatment increase by 21.6% and 28.5%, while the electrical and thermal conductivity decrease by 5.45% and 3.89% compared with that of pure copper respectively.

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1. Introduction

Copper alloys are widely applied in most industrial departments due to excellent physical properties, mechanical performance and formability. With the development of industrial technology, the copper alloys with not only high electrical conductivity, but also high strength and other excellent properties are required in more and more application fields [1]. Therefore, developing high-strength and high-conductivity copper alloys has became one of the hot topics of intensive interest in recent years [2]. Presently, about 70 categories of high- strength and high-conductivity copper alloys have been developed, such as Cu-Cr- Zr, Cu-Ni-Si, Cu-Fe and so on [3]. However, difficulties in adding alloy element and low electrical conductivity still existed in those materials, as a result, exploring new system of copper alloys is necessary [4]. The previous research showed that tensile strength of copper alloys could be improved by adding Te into pure copper, the electrical conductivity could reach 94%~98% IACS (International Annealed Copper Standard), and other special properties, such as free-cutting, electrical erosion resistance could be optimized. Meanwhile, by adding active element of Li, the oxygen and sulfur as impurity in raw materials could be removed, and Li could also control recrystallization and increase the recrystallization temperature [5].

Cu-Te-Li alloys could be applied as contact wire, switch contacts, and other electrical materials which need higher electrical conductivity and tensile strength [6]. To our knowledge, there have been a few studies about Cu-Te-Li alloys so far. Zhu et. al [7] studied on the aging process of Cu-Te alloys and the results exhibited that the optimal properties of Cu-Te alloys gained after aging treatment under 420 °C for 6 h. However, few reports of research on other properties of Cu-Te-Li alloy could be found [8]. In order to expand property research and application field of Cu-Te-Li alloys, the mechanical performance, electrical and thermal conductivity, and microstructure of Cu-Te-Li alloy sticks after different processing were investigated in the paper, expecting to offer some guidance for engineering application.

2. Experimental details

Cu-Te-Li alloys were melted in a ZG-25 vacuum induction furnace by adding different amount of Te and Li into industrial copper in an argon protective atmosphere. Te and Li content in different areas of alloy ingots was detected by an ICPA9000 (N+M) plasma spectrometer according to ICP-AES analysis method, the designed and measured contents of Te and Li were shown in Table 1.

Table 1. The content of Te and Li for design and measurement in samples.

No. of Samples	1#	2#	3#	4#	5#	6#
Te content for design	0.00	0.20	0.35	0.50	0.60	0.70
Li content for design	0.00	0.03	0.03	0.02	0.02	0.02
Te content for measurement	0.00	0.17	0.315	0.388	0.448	0.505
Li content for measurement	0.00	0.001	0.002	0.001	0.001	0.001

The Cu-Te-Li ingots were forged and hot-extruded to copper sticks with a diameter of 8 mm through a XS-ZY-5008 extruding machine, and then cut off into sticks with length of 300 mm. The copper alloy sticks were solid solution treated at 850 ℃ for 2 hours, and subsequently annealed at 420 ℃ for 6 hours in vacuum resistance furnace.

The micro hardness of copper alloy sticks was measured by a MVC-100A1 hardness Tester. The tensile test was carried out on a DDL100 electronic universal testing machine at room temperature. The electrical resistance was tested by a SB2230 digital electric bridge, and the results were transformed into electrical conductivity according to the formula of $\rho = R_x \cdot S/L$. The thermal conductivity was detected by a DRPL-I coefficient of thermal conductivity instrument at 45 ℃. Metallographic specimen were sampled from the longitudinal surface of copper sticks and observed by CMM-20 metallographic microscope after polishing and corroding.

3. Results and discussion

3.1. Mechanical properties

The tensile strength and hardness of Cu-Te-Li alloy sticks after different processing were tested for several times, and then the average values were computed as results and displayed in Fig. 1. It can be seen from Fig. 1 that the tensile strength and micro hardness varies with Te content correspondingly. As for the same content, alloy sticks after hot-extrusion gained higher tensile strength and hardness than those after solid solution and aging treatment. With Te content rising, the tensile strength and hardness increased after the same processing, especially after aging treatment. The tensile strength and hardness of alloy sticks with Te content of 0.505% after aging treatment improved by 21.6% and 28.5% compared with that of pure copper respectively.

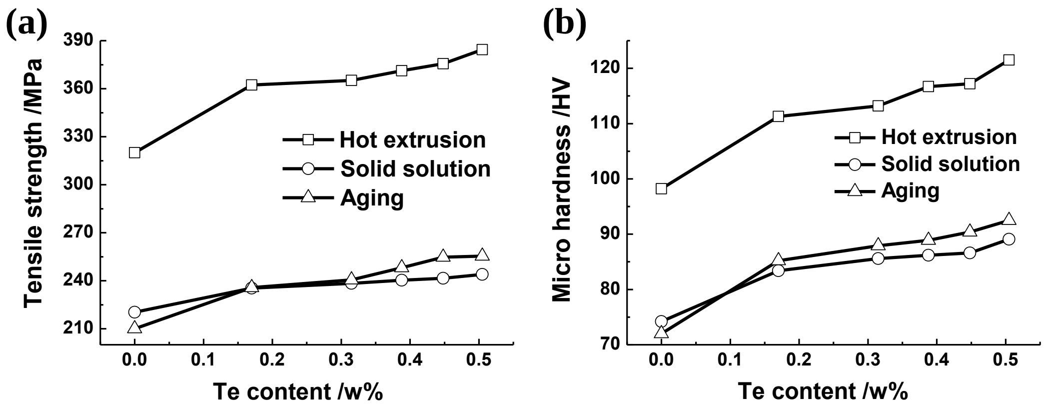

Fig. 1. (a) Tensile strength and (b) Micro hardness of Cu-Te-Li alloy sticks with various Te content.

3.2. Electrical and thermal conductivity

The electrical resistance of Cu-Te-Li alloy sticks after different processing was measured at room temperature and transformed into electrical conductivity, shown as the percentage of IACS% in Fig. 2(a). Considering the practical operating environment of the alloy, the thermal conductivity was tested at 45 ℃ and presented in Fig. 2(b). The electrical and thermal conductivity of the hot extruded Cu-Te-Li alloy is lower than that of Cu-Te-Li alloy after solid solution and aging, varying with different Te content correspondingly. As Te content growing, the electrical and thermal conductivity decreased, especially after solid solution treatment. Nonetheless, the electrical and thermal conductivity of Cu-Te-Li alloys are still at a high level. Even the content of Te reached 0.505%, the electrical conductivity of copper alloys after aging treatment could still keep more than 93% IACS, and thermal conductivity could maintain 368 w/(mk), which only declined 5.45% and 3.89% compared with that of pure copper respectively.

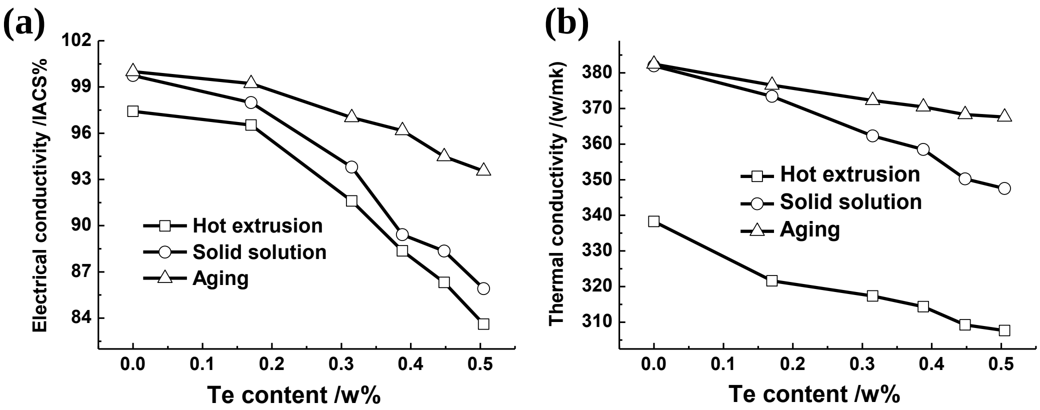

Fig. 2. (a) Electrical conductivity and (b) Thermal conductivity of Cu-Te-Li alloy sticks.

3.3. Microstructure

The metallographic structure of longitudinal surface of Cu-Te-Li alloy sticks after different processing were observed and shown in Fig. 3. As can be seen from Fig. 3(a), the microstructure of longitudinal surface of copper sticks after hot extrusion presented as fibrous grains, which told that a certain amount of plastic deformation had emerged. Fig. 3(b) presents that the fibrous grains disappeared after solid solution treatment, and the grains had grown up slightly. From Fig. 3(c), the second phase precipitated out around grain boundaries and some annealing twins appeared during the process of aging treatment.

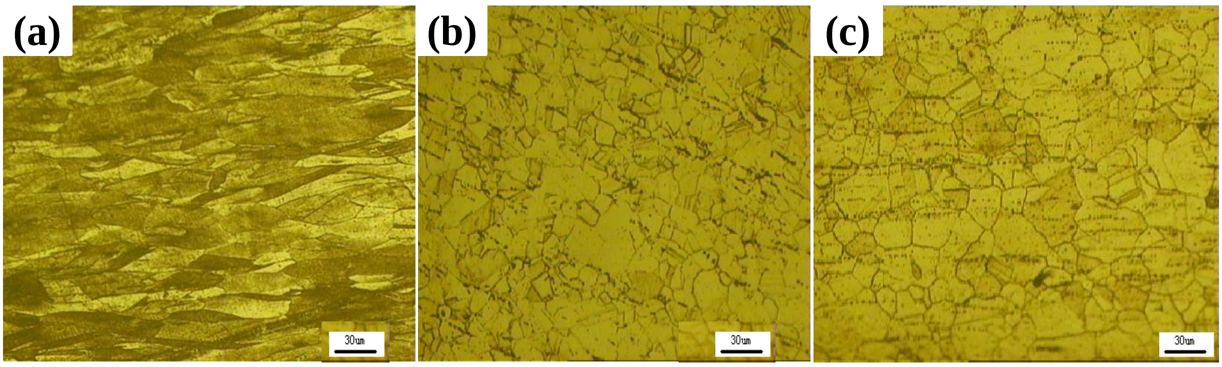

Fig. 3. Metallographic structure of sample 4#: (a) Hot extrusion; (b) Solid solution; (c) Aging.

3.4. Chemical composition of aging precipitation phases

The chemical composition of aging precipitation phases of No.4 sample after aging treatment were analyzed by EDS and the results were showed in Fig. 4 and Table 2. In combination with Cu-Te phase diagram [9], according to the study on aging precipitation of Cu-Te alloys by Zhu [7], it could be concluded that the element of Te precipitated as a second phase of Cu_2Te.

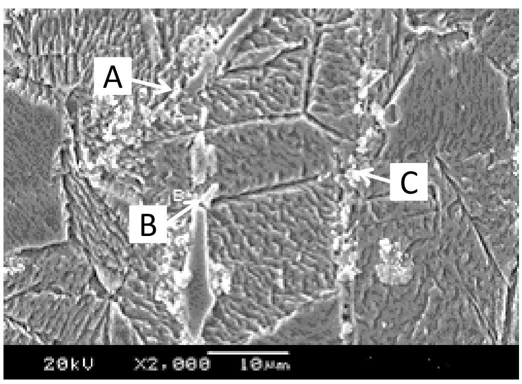

Fig. 4. The energy spectrum spots on precipitation phases.

Table 2. The composition analysis of different energy spectrum spots.

Element	A		B		C	
	Te-L	Cu -K	Te-L	Cu -K	Te-L	Cu -
Atom (%)	30.61	69.39	33.93	66.07	30.64	69.36
Weight (%)	46.97	53.03	50.77	49.23	47.01	52.99

After hot extrusion, a certain amount of plastic deformation emerged in the copper alloys, which could be observed from the longitudinal surface of copper stick obviously, the grains were stretched and the defect density increased. Because of the interaction between vacancy, dislocation and other defects which result in work hardening, coupled with the effect of solid solution strength owing to Te dissolving into Cu matrix, the tensile strength and hardness increased sharply [10]. However, the density of defect increased, which would intensify the electronic scattering, thus, leading to a lower electrical conductivity. The heat transferred in the alloy mainly through migration of free electrons and vibration of crystal lattice, so the thermal conductivity corresponds to electrical conductivity well according to the Wiedemann-Franz Law [11]. Te element which was added into copper would destroy the integrity of crystal grain and disturb the movement of free electrons, so the coefficient of thermal conductivity of Cu-Te-Li alloys is lower than that of pure copper. Owing to the measured temperature is at 45 ℃ which would increase the vibration of crystal lattice and make it difficult for heat to conduct over a long distance, as a result, the thermal conductivity decreased.

After solid solution treatment, the recrystallization of deformed structure finished completely. The element of Te dissolved into Cu matrix and supersaturated solid solution in which Te element was rich formed, as a result, the effect of solution strength intensified. However, the deformed structure disappeared essentially and the grains grown up, so the tensile strength and hardness decreased notable. Along with the content of Te increasing, the tensile strength and hardness of Cu-Te-Li alloys increased, but the solid solubility of Te in copper is low, and Te acted as a substitutional element in Cu matrix, therefore, the effect of solution strength appeared unclearly. In addition, the crystal lattice of Cu matrix distorted owning to the solid solution of Te, which would destroy the periodicity of crystal lattice potential field and increase the probability of electrical scatting. As a result, the electrical conductivity of alloy decreased. Nevertheless, the deformation from hot-extrusion disappeared, so the electrical conductivity for solid solution is better than before.

During the process of aging treatment, the second phase precipitated. On the one hand, the decrease of deformation extent and coarsen of grains would decline the tensile strength; on the other hand, the dispersive and small precipitation would improve it. Because of the interaction between precipitation and dislocation, the second phase (Cu_2Te) would assemble around the dislocation and prevent dislocation from moving [12]. With time prolonging, the precipitation was growing up, the hardness of Cu_2Te is low and distributed around grain boundaries mainly [13], so the tensile strength and hardness of Cu-Te-Li alloys improved unremarkable, and also had some negative effect on the plastic of the material.

As the aging treatment proceeding, the electrical conductivity of alloys was decided by two aspects. On the one hand, the defects decreased and solute atoms precipitated would improve the electrical conductivity; on the other hand, the increasing and growing up precipitated phase would generate additional scatting to electrons which would decrease the electrical conductivity. Based on the Mathiessen Theory [11], the influence of solute atoms on the electrical conductivity is more obvious than precipitated phase. As a result, with aging process being more sufficient, the electrical conductivity after aging is better than that under solid solution state. Simultaneously, due to the effect of Te on the lattice distortion decreased, the thermal conductivity became better than that after solid solution. With Te content increasing, the recovery rate of electrical and thermal conductivity presented more significantly. However, the aggregation around grain boundaries of the second phase would prevent heat conducting. Moreover, along with Te content rising, more precipitated phase would intensify the blocking effect. As a result, the electrical conductivity and thermal conductivity decreased as a whole.

4. Conclusions

After solid solution and aging treatment, the tensile strength and hardness improved because the element of Te precipitated as a second phase of Cu_2Te. However, Cu_2Te was detected softly and distributed around grain boundaries mainly, the mechanical performance of Cu-Te-Li alloys optimized non-significantly. When the content of Te reached 0.505%, the tensile strength and hardness of Cu-Te-Li alloy sticks after aging treatment increase by 21.6% and 28.5% compared with pure copper.

With Te content increasing, the electrical and thermal conductivity reduced slightly, still with high electrical and thermal conductivity. For Cu-0.505Te-0.001Li alloy after aging treatment, the electrical conductivity could still keep more than 93% IACS, and thermal conductivity could maintain 368 w/(mk), which only declined 5.45% and 3.89% compared with that of pure copper respectively.

Acknowledgements

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