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Study on Microstructure Control and Performance Optimization of Cu-15Ni-8Sn Alloy

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Abstract: Copper alloys have high strength, high hardness, high elasticity, low processing cost, and are non-toxic and environmentally friendly. They are widely used in fields such as aerospace, navigation ships, electronic appliances, and communication engineering. Cu Ni Sn alloy is a typical Spinodal type alloy, which can achieve strengthening effect by precipitating ordered phases through amplitude modulation decomposition. It can be used as conductive contact springs in relays, potentiometers, switches, and elastic sensitive components in precision instrument sensors. At present, the main preparation technologies for this type of copper alloy include vacuum casting technology, rapid cooling solidification technology, mechanical alloying method (MA method), and powder metallurgy method. However, due to the tendency of discontinuous cellular precipitates to precipitate at grain boundaries during the amplitude modulation decomposition process, the strength and plasticity of the alloy decrease, and the alloy performance deteriorates. Therefore, certain measures need to be taken to suppress the precipitation of discontinuous precipitates. Therefore, the systematic study of the microstructure.
Keywords: Copper alloy ; Organization; Regulation and controlevolution law of Cu-15Ni-8Sn alloy and its influence on mechanical properties is of great significance for the control of the microstructure and properties of this type of copper alloy

1. Cu-15Ni-8Sn tissue regulation and its influencing factors

Trace elements have a significant impact on the microstructure of Cu-15Ni-8Sn alloy. The addition of trace element Ti significantly refines the grain size of the alloy. When the Ti content is 0.02%, the grain size significantly decreases. When the Ti content is high, Ni and Ti form Ni3Ti, promoting recrystallization nucleation. The Ni3Ti distributed within the crystal hinders dislocation movement and plays a second phase strengthening role, while the coarsened Ni3Ti plays a cutting role relative to the matrix, reducing the plasticity of the alloy . Yanhui Wang et al. studied the effect of Si on the microstructure of Cu-15Ni-8Sn alloy, and the results showed that Si mainly combines with Ni to form Ni3Si phase to suppress discontinuous precipitation. This inhibitory effect is strongest when the Si content is 0.3Si, and as the Si content increases, its effect actually weakens. Therefore, the most suitable amount of Si addition in Cu-15Ni-8Sn alloy is around 0.3%[1]. Xukun Yang et al. studied the effect of rare earth element Y on the microstructure of Cu-15Ni-8Sn alloy. The addition of rare earth element Y can refine the dendritic morphology of Cu-15Ni-8Sn alloy, resulting in the finest microstructure [2]. The preparation method is another factor that affects the microstructure of Cu-15Ni-8Sn alloy. Qianxiang Zhang et al. used the spray forming method in rapid cooling solidification technology to prepare Cu-15Ni-8Sn alloy. The results showed that there were significant differences in the microstructure between the bottom and upper middle parts of the deposited billet, with the bottom being a multiphase structure and the rest being a single-phase alpha solid solution structure [3].Yuewu Zeng et al. compared and studied the effect of mechanical alloying and vacuum melting methods on the microstructure of Cu-15Ni-8Sn alloy. The results showed that the alloy prepared by mechanical alloying had small grains, while the alloy prepared by vacuum melting had higher density. However, its grain size and Sn element distribution were uneven, weakening the solid solution strengthening effect [4].

Solid solution Cu-15Ni-8Sn alloy undergoes amplitude modulated decomposition and discontinuous precipitation during the aging process. As the amplitude modulation decomposition continues, discontinuous precipitation becomes the main form of precipitation, and the original DO22 type gamma phase is also replaced by the DO3 gamma phase.Fang Han and others have shown that with the increase of aging temperature and the extension of aging time, the size of the GP zone (Guinier Reston) rapidly increases, forming a completely coherent θ phase with the matrix. Continuing to age, the θ phase transforms into a θ ‘phase, and the alloy is in the over aging stage. Continuing the aging process and transitioning from the θ ‘phase to the stable θ phase will completely lose its coherent relationship with the matrix. At lower solid solution temperatures, there are loose voids in the grains, and undissolved white bright rich Sn phases exist between grain boundaries and within the grains. As the solid solution temperature increases, the porosity improves and the insoluble Sn rich phase decreases [5]. The above results indicate that Cu-15Ni-8Sn alloy can improve the microstructure of copper alloy by adding alloying elements, trace elements, and heat treatment.

2. Mechanical properties and influencing factors of Cu-15Ni-8Sn

The elements in the alloy affect the mechanical properties such as strength, plasticity, and toughness of the alloy by affecting its phase or structure. The study by Yanhui Wang et al. shows that in Cu-15Ni-8Sn alloy, a second phase is formed between Si and Ni, which can effectively suppress the growth of recrystallized grains and obtain a fine-grained structure [6]. Xun Wang et al. believe that Si element can significantly inhibit the growth of recrystallized grains and secondary recrystallization process in hot extruded Cu-15Ni-8Sn alloy, resulting in a fine recrystallized structure and the best comprehensive mechanical properties of the alloy [7]. Bohong Jiang et al. promoted the amplitude modulated decomposition of Cu-15Ni-8Sn alloy by adding Nb element, and adopted a short-term aging process to significantly improve the comprehensive properties of the alloy, achieving good strength and plasticity coordination [8] . Due to the presence of niobium rich phases at grain boundaries, grain refinement is achieved, which delays the growth of discontinuous precipitates during the aging process, and the alloy achieves higher tensile strength (>1030MPa). When the Ti content is 0.3%, the hot extruded alloy maintains good plasticity while improving its strength, achieving the best comprehensive mechanical properties. From this, it can be seen that the macroscopic properties of this type of alloy can be controlled through the control of alloying elements。 Hairong Le [9] et al. found that Spinodal decomposition has a positive effect on hardening, and the formation of γ - metastable phase also causes significant hardening of the alloy. These two factors will increase the hardness of the aging alloy. However, during the aging process, discontinuous γ phase will be desolved and precipitated, and the large amount of discontinuous precipitated γ phase will cause a decrease in the hardness of the alloy. In addition, Yuxuan Liu et al. [10] analyzed that the friction coefficient of the aged Cu-15Ni-8Sn alloy is lower than that of the cast alloy, and the wear rate of the aged alloy is also lower than that of the cast alloy. This is because the hardness and yield strength of the cast alloy are lower than those of the aged alloy, which is prone to premature formation of cracks and fatigue peeling pits. A large number of fatigue peeling pits will also make the friction coefficient higher. When the alloy ages at the critical amplitude modulation decomposition temperature (350 °C~450 °C), continuous and alternating composition changes occur in the Sn rich and Sn poor regions. The periodic strain field generated by this amplitude modulation structure can strongly hinder the movement of dislocation lines, leading to alloy strengthening. As the aging time prolongs, metastable DO22 type ordered phase (CuxNi1-x) 3Sn particles begin to form in the Sn rich region, followed by the precipitation of metastable L12 type ordered phase (CuxNi1-x) 3Sn particles. At this point, the alloy strength reaches its peak, indicating that DO22 and LI2 coexist to achieve the best strengthening effect. If aging continues, the layered α+γ discontinuous precipitates formed at the grain boundaries of the solid solution will be replaced by the original DO22 type ordered phase and DO3 type γ phase. At this time, the hardness, strength, and plasticity of the alloy will decrease. To improve the mechanical properties of Cu-15Ni-8Sn alloy, cold deformation is generally carried out after solid solution of the alloy. On the one hand, it has the effect of deformation strengthening, and on the other hand, it can promote the aging strengthening process. Cu-15Ni-8Sn alloy can achieve the best mechanical properties after solid solution at 800-850 °C, cold deformation of over 70%, and aging at 400 °C (2 hours). Yuxuan Liu et al. found that the tensile strength of the alloy first increases and then decreases with the increase of aging temperature, reaching its peak at 400 °C, while the elongation changes in a wavy manner. As the solid solution temperature increases from 800 °C to 860 °C, the tensile strength, yield strength, and elongation of the alloy all show a decreasing trend. After solid solution aging treatment at 800 °C/30min+400 °C/4h, the compressive strength of the alloy can reach 1705MPa, the hardness is 35HRC, and the elongation is 3.5%. Yang Liu et al. believe that by prolonging the solid solution time at 880 °C, a large amount of solute elements dissolve into the matrix, forming a solid solution strengthening effect, and the hardness begins to show an upward trend. When the solid solution time is 2 hours, the maximum hardness is 79HRB. Hai Huang et al. believe that an 80% deformed alloy reaches its peak hardness of 394HV after only half an hour of aging at 400 °C, while the undeformed sample only reaches its peak hardness of 338HV after three hours of aging [11].

The above explanation shows that the mechanical properties of Cu-15Ni-8Sn alloy are mainly affected by the addition of elements, which affects its structure and properties. The heat treatment of this alloy is mainly a solid solution and aging treatment method, and in order to achieve better strengthening effects, a deformation pre-treatment before aging is often added. In the aging process above the critical amplitude modulation decomposition temperature, discontinuous precipitation is predominant; In the aging process above the critical amplitude modulation decomposition temperature, amplitude modulation decomposition is carried out first, followed by discontinuous precipitation during aging. Changing the solid solution temperature in the heat treatment process can increase or decrease strength and plasticity; As the solid solution time prolongs, the strength and hardness will change; Different aging temperatures and times can lead to changes in the peak aging strength or the distance from the peak aging time, thereby affecting the strength.

3. Conclusion and Outlook

(1) Adding elements such as Ti, Si, and Y to Cu-15Ni-8Sn is beneficial for refining the structure and suppressing the precipitation of discontinuous phases, but there is a critical amount of addition. By controlling the solid solution aging temperature and time to regulate the amplitude modulated decomposition process, the refinement of the structure and inhibition of the precipitation of discontinuous phases can be achieved, resulting in a fine crystalline structure.

(2) The addition of alloying elements has a significant impact on the strength and plasticity of Cu-15Ni-8Sn alloy, and the optimal strength and plasticity match can be achieved when the Si and Ti addition amounts are 3%; 400 °C aging treatment can cause sufficient amplitude modulation decomposition to form fine grain structure, achieving the best strength plasticity matching. If the temperature is too high or too low, it is difficult to avoid the formation of discontinuous precipitation or coarse phases, which will deteriorate the mechanical properties of the alloy.

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