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Study of Microstructure and Properties of Gold Based Material for Electric Conductive Slip Ring

Xiumei Shi[1, 2], Lei Jiao[2, 3], Feng Wang[2, 4], Richu Wang[1], Linlin Yuan[2, 3]

[1]School of Materials Science and Engineering, Central South University, Changsha, China
[2]Beijing Non-ferrous Metals and Rare Earth Research Institute Co., Ltd., Beijing, China
[3]Beijing Engineering Research Center of New Brazing Materials for Electronic Information, Beijing, China
[4]School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing, China

Email address:
6918541@qq.com (Xiumei Shi)

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Abstract: The space vehicle is powered by solar panels, and as a key component in the rotation mechanism of the panels, the sliding friction pair is an important power and signal transmission channel for the aircraft. In addition to ensuring high reliability in structure, conductive slip ring materials should also select electrical contact materials suitable for the space environment. In this paper, the corresponding relationship among the preparation process, properties and microstructure of AuAgCu35-5 alloy, which is used as a conductive slip ring, is studied, especially for the process link of key performance changes. AuAgCu35-5 alloy was prepared and investigated in order to obtain excellent mechanical properties by optimizing the heat treatment conditions. Studies have shown that with the increase of processing rate, the mechanical properties (tensile strength, hardness) of the material continue to improve. The relationship between tensile strength and processing rate is essentially linear. The hardness increases linearly with the increase of the machining rate at first, and then remains unchanged. Even though the processing rate continues to increase, the hardness no longer changes significantly. The AuAgCu35-5 alloy has an aging strengthening phenomenon, and the hardness increases when the temperature is kept at 400°C. The optimal heat treatment process of AuAgCu35-5 alloy is heating at 400°C for 30 minutes.

Keywords: Noble Metal, Sliding Friction Pair, Conductive Ring, Structure, Property

1. Introduction

Spacecraft plays an irreplaceable role in national defense and national economy because it can be used in military reconnaissance, communication broadcasting, resource detection and other fields [1]. The endurance of a spacecraft mainly depends on the conversion of solar energy, hence solar panels are extremely important for the service life and reliability of aircraft [2]. The solar panel drive mechanism is mainly composed of a drive motor and a conductive slip ring [3]. Conductive slip rings provide continuous signal and power transmission in vacuum for spacecraft such as space shuttles, satellites, manned spacecraft, and manned space stations [4]. The satellite conductive slip ring should be made up of the precious metal with good wear resistance, low friction coefficient, contact resistance, electrical noise value and good storage stability in order to adapt to the special use environment of high vacuum, radioactivity and poor heat dissipation [5-9]. Liu [10] studied the friction and wear characteristics of AuAgCu35-5/PtIr25 and AuAgCu20-10/AuCuPtAg14-9-4. Zhou [11] explored the contact performance and longevity of slip ring friction pairs from a microcope point of view by introducing pure mechanical contact model and the contact model of multi-physics coupling effect of thermo-elastic-electro. Li [12] simulated the factors affecting temperature rise of friction pair by creating a steady thermal model for copper wire/copper-dipped carbon plate of pantograph and catenary system based on ANSYS finite element method. However, the preparation process of slip ring with electrical contact and the corresponding relationship between the preparation process, material properties and microstructure have not been studied.

In this paper, AuAgCu35-5 alloy was prepared and investigated in order to obtain excellent mechanical properties by optimizing the heat treatment conditions. In addition, the effects of deformation rate on the tensile strength and microhardness were discussed.

2. Experiments

2.1. Melting and Casting

Melting and casting of AuAgCu alloy was made in vacuum induction melting under dynamic argon atmosphere. The targeted composition for melt was AuAg (35±0.5) Cu (5±0.5). After cleaning with acetone, high purity Au, Ag and Cu ingots of 99.999% purity were charged in the graphite crucible. Melting was done under inert atmosphere by first evacuating the furnace to 0.001 mbar and then by purging with argon. After holding for a determined time period, the melt was cast into a graphite mold. Table 1 shows the chemical composition of AuAgCu35-5 alloy obtained in this work.

Table 1. *Chemical composition of AuAgCu35-5 alloy obtained in this work (wt%).*

Alloy	Ag	Cu	Au
AuAgCu35-5	34.9	5.2	Bal.

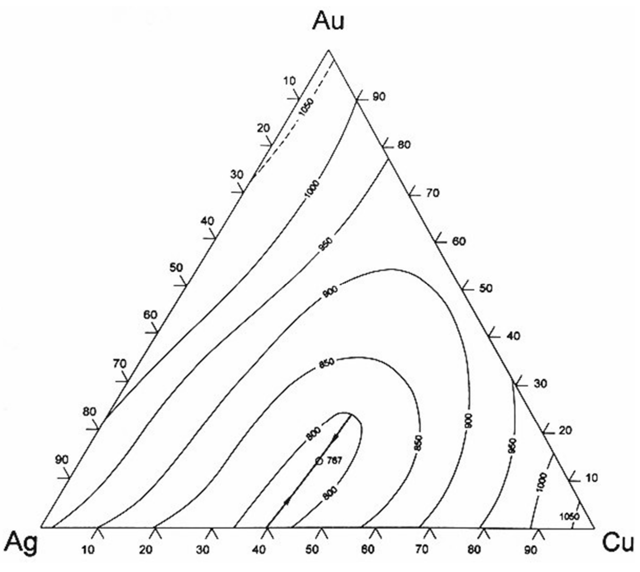

Figure 1. *Liquidus of Au-Ag-Cu alloys.*

2.2. Secondary Processing

The casting slab was processed into ≠1.0 mm plate with a total deformation rate of 90% subsequently. The Au-Ag-Cu phase diagram is shown in Figure 1 [13]. According to Figure 1, it can be seen that almost all ternary alloys are two-phase alloys except the Au-rich alloys near the Au angle, which are single-phase solid solutions. The (Cu)+(Ag) two-phase region originating from the Ag-Cu system keeps expanding and the Au-rich single-phase region keeps shrinking as the temperature decreases. In the Au-Ag-Cu alloy, the chemical stability of the alloy is mainly affected by Au, the melting temperature, strength, hardness, age-hardening strength and other properties of the alloy are affected by the ratio of Ag and Cu [14]. The samples for mechanical properties evaluation were prepared with heat treatments at 200°C, 300°C, 400°C and 500°C for 1h after drawing. To explore the impact of holding time on hardness of AuAgCu35-5 alloy, samples were also prepared with heat treatments at 300°C for 15 min, 30 min, 60 min and 120 min.

2.3. Characterization

The microstructure was observed by metallographic microscope (Observer A1) and scanning electron microscopy (SEM, Hitachi SU-1510). The metallographically prepared samples were etched with the mixed solution as follows: 10ml 68% nitric acid, 50ml 37% concentrated hydrochloric acid and 60ml pure water. An energy dispersive spectroscope (EDS) was also adopted to determine element composition of the microstructural characteristics and element distribution. Vickers hardness was measured using a 100 g load and a 15 s loading time (Micromet 2100, Buehler). The tensile tests were carried out using a universal testing machine (CMT4105) to investigate the tensile properties of the alloy. The loading speed was 0.5 mm/min. Three specimens were used for each test and the average value was taken into account.

3. Results and Discussion

3.1. Microstructures of AuAgCu35-5 Alloy

Figure 2 displays a metallographic picture of AuAgCu35-5 alloy. The obvious dendrite structure can be seen in the as-cast structure as given in Figure 2(a). The grain size is small and relatively consistent. The microstructure of as-processed AuAgCu35-5 alloy is shown in Figure 2(b), the dendrite structure is transformed into fibrous structure after rolling deformation.

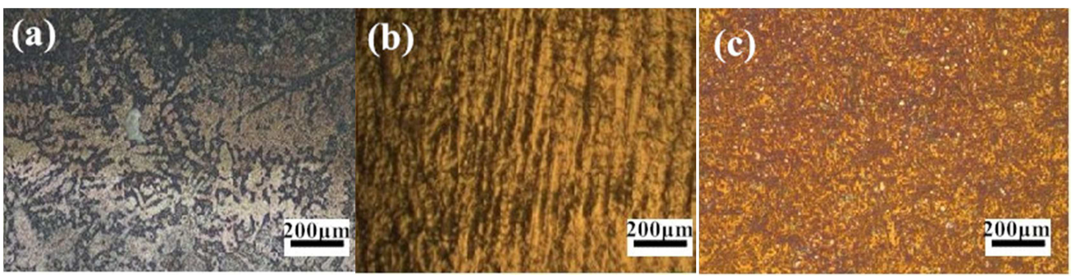

Figure 2. *AuAgCu35-5 alloy metallographic (a: cast state; b: processed state (deformation rate 90%); c: ageing state (400°C, 0.5h).*

In order to further determine the impact of the roll forming on microstructure of AuAgCu35-5, energy spectrum analysis was performed by using scanning electron microscope. As shown in Figure 3, the dendrite structure marked as A is rich Ag. The rich Ag phase is the tip of the dendrite, and the composition segregation leads to a lower melting point, which leads to nucleation and precipitation during solidification. The surrounding white part marked as B is rich Au according to Table 2.

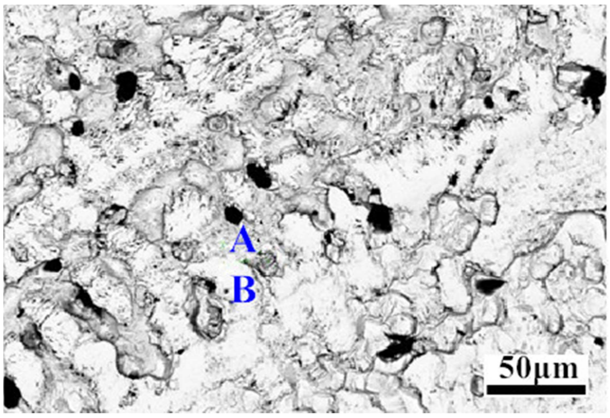

Figure 3. *SEM image of as-cast AuAgCu35-5 alloy.*

Table 2. *Chemical analyses at areas shown in Figure 3.*

Symbol	Average chemical analyses, at. %		
	Au	Ag	Cu
A	34.66	62.82	2.52
B	78.47	18.02	3.51

The microstructural image of AuAgCu35-5 after roll forming is given in Figure 4 and the stripe figures are observed. EDS analysis was performed on each area, and the result is shown in in Table 3. It seems that the content of Cu in area C is higher that that in area D.

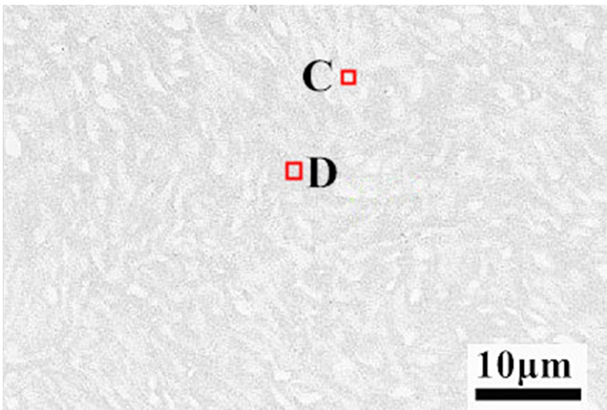

Figure 4. *SEM image of processed state AuAgCu35-5 alloy.*

Table 3. *Chemical analyses at areas shown in Figure 4.*

Symbol	Average chemical analyses, at. %		
	Au	Ag	Cu
C	59.64	31.16	9.21
D	48.71	49.52	1.78

3.2. Mechanical Properties of AuAgCu35-5 Alloy

In order to study the performance of the alloy after plastic deformation of the material with different deformation rates, five deformation rate levels ranging from 0% to 96% were set in the experiment. The trend curves of tensile strength, elongation and Vickers hardness with deformation rate are shown in Figure 5 and Figure 6.

It can be seen that the tensile strength continues to increase with the increase of the deformation rate, while the elongation gradually decreases. However, the growth rate of tensile strength decreases with the increase of processing rate. This indicates that the processing rate of 96% has reached its limit for AuAgCu35-5 and excessive processing rate may cause material fracture.

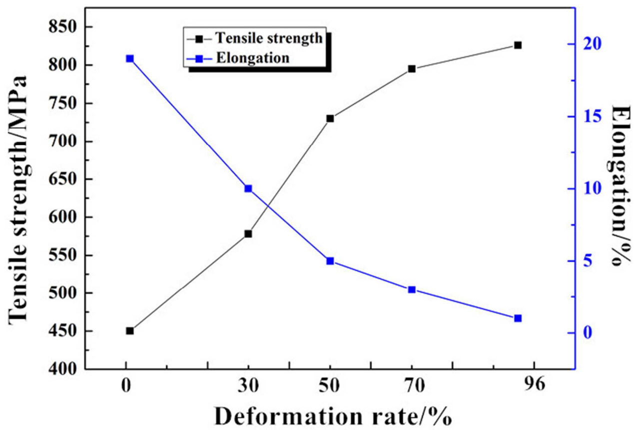

Figure 5. *Tensile properties of samples with different deformation rate.*

The hardness increases with the increase of processing rate, and the increase rate decreases gradually as given in Figure 6. The rising trend of hardness slows down when the processing rate reaches to 30%. This is due to the low strength of the alloy caused by the rich Ag.

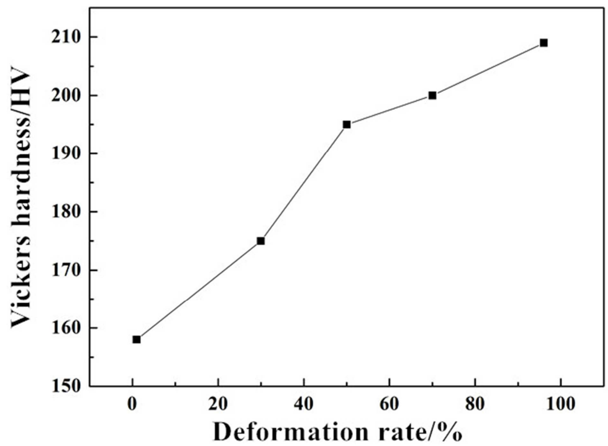

Figure 6. *Vickers hardness for the samples with different deformation rate.*

The hardness test result after heat treatment of the AuAgCu35-5 alloy with a working rate of 96% is shown in the Figure 7. It is observed that the hardness increases significantly at 400°C because of the ageing strengthening, and then decrease gradually with over aging.

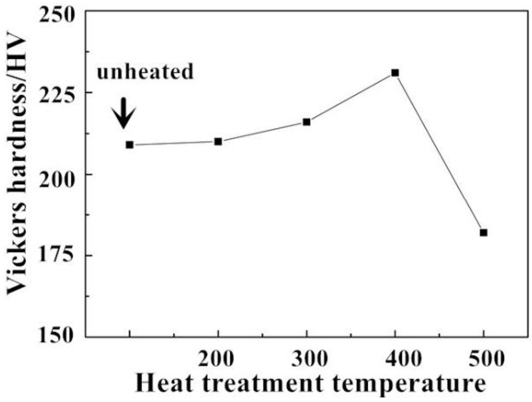

Figure 7. *Vickers hardness for the sample with 96% deformation rate under different heat treatment temperature.*

The effect of holding time at 400°C on the hardness of AuAgCu35-5 alloy is shown in Figure 8. It is observed that the hardness of alloy increases gradually until the holding time reaches to 60min. However, the aging strengthening effect is not obvious with the extension of the holding time. Therefore, the optimum holding time is 30 min in order to improve efficiency and reduce oxidation of alloy surface.

Au_3Cu phase is precipitated gradually during the heat treatment. Au_3Cu is also a kind of ordered phase, which is the main reason of aging strengthening phenomenon. The hardness increases because of the ordered phase precipitation. However, the hardness decreases as the temperature increases or the holding time increases due to grain growth. Au, Ag and Cu is decomposed from a single phase into Au and AuCuI or AuCuII containing Ag-rich phases during the heat treatment of alloy. The age-hardening behavior of the alloy is related to the decomposition of the parent phase into Cu-rich and Ag-rich phases by amplitude-modulated decomposition. The phase (or metastable phase) formed by the decomposition may then be transformed into an ordered phase with tetragonality, and the amplitude-modulated decomposition is generally accompanied by a rapid diffusion of atoms and a rapid increase in hardness [15].

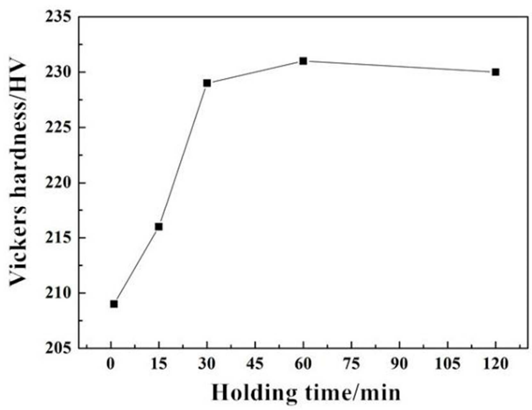

Figure 8. *Vickers hardness for the samples heat-treated at 300°C for different holding time.*

4. Conclusions

In this paper, a systematic study of the corresponding relationship between the alloy preparation process, material properties and microstructure is carried out to provide a theoretical basis for formulating the optimal process route. The effects of working rate and heat treatment process on the microstructure and properties of the AuAgCu35-5 alloy were investigated. Primary conclusions are summarized as follows.

(1) The as-cast microstructure of AuAgCu35-5 is mostly consisting of dendrite, and the processed microstructure is dominated by Fiber structure. No obvious change of microstructure is observed after heat treatment. Cu accumulation at grain boundaries is observed by EDS analysis.

(2) The tensile strength and hardness of AuAgCu35-5 increase with the increase of deformation rate, while the elongation decreases. However, the hardness tended to remain changeless when the deformation rate is greater than 50%. The elongation tends to remain unchanged when the deformation rate is greater than 70%.

(3) AuAgCu35-5 alloy shows obvious aging strengthening when the heat treatment temperature reaches to 400°C. The continuous solid solution decomposes and the Au_3Cu phase continues to precipitate. The hardness of alloy changes little when the holding time exceeds 30min.

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