Effects of High Pressure Heat Treatment on Thermal Conductivity and Electrical Conductivity of CuAlBi Alloy

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The thermal conductivity and electrical conductivity of CuAlBi alloy before and after 1–6 GPa high pressure treatment were measured by thermal constant tester and conductivity gauge when it was heated at 700°C and lasted for 30 min. And the effects of high pressure heat treatment on thermal conductivity and electrical conductivity of CuAlBi alloy were discussed by its microstructure. The results show that the thermal conductivity variation trend of CuAlBi alloy before and after 3 GPa pressure heat treatment is almost the same in range of 25–600°C; high pressure can reduce the thermal conductivity and electrical conductivity of CuAlBi alloy, the thermal conductivity and electrical conductivity of the alloy decrease with the increment of pressure in less than 3 GPa, when the pressure is over 3 GPa, the variation of thermal conductivity and electrical conductivity are not obvious. [doi:10.2320/matertrans.M2013131]

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1. Introduction

Cu alloy is widely applied in electric appliance, instruments and mechanical due to its high strength, corrosion resistance, good properties of thermal conduction and the electric conduction. With the rapid development of modern industry, people put forward higher demands for it, special in the strength and the properties of thermal conduction and the electric conduction. Therefore, it is very important practical significance to study the improvement in properties of Cu alloy. Many researches on improving properties of Cu alloy were performed by materials scientists. In recent years, the research results have shown that high pressure heat treatment can improve the microstructure and mechanical properties, but the reports on the thermal conduction and the electric conduction properties of Cu alloy after high pressure heat treatment have been seldom involved. Furthermore, some mechanical components made of Cu-alloy are on active service at a certain temperature, so it is necessary to study the properties of thermal conduction of Cu alloy after high pressure heat treatment at a certain temperature. Accordingly, the thermal conductivity and electrical conductivity of the CuAlBi alloy was discussed based on different high pressure heat treatment in the paper.

2. Experiment

The experimental material was as-cast CuAlBi alloy, its chemical composition is, 89.11%Cu, 10.65%Al and 0.18%Bi, the other 0.06% (mass%). Firstly, the as-cast samples is sealed in graphite sleeve that is isolated from it by BN powder, and then the graphite sleeve is embedded in pyrophyllite mould, the pyrophyllite is pressure transmitting medium, heat treatment was done on CS-IB type six level top press under high pressure which is 1, 3 and 6 GPa, respectively. After heating at 700°C and lasting for 30 min by electrical resistance, shutting off power and cooling to room temperature on holding up pressure, the circulating water flow of cooling pressure head is about 1.0 L/min. Secondly, the samples before and after high pressure heat treatment were processed into 910 mm × 12 mm and polished by 1200# emery paper. Then, the thermal conductivity were measured by a TC-7000 thermal constant tester at different temperature continually, electrical conductivity are measured by WD-Z eddy current conductivity meter before and after high pressure heat treatment. To observe phase change of the CuAlBi alloy in the process of heating, specimen of the CuAlBi alloy before and after high pressure heat treatment was used in a STA449C thermal analysis instrument with the heating temperature of 700°C, heating rate of 20°C/min (DSC: Differential Scanning Calorimetry). Finally, the microstructure of the CuAlBi alloy before and after high pressure heat treatment were observed and analyzed by Axiover200MAT metallographic microscope and H-800 transmission electron microscope and D/MAX-rB type X-ray diffraction instrument (with graphite monochromator, Kα radiation) and KYKY-2800 type scanning electron microscope attached on X-ray energy dispersive spectrometer (EDS).

3. Experiment Results and Discussion

3.1 Microstructure structure

The microstructure of the CuAlBi alloy before and after high pressure heat treatment is shown as Fig. 1. As can be seen, the microstructure of as-cast CuAlBi alloy is coarser, after high pressure heat treatment there are fine white granule and thin strip and it is obviously refined, and refinement effect increases along with the pressure increasing firstly and then decreases, when the pressure is 3 GPa, the microstructure is the finest. The XRD (X-ray diffraction) shows that the CuAlBi alloy before and after high pressure heat treatment both are composed of α solid solution and Al4Cu9 phase, the α solid solution is white bar and Al4Cu9 phase is mainly in black area and it can be known from the EDS analysis (Table 1) that high pressure heat treatment can not almost cause obvious change for α phase composition,.

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Al4Cu9 phase is an electron compounds that the atom ratio of Al and Cu is 4:9, and its composition do not change before and after high pressure heat treatment. The high pressure heat treatment do not result in new phases, it only change the shape, size and distribution of the phase of the CuAlBi alloy. According to the TEM (see Fig. 2), the number of dislocations increase obviously in the CuAlBi alloy before and after high pressure heat treatment, and the larger pressure, the more number of dislocations.

3.2 Thermal conductivity

The relation curve between the thermal conductivity and pressure of the CuAlBi alloy before and after high pressure treatment is shown as Fig. 3. It can be seen that the high pressure treatment can decrease the thermal conductivity of the CuAlBi alloy that decreases with the increment of pressure. When the pressure is 3 GPa the thermal conductivity is 48.537 W·m\(^{-1}\)·K\(^{-1}\), decreased 16.62% than that of without high pressure treatment. When the pressure is over 3 GPa it is not obvious. From relation curve between thermal conductivity of the CuAlBi alloy and temperature (see Table 1 EDS analysis showing the composition (mass%) of \(\alpha\) phase in CuAlBi alloy.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Cu</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-cast</td>
<td>90.75-90.94</td>
<td>9.06-9.25</td>
</tr>
<tr>
<td>1 GPa treatment</td>
<td>90.73-90.95</td>
<td>9.05-9.27</td>
</tr>
<tr>
<td>3 GPa treatment</td>
<td>90.76-90.92</td>
<td>9.08-9.24</td>
</tr>
<tr>
<td>6 GPa treatment</td>
<td>90.74-91.96</td>
<td>9.04-9.26</td>
</tr>
</tbody>
</table>

Fig. 1 Microstructure of CuAlBi alloy before and after high pressure treatment: [(a) As-cast, (b) 1 GPa, (c) 3 GPa, (d) 6 GPa].

Fig. 2 TEM images of CuAlBi alloy before and after high pressure treatment: [(a) As-cast, (b) 3 GPa, (c) 6 GPa].

Fig. 3 Relationship between thermal conductivity of the CuAlBi alloy and pressure.
Fig. 4), it can be seen that the thermal conductivity of the CuAlBi alloy after 3 GPa pressure treatment is smaller than that of without high pressure treatment in range of 25–600°C, and the higher temperature, the smaller difference of thermal conductivity, for example, when temperature is 25°C, the difference of thermal conductivity is 9.644 W·m⁻¹·K⁻¹ before and after 3 GPa pressure treatment, while the temperature is 600°C, it is 1.221 W·m⁻¹·K⁻¹. From the thermal conductivity variation trend of the CuAlBi alloy, it can be seen that the variation trends of the thermal conductivity following temperature of the CuAlBi alloy before and after 3 GPa pressure treatment are almost the same, as can be seen in Fig. 5.

3.3 Electrical conductivity

The relation curve of the electrical conductivity of CuAlBi alloy with pressure is shown as Fig. 6. It can be seen that the high pressure treatment can reduce the electrical conductivity of CuAlBi alloy and it decreases with the increment of pressure. When the pressure is 3 GPa, the electrical conductivity is 18.96% IACS, decreasing by 19.18% IACS than that of without high pressure treatment. When the pressure is over 3 GPa, it is almost invariable.

3.4 Discussion

The thermal conduction and electric conduction of the CuAlBi alloy is composed of two parts, one is the α solid solution phase, the other is Al₄Cu₉ phase. The high pressure heat treatment cannot generate any new phase, and cannot change composition of each phase in the CuAlBi alloy, but refines the microstructure and increases the volume fraction of grain boundaries. At the same time, it increases defects quantity such as the lattice distortion and dislocation in the structure of the alloy. The grain boundaries and defects make the electronic scattering stronger that can reduce the thermal conductivity and electrical conductivity. In general, the higher pressure, the larger amount of defects such as dislocation in the microstructure, the more obvious refinement, and the lower thermal conductivity and electrical conductivity. In fact, the CuAlBi alloy after 3 GPa pressure treatment has the finest grain, the highest grain boundary density. When the pressure is over 3 GPa, the amount of defects such as dislocation in the microstructure of the alloy increases and the effects of grain refinement weakens and grain boundary density decreases. In view of affects of grain boundary and defects such as dislocation for electronic scattering, when the pressure is over 3 GPa the variation of thermal conductivity and electrical conductivity is not obvious.

As for the higher temperature, the difference between the thermal conductivity of CuAlBi alloy before and after high pressure treatment is smaller. It is because the residual stress generated by high pressure treatment eliminated with temperature rising, and the density of defects such as lattice distortion and dislocation decreases that reduces the scattering of electronic. Compared with alloys of without high pressure treatment, the thermal conductivity of the alloy after high pressure treatment is increased significantly, difference between the thermal conductivity of CuAlBi alloys before and after high pressure treatment is reduced with the temperature increasing. Figure 7 shows one endothermic peak can be seen clearly on each DSC curve of the CuAlBi alloy before and after high pressure treatment in range of 555–580°C. It can be concluded that endothermic peak resulted from the solid state phase transformation α(Cu) + γ₂(Al₄Cu₉) → β(Al₃Cu) in heating process. The solid state phase transformation occurs at 555–580°C, and has ended at 600°C, which made the shape, size and distribution of CuAlBi alloys phases change before and after high pressure treatment. It may be accounted for the proximity of thermal conductivity of CuAlBi alloys before and after high pressure treatment at 600°C.
4. Conclusions

(1) The high pressure treatment can refine the microstructure of CuAlBi alloy and increase the density of dislocation that reduce the electrical conductivity and thermal conductivity of it.

(2) The thermal conductivity and electrical conductivity decrease with the pressure increasing. When the pressure is 3 Gpa the thermal conductivity and electrical conductivity of CuAlBi are $48.537 \text{ Wm}^{-1}\text{K}^{-1}$ and 18.96% IACS, reducing by 16.62 and 19.18% than that of without high heat treatment respectively. When the pressure is over 3 Gpa the variations of thermal conductivity and electrical conductivity both are not obvious.

(3) In range of 250–600°C, the thermal conductivity of CuAlBi alloys after 3 GPa pressure treatment is lower than that of without high pressure treatment. With increment of temperature, the difference from the thermal conductivity of them gradually reduces, but the variation trend of the thermal conductivity with temperature don’t change.

REFERENCES