Localized Deformation Behavior of W-80 vol%Cu Composite at Room Temperature

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Plastic strain of about 10% was added to the W-80 vol%Cu composite at room-temperature using a three-point bend testing machine. Positions of the specific W-particles were measured before and after deformation using high-magnification SEM photographs. Then the localized deformation behavior of the composite was investigated by comparing the measured and the calculated positions of these specific W-particles after deformation. Results are summarized as follow. (1) In the region without pore, heterogeneous deformation did not occur. (2) In the region near the large pore, heterogeneous deformation occurred as expected. [doi:10.2320/matertrans.48.775]

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1. Introduction

Tungsten-copper composites (W-Cu composites) have good wear resistance and excellent thermal and electrical conductivity. From these viewpoints, W-Cu composites are used as electric and electronic materials such as heavy-duty electrical contacts, high-current circuit breakers, resistance welding electrodes and contact tips in gas-metal arc welding guns.1-6 The mechanical properties of W-Cu composites generally depend on both the microstructure and the chemical composition.1,3,4,6-10 Hiraoka et al.11 investigated the deformation behavior of W-Cu composites that had been produced alternatively by infiltrating a tungsten skeleton with liquid copper or by pressing and sintering the mixed powders of tungsten and copper. It was shown that the composites containing copper of more than 48 vol% (30 mass%) demonstrates very high ductility at room temperature.

Hiraoka et al.12 investigated the deformation behavior at room temperature for W-80 vol%Cu (W-65 mass%Cu) composite. They measured the shape and the size of W-particle using high-magnification SEM photographs before and after plastic deformation. For example, the typical length and width of the particle were between 0.5 and 4µm. It was shown that both the shape and size of the particle(s) do not change after the plastic deformation of about 10%. In this study, therefore, we used such a W-particle as a marker. By the comparison between the measured position of the W-particle and the calculated position after the plastic deformation, we deduced whether the heterogeneous deformation occurs or not around the specific particle.

2. Experimental Procedures

Tungsten powder (99.9 mass% purity, about 3µm particle size) and copper powder (99.8 mass% purity, about 3µm particle size) were used in this study. The mixed powders of tungsten and copper were pressed into a compact sheet of 26 × 50 × 5.6 mm. The compact was sintered at a temperature of 1373 K in dry hydrogen atmosphere.

Rectangular specimens of 5.6 × 26 × 1.5 mm were cut out from the sheet. Apparent volume fraction of pore in the composite was about 7%. Top surfaces of the specimen were mechanically polished using emery papers of #180-#600 and buff cloths. The polished surface of the composite was observed using a scanning electron microscope, SEM (HITACHI Field Emission Scanning Electron Microscope S-4700). Typical microstructure of the composite before deformation is shown in Fig. 1. Bright (marked by A) and dark (marked by B) regions indicate the W-particle (W-phase) and the small pore, respectively. Remaining region is Cu-phase.

A set of four indentations with an interval of about 100µm were introduced on the top surface of the specimen using a micro-Vickers hardness tester as schematically shown in Fig. 2, in order to perform the SEM observation with pinpoint accuracy. Each site was designated as C-3L, C-2L, C-1L, C-0, C-1R, C-2R, C-3R... One SEM photograph was taken for each site which is partitioned by these four indentations as shown in the figure.

Fig. 1 Typical microstructure of the composite before deformation.
Plastic strain of about 10% was added to the specimen at room temperature (about 300 K) using a three-point bend testing machine with a crosshead speed of 0.017 mm/s. After deformation, one SEM photograph was again taken for some selected sites. The averages of longitudinal strain and transversal strain of some selected sites before and after deformation were about 10% and −1%, respectively.

Localized deformation behavior of W-80 vol%Cu composite was investigated as follows. We selected several specific W-particles as markers and their positions before and after deformation are schematically shown in Figs. 3(a) and (b), respectively. Actually the digital SEM image (2448 x 1976 pixels) was printed out to a sheet of A1 size (594 x 841 mm) using an inkjet printer (EPSON PM-7000). First, a set of four W-particles with intervals of 70–100 µm (in longitudinal direction) and 50–70 µm (in transversal direction) marked by O, A, B, C and O, A’, B’, C’ were selected in the site partitioned by the four indentations. Here, the lower, right W-particle (O) was fixed as a standard point, and x-axis and y-axis were determined as shown in the figure. Then a specific W-particle, for example, marked by “D” and “D’” were selected inside the quadrangles OABC and OA’B’C’, respectively. The calculated position (D*) of the specific W-particle after deformation was obtained assuming that the quadrangle region itself deforms homogeneously. Positions of these W-particles before and after deformation are given by the following equations.

\[ m : n = d_s : (a_s - d_s) \]  
\[ f : g = (d_x - a_x) : (b_x - d_x) \]  
\[ h : i = (b_y - d_y) : d_y \]  
\[ j : k = (c_x - d_x) : d_x \]  
\[ (1) \quad (2) \quad (3) \quad (4) \]

Assuming that the quadrangle OABC deforms homogeneously and the partition ratios as shown by eqs. (1)–(4) do not change even after deformation, the positions, P’, Q’, R’ and S’ after deformation are given by the following equations.

\[ P' = (ma'_x/(m + n), ma'_y/(m + n)) \]  
\[ Q' = ((ga'_x + fb'_y)/(f + g), (ga'_x + fb'_y)/(f + g)) \]  
\[ R' = ((ib'_x + hc'_y)/(h + i), (ib'_x + hc'_y)/(h + i)) \]  
\[ S' = (kc'_x/(j + k), kc'_y/(j + k)) \]  
\[ (5) \quad (6) \quad (7) \quad (8) \]

The position of the W-particle after deformation, D* (d_x*, d_y*) is calculated as the intersection point of the line P’R’ and the line Q’S’. Considering the difference between the calculated position (D*) and the measured position (D’), it was deduced whether the deformation in the localized region surrounding this W-particle is homogeneous or heterogeneous. In case that such a difference is small or negligible, the localized deformation in the region around the W-particle is homogeneous. In case that such a difference is relatively large, in contrast, the localized deformation in the region around the W-particle is heterogeneous.

3. Result and Discussion

Applied stress-strain curve of W-80 vol%Cu composite is shown in Fig. 4. The arrow in the figure indicates a point at which deformation was suspended. It is already reported that W-80 vol%Cu composite demonstrates a large plastic strain before fracture.\(^\text{11,12}\) SEM photographs of the site C-1R and the C-2R, respectively, before and after deformation are shown in Figs. 5 and 6. In the figure, the quadrangle and twenty specific W-particles are painted with white lines and black ink, respectively. It is noted that these two sites are positioned almost at the center of the specimen, and no large pores are recognized in the regions.
The comparison between the calculated and the experimental positions of the W-particle after deformation is given in Fig. 7(C-1R) and Fig. 8(C-2R). The white and the black data points indicate the calculated and the measured positions, respectively, of the specific W-particles after deformation. On measuring the position of the W-particle, the experimental error of 1–1.5 μm is expected. In this study, for convenience, it was deduced that the localized deformation is heterogeneous in case that the difference between the calculated and the measured positions is more than a critical.
value of 2 µm. From Figs. 7 and 8, it is concluded that localized deformation in the site C-1R and C-2R is not heterogeneous.

Figure 9 shows the SEM photograph of the site C-1L involving two large pores. The quadrangle and twenty specific W-particles are painted in a manner similar to Figs. 5 and 6. It is obvious that both the length and the width of such a large pore increased significantly after deformation. The pronounced morphology change of the pore is due to the
development of cracking along the interfaces between the W-particle and the Cu-phase and/or between the W-particles.\textsuperscript{12)} Comparison between the calculated (white data point) and the measured (black data point) positions of the twenty W-particles is given in Fig. 10. It is obvious that significant difference was obtained at the eight W-particles as marked by arrows in the figure. This result suggests that the localized deformation in the region around these W-particles is heterogeneous. It is interesting that such a significant difference was recognized particularly at the W-particles near the large pore(s).

In the next step, we tried to revise the calculated position of the W-particles considering the pronounced morphology change of the large pore(s). Morphology of the pore and the positions of the twenty W-particles before and after deformation are schematically shown in Figs. 11(a) and (b), respectively. The white thick lines crossing the pore(s) in the figures indicate the longitudinal or the transversal size of the pore before and after deformation. Here the calculated position of the W-particle is revised by subtracting these morphology changes of the pore from the position of the W-particles. The comparison between the calculated positions after revision (white data point) and the measured positions (black data point) is given in Fig. 12. This result suggests that the localized deformation in the region around the W-particles near the large pore(s) is heterogeneous. It is interesting that such a significant difference was recognized particularly at the W-particles near the large pore(s).

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4. Conclusions

(1) In the region involving no large pores, the localized deformation was not heterogeneous.

(2) In the region involving large pore(s), heterogeneous deformation occurs particularly near the pore. However, by considering the pronounced morphology change of the pore, it is revised that heterogeneous deformation did not occur even near the large pore.

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REFERENCES


<table>
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<tr>
<th>Site No.</th>
<th>C-1R</th>
<th>C-2R</th>
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<td>17</td>
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<tr>
<td>Average of transversal strain (%)</td>
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<td>−1</td>
<td>−2</td>
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