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Interfacial Microstructures and Bonding Characteristics of ODS-Ag/Cu Alloy Electric Contact Materials

Yasuhiro Morizono, Minoru Nishida*, Akira Chiba*, Takateru Yamamuro*, Masayuki Muto** and Takao Asada***
Shock Wave and Condensed Matter Research Center, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan
Fax: 81-96-342-3710, E-mail: morizono@gpo.kumamoto-u.ac.jp
* Department of Mechanical Engineering and Materials Science, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan
Fax: 81-96-342-3710, E-mail: nishdia@gpo.kumamoto-u.ac.jp, chiba@gpo.kumamoto-u.ac.jp, yamamuro@alpha.msre.kumamoto-u.ac.jp
** Graduate student, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan
*** Tanaka Kikinzoku Kogyo K. K., Iwate Plant, Esashi, Iwate 023-1101, Japan
Fax: 81-197-35-5910, E-mail: takao-asada@ml.tanaka.co.jp

Oxide dispersion strengthened silver (ODS-Ag), which is one of electric contact materials, has been bonded to Cu and phosphor bronze (Cu-Sn-P) by diffusion bonding and explosive welding. The ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints diffusion-bonded at 973 K for 3.6 ks in a vacuum show a bonding strength of less than 40 and 10 MPa, respectively. These values are inferior to that of Ag/Cu joint produced in the same way. This indicates that their bondability is poor due to oxide particles in Ag matrix. On the other hand, the explosive welded joints have no defect such as un-bonded area in the collision interface. From the microstructural aspects in the joint deformed by bending, it is considered that the explosive welding contributes greatly to formation of substantial bond between the ODS-Ag and the Cu materials. The interfacial microstructures of the diffusion-bonded and explosively welded joints are also discussed.

Key words: electric contact material, oxide dispersion strengthened silver, copper, phosphor bronze, diffusion bonding, explosive welding

1. INTRODUCTION

Electric contact such as power switch and relay is a mechanical part in electrical circuit and has several problems associated with arc discharge and Joule heat in action. For example, insulation, welding and locking are well known as a cause of trouble in the electric contact. To improve its reliability, a large variety of the electric contact materials has been developed in response to applications [1]. Among them, Ag base composite material with cadmium oxide particles, which is one of ODS-Ag materials, attracts attention because of its excellent welding, erosion and contact resistances.

On the other hand, it is desired that the electric contact materials containing precious metals are joined to dissimilar materials such as Cu alloys in order to reduce the product price. In general, such combined contact materials are fabricated continuously by rolling and become a tape shaped product with inlay- and overlay-type structures. However, the ODS-Ag is difficult to be joined to the dissimilar materials in the same way due to its poor ductility and workability. In the present study, the ODS-Ag is bonded directly to Cu and Cu-Sn-P by diffusion bonding and explosive welding, and their bondability is discussed on the basis of interfacial microstructures and bonding characteristics.

2. EXPERIMENTAL PROCEDURES

The used ODS-Ag contained SnO_2 and In_2O_3 particles instead of CdO, since cadmium has ill effects on the human body. The volume fraction of these oxide particles in the ODS-Ag was 12.5 vol%. Its dimensions were 4 mm X 4 mm X 0.5 mm for diffusion bonding and 40 mm X 4 mm X 0.5 mm for explosive welding. For comparison, Ag with same dimensions was also prepared. Meanwhile, pure Cu and Cu-Sn-P plates established by Japanese Industrial Standards Committee were selected as a cladding metal. The Cu-Sn-P was one of Cu alloys for spring, and this characteristic is also indispensable to electric contact materials. The purity of Cu (JIS H 3100-C1100) was 99.96 mass%, and the Cu-Sn-P (JIS H 3130-C5210) contained more than 99.7 mass% Cu+Sn+P. These dimensions were 7 mm X 7 mm X 2 mm for the diffusion bonding and 90 mm X 30 mm X 2 mm for the explosive welding. Before bonding treatment, all materials were annealed at 773 K for 3.6 ks in a vacuum of less than 3 X 10^{-3} Pa. These bonding surfaces were mechanically ground to remove oxide scale and then were polished with emery papers. Subsequently, these were cleaned by immersing in an aqueous solution containing 10 vol% HNO_3 and by degreasing in acetone with ultrasonic cleaner.

The stacking sequence for the diffusion bonding was Cu (or Cu-Sn-P), ODS-Ag and Cu (or Cu-Sn-P). Diffusion bonding was carried out at 973 K for 3.6 ks in a vacuum of less than 3 X 10^{-3} Pa.

The explosive welding was performed using

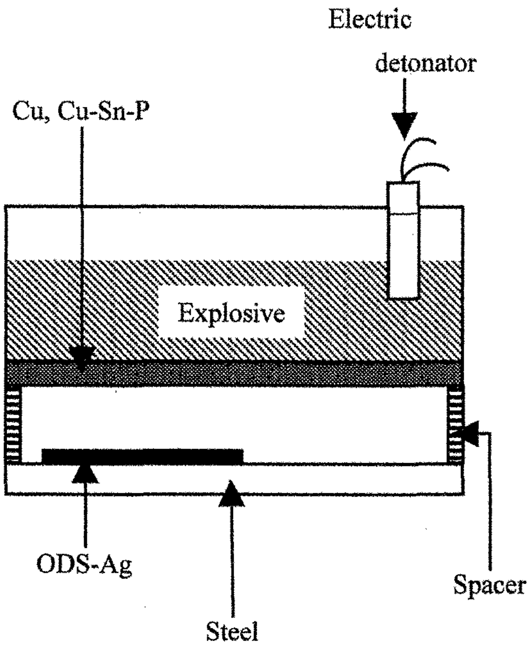

Figure 1. Experimental assembly for explosive welding.

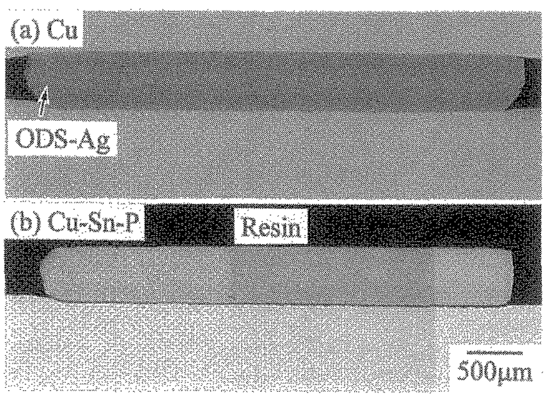

Figure 2. Cross sectional views of (a) ODS-Ag/Cu and (b) ODS-Ag/Cu-Sn-P joints bonded at 973 K for 3.6 ks.

experimental assembly shown in Fig. 1. The ODS-Ag is located parallel to the Cu materials at a distance of 10 mm. The used explosive is powdery one consisting mainly of ammonium nitrate. Its detonation velocity is about 2400 m/s. In some cases, the Cu plate was inserted between the ODS-Ag and the steel anvil to obtain three-layered joints for transmission electron microscopic (TEM) observations. After explosive welding, some specimens were annealed at 773 K for 3.6 ks in a vacuum of 3 X 10^{-3} Pa to relax internal stress.

The bonding interface in the obtained joints was examined by optical microscopy, scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectroscopy (EDX) and TEM. Their mechanical properties were evaluated at room temperature by hardness, shear and bending tests. The bending test in the present study was a qualitative examination on the basis of microstructural aspect. This was conducted for the joints fabricated by the explosive welding, because conventional strength tests were limited by the shape of the specimen.

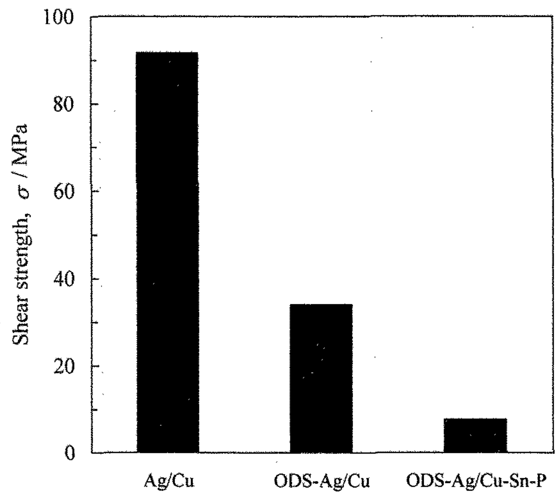

Figure 3. Shear strength of Ag/Cu, ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints bonded at 973 K for 3.6 ks.

3. RESULTS AND DISCUSSION

3.1 Diffusion Bonding

ODS-Ag has to be joined in solid state to avoid the change of its properties. Hence, diffusion bonding of the ODS-Ag to the Cu materials was carried out at 973 K, since the combination of Ag and Cu has eutectic reaction at 1052 K. Figures 2(a) and 2(b) show cross sectional views of the ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints bonded at 973 K for 3.6 ks, respectively. Brown parts in the figures correspond to the Cu materials. In the ODS-Ag/Cu joint, the diffusion bonding appears to be well achieved. The bonding surface of Cu smoothed with polishing is deformed at the edge of the interface. This indicates that plastic deformation of Cu at elevated temperatures serves as an adhesion promoter on the bonding process. However, reaction layer due to interdiffusion between Ag and Cu is not observed. On the other hand, some joints with sandwich structure consisting of one ODS-Ag and two Cu-Sn-P plates were broken at the interface after bonding. Black area denoted by "resin" in Fig. 2(b) reflects such a situation. The un-bonded area is also seen in the location keeping in contact, though the bonding surface of the Cu-Sn-P, as well as the case of the ODS-Ag/Cu joint, is deformed during the diffusion bonding.

Figure 3 shows the bonding strength of the ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints bonded at 973 K for 3.6 ks. For comparison, Ag/Cu joint was prepared in the same way. 5-times-test was conducted for each specimen, and the average value is plotted in the figure. Shear strength of the Ag/Cu joint is about 90 MPa and is found to be relatively low. This tendency is also supported by the report that tensile strength of the Ag/Cu joint bonded at 973 K is about 50 MPa [2]. The ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints show the shear strength of less than 40 and 10 MPa, respectively. It is thought that the contact between parent materials is promoted by plastic deformation as seen in Fig. 2. Thus the diffusion bondability for these combinations seems to degenerate with oxide particles in Ag matrix. Additionally, the difference of the bonding strength between the ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints may be attributed to constituent elements in the Cu materials rather than the influence of thermal stress occurring during the diffusion bonding, because thermal expansion coefficient of Cu is approximately equal to that of Cu-Sn-P.

As described in previous section, the ODS is difficult to be joined by rolling. This reason is considered to be that not only its ductility and workability but also diffusion bondability is poor. These facts show the difficulty in bonding the ODS-Ag to the Cu materials.

3.2 Explosive welding

Explosive welding is basically a solid state welding process. One of its advantages is the formation capability of substantial bond between two materials, which cannot be joined by conventional methods. Hence this process was applied to the bonding of ODS-Ag to Cu materials.

Figure 4(a) shows a SEM micrograph of the collision interface in explosively welded ODS-Ag/Cu joint. Cu is the upper side and ODS-Ag is lower side in the micrograph. The joint has a typically wavy interface, and there is no defect such as un-bonded area. Plastic flow occurred by high energy collision is also seen in the Cu side near the interface. The cap of a wave indicated by arrow is enlarged in Fig. 4(b). Region I in the micrograph exhibits a different aspect from parent materials. In this region, both parent materials are considered to be mechanically mixed and melted during the explosive welding. On the other hand, interfacial microstructure after annealing at 773 K for 3.6 ks is shown in Fig. 4(c). The wavy interface is retained, while the plastic flow in Cu cannot be observed. The region indicated by arrow is the so-called front vortex zone, and its enlarged SEM micrograph is shown in Fig. 4(d). Since etching for Cu was applied before observations, region II in the micrograph corresponds to eutectic structure of Ag-Cu binary system. This region before annealing, as well as the region I in Fig. 4(b), was a mechanically mixed zone of the parent materials. Thus, it is found that supersaturated solid solution such as the region I makes the transition to equilibrium state shown in Fig. 4(d) by annealing at 773 K. Similar microstructural modifications were confirmed in the case of the explosively welded ODS-Ag/Cu-Sn-P joint.

TEM observations were carried out to examine the interfacial microstructures in detail, because it was difficult to characterize them on a SEM scale. Figure 5 shows a bright field image of the collision interface in explosively welded ODS-Ag/Cu joint. Cu is upper side and the bonding interface is indicated by arrows. ODS-Ag and Cu are directly connected by the impact pressure, and there is no reaction product in the inflected interface. In some places, the formation of molten layer, which was about 100 nm in thickness, was also recognized. Consequently, the joint produced by the explosive welding has two morphologies at the collision interface, but the reason is unclear now. In both cases, it is expected that the explosive welding contributes greatly to the formation of substantial bond between the ODS-Ag and the Cu materials, as well as explosively welded titanium clad materials [3 - 5]. It is noteworthy that deformative crystal grains in the ODS-Ag due to high energy collision are hardly seen in Fig. 5. This results from dispersed oxide particles in Ag matrix, and

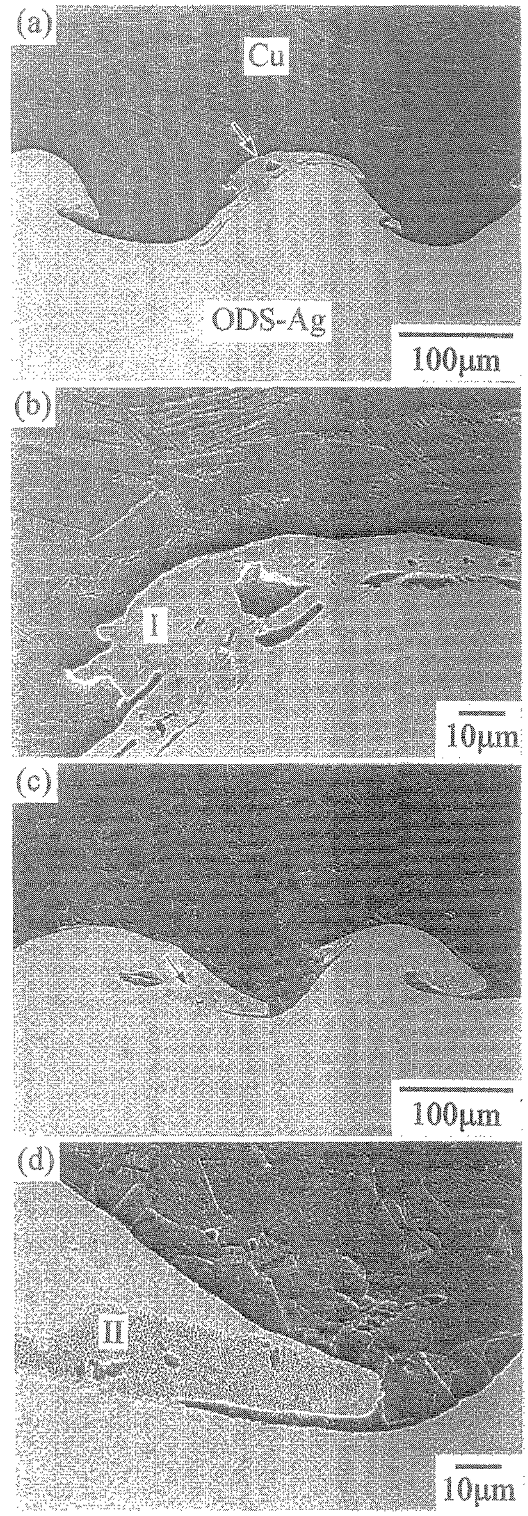

Figure 4. SEM micrographs of the bonding interface in explosively welded ODS-Ag/Cu joint. (a) and (b) As-welded joint. (c) and (d) After annealing at 773 K for 3.6 ks.

suggests that the ODS-Ag may have applicability to the explosive welding with higher impact pressure.

Measurement of Vickers hardness around the collision interface was carried out in the explosively welded ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints. Both joints generated strain hardening around the interface. Especially, the hardness of the Cu materials increased immensely, and returned to that of starting materials after annealing at 773 K. This tendency was consistent with microstructural modifications shown in Fig. 4. On the other hand, the ODS-Ag in explosively welded joint showed almost the same hardness as before bonding. This fact may be also related to the microstructure of the ODS-Ag shown in Fig. 5.

It was necessary to evaluate the bonding strength of the explosively welded ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints. However, the conventional tests could not be applied, since these joints showed inlay-type structure; that is to say, the ODS-Ag was embedded into the Cu materials. Therefore, the specimen whose dimensions were 30 mm X 2 mm X 2 mm was mechanically bent like schematic illustration shown in Fig. 6, and its interfacial aspect was observed by optical microscopy. Figures 6(a) and 6(b) show cross sectional views of the ODS-Ag/Cu and ODS-Ag/Cu-Sn-P joints, respectively. Since the strain hardening in the as-welded joint interfered with the deformation by bending, the specimens annealed at 773 K are used. The bond between ODS-Ag and Cu is retained even after bending, while cracks are introduced in the ODS-Ag/Cu-Sn-P joint. It should be noted that the fracture of the joint occurs not only at the interface but also in the ODS-Ag as indicated by arrows in Fig. 6(b). Such a situation is also confirmed in the case of bending to the opposite side. This is one of evidences that the substantial bond is formed at the interface by the explosive welding. It is predicted that the as-bonded joint has more substantial interface, since its strength is generally lowered by heat treatment [4].

In summary, explosive welding is recommended as a bonding method of the ODS-Ag to the Cu materials.

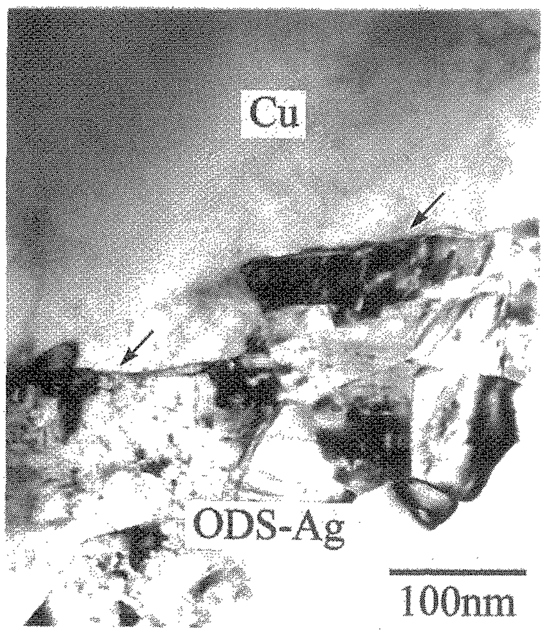

Figure 5. Bright field image of the collision interface in explosively welded ODS-Ag/Cu joint.

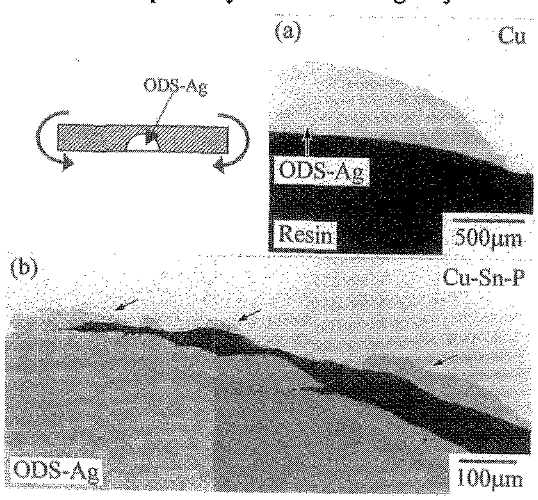

Figure 6. Cross sectional views of (a) ODS-Ag/Cu and (b) ODS-Ag/Cu-Sn-P joints deformed by bending. These joints were annealed at 773 K for 3.6 ks after explosive welding.

4. CONCLUDING REMARKS

ODS-Ag, which is one of electric contact materials, is bonded directly to Cu and Cu-Sn-P by diffusion bonding and explosive welding. The main conclusions are summarized as follows.

(1) Diffusion bondability of the ODS-Ag to the Cu materials is poor due to oxide particles in Ag matrix.

(2) The explosive welding, which is a solid state welding with high energy collision, is concluded to have a beneficial effect on the improvement of bondability of the ODS-Ag to the Cu materials.

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