JOURNAL OF MATERIALS SCIENCE 27 (1992) 1179–1183

Manufacturing process and material characteristics of Ag–Ni contacts consisting of nickel-compounded particles

K. TSUJI, H. INADA, K. KOJIMA
Materials Research and Development Laboratory, Matsushita Electric Works Ltd 1048 Kadoma, Osaka 571, Japan
M. SATOH, K. HIGASHI, K. MIYANAMI, S. TANIMURA
College of Engineering, University of Osaka Prefecture, 4-804 Mozu-Umemachi, Sakai, Osaka 591, Japan

Using a high-speed, high-shear mill, particle surfaces of Ag–Ni alloy in which Ni is finely dispersed in the Ag matrix were coated and compounded with Ni powder. Particles thus compounded can be processed into a wire. Post-processing compounded Ni forms a fibrous texture on the wire longitudinal section and a network on the cross-section. This characteristic metallurgical structure improves the contact performance (fusion and wear resistances).

1. Introduction

Contacts are used in relays, magnetic switches, contact breakers and similar current-switching devices. From the standpoint of conductivity and corrosion resistance, Ag-base materials, particularly Ag–metal oxide and Ag–Ni, are most often in service [1, 2]. Ag–Ni contacts, well known as having high workability and low contact resistance, are used as medium to weak current contacts [2].

The size of particles dispersed in Ag affects the contact performance [3–5], and a number of reports have been publicized with regard to improved performance by the fining of CdO [4] and Ni [3]. In another report [2] it is reported that contact performance is improved by using as the contact surface a section of 5 μm or less of fibrous Ni dispersed in the longitudinal direction. Thus, although better contact performance is anticipated by fining fibrous Ni, such fining is difficult with the conventional manufacturing process, which is limited to an average of 3 to 5 μm. The reason is as follows. Ag–Ni contacts are obtained by forming and bringing to normal sintering the mixture of electrolytic Ag powder and carbonyl Ni powder. With 1 μm or finer particles, dispersion down to primary particles is difficult, because of agglomeration. Moreover, the particle surfaces adsorb gas, and this represents an additional difficulty for obtaining a sintered body of the theoretical density.

Recent reports [6–8] propose the so-called dry particle compounding process, a method of compounding two types of particle by coating mother particle surfaces with fine particles using a high-speed, high-shear mill.

In the present study this process was applied to contact manufacture. We propose a new manufacturing process to provide Ag–Ni contacts with fine fibrous Ni, revealing the advantages of the new method. This report describes the metallurgical structure, material characteristics and contact performance of a material prepared by forming, sintering, extruding and drawing using Ni-coated Ag–Ni alloy particles.

2. Experimental procedure

Ag–Ni alloy particles were obtained by melting 99.99% Ag and Ni, bringing the molten metal ejected from a nozzle to rapid cooling by the water-atomizing method, and finely dispersing Ni in Ag. The particle surfaces were coated with Ni fines and compounded to high concentration with a high-speed, high-shear mill. The mill used was a modification of a fine grinding mill. Fig. 1 shows the construction. In this mill the rounded piece was made of hard alumina so as to prevent the mixing of worn powder.

Compounded particles thus obtained were formed, sintered, hot-extruded, and drawn into wires. Fig. 2 provides the flow chart of this series of processing. In this chart swaging and drawing are steps for wire forming, and revet-forming is a step to prepare samples for the evaluation of contact performance. Wires consisting of uncompounded Ag–Ni alloy particles only were also produced by the same procedures to be used as a control.

With these two types of wire, high-temperature hardness up to 823 K was measured, tensile tests at normal temperature performed, and mechanical characteristics studied. Further, with revet-shape contacts, contact performance, i.e. fusion and wear resistances, was studied.

3. Results and discussion

Fig. 3 shows scanning electron micrographs of a section of Ag–Ni alloy particles prepared by the rapid

0022–2461

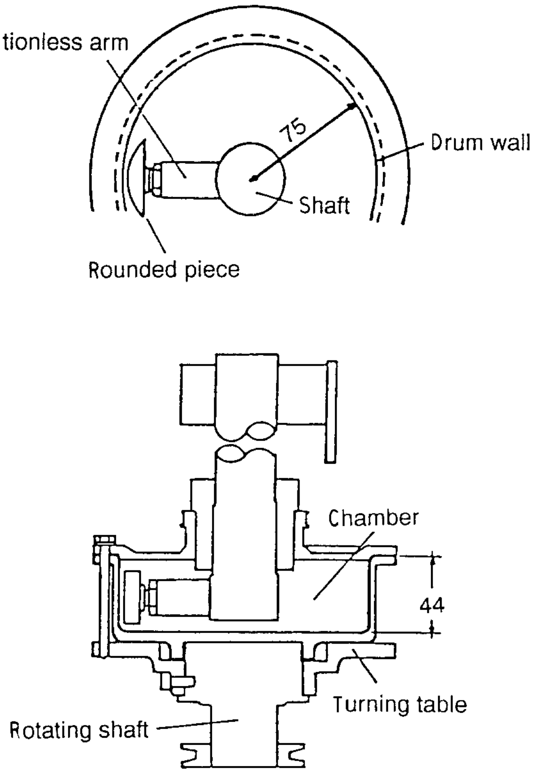

Figure 1 Construction of high-speed, high-shear mill (dimensions in mm).

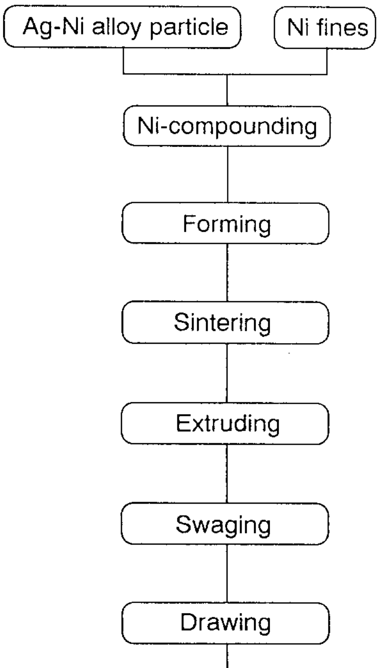

Figure 2 Ag–Ni contact manufacturing process.

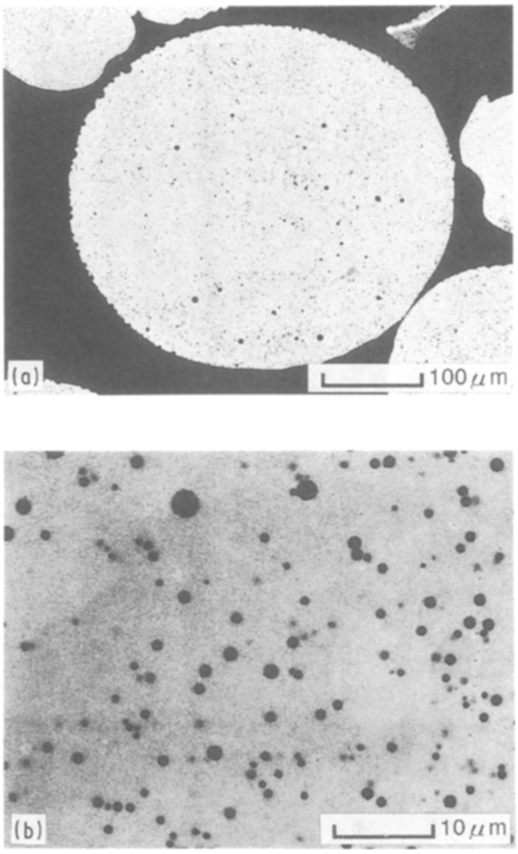

Figure 3 Section of Ag–Ni alloy particle: (a) external view, (b) magnified interior (SEM).

cooling method. Fig. 3a represents the entire view of a particle, and Fig. 5b a magnified view of its interior. These views reveal that Ni molten at high temperature separates as a result of rapid cooling, finely dispersing at 1 μm or less in mean diameter in the Ag matrix. The mean diameter of the alloy particle is 210 μm. The proportion of Ni analysed with inductively coupled plasma (ICP) was 5.2 wt %. The reason for using alloy particles in which Ni is dispersed in advance is to achieve improved contact performance by virtue of the strength of dispersed Ni in the Ag matrix, and to prevent plastic deformation of particles due to compression and shear during Ni compounding with a high-speed, high-shear mill, thus obtaining uniform and tight Ni coating.

The compounding process using a system as shown in Fig. 1 is as follows. The drum rotates at high speed. The rounded piece fixed inside the drum with a given spacing in-between presses (against the drum wall) particles charged in the drum and pressed on to the drum wall due to the centrifugal force. Particles thus packed between the drum wall and the rounded piece undergo strong compression and shear. With this process repeated, the compounding proceeds [6–8].

Fig. 4 shows a scanning electron micrograph of the Ni particles used. Fig. 5 shows this Ni, 1 μm in mean diameter, added to a total of 10 wt % and treated for 4500 s in an argon atmosphere at a rotational speed of 17.2 rps, with the drum–piece clearance set at 3.9 mm. In this process 1 mm zirconium beads were used as a medium to prevent fine particles from sticking to the drum wall and the rounded piece, so as to improve the dispersion effects of Ni particles and shear and compression effects. Fig. 5a shows a secondary electron micrograph of a section of the compounded material, and Fig. 5b the X-ray micrograph (NiK_α). The particle surfaces are coated with Ni to a thickness of 5 to 15 μm, and the Ni layer is tightly packed. This is attributed to strong compression and shear and high frictional heat. The Ni proportion after compounding

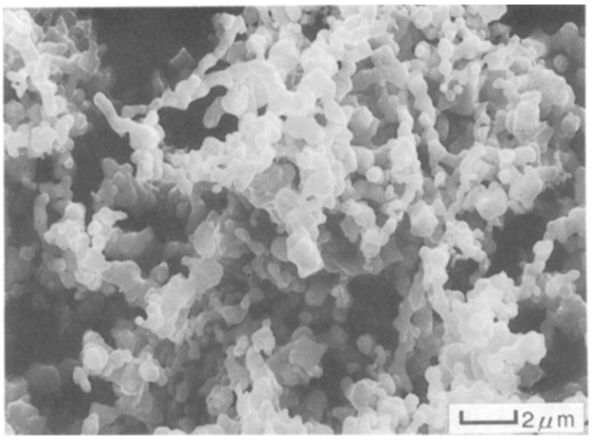

Figure 4 Ni particles used for compounding (SEM).

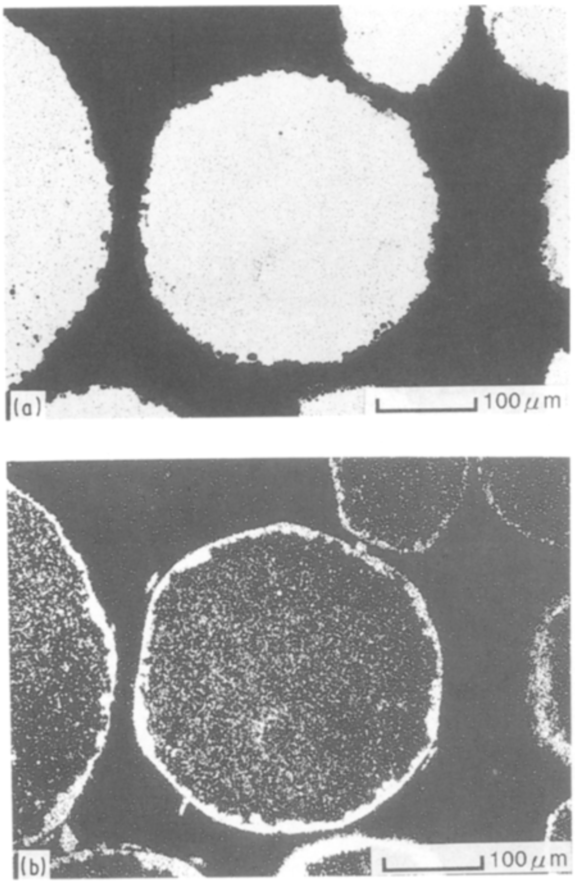

Figure 5 Section of a particle Ni-compounded with a high-speed, high-shear mill: (a) secondary electron micrograph, (b) NiK_α image.

(actually after ultrasonic cleaning) is 8.9 wt %, which indicates that 77% of added Ni contributes to compounding.

The material obtained by Ni compounding was formed into wire using the normal sintering technique under the following conditions:

Forming	900 MPa, 693 K, 600 s, 35 mm in diameter
Sintering	1173 K, 14.4 ks, in vacuum (10^{-6} torr)
Extruding	900 MPa, 1073 K, 8 mm in diameter
Swaging (drawing)	8 mm into 2 mm in diameter

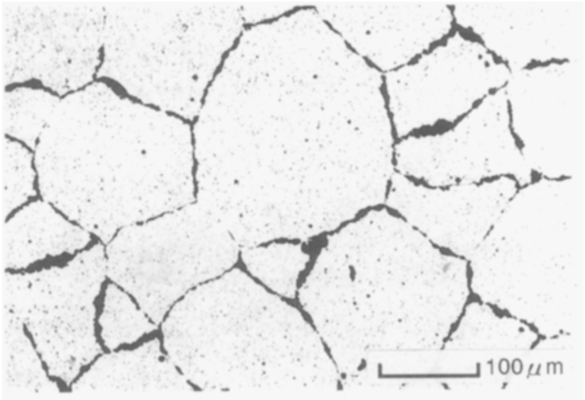

Figure 6 Metallurgical structure of Ni-compounded particles after extrusion.

Fig. 6 shows the metallurgical structure the material using compounded particles after extrusion. It is known that Ni arrays in a network with a width of 3 to 15 μm on the grain boundary, and that the Ag–Ni alloy particle diameter ranges from 80 to 260 μm with Ni fines dispersed among the particles. Fig. 7 reveals the metallurgical structure after drawing. Fig. 7a and b indicate the cross-section and Fig. 7c and d the longitudinal section. Fig. 7a and c are secondary electron micrographs and Fig. 7b and d X-ray micrographs (NiK_α). The network structure is maintained on the cross-section even after drawing. The Ag–Ni alloy particle diameter is compacted to 15 to 40 μm in the Ni width of 0.4 to 5 μm on the grain boundary, thus forming a tighter network (Fig. 7a and b). On the longitudinal section Ni extends in the longitudinal direction of the wire as a result of extruding and drawing, providing a fibrous texture with a length of about 20 to 50 μm, and Ni fines separated in advance among the fibrous Ni particles are dispersed (Fig. 7c and d).

Figs 8 and 9 illustrate the mechanical characteristics of drawn wires. Fig. 8 indicates the nominal stress–strain (σ–ε) characteristics leading to breakage at normal temperature. Ni compounding increases the tensile strength. Fig. 9 shows the temperature–hardness characteristics. Ni-compounded particles (solid squares), in comparison with uncompounded particles (open squares), exhibit a higher hardness over the entire measuring temperature range up to 823 K, suggesting that the material strength is increased. On either side of 523 K the slopes of temperature versus hardness vary, probably because recrystallization begins at 523 K or higher, removing the strain due to processing. In Ag–CdO contact materials it is reported that materials with high hardness also have high fusion resistance [4]. The present results predict that in Ag–Ni materials the Ni-compounded materials are superior in fusion resistance as well.

Fig. 10 shows the appearance of completed rivet contacts. Fig. 11 shows the results of performance evaluation of rivet contacts using an ASTM tester. Fig. 11a represents the fusion characteristics and Fig. 11b the wear characteristics. The test was conducted

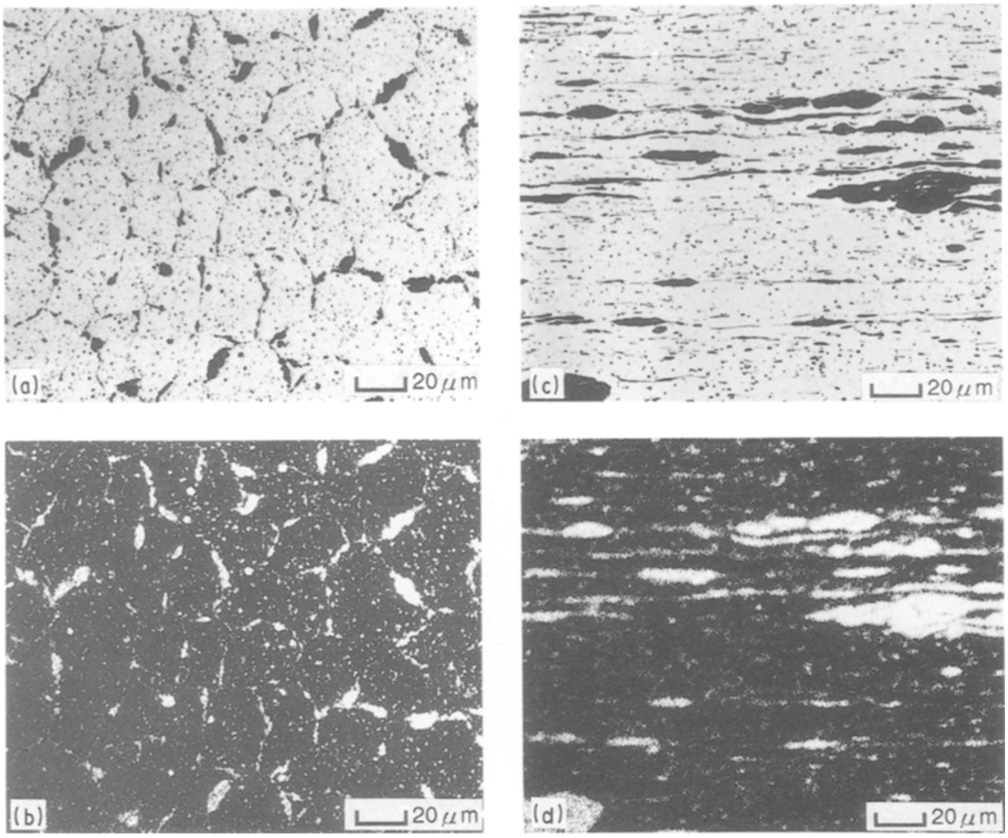

Figure 7 Metallurgical structure of Ni-compounded particles after drawing: (a) cross-section (secondary electron micrograph), (b) cross-section (NiK_α), (c) longitudinal section (secondary electron micrograph), (d) longitudinal section (NiK_α).

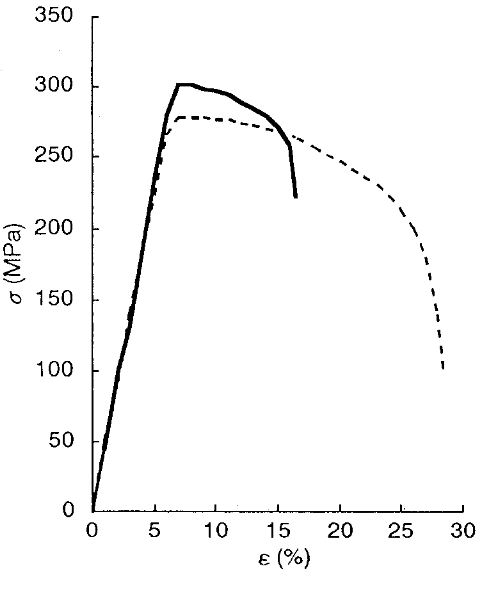

Figure 8 Nominal stress–nominal strain (σ–ε) characteristics of drawn material: (——) Ni-compounded, (– – –) uncompounded particle.

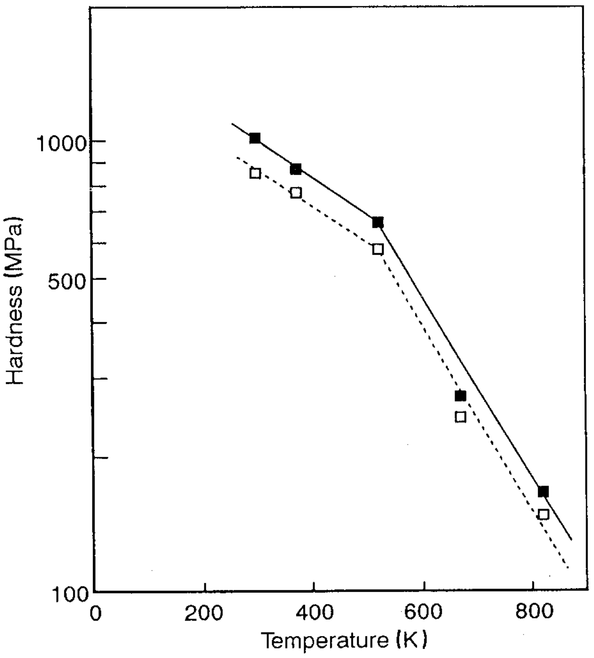

Figure 9 Temperature–hardness characteristics of drawn material: (■) Ni-compounded, (□) uncompounded particle.

under a resistance load at 100 V, 40 A, 200 gf of opening force and 140 gf of closing force, repeating the opening/closing cycle 50 000 times. From this diagram it is safe to say that material with fibrously dispersed Ni is better than uncompounded material in the number of fusion occurrences and the amount of wear. Wear in particular is reduced by almost half.

Contact material using compounded particles has the following features. As shown in Fig. 7c and d, fibrous Ni arrays perpendicular to the contact surface. The contact surface is sectioned by network Ni into cells, whose interior is reinforced by Ni fines. These features synergistically work to decrease spattering due to arcing and consequently reduce the wear.

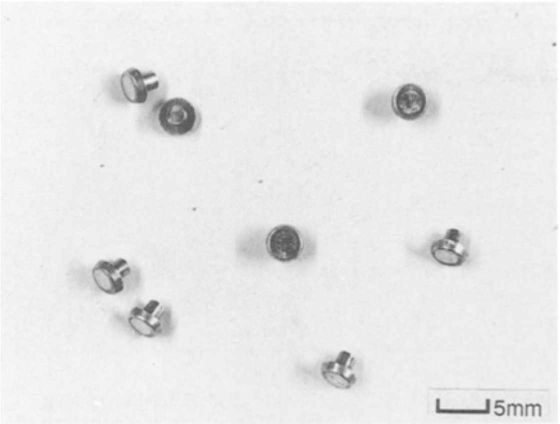

Figure 10 Appearance of Ag–Ni contacts.

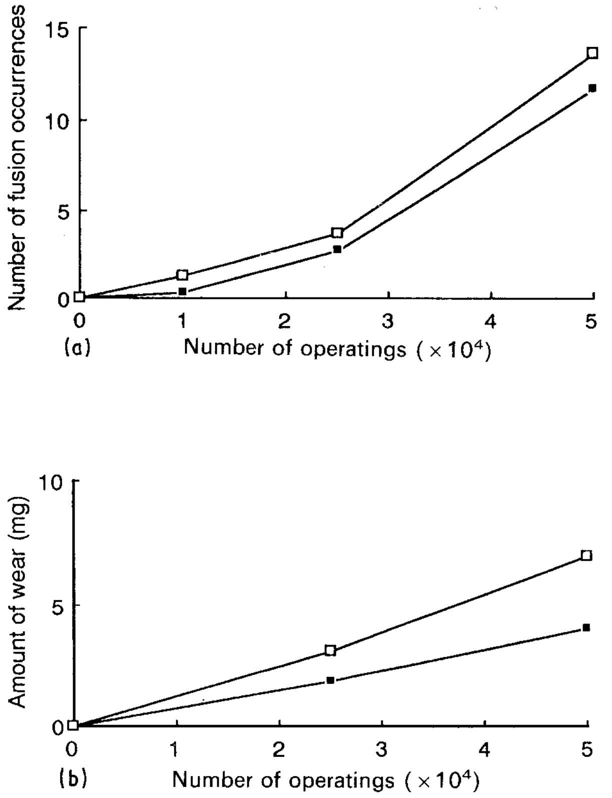

Figure 11 Contact performance test results for (a) fusion and (b) wear: (■) Ni-compounded, (□) uncompounded particle. Test conditions: 100 V, 40 A, loaded with resistance.

Furthermore, since the area of material made molten by arcing is localized by these effects, fusion occurs less frequently.

In the present study the mean diameter of Ag–Ni alloy particles was 210 μm. Smaller diameters than this would increase the particle surface area, thus thinning the Ni layer after compounding. In consequence, fibrous Ni and the cells can be further fined in cross-sectional diameter, which was difficult to achieve with the conventional technique. With regard to Ag–CdO materials a report indicates the improvement of contact performance as a result of fining [4]. Thus, in Ag–Ni materials as well, an improvement of material strength and contact performance is anticipated, and in this sense the present Ag–Ni contact manufacturing process is considered to be hopeful.

4. Conclusions

Regarding a new Ag–Ni contact material whose Ag–Ni alloy particle surfaces were compounded with Ni, its manufacturing process, material characteristics and contact performance were studied. The results can be summarized as follows.

1. Processing with a high-speed, high-shear mill Ni particles and Ag–Ni alloy particles in which Ni was dispersed in Ag to increase the strength allowed particle surfaces to be coated and compounded with Ni. Compounded particles can be formed into wires and rivet contacts using the conventional sintering technique.
2. Such wires have a characteristic metallurgical structure with Ni fines dispersed in the Ag matrix, fibrous Ni on the longitudinal section, and a network of Ni on the cross-section.
3. In comparison with uncompounded material, Ni-compounded material with this metallurgical structure has superior characteristics in contact performance, reducing the wear due to contact opening/closing to almost half.

Acknowledgements

We thank Mr Y. Takegawa of Matsushita Electric Works, Ltd for their great efforts in contact prototype production, including forming and performance evaluation, and Mr Y. Akechi of the same company for his co-operation in electron probe microanalysis.

References

1. S. STOIARZ, *Sci. Sintering* **7** (1975) 169.
2. K.-H. SCHRÖDER, IEEE CH2453, 4, 87, 163 (1987).
3. M. KUNTCHEVA, J. DIMITROVAND and R. TODOROV, Proceedings of 8th International Conference on Electrical Contact Phenomena (1976) p. 523.
4. S. YAMADA, K. TSUJI, K. YAMADA and H. MOTOKAWA, in Proceedings of 37th Relay Conference (1989) p. 3–1.
5. M. SATOH, *J. Jpn Inst. Metals* **43** (1979) 1095.
6. K. TANNO, F. YOKOYAMA and K. URAYAMA, *J. Soc. Powder Technol. Jpn* **27** (1990) 153.
7. M. ALONSO, M. SATOH and K. MIYANAMI, *Powder Technol.* **59** (1989) 45.
8. K. HIGASHI, M. SATOH, F. HAMANO, K. MIYANAMI, S. TANIMURA, T. ITO, M. KUMAYA, K. SHIBUE and H. YOSHIDA, *J. Jpn. Soc. Powder Metall.* **37** (1990) 292.

Received 29 October 1990
and accepted 25 March 1991