The Journal of CPRI,
Vol. 5, No. 2, September 2009 pp. 19–24

Optimization of ARC Erosion Resistance of Silver Tin Oxide Electrical Contacts Prepared using the Electroless Route

Godkhindi S S, Grewal G S, Joshi P B*, Ramamoorty M** and Buch N J

The use of cadmium and cadmium oxide containing contact materials has been strongly discouraged in most parts of the world in view of the toxicity of these materials and resultant environmental and health hazards. Tin oxide has emerged as a substitute material in place of cadmium oxide as the major modern silver-metal oxide contact system for industrial application. The traditional methods of synthesis of silver-cadmium oxide composite contacts (namely internal oxidation and powder metallurgy route of co-precipitation) have been found to be unsuitable for production of silver-tin oxide contact material mainly because of incompatibility of existing compounds of tin metal that are water soluble and which can be used for co-precipitation with silver salt such as silver nitrate as well as the very slow rates of internal oxidation of tin in silver-tin oxide system as compared to that of cadmium in silver-cadmium oxide system. For synthesis of silver-tin oxide powders, a novel method based on electroless coating, has been developed. In the present work, an optimization study has been undertaken for improving the arc erosion characteristics of silver tin oxide contacts, prepared using the novel electroless route with additions of a tertiary stabilizing tungsten oxide dopant. The work has been undertaken in a Statistical Factorial Design of Experiment (SDOE) setting using the one way ANOVA technique.

Key words: *Silver cadmium oxide, silver tin oxide, electroless and arc erosion resistance*

1.0 INTRODUCTION

Silver cadmium based contact materials are being replaced with silver tin oxide contact materials due to serious health hazards posed by cadmium [1-6]. However, silver tin oxide contact materials show poor heat dissipation characteristics. This enhances the tip temperature during operation, increases arc induced metal vaporization and melting and thus increases the erosion rate. One method of over-coming this limitation is by the addition of threshold levels of tertiary–high melting point–dopants such as tungsten oxide, indium oxide, bismuth oxide, etc., [7-18].

Silver-tin oxide contacts are commonly manufactured by internal oxidation and powder metallurgy route. This requires silver powder of high purity, fineness and spherical morphology. This increases the cost. In addition to this, these methods have other limitations. As typical examples, internal oxidation is known for its inability to incorporate greater than 10% tin oxide and requires long processing times. Further, in the powder metallurgy process, needle-like structures are formed which lead to embrittlement of the material [4].

In the present work, the aforesaid limitations have been overcome by using a novel method

Electrical Research and Development Association, ERDA Road, Makarpura, Vadodara 390 010
* Professor, Metallurgical and Materials Engineering Department, Faculty of Technology and Engineering, M.S. University of Baroda, Vadodara-390 001
** Former Director, ERDA

for preparing $AgSnO_2$ contact tips, where tin oxide particles are coated by silver by an electroless coating technique and dopant is also concurrently incorporated. Subsequently, the powders are consolidated into contact tips by the powder metallurgy route.

2.0 STATISTICAL DESIGN OF EXPERIMENTS

In the first phase of the study, process parameters for the manufacture of tungsten oxide doped silver tin oxide contacts are optimized using a nominal level of the tertiary dopant. The optimized process parameters include concentration of tin oxide, particle size of tin oxide, dosing rate, sintering time and temperature, cold compaction pressure, etc. In the second phase, a systematic factorial experiment in the univalent space of tertiary dopant concentration (tungsten oxide) is undertaken, and results analysed in the frame work of the one way ANOVA model. The various response variables studied include as-sintered density, micro-hardness, electrical conductivity, and uniformity of the generated microstructure.

The contact tips developed in the phase–II work are subjected to electrical performance testing as per IEC 947-4-1 (1990) and IS 13947 Section-4. The response variable for the performance testing is the erosive loss of contact tip mass. The contact tip mass loss is modelled using one factor–three level–algorithm using the additive–effect formulation as below:

$$\widehat{W}_i = \mu + \Delta W_i + \widehat{\varepsilon}\left[o, \sigma^2\right] \quad (1)$$

Where

$\widehat{W}_i$ = Random variable denoting "arc-erosion" driven percentage mass loss, in mass %.

μ = Global constant

ΔW_i = Dopont level

$\widehat{\varepsilon}$ = Noise variable, modelled as a SNRV $\equiv N\left[0, \sigma^2\right]$

Using a variance optimization algorithm, the estimators for $\mu(\widetilde{\mu})$ and $\Delta W_i\left(\Delta\widetilde{W}_i\right)$ are extracted and the estimated mass loss percent, $\widetilde{W}_i$ plotted as a function of the dopant concentration.

3.0 EXPERIMENTAL METHODOLOGY

Silver-tin oxide contact tips with different concentrations of tungsten oxide (dopant) are prepared by coating collidal tin oxide particles with silver by electroless deposition technique. During the deposition, tungsten oxide dopant is also added. The obtained composite powder is washed and dried. Next the contact tips are consolidated by powder metallurgy route (press –sinter and hot pressing). The presence of the added constituents is confirmed using SEM/ EDAX (Fig. 1).

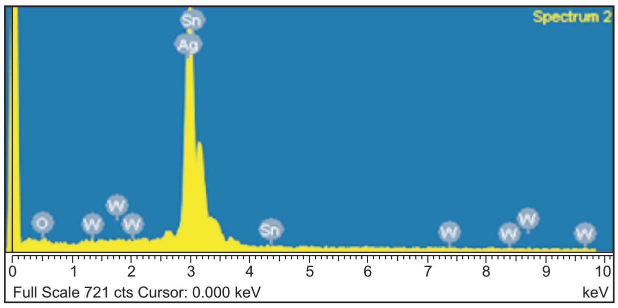

FIG. 1 EDS SPECTRUM SHOWING THE PRESENCE OF SILVER-TIN OXIDE AND TUNGSTEN OXIDE IN THE CONTACT TIP

Subsequently, the contact tips are brazed on lugs in a commercially available contactor and subjected to conventional operational performance study (Endurance test) for AC3 rating test at 32 A as per IS 13947–Section-4 Part-1 (1993) and IEC 947-4-1(1990) test standards. The weight loss of the contact material at the end of the testing is measured, and subjected to analysis using Equation (1).

4.0 RESULTS AND DISCUSSION

4.1 Physical and micro-structural characterization

4.1.1 Density, Micostructure, Hardness and Conductivity

4.1.1.1 Density

For the contact tips without addition of dopant, the maximum value of density obtained is about 98.6% of the theoretical density. For contact tips with optimized tin oxide content of 8.7 wt % along with 0.3 wt % of tungsten oxide (WO_2), the density obtained is 98.4% of the theoretical density. Similarly, in case of tin oxide of 8.7 wt % with 0.5 wt % dopant, the density obtained is 98.3% of the theoretical density which is relatively lower than the density obtained for contact tips containing 0.3 wt % tungsten oxide. In case of tin oxide of 8.7 wt % with 0.7 wt % dopant, the density obtained is 97.5% of the theoretical density, which is lower than that obtained for contact tips containing 0.3 wt % and 0.5 wt % tungsten oxide. These observations show that as the tungsten oxide content increases, the density of the contact tip decreases. This may be due to poor ductility of tungsten oxide, which prevents attainment of adequate densification during the die-pressing operation.

4.1.1.2 Hardness

Hardness of the silver tin oxide composite is affected by the microstructure, wt % of tin oxide, the particle size, porosity level and grain size of the compact.

In the present work, the tin oxide particles used are fine and uniformly distributed and hence the hardness is uniform and high. The hardness obtained without tungsten oxide as well as with 0.3 wt %, 0.5 wt % and 0.7 wt % tungsten oxide, levels is in the range of 86-87 VPN. This indicates that the presence of tungsten oxide in the range 0.3 – 0.7 wt % does not affect contact tip hardness.

4.1.1.3 Conductivity

Electrical conductivity measurements indicate that silver tin oxide contacts prepared by the electroless coating technique have conductivity comparable to Ag-CdO contacts. For Ag-SnO_2 contact without incorporation of tungsten oxide dopant, the conductivity was 84% ICAS. After incorporation of 0.3 wt %, 0.5 wt % and 0.7 wt % dopant levels, the conductivity values are in the range 78% to 76%. The trend of decreasing conductivity with increasing dopant content is expected.

The results for density, hardness, conductivity measurements are summarized in Table-1.

TABLE 1

PHYSICAL PROPERTIES OF CONTACT TIPS AT VARIOUS LEVELS OF THE TERTIARY DOPANT

Sr. No.	Type of Contact Material	Densifi-cation,%	Micro-hardnessat 40 g, VPN	Conducti-vity, % IACS
1	Without dopant	98.6	86	84
2	0.3 wt % dopant	98.4	87	74
3	0.5 wt % dopant	98.3	87	77
4	0.7 wt % dopant	97.7	87	76

4.1.1.4 Microstructure

Microstructures at all levels of the phase – II work show uniform dispersion of tin oxide particles in silver matrix. In general, results indicate that electroless deposition technique allows easy control over degree of agglomeration of the particulates. In addition to this, volume loading of tin oxide can be controlled. The well dispersed tin oxide particles serve to increase the arc welding resistance at the contact points. Further, such particulates are not expected to grow into needle-like crystals on thermal aging as they are well separated from each other. The uniform dispersion of tin oxide particulates in Ag matrix is expected to give a uniform erosion resistance and hence longer useful life of the contacts. Further, the presence of tungsten oxide in the contact tips does not effect the basic microstructure of the Ag-SnO_2 composite, (Fig. 2).

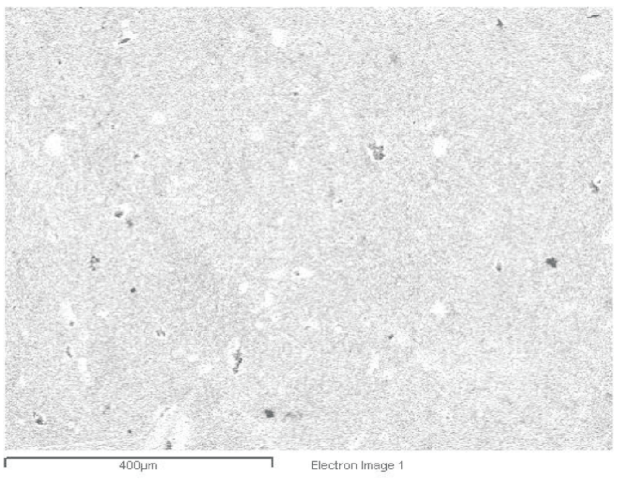

FIG 2 MICRO STRUCTURE SHOWING UNIFORM DISTRIBUTION OF TIN OXIDE IN SILVER MATRIX

4.3 Electrical evaluation of contact tips

In order to study the electrical performance of the contacts, a commercially available contactor was used. The contact tips of required sizes and shape needed for this commercial contactor were prepared and brazed onto the lugs and subsequently subjected to the AC-3 rating study as per IS: 13947 (Part-I) Section 4–1993 and IEC: 947-4-1(1990) (specification for low voltage switchgear and controlgear) for conventional operational performance study.

4.3.1. Performance Test

For carrying out make break testing, parameters used for testing were as per clause No. 8.3.3.6. of IS: 13947 (Pt. IV) Section 1–1993 and IEC 947-4-1(1990) (specification for low voltage switchgear and controlgear). For evaluation of the performance of the contact tips, loss of material in terms of mass % after completion of testing is computed.

Conditions for the testing:

Utilization Category	:	AC3
Rated operational Voltage (Ue)	:	415 V
Rated Operational current (Ie)	:	32 A

Required test parameters	Measured parameters, (Value)
Applied voltage (V): 415 x 1.05= 436	447V
Test current (I): 64 A	64.4A
Power Factor (cos Φ): 0.45	0.448

Total No. of operations	:	6000
On time	:	50 ms
Off time	:	10 ms

It is observed that the 0.3 wt % tungsten oxide containing contacts show minimum wear among other compositions i.e. without dopant and 0.5 wt % and 0.7 wt % tungsten oxide containing contacts. It is also observed that contact material with 0.7 wt % tungsten oxide shows maximum wear. Thus, there appears to be an optimal level of tungsten oxide incorporation beyond which the wear properties markedly degrade, see Fig. 3.

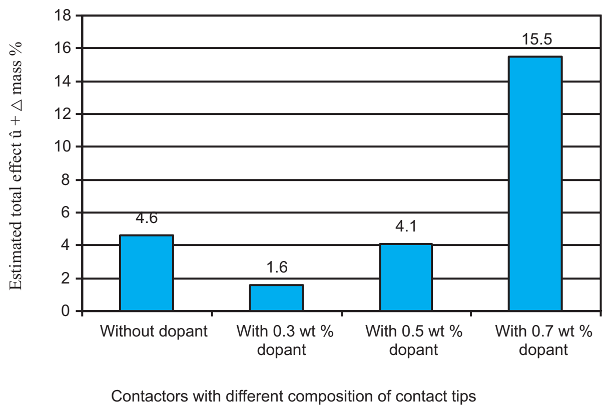

FIG. 3: ESTIMATED WEIGHT LOSS OF CONTACT TIPS AS A FUNCTION OF DIFFERENT LEVELS OF TUNGSTEN OXIDE.

5.0 CONCLUSIONS

Based on the two stage experimental program undertaken in a rigorous SDOE and analysis of various setting, the following central conclusions are derived.

1) It is possible to obtain dense and uniform deposition of silver on tin-oxide (in a colloidal solution) using the electroless deposition technique.

2) It is also shown that concurrent deposition of silver and tungsten dopants can be efficiently conducted using the electroless coating technique.

3) The post sintered microstructures of silver -tin oxide-tungsten oxide, $Ag\text{-}SnO_2\text{-}WO_2$ system show a uniform distribution of tin-oxide, SnO_2 in a silver matrix.

4) AC3 Performance testing on the silver - tin oxide-tungsten oxide $Ag\text{-}SnO_2\text{-}WO_2$ system indicate that the most optimal degradation and wear resistant properties are obtained with incorporation of about 0.3 wt % dopant.

6.0 ACKNOWLEDGEMENTS

We gratefully acknowledge the Research Scheme Of Power (RSOP) of the Ministry of Power, Government of India for supporting this work.

REFERENCES

[1] Joshi P B and Ramakrishnan P. "Materials for electrical and electronic contacts–processing, properties and applications," Science Publishers Inc., USA, (2004).

[2] Behrens N, Bohm W, Braumann P and Kleoo G. "Experiences with the contact material A_g/S_nO_2", Proc. of Holm conf. on electrical contacts", (1984), pp. 185–191.

[3] Verma A and Anantharaman T R. "Processing and properties of internally oxidized silver-tin oxide electrical contact materials without additives", Metals, Materials and Processes, Vol. 6, No. 2, (1994), p. 125.

[4] Chang H, Pitt C H and Alexander G B. "Novel method for preparation of silver-tin oxide electrical contacts", J. of Matls. Engg. And Performance, Vol. 1(2), (1992), p. 255.

[5] Poniatowski M, Schulz E and Wirths A. "The replacement of silver-cadmium oxide by silver-tin oxide in low voltage switching devices", Proc. of Holm Conf. on Electrical Contacts (1976), p. 359.

[6] Wingert P C and Leung C H. "The development of silver-based cadmium-free contact materials," Proc. of Holm Conf. on Electrical Contacts, Vol. 12, No. 1, march 1988, p. 31.

[7] Shibata A. "Silver metal oxide contact material by internal oxidation process" Proc. 71CECP, Paris 1974, pp. 749–754.

[8] Yamasaki H, Oda S, *et al.*, "Sintered silver tin oxide materials for electrical contacts" Proc. 10 ICECP, Budapest 1980, pp. 799–808.

[9] Jeannot D, Pinard J, Ramoni P and EM Jost "Physical and chemical properties of metal oxide addition to silver tin-oxide contact materials and prediction of electrical performance." IEEE transaction on Components, Packaging and Manufacturing Technology Part A, Vol. 17, No. 1, March 1994, pp. 17–23.

[10] Wingert P C and Chi-Hung Leung "The development of silver based cadmium free contact material" IEEE Transaction on Components, Hybrids and Manufacturing Technology, Vol. 12, No. 1, March 1989, pp. 16–20.

[11] Gengenbach G and Michal R. "Erosion characteristics of silver based contact material in a DC contactor." Electrical contacts 1984, pp. 201–207.

[12] Behrens N and Bohm W. "Switching performance of different silver tin oxide contact materials made by powder metallurgy", Proc 11th ICECP, Berlin 1982, pp. 203–207.

[13] Gangenbach B, Mayer U, Michal R, *et al.*, "Investigation on switching behavior of silver tin oxide material in commercial contactor"; Proc. 13, Holm conf. Electrical contact, Chicago 1984, pp. 243–247.

[14] Michal R and Saeger K E. "Application of silver based contact materials in air break switching devices for power engineering" Proc. of 34th IEEE Holm conference of electrical contacts 1988, pp. 121–127.

[15] Hetzmannseder E and Rieder W F. “The influence of bounce parameters on the make erosion of silver/metal oxide contact materials” IEEE Transaction on Components, Packaging and Manufacturing Technology Part A Vol. 17, No. 1, March-1994, pp. 9–15.

[16] Yuan Shou Shen, Lawrence “Erosion modes of internally oxidizes Ag-CdO and Ag (Sn, In) O material. IEEE Transaction on Components, Packaging and Manufacturing Technology Part A, 1987, pp. 157–161.

[17] Herz K and Sauter E. “Erosion, welding and contact resistant characterizes of several powder metallurgical, silver contact material. IEEE Transaction on Components, Packaging and Manufacturing Technology Part A, 1984, pp. 215–221.

[18] Gengenbach, Jager K W, Mayer U, *et al.*, “Mechanism of arc erosion on silver tin oxide contact materials” Proc. 11 ICECP Berlin 1982, pp. 208–211.

Readers are invited to offer their comments on the article. Please fill in the Reader’s Forum.