An Experimental Study of the Photoelectron Work Function Change of Silver-Based Contacts Induced by Arcing in Air

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The influence of industrial conditioning (polishing, mechanical shocks and electrical arcs in air) on the electron emission and morphology of contact pastilles made of pure silver [Ag (99.999%)], silver–nickel alloy [Ag–Ni (60/40)], silver–tungsten alloy [Ag–W (50/50)], and silver–tungsten carbide [Ag–WC (50/50)] was investigated. The electronic emission behavior of pure silver Ag and silver-metal alloys (Ag-Me), for both virgin and arced electrical contacts, were studied.

Contacts were mounted in a contactor working repeatedly on air (laboratory atmosphere). When submitted to 500 opening electric arcs, the electron work function of an electromechanically conditioned contact Ag-Ni (60/40), measured photoelectrically by using Fowler's method of isothermal curves, is $\varphi = (4.50 \pm 003)$ eV at room temperature, while for virgin Ag contacts, it was (4.30 ± 003) eV. The increase in the electron work function (EWF) is due to the progressive inclusion of silver oxide in the Ag contact surface during arcing in air.

The conditioned (500 arcs) silver-metal alloys studied in this work exhibit the same electronic emission behavior, namely arcing in air increases their EWF. We demonstrated that the electromechanical conditioning by successive electrical arcs affects the surface characteristics such as microstructure, roughness and photoelectron work function.

Keywords: electron work function, photoemission, Fowler's method, contact materials, electrical arcs, cathode phenomena

1 INTRODUCTION

Materials used to provide both electrical current flow and creation of electric arc in low voltage switchgear devices such as contactors, relays, circuit breakers and switches, are made of pure silver Ag (99.99%) and silver based alloys namely Ag-CdO (88/12), Ag-ZnO (92/8), Ag-SnO_2 (88/12), Ag-Ni (70/30), Ag-Ni (60/40) and Ag-W (50/50) [1], [2]. These alloys have been extensively used as electrical contact materials in current switching devices because of their high conductivity and good resistance to corrosion, fusion and wear [3], [4]. We present in this paper, the measurement of the photoemission electron work function for electrical contacts made with pure silver Ag (99.99%) and Silver-Nickel Ag-Ni (60/40) electrical contacts, in which occurs the industrial conditioning of the contact surface.

Experimental method developed and used is based on measuring, in ultrahigh vacuum conditions, photoelectric currents emitted by small electrode exposed to ultraviolet radiations of different wavelengths and same intensity. The electron work function (EWF) of silver arced contacts was measured using Fowler's method of isothermal curves [5-11].

2 EXPERIMENT

To bring our measurements to a successful conclusion, an adapted experimental set up, has been built (it has been given in much detail in previous papers) [6, 9, 10]. The work function of silver is 4.3 eV [13]. So, the measurements have been made under ultraviolet illumination close to the threshold, i.e. by using ultraviolet light with a wavelength of less than 290 nm.

To measure the photocurrent, a simple device (although not very easy to achieve) shown in figure 1 is used. In order to study the effects of arcing in air on the photo-EWF and morphology of silver and silver nickel contacts, the experiments were carried out in an experimental contactor with horizontally moving contact driven by pneumatic device (figure 2).

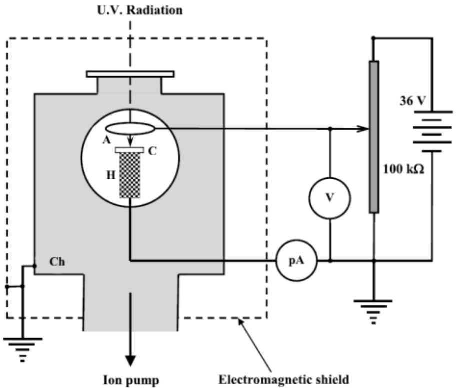

Fig. 1: Principle of measurement

A cycle consisted on opening contacts on charge with production of an electric arc with adjustable duration and closing some seconds after arc extinction on zero voltage. The test parameters of the experimental contactor were : initial gap distance 5 mm, arc duration $4\text{x}10^{-3}$ s, number of applied arcs 1÷500, arc current: linear variation with time from 36 to 12 amps, arc voltage : linear variation with time from 12 to 35 volts, opening velocity 1 m.s^{-1}, arc study in air at atmospheric pressure.

Furthermore, a careful electrical shielding, was required to measure photoelectric current (about 10^{-13} A) with a Keithley picoammeter (model 486); it allows the stabilization of photoelectric current measurement and the decrease of background noise. The system operated repeatedly and all tests in the experimental contactor were breaking tests. After a suitable industrial treatment, made with the aid of the experimental contactor, the cleaned test contact is introduced into the UHV experimentation chamber. A vacuum of the order of 10^{-9} mbar is required to determine the photoelectric work function. The contact removed from the UHV experimental device is then placed in the vacuum chamber of the SEM to investigate its surface morphology.

The changes of cathode surface morphology and the distribution of alloyed metals and their oxides during arcing have a very great influence on electron emission and arc erosion in silver-based material contacts.

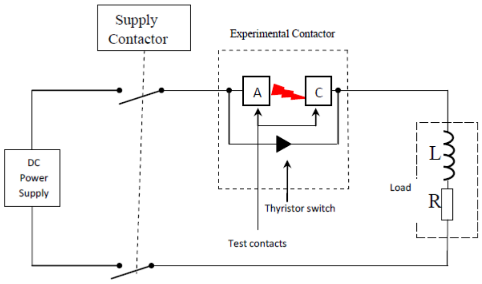

Fig. 2: Schematic diagram of the experimental contactor

3 RESULTS AND DISCUSSION

We demonstrated that the electromechanical conditioning by successive electrical arcs affects the surface characteristics such as microstructure, roughness and photoelectron work function

3.1 INFLUENCE OF ARCING

When an electric field is applied for the first time between virgin electrodes, a high electrical conductivity is observed for weak macroscopic fields, regardless of the method used to clean the surface of the electrodes. When one or more electric arcs break out between the metal electrodes, various natural phenomena are induced in the contact material. These are mainly thermal and hydrodynamic effects. Considering these effects, the contact materials must possess a number of qualities, including mainly: high electrical conductivity, good thermal conductivity, high properties of "non-sticking", suitable properties of resistance to erosion by the arc, a very good resistance to mechanical wear, and low contact resistance with good stability over time. We will present some photographs performed by a scanning electron microscope (SEM) to show the changes in surface morphology of the contact material conditioned by 500 arcs.

3.2 ELECTRON WORK FUNCTION MEASUREMENTS

The metallic samples were subjected to electric arcs in air, at atmospheric pressure and room temperature, afterwards introduced into the vacuum chamber of the experimental set-up for EWF measurements.

a. Pure silver Ag(99.99%)

The EWF of the surface of a silver contact, determined at room temperature, was found to be equal to (4.26 ± 0.03) eV. These results have been given elsewhere in details [6,7,10]. After conditioning the contact (cathode) of silver with 500 electrical opening arcs in air, the EWF rises to (4.50 ± 0.03) eV. This increase is due to the oxidation of the eroded contact surface by the numerous electrical opening discharges in air.

b. Silver-nickel alloy Ag-Ni (60/40)

In determining the EWF, the emitted electron current was measured as a function of photon energy. Typical curves of photoelectron spectral distributions for unconditioned and conditioned (100 and 500 arcs) silver-nickel contacts, at room temperature, and ultra high vacuum (UHV) conditions, are given in figure 3.

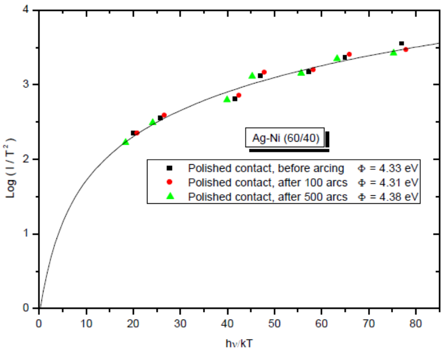

Fig. 3: Fowler isothermal curve for silver-nickel contacts before and after arcing

A same EWF measurement made after 500 make-and-break operations gives (4.38 ± 0.03) eV. In this case too, the EWF increasing is due to progressive inclusion of oxide on alloy surface. Hence, we were dealing with a layer of silver oxide, because usually, the work function of a metal oxide is greater than that of the corresponding metal because of the Fermi level change. As the metal is oxidized, it loses its electrons resulting in a decrease of Fermi level. Covalent oxygen adsorption on metals (Ag, Ni) involves localized orbital overlap and charge transfer between the adsorbate and surface atoms. The EWF values of allied metals are small compared to the energy of ionization of the oxygen (13.618 eV); the oxygen having unoccupied energy levels, the electron transfer is for its benefit. Consequently, the surface is then covered with a negative layer, and the work function increases. In other words, the negative pole of the oxygen molecule points towards the vacuum, so the surface space charge or surface dipole presents an electrostatic field that causes an increase in the work function [14]. It is important to note that during the successive electrical opening discharges in air, silver and nickel oxides formed during the previous electric arcs will decompose and absorb then the energy dissipated by the arc. This behavior will reduce erosion of electric contact matrix.

3.3 MORPHOLOGY OF ARCED CONTACT SURFACE

Figure 4 shows the morphology of a silver contact Ag (99.99%) (Fig. 4 (a)), and a silver-nickel Ag-Ni (60/40) (Fig. 4 (b)), conditioned by 500 electrical opening discharges in air, (load current 45 A, arc voltage 45 V).

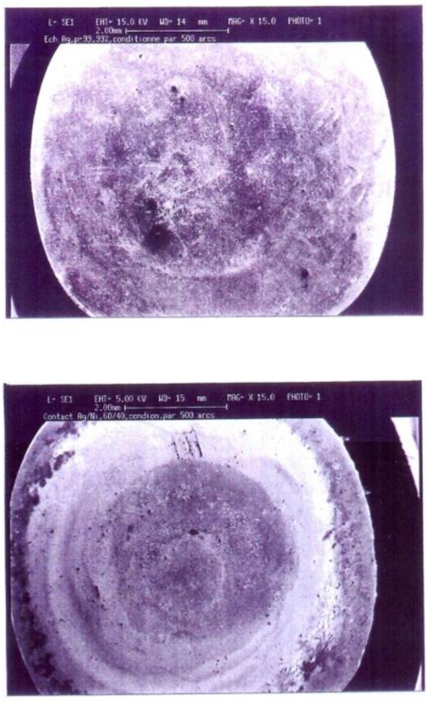

Fig. 4: Micrographs of arced electrical contacts, SEM magnification x15, Ag (99.99%) and Ag-Ni(60/40), respectively

The electromechanical conditioning taking place in air, we see the appearance of oxide thin films on the surface of contact. The observation of the contact conditioned by 500 electric arcs shows that the cathode spot corresponding to silver-nickel (60/40) contact is almost smaller than that of pure silver contact (99.99%) (figures 4 (a) and 4 (b)). The latter is narrower in comparison with other contacts, because the molten metal is slightly moved for this pseudo-alloy of silver because of its high viscosity. Indeed, with the new Ag-Me materials (Ag-Ni, Ag-W, …), the flow of molten metals from the melt is much lower because of the increase in viscosity due to metal (Ni, W, …).

4 CONCLUSION

The effects of arcing on silver EWF have been studied by photoelectron emission under ultraviolet illumination close to the threshold. Precisely, the change in EWF of conditioned Ag electrical contacts was investigated by using Fowler's method of isothermal curves, a method which has the advantage over contact potential difference techniques of being both absolute and precise. An analysis of the results of this investigation leads to the following conclusions:

1. After baking the UHV chamber at a temperature of 200 ° C, for 24 hours, and after cooling, the obtained EWF of the virgin and polished contacts, made in pure silver Ag and silver-nickel alloy Ag-Ni(60/40), are (4.30 ± 0,03) eV and (4.33 ± 0,03) eV, respectively, in good agreement with the results already obtained. These experiments were carried out at room temperature and a residual gas pressure or $1.4x10^{-7}$ eV [10-12].
2. Once a conditioning with 500 opening arcs is completed, the cleaned contact (cathode) is placed in the vacuum chamber, which will be baked at a temperature of 200 ° C, for 24 hours. The EWF of the cathode found, after cooling, rises to Φ_{Ag}(500 arcs) = (4.50 ± 0,03) eV and $\Phi_{Ag\text{-}Ni}$(500 arcs) = (4.38 ± 0,03) eV, for Ag(99.99%) and Ag-Ni(60/40) respectively. This increase is probably due to the oxidation of eroded surface of contact due to undergone multiple and repetitive electric arcs.

REFERENCES

[1] Anders S, Jüttner B, IEEE Trans. Plasma Sci. 19 (1991) 705-712.

[2] Nachtigall K P, Mentel J, IEEE Trans. Plasma. Sci. 19 (1991) 942-946.

[3] Arifov U A, et al., Electric arc treatment of parts, European Patent N° 0468110. Date of filling: 24.07.1990.

[4] Arustamov V N, Ashurov Kh B, Kadirov Kh Kh, Khudaykulov I Kh, Influences of surface-active substances on specific power consumption and on surface roughness of metal product under plasma vacuum arc treatment, In: Proc. 13th Int. Conf. Plasma Surf. Engine, Garmish-Partenkirchen, Germany, Sept. 2012, pp. 207-210.

[5] Fowler R H, Phys. Rev. 38 (1931) 45–56.

[6] Akbi M, Lefort A, J. Phys. D: Appl. Phys. 31 (1998) 1301–1308.

[7] Akbi M, Bouchou A, Ferhat-Taleb M, Vacuum 101 (2014) 257–266.

[8] Akbi M, Bouchou A, Zouache N, Appl. Surf. Sci. 303 (2014) 131–139.

[9] Akbi M, IEEE Trans. Comp. Pack. Manuf. Techno. 4 (2014) 1293–1302.

[10] Lefort A, Akbi M, Parizet M J, Experimental determination of work function about silver alloys, In: Proc. 2nd Int. Conf. on Elect. Contacts, Arcs, Apparatus and their applications, Beijing, China, May 1993, pp. 363–367.

[11] Lefort A, Akbi M, Parizet M J, Electron emission of silver alloys used for breakers, In: Proc. SPIE, XVI International Symposium on Discharges and Electrical Insulation in Vacuum, vol. 2259, Moscow-St. Petersburg, Russia, May 1994, pp. 486–490.

[13] Fomenko V S, Handbook of Thermionic Properties, New York, USA, Plenum Press Data Division, 1966.

[14] Oura K, Lifshits V G, Saranin A A, Zotov A V, Katayama M, Surface Science, An Introduction, Berlin , Germany, Springer, 2003.