Effects of Arcing in Air on the Microstructure, Morphology and Photoelectric Work Function of Ag-Ni (60/40) Contact Materials

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Abstract—The present work aims to throw light on the effects of arcing in air on the surface state of contact pastilles made of silver-nickel Ag-Ni (60/40). Also, the photoelectric emission from these electrical contacts has been investigated in the spectral range of 196-256 nm. In order to study the effects of arcing on the EWF, the metallic samples were subjected to electrical arcs in air, at atmospheric pressure and room temperature, after that, they have been introduced into the vacuum chamber of an experimental UHV set-up for EWF measurements. Both Fowler method of isothermal curves and linearized Fowler plots were used for the measurement of the EWF by the photoelectric effect.

It has been found that the EWF varies with the number of applied arcs. Thus, after 500 arcs in air, the observed EWF increasing is probably due to progressive inclusion of oxide on alloy surface. Microscopic examination is necessary to get better understandings on EWF of silver alloys, for both virgin and arced electrical contacts.

Keywords—Ag-Ni contact materials, arcing effects, electron work function, Fowler methods, photoemission.

I. 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 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]. They are also characterized by reduced erosion rates due to the rheological properties of molten composite which stabilize the arc feet and limit the ejection of molten metal particles.

Nickel is a well-known refractory material (melting point 1455°C) which increases both hardness and resistance to erosion for low power arcs when added to silver with 30% or 40% of mass fraction. Therefore, silver-nickel materials exhibit good contact and switching properties such as, high arc erosion resistance, resistance against welding, good arc moving properties, good arc extinguishing properties and good or sufficient ductility depending on the Ni content. Moreover, the improved mechanical properties are maintained even after

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undergoing arcing. Silver-nickel system contacts, well known as materials with high workability and low contact resistance, are used as medium to weak current contacts [4] in power switch and breaker apparatus because of its excellent thermal and electrical conductivities, low and steady contact resistance and good arc-ablation resistance. Among other applications, the Ag-Ni electrical contacts are used as relay for vehicles, thermostats, power relays, current-limiting breakers, electromagnetic switches and small contactors with nominal current > 20A. Further, silver-nickel composite materials with higher Ni contents can only be produced by powder metallurgy because silver and nickel are note soluble in each other in solid form and in the liquid phase have only very limited solubility. The typical application of Ag-Ni contact materials is in devices for switching currents up to 100A. In this rang they are significantly more erosion resistant than silver or silver alloys [5].

The Electron Work Function (EWF) is an important characteristic of the surface state of metals and alloys, which determines their emission properties [3], [6], [7]. The EWF, denoted by Φ and measured in electron volts, is equal to the minimum work that must be done to remove an electron from the surface of metal at 0 K [8]. The EWF has two terms: a bulk term due to the fact that the environment of the electron is different in the solid and the vacuum, and a surface term which arises from the existence in the surface area of a dipole moment. The surface term depends on arrangement of atoms on the surface contact and also the potential distribution of foreign atoms adsorbed or attached by chemical bonds. The EWF of a metal is extremely sensitive to the chemical and physical conditions at its surface. Small amounts of contaminants present at a surface can invalidate EWF measurements. Furthermore, EWF measurements on alloys are subject to the complication that the alloy surface composition can be appreciably different from the bulk composition [9].

Despite intense research over the past few decades, it must be recognized that little has been known on EWF of alloyed electrical contacts and their surface composition dependence. One of the main difficulties in studying EWF changes is the surface segregation which occurs during thermal treatment in vacuum, and thus modifies the chemical composition of the contact surface. On the other hand, surface contamination of the electrical contact increases its EWF. The most common contaminant species are oxides formed during thermal diffusion and vacuum outgassing processes [10]. For most metals, experimental and theoretical values of the EWF values

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have been reliably determined [11], [12]. Unfortunately, up to the present time, EWF data for silver-metal alloys (Ag-Me) and pseudo-alloys such as silver-metal oxide (Ag-MeO) are still unavailable.

To obtain a better understanding of electron emission occurring in a cathode alloy subject to vacuum outgassing and heat treatment, Fowler's method of isothermal curves is used [13] to determine accurately the EWF. In a previous paper [14], the effects of surface treatments by vacuum outgassing on EWF silver-nickel Ag-Ni (70/30) were described. The numbers between brackets represent the mass proportion of pure silver and pure nickel. Further, the effects of vacuum heat treatment on the EWF and morphology of silver-metal alloys have been investigated in much detail [15], [16]. The aim of this work is to measure and explain the phenomenon of electron emission occurring at the surface of arced silver based cathode alloys namely Ag-Ni (60/40). A scanning electron microscope (SEM) with energy dispersive X-ray spectrum was used for the microstructure measurements. Fowler's method of isothermal curves is used to study the effect of arcing in air on surface morphology, microstructure, and the EWF of the Ag-Ni alloys. This paper also attempts to explain the correlation between EWF and surface morphology of the alloys when subject to vacuum heat treatment. Therefore, the role of the metal alloy nanoparticles (Ni) will be more clearly defined.

We present in this paper, the measurement of the photoemission electron work function for electrical contacts made with silver-nickel, in which occurs the industrial conditioning by arcing in air of the contact surface. In order to get some proofs of the obtained results, the SEM observations and Energy Dispersive Spectrometry analyzes (EDS) are used to determine morphology and composition of the eroded 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 [6], [14], [15] and linearized Fowler plots [18]-[20]. We show in this paper how the EWF of Ag-Ni (60/40) electrical contacts vary with the industrial conditioning, namely arcing in air.

II. EXPERIMENT

A. UHV Experimental Device

To bring our measurements to a successful conclusion, an adapted experimental set up has been built (it has been given in previous papers) [6], [17], [21]. However, we will briefly recall the main components of the experimental device shown in Fig. 1. The latter essentially comprises a UHV chamber and its associated pumping system ($\approx 10^{-9}$ mbar), a drying system of the enclosure, a device for exciting the surface of the test contact by monochromatic ultraviolet radiation, a heating system under UHV conditions and an equipment measuring the photocurrent (some picoamperes).
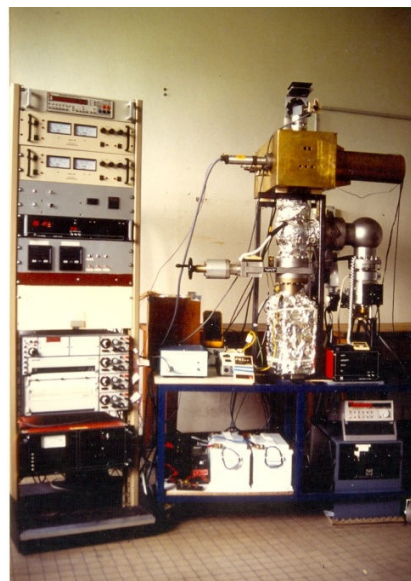

Fig. 1 Vacuum device and instrumentation

The work function [22] of silver is 4.3 eV. For this reason the measurements had to be made using ultraviolet light with a wavelength of less than 290 nm. After careful consideration of several ultraviolet light sources which give usable radiation up to at least 290 nm, it was decided to use a 30 W deuterium lamp type L1626 manufactured by Hamamatsu Photonics, which provides a sufficient intensity for our measurements where light must be irradiated on the whole contact surface. This is important because a large spot size of the light source on the cathode will emit from the entire surface, while a smaller one might have the ability to select from certain regions on the cathode. Furthermore, the spectral intensity curve of the deuterium lamp is continuous over a wide range, and the intensity at the wavelength interval [196 nm, 255.4 nm] was adequate for the work function measurements. Seven interferential filters with the following wavelengths: 196.0 nm, 206.1 nm, 213.1 nm, 223.4 nm, 229.1 nm, 247.8 nm, and 255.4 nm were used. The plane of the cathode is oriented normal to the path of the UV light beam entering through a sapphire window which shows a high transmission factor in the working wavelength range. The choice of this window is dictated by the desire to see the maximum radiant intensity reaching the test cathode to extract the maximum of electrons. First, incident radiation goes through the interchangeable interference filter and later through the sapphire window. A quartz window is located in the frontal side of the vacuum chamber for observing the heating device operating in vacuum which has been installed to the heat cathode and temperature measurement. A chromel-alumel junction thermocouple is attached directly to the back of the cathode to make possible temperature measurements. The calibration curve shown Fig. 2 gives cathode temperature versus furnace temperature. Thus knowing the furnace temperature, the cathode temperature is determined by using the calibration curve.

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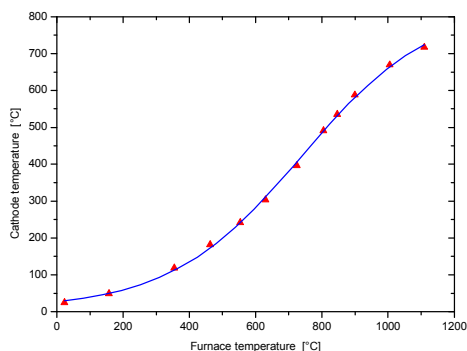Vol:9, No:2, 2015

Fig. 2 Cathode temperature versus furnace temperature

However, measurement of the temperature of the studied cathode has been done indirectly because its contact with the thermocouple disturbs photoelectric measurement. Moreover, measuring the temperature by an optical pyrometer or a thermal camera was not possible because the cathode was not on the line of sight. Furthermore, 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.

B. Experimental Contactor

For industrial treatment of electrical contacts purposes, an experimental contactor working in air was developed in the laboratory (LAEPT, Clermont-Ferrand - France). Contactor operation allowed us to follow the evolution of the contact surface after the various openness arcs and to study its influence on the electron work function. This device created an electric discharge with both variable duration and intensity between two moving contacts initially driven by a current.

The experimental contactor is the mistress piece of the contacts test device. This device (Figs. 3 and 4) consists of four main elements:

- A power supply of ripple current built at the laboratory, it can deliver a current of 200 A at a voltage of 120 V.
- A power contactor ensuring switching off of the supply.
- A contactor test designed at the laboratory to create an arc of varying duration and intensity between two moving metal contacts driven by a direct current.
- A charge consisting of an inductor L for smoothing the current (0.8 mH / 0.1 Ω) and a resistor R for limiting the charging current I_{ch} (Ω / 40 kW).
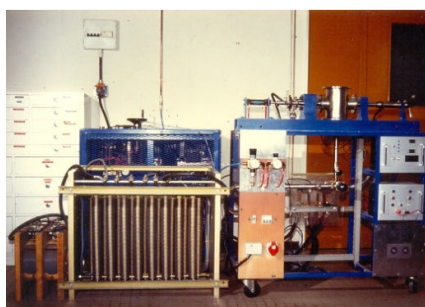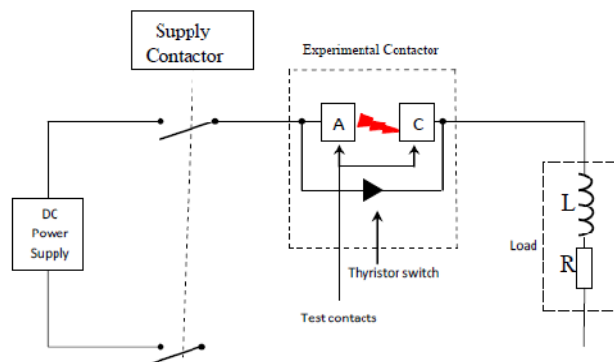

Fig. 3 Experimental contactor

Fig. 4 Schematic diagram of the experimental contactor

Experiments were carried out in an experimental contactor with horizontally moving contact driven by pneumatic device. 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 4×10^{-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.

The system operated repeatedly and all tests in the experimental contactor were breaking tests. The material combinations were the following symmetric combinations: Ag-Ni (70/30) cathode with Ag-Ni (70/30) anode, Ag-Ni (60/40) cathode with Ag-Ni (60/40) anode and Ag-W (50/50) cathode with Ag-Ni (50/50) anode. The measured data were processed in each operation in a real time, and the arc voltage waveform was stored in an automatic data acquisition system. The current-voltage characteristics for silver-nickel Ag-Ni (60/40) are shown in Fig. 5.

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-base material contacts. Therefore, it would be extremely helpful to study the electron emission and the contact erosion of the contact pastille made with composite materials versus silver atomic proportion and surface industrial treatments (by applying electric arcs and repeating mechanical shocks). To investigate the mechanism of these phenomena, contact surfaces especially virgin cathodes and eroded ones, were observed with the SEM and analyzed by X-ray spectrometry (EDS line analysis).

C. Preparation and Analysis of Contacts

The test electrodes were in the form of cylinders of pure silver (99%) which were screwed on the silver contact pastilles, provided by SAMEC (Courville-sur-Eure, France). This manufacturer has provided us with two types of silver contact: the cathode has a slightly convex surface (radius of curvature 16 mm), whereas that used for the anode is planar. This configuration allows focusing the opening arc somewhat at the center of the contacts. The tested contacts were pre-

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polished with the silicon carbide paper (# 1200), then polished with polishing cloths associated with a pure alumina powder (grain size 1 μm and 0.3 μm), in suspension in demineralized water.
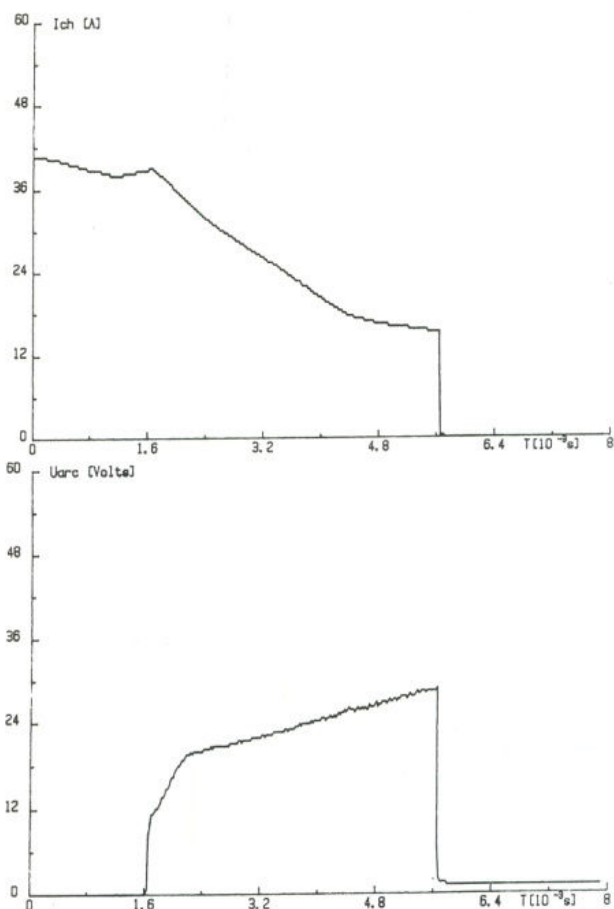

Fig. 5 Current-arc voltage characteristics for Ag-Ni (60/40) electrodes, after 500 electrical discharges in air. The arc voltage is given by the lower curve and the arc current by the upper curve. Loading current 45 A, arc duration 4 ms, gap between electrodes 5mm

This metallographic polishing produce a flat surface, flattens remaining protrusions, and removes impurities and other surface defects. Each electrode is then subjected to a cleaning in ultrasonic tank (# 15 min), in a bath of trichloroethylene, rinsed with water, then cleaned with a lint free paper soaked in acetone [6], [17], [21]. This kind of conditioning allows surface cleaning and impurity elimination (adsorbed molecules and atoms).

After a suitable industrial treatment, made with the aid of the experimental contactor, the 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 is then placed in the vacuum chamber of the SEM to investigate the morphology of the surface. Analysis by X-ray spectrometry (Energy Dispersive X-ray Spectrometry) allows determining the chemical composition of the eroded surface of the contact.

D. Experimental Method

In determining the work function, 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 UHV conditions, are given in Fig. 6.
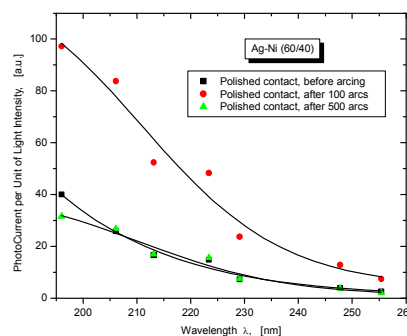

Fig. 6 Spectral distribution curves for an outgassed polished contact Ag-Ni (60/40) before arcing, and after 100 arcs and 500 arcs in high vacuum 1.4×10^{-7} mbar

The EWF data were obtained with the aid of Fowler's theory for the photoelectric current. Fowler has developed a theory of the energy distribution of electrons, based upon the assumption that the free electrons in a metal obey the Fermi-Dirac statistics. According to this theory the photocurrent is given by:

$$Log\left(\frac{I}{T^2}\right) = B + F(x); \qquad x = \frac{h(\nu - \nu_0)}{kT} \qquad (1)$$

where T is absolute temperature of the emitting surface, h is Planck's constant, k is Boltzmann's constant. F(x) is an increasing function of the variable x, it is so-called Fowler universal curve, whose shape is the same for all metals and alloys; the numerical values of F(x) are given in a table in reference [23].

For an experiment in which the illuminated area of the sample is constant and the photocurrents are expressed at constant light intensity, the EWF is calculated readily from the displacement needed to fit the experimental curve to the theoretical Fowler curve. These curves have same shapes and can be superposed by two translations parallel to coordinate axis. Vertical translation gives B and horizontal one gives Φ. A computer program, using least square method, makes the superposition and gives EWF value Φ and Fowler constant B. The comparison of the theoretical curve of Fowler with measurements for the above-mentioned contacts is shown in Fig. 7.

On the other hand, the EWF evaluation may also be based on simplified Fowler's theory [11], [12] which predicts a linear relationship between the square root of the photoelectron yield, $\sqrt{I}$, and the energy of the incoming photons $h\nu$ according to [18]-[20]

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$$\sqrt{I} \propto (h\nu - \Phi) \qquad (2)$$

The extrapolation to $\sqrt{I} \to 0$ leads to

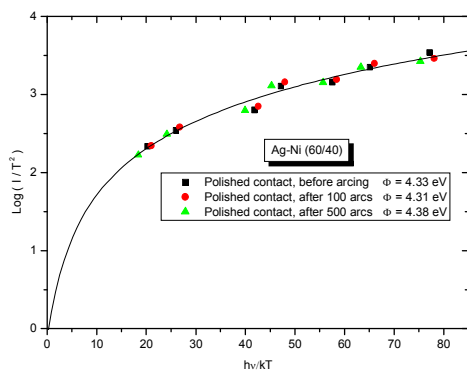$$\nu = \nu_0 = \frac{\Phi}{h} \qquad (3)$$

Fig. 7 Comparison of the theoretical curve of Fowler obtained with (1), with measurements for the outgassed polished contact Ag-Ni (60/40), before arcing, and after 100 arcs and 500 arcs, in high vacuum 1.4×10^{-7} mbar

Thus, the Fowler plot directly provides the EWF $\Phi = h\nu_0$ from an adequate extrapolation of the straight lines in Fig. 8. The intercepts of the abscissa yields I = 0 and consequently the EWF $\Phi = h\nu_0$. The photoelectric threshold is often confused but not necessarily, with the EWF. The Fermi level in insulators and semiconductors may fall into a forbidden energy gap. The threshold is then higher than the EWF of the difference between the Fermi level and the highest occupied level [24], [25].
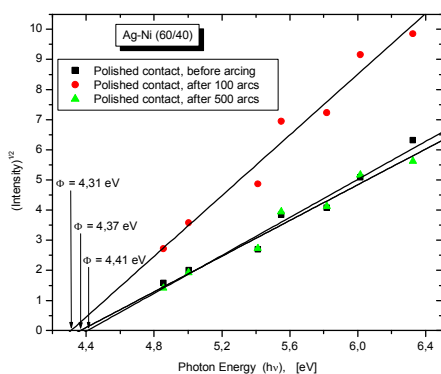

Fig. 8 Typical Fowler plots obtained by using (2) from EWF measurements for the polished Ag-Ni (60/40) contact, before arcing, and after 100 arcs and 500 arcs, in high vacuum 1.4×10^{-7} mbar

III. EXPERIMENT

The EWF is one of the important characteristics of the surface state of metals and alloys, which controls thermionic and field emission. Both bulk and surface contribute to the EWF. The former is responsible for the energy difference between the Fermi Level and the vacuum level. The latter's contribution is due to electrostatic dipole barrier as a result of surface states. Therefore the EWF differs from one surface to another for the same material.

In this paper, we report the surface state changes of the contact pastille with electromechanical treatments. We demonstrated that the electromechanical conditioning by successive electrical discharges in air affects the surface characteristics such as microstructure, roughness and photoelectron work function. Moreover, for most metals, the EWF values have been reliably determined [11], [12], while for arced contacts investigation is still in its infancy or almost inexistent.

A. Electrodes Conditioning

The electromechanical conditioning is all processes that contribute on one hand to eliminate microscopic protrusions and spikes in order to decrease the surface roughness, and on the other hand to desorb the occluded gas. This improves voltage handling of the inter-electrode space and stabilizes the emission current. During conditioning, the electrode surface is microscopically cleaned (degassed) and polished (vaporization of spikes, grubbing of impurities weakly attached to the surfaces).

There are several conditioning techniques among which can be mentioned:

– cleaning (trichloroethylene, alcohol, detergents, ultrasound, electrolytic pickling) that promotes the surface degreasing of the electrodes,
– polishing electrodes which helps to eliminate surface microscopic protrusions and spikes and decreases surface roughness.

B. 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 E_0 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 effects: contact materials are the seat of extremely rapid and intense heat processes (melting, decomposition and vaporization),
– hydrodynamic effects: the liquid from the melting of the contact material is subjected to forces in presence which can be volume forces or surface stresses.

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,
– low contact resistance with good stability over time.

In this paper, we present results relative to work function for silver-nickel contacts, for industrial surface treatments by electric discharges. The cathode surface state is principally

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influenced by the way of cathode conditioning, the adsorption of impurities on the cathode surface, the composition of both metals and the cathode gas content [26], [27].

In order to study the effects of arcing on the EWF, the silver-metal samples were subjected to electric arcs in air, at atmospheric pressure and room temperature, and after that introduced into the vacuum chamber of the experimental set-up for EWF measurements. The experiments described in this paragraph were performed with Ag-Ni (60/40) contacts. The material composition of each pair of the tested contacts was the same. However, only cathodes were investigated.

Contacts were mounted in a contactor working repeatedly on air (laboratory atmosphere). When submitted to 100 electric arcs, Ag-Ni (60/40) contact EWF varies from (4.33 ± 0.03) eV to (4.31 ± 0.03) eV. To obtain a very good vacuum for work function measurements, we had to clean contact before measuring it. It is obvious that measurement value should not be the same if oxide created on surface remained on it. A same measurement made after 500 make-and-break operations gives (4.38 ± 0.03) eV. In this case, the EWF increasing is due to progressive inclusion of oxide on alloy surface. Hence, we were dealing with a layer of both nickel oxide and 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.

C. Surface Analysis

The scanning electron micrograph of damage on a silver-nickel Ag-Ni (60/40) after 500 make-and-break operations shows several small individual craters, especially in the central area of the surface electrode, and a large number of protuberances and submicron spheres at the cathode periphery. Examination of the contact centre in Ag-Ni (60/40) conditioned with 500 arcs (Fig. 9) shows a disturbed area where the ripples of molten metal are fixed, with surrounding dark hollow areas and relatively uniform areas. Spectra analyzes of three representative points corresponding to various regions (Fig. 9) indicate the presence of nickel, silver, carbon and oxygen in varying proportions.

The melting point of silver (960.5°C) is lower than that of nickel (1455°C), thus it is likely that the most regions affected by the electrical discharge are the beaches of silver. Furthermore, it is also probable that the arc ignition would occur preferably from one of these argentic areas, since the value of the photoelectron work function of silver (4.26 ± 0.03) eV, is lower than that corresponding to nickel (4.51 ± 0.03) eV. In addition to that, it can be noted that the spectrum analysis of three various points in the contact centre, as shown in Figs. 9 (a)-(c), show a predominance of silver, nickel, and sometimes oxygen atoms, and the almost complete absence of additives.

The latter have migrated to the periphery of the contact and were evaporated; thus, we are witnessing a cleaning of the cathode by opening arcs. One starts with the centre of the contact and extending towards the periphery, in such a way that the number of opening arcs increases. The droplets

deposited on the side of the contact suggest strong ejections of liquid metal when a sufficient melt is formed on the surface of the electrode. However, because of polishing, Si and Al particles were observed on the whole contact surface.

Examination of the contact periphery shows a scratched surface, unaffected by the electromechanical conditioning, on which are deposited droplets of molten metal radially ejected; it also shows macroscopic droplets of molten nickel (Fig. 10 (a)) on which are clustered a multitude of grains of liquid sodium.
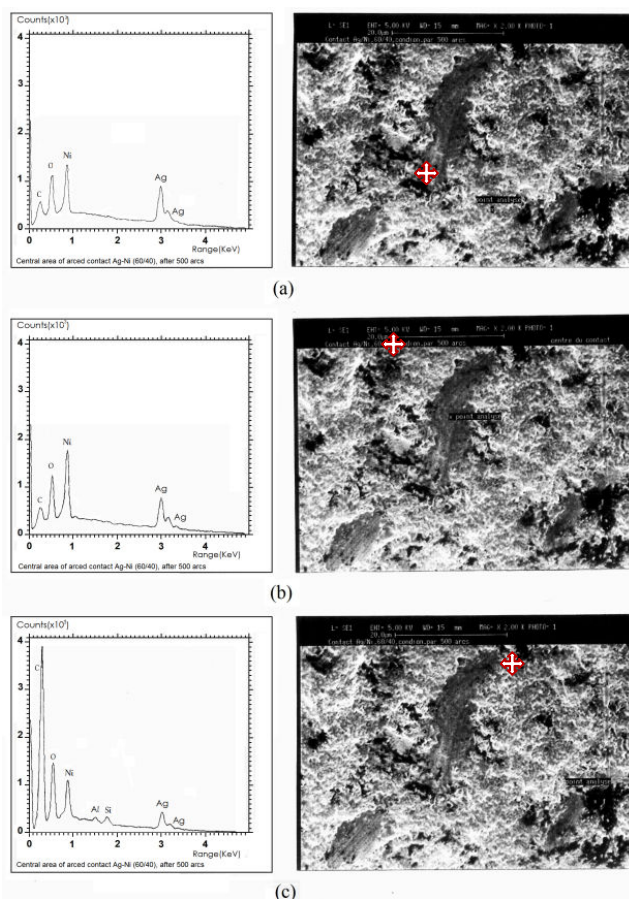

Fig. 9 EDS line scans of silver and nickel oxides formed on the centre of Ag-Ni (60/40) cathode surface conditioned by 500 electric arcs in air. Three representative points ((a), (b) and (c)) situated at different locations were analyzed, SEM magnification x 2000

The EDS lines analysis show sometimes a predominance of nickel (Fig. 10 (b)), and in some cases a significant presence of silver (Fig. 10 (c)).

D. Influence of Additives

It must be noted that even few hundreds of ppm of sodium may change the EWF of silver materials containing additives [28]. The alkaline additive has been added to the contact material as a salt during the blending process (Na_2SO_4, K_2CO_3, and Li_2CO_3). According to these authors, in the absence of data, it is possible to use estimation, assuming that emission in a composite material follows the law of mixture [29]:

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$$J_T = 1.2 \cdot 10^{-6} T^2 \left[(1 - a_i) \exp\left(-\frac{e \Phi_A}{kT} \right) + a_i \exp\left(-\frac{e \Phi_i}{kT} \right) \right] \qquad (4)$$

where Φ_a is work function of basic metal, Φ_i is work function of the additive, a_i is proportion of additive, k is Boltzmann constant, e is electron charge and T is temperature. Thus,

for pure Ag, $\qquad$ $J_T = 5.10^3$ A.m^{-2}
for Ag + 460 ppm Na, $\qquad$ $J_T = 10^6$ A.m^{-2}

IV. DISCUSSION

Chemical composition of contact surface and atom arrangement on it governs its mechanical, electronical and chemical properties. We have seen in our experiments that EWF is largely influenced by surface nature of contact when it is measured. So, mechanical, thermal and electrical conditionings modify physicochemical properties of contact surface and sometimes important variations of EWF occur.
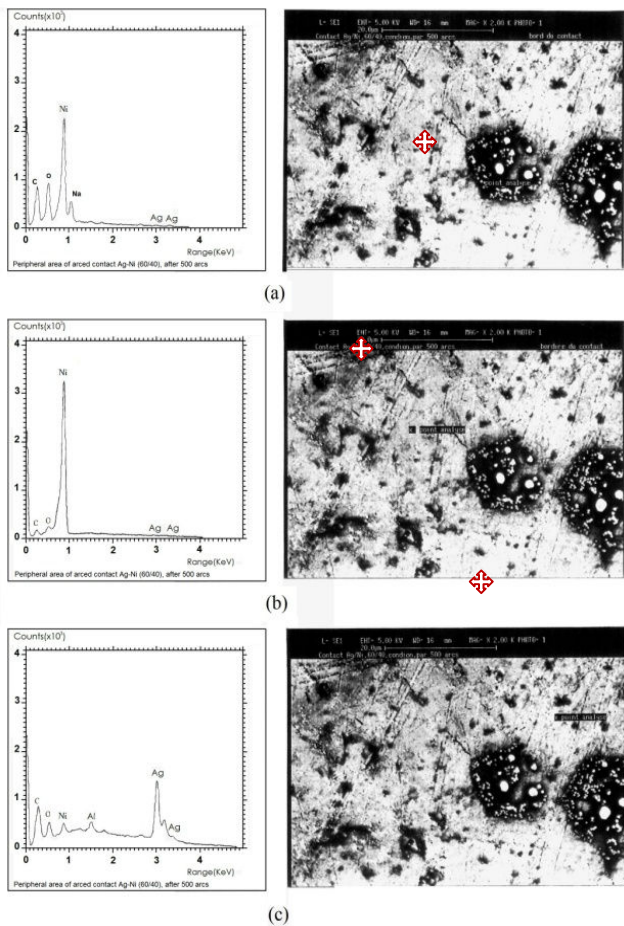

Fig. 10 EDS line scans of silver and nickel oxides formed on the periphery of Ag-Ni (60/40) cathode surface conditioned by 500 electric arcs in air. The additives have migrated towards the cathode periphery. Three representative points ((a), (b) and (c)) situated at different locations were analyzed, SEM magnification x 2000

It is important to note that EWF variation of order of 0.2 eV has a significant effect on physical properties of the new-born spot; underlying material does not reach immediately working temperature. It would be interesting to measure EWF of material reaching its melting point. Measuring the EWF of silver alloys electrodes during operation would be strongly helpful for a better understanding of the physical behavior of the cathodic spot. The temperature in the cathode spot is greater than 2000 K, and there is an enormous pressure of metal vapor. Question arises as to how we can apply the obtained results to a temperature lower than 1000 K and under vacuum. There is still a lack of understanding of the physics of this phenomenon. Further experimental investigation would be extremely helpful for a better knowledge of the electron emission for the new contact materials (Ag-Me and Ag-MeO) during operation under industrial use. At the time of establishment of the arc, the temperature at the cathode, near 3500 K will increase the diffusion and evaporation of the various components of the metal alloy, altering the structure of the contact surface. The surface of contact is the seat of thermal and mechanical stresses generated by the arc. Following the power of interrupted current, these stresses cause the melting evaporation and the projection of a metal amount more or less important by turning the surface appearance and the metallographic structure of the pastille. The work function measurement of the contact eroded will allow the study of evolution of electric current density on electrical contacts.

When the industrial conditioning of contacts by arcing takes place in air, some thin oxide films appear upon the surface of the contacts. These films are colored due to the interference between the light rays reflected from the outer and inner faces of the film, and their color changes with metal thickness. Due to anisotropy of growth phenomenon, when a polycrystalline contact is oxidized, different colors appear on the different metal grains, in the area of the interference film and are delimited by the contours thereof.

It is worth pointing out that adsorption of atoms or molecules changes the dipole layer and hence the work function: electronegative adsorbates (e.g. O, C, S) increase the work function, electropositive adsorbates (e.g. Na, K, Cs) decrease the work function.

V. CONCLUSION

The effects of arcing on silver EWF have been studied by ultraviolet photoelectron emission. 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 work function of the virgin Ag-Ni (60/40) contact (polished), determined at room temperature, is equal to 4.33 eV, in good agreement with the results already obtained.
2. Once a conditioning with 100 opening arcs is completed, this contact (cathode) is placed in the vacuum chamber, which will be baked again under the same conditions. The

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EWF found, after cooling, is equal to Φ(100 arcs) = 4.31 eV (Fig. 9). It is therefore observed that after 100 arcs, the work function of the silver contact remains close to unconditioned contact.

3. Subsequently to an additional conditioning of 400 electric arcs for the same electrodes, the EWF of the cathode rises to Φ(arcs 500) = 4.38 eV. This increase is probably due to the oxidation of eroded surface of contact due to undergone multiple and repetitive electric arcs.

4. The observations by a SEM and the analysis by EDS enabled us to show the presence of silver oxide and additives over the eroded Ag-Ni contact surface. Thus, the EWF increasing due to oxidation by arcing has been demonstrated, although this kind of conditioning increases contact roughness and consequently its electronic emission.

5. The photoelectric emission measurements were useful for investigating the changes of the EWF for commercial electrical contacts made in silver-nickel after electric arcs conditioning.

Further work would be focused on the arcing effects of photoelectric work function for metallic electrical contacts (Ag, Cu, Ni, …) and subsequently for silver based contact materials Ag-Ni (70/30), Ag-W (50/50), AgCdO (88/12), AgSnO$_2$ (92/8) and AgZnO (92/8)). Additional investigations are thus needed for a better understanding of such complicated phenomena for which the physics is not yet sufficiently clear.

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