Influence of Oxides on Material Transfer Behavior of Silver Base Contacts Containing Various Metal Oxides*

By Mitsunori Sato**, Masayuki Hijikata** and Ichiro Morimoto**

Silver base contacts containing magnesium, aluminium, manganese, zirconium, lanthanum and cadmium oxides are prepared by internal oxidation. The material transfer or erosion characteristics of these contacts are investigated in the range of applied voltages from 40 to 212 V and currents from 6.4 to 80.1 A in direct current, alternating current and rectified full sinusoidal wave current circuits.

The characteristics of the material transfer or erosion for switching contacts in direct current and alternating current can be clarified in many respects by a switching test of rectified full sinusoidal wave current. In the switching of rectified full sinusoidal wave current, the direction of the material transfer depends on the value of the testing current. In the range of lower current than the transition one the material transfer occurs in a direction from cathode to anode, and in the higher current range from anode to cathode. The direction of the material transfer and the amount of erosion are affected remarkably by the kind of containing oxides, and particularly by the materials of the electrode in which erosion occurs. In the range of material transfer from cathode to anode in direct current and rectified full sinusoidal wave current, the amount of cathode erosion is approximately proportional to the arc energy in contact breaking at a constant applied voltage. Moreover, the ratio of the amount of material transfer to the arc energy varies with the oxides contained.

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I. Introduction

Silver and its alloys are used extensively as electrical contact materials. The characteristics of these contacts such as the material transfer or erosion, the welding adhesion and the contact resistance depend on the circuit conditions whether testing is done in direct current or alternating current(1)–(3). The characteristics of the welding adhesion and the contact resistance are remarkably affected by the migrated layer formed on electrodes as a result of material transfer(4). Therefore, the material transfer or erosion which is one of the most important characteristics of an electrical contact is remarkably affected by a switching arc(5)–(8). It depends strongly on the breaking arc, so long as the chattering does not occur in contact making. The breaking arc behavior is closely related with an electron emission mechanism of contact materials. The silver contact belongs to a field emission type (T–F mechanism)(9). In order to keep the stable cathode spot of the switching arc, it is necessary that an element with high electron affinity and high electron affinity, such as oxygen, exists on the contact surface(10). Subsequently, the relation between the direction of material transfer and the applied voltage or current is investigated in direct current(11)(12). However, many problems are left unexplained. One of them is what kinds of properties of material influence the above behavior. When various oxides are contained in silver(13), the electron emission behavior is affected by those oxides. Namely, the distribution of the arc energy to both electrodes varies, causing changes in the characteristics of material transfer or erosion.

In the present work, therefore, the behavior of material transfer or erosion of silver base contacts containing various oxides prepared by internal oxidation is investigated in the circuit of direct current, alternating current and rectified full sinusoidal wave current with a load of non-inductive resistance, under whose conditions switching arc necessarily generates. The effects of such conditions on the material transfer or erosion, as the kind of containing oxides, the applied voltage and current, the breaking arc energy, the polarity in electrodes, and the breaking and making operation speed, are investigated. The characteristics of material transfer or erosion in direct current and alternating current are discussed on the basis of the results of the switching test in a rectified full sinusoidal wave current.

II. Experimental Procedure

1. Specimens

The chemical compositions of the contact materials are shown in Table 1. The specimens used are prepared from a 6 mm rod, 6 mm in diameter and 20 mm in a radius of curvature on its contact surface, and are internally oxidized in air at the temperatures specified in Table 1. Among them silver-molybdenum oxide and silver-silver chloride specimens are sintered by means of a hot press method with powders of silver, molybdenum and silver chloride. Hardness of specimens is also shown in Table 1.

2. Experimental procedure

The measurements are made with a contact switching testing machine constructed as a trial(2), which
Table 1 Chemical composition, oxidation temperature and hardness of specimens.

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>Ag(%)</th>
<th>°C</th>
<th>Hv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>—</td>
<td>99.9</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ag-Mg oxide</td>
<td>1.10</td>
<td>Mg at%</td>
<td>650</td>
<td>163</td>
</tr>
<tr>
<td>Ag-Al oxide</td>
<td>0.95</td>
<td>Al at%</td>
<td>650</td>
<td>150</td>
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<td>1.07</td>
<td>Mn at%</td>
<td>650</td>
<td>122</td>
</tr>
<tr>
<td>Ag-Zr oxide</td>
<td>0.97</td>
<td>Zr at%</td>
<td>650</td>
<td>74.5</td>
</tr>
<tr>
<td>Ag-La oxide</td>
<td>1.14</td>
<td>La at%</td>
<td>650</td>
<td>58.2</td>
</tr>
<tr>
<td>Ag-8 CdO</td>
<td>7.8</td>
<td>Cd wt%</td>
<td>750</td>
<td>67.8</td>
</tr>
<tr>
<td>Ag-12 CdO</td>
<td>11.5</td>
<td>Cd wt%</td>
<td>750</td>
<td>76.8</td>
</tr>
<tr>
<td>Ag-15 CdO</td>
<td>15.1</td>
<td>Cd wt%</td>
<td>750</td>
<td>84.3</td>
</tr>
<tr>
<td>Ag-Mo oxide</td>
<td>5.0</td>
<td>Mo wt%</td>
<td>480</td>
<td>37.0</td>
</tr>
<tr>
<td>Ag-AgCl</td>
<td>1.05</td>
<td>AgCl wt%</td>
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has a making force of 200g, a breaking force of 300g, and a range of making and breaking operation speeds from 26 to 126 mm/sec. The circuit conditions are an applied voltage range from 40 to 212 V and a testing current range from 6.4 to 80.1 A in direct current, alternating current and rectified full sinusoidal wave current at a load of non-inductive resistance. For alternating current and a rectified sinusoidal wave current, the values of the applied voltage and current are represented by the maximum of the sinusoidal wave. The amounts of material transfer or erosion in electrodes are weighed after the operation of $5 \times 10^4$ times by the use of a microbalance accurate to $1/1000$ mg; the transfer gain is expressed by the plus sign and the erosion by the minus sign.

III. Experimental Results

1. Material transfer in switching contacts of direct current

(1) Effect of containing oxides

In the case of switching contacts of direct current the material transfer is affected by the polarity of electrodes. The amount of material transfer and its direction may depend on the kind of the oxide contained in silver. The measurement is done by changing the current under an applied voltage of 40 V and an operation speed of 63 mm/sec. The amount measured is shown in Fig. 1 for various silver contacts containing metal oxide. As shown in Fig. 1(a), the material transfer occurs in a direction from cathode to anode for all contacts. The amount of material transfer and erosion varies with the kind of the oxide contained in silver. Generally, the amount increases with increasing current, except silver-zirconium oxide contacts having a region where the amount decreases with increasing current. As shown in Fig. 1(b), for silver-cadmium oxide contacts the material transfer occurs in a direction from cathode to anode at a testing current of 6.4 A, but it occurs in the opposite direction, from anode to cathode, in the neighborhood of 10 A. This current in which the direction of material transfer changes is called the transition current. Moreover, the amount of material transfer first decreases in the neighborhood of the transition current and then increases remarkably\(^{11}\)\(^{12}\).

![Fig. 1 Amount of material transfer $W$ in electrodes as a function of testing current $I$. Applied voltage is d.c. 40 V and breaking speed is 63 mm/sec.](image)

(2) Effect of breaking and making operation speed

The behavior of material transfer is well known to be closely related with the breaking arc behavior. The arc varies with the breaking speed, namely, the arc duration $T$ given by\(^{14}\)

$$T = \frac{L}{v},$$

(1)

where $L$ is the arc length and $v$ the breaking speed. Moreover, the arc length $L$, the arc voltage $e$, and the arc current $i$ in a contact breaking have been obtained from the circuit conditions and the physical properties of materials by present authors\(^{15}\). The arc energy $J$ is given by

$$J = \int_0^T e i \, dT.$$  

(2)

Therefore, the arc energy is inversely proportional to the breaking speed. In this case, the rate of the distribution of the arc energy to each gap distance between electrodes does not change with the breaking speed. The relation between the amount of material transfer and the breaking speed is shown in Fig. 2, which is measured with silver contacts at various operation speed under an applied voltage of 40 V and a testing current of 10 A. In the range of lower speeds than 100 mm/sec, the amount of material transfer increases in almost inverse proportion to the operation speed and consequently is proportional to the arc energy in contact breaking. However, when the breaking speed is more than 120 mm/sec the amount increases contrariwise. In this case, the making arc which is generated by chattering is observed with an oscilloscope, resulting in an increase of the amount of material transfer.
2. Erosion in switching contact of alternating current

(1) Effect of containing oxides

The oxide contained in silver may also have an effect on the erosion behavior in alternating current. The amount of erosion is shown in Fig. 3, which is measured with the change of the current under an applied voltage of 141 V and an operation speed of 63 mm/sec for various silver contacts containing a different kind of metal oxide. In this figure, the amount of erosion \( W \) is denoted by the sum of the erosion in both electrodes. In Fig. 3(a), the kind of oxides which has high erosion resistance in alternating current is found to be different from the results on switching contacts in direct current. In alternating current, silver-magnesium oxide contacts have the least amount of erosion. For all contacts the amount of erosion increases drastically in the neighborhood of a testing current of 50 A. In Fig. 3(b), for silver-cadmium oxide contacts the minimum of erosion is given by 8% cadmium oxide. This result is in agreement with the content of cadmium oxide which gives the minimum of erosion for silver-cadmium oxide-nickel oxide contacts\(^3\).

(2) Effect of breaking and making operation speed

The amount of erosion may also vary with the operation speed in the contact switching of alternating current. The amount of erosion which is measured with silver contacts with the change of the operation speed under an applied voltage of 141 V and testing currents of 28.3 and 42.4 A, is shown in Fig. 4. The amount of erosion changes with the operation speed. Therefore, the operation speed is one of the most important factors for the erosion behavior as well as a contact force and circuit conditions.

3. Material transfer in switching contact of rectified full sinusoidal wave current

In the contact breaking of direct current, the arc length becomes considerably longer with an increase of the applied voltage and current. This makes it difficult to measure the amount of erosion over a wide range of circuit conditions. On the other hand, in most cases of contact breaking of alternating current the arc disappears in a duration of half a sinusoidal wave. This means that each contact breaking gives polarized erosion in electrodes. However, by a repeated contact breaking, the change in polarity occurs in both electrodes, thus cancelling out the influence of the polarity on the erosion behavior, by its mutual compensation. The results obtained from the switching test with rectified full sinusoidal wave current seem to be effec-
tive for obtaining information on the material transfer or erosion behavior.

(1) Effect of containing oxides

The effect of containing oxides on the material transfer in a switching contact of rectified full sinusoidal wave current which is examined with the change of the current under an applied voltage of 141 V and an operation speed of 63 mm/sec for various silver contacts containing a different kind of metal oxide, is shown in Fig. 5. In Fig. 5(a), the direction of the material transfer is found to depend on the testing current, and the transition current in which its direction changes appears. The transition amperage and the amount of material transfer are changed by the kind of containing oxides. For the silver-aluminium oxide, silver-zirconium oxide and silver-lanthanum oxide contacts, the transition currents are lower than that of silver contacts. Moreover, in the case of direct current as shown in Fig. 1(a), silver-zirconium oxide contacts have a region in which the amount of material transfer decreases with increasing current. It may be due to the lowering of the transition amperage by the zirconium oxide contained. On the other hand, when the magnesium or manganese oxides are contained the transition current becomes high. Therefore, for the silver-magnesium oxide and silver-manganese oxide contacts, the direction of material transfer does not change in the range of the present testing conditions, and the amounts of the material transfer of these materials are greater than those of the materials of lower transition current in the region of the transfer direction from cathode to anode. For silver-zinc oxide contacts the characteristics is much the same as those of silver contacts, and, therefore, the effect of containing zinc oxide does not appear. In Fig. 5(b), for all contacts the material transfer occurs in a direction from anode to cathode, differing from that of the contacts shown in Fig. 5(a). For the silver-cadmium oxide contacts, the amount of material transfer first decreases in the neighborhood of the transition current and then increases remarkably as shown in Fig. 1(b). Silver-molybdenum oxide and silver-silver chloride contacts have similar transfer characteristics to those of silver-cadmium oxide contacts. In these cases, the molybdenum oxide is found to have such a high vapor pressure as cadmium oxide and to sublime vigorously at 795°C. In consequence, the chlorine is known to have powerful electro-negativity and high electron affinity\(^{(16)}\). From these characteristics their erosion behavior may be explained.

(2) Comparison with erosion behavior in alternating current

In the case of contact switching in rectified full sinusoidal wave current, the rate of the transfer gain on one electrode to the erosion loss on the other electrode is high in a region of material transfer from cathode to anode. On the other hand, when the transfer direction changes from anode to cathode, the rate becomes low as shown in Fig. 5. The transition current above which the amount of erosion increases remarkably in alternating current may be closely related with the transition current in which the direc-

![Fig. 5 Amount of material transfer \( W \) in electrodes as a function of testing current \( I \) at rectified full sinusoidal wave current. Applied voltage is 141 V and breaking speed is 63 mm/sec.](image-url)
tion of material transfer in rectified full sinusoidal wave current changes. Figure 6 shows the effect of containing oxides on the difference of the material gain and loss in switching contacts of rectified full sinusoidal wave current. These results show a similar tendency to that of the erosion behavior in switching contacts of alternating current as shown in Fig. 3.

(3) Effect of applied voltage and current

The behavior of material transfer may be affected by the applied voltage and current. The amount of material transfer for silver contacts which is measured with the change of the applied voltage and current is shown in Fig. 7. The direction of material transfer changes in the neighborhood of a testing current of 60 A with varying applied voltage, and the influence of the applied voltage on the transition current in which the direction of material transfer changes is extremely weak in a range from 42.4 to 212 V. Therefore, the direction of material transfer depends on the testing amperage, namely, in a lower range than the transition current the direction of material transfer is that from cathode to anode, and in a higher range, from anode to cathode. In the lower range the amount of material transfer increases with increasing applied voltage and current. On the other hand, in the higher range the amount increases remarkably.

(4) Effect of polarity in electrodes

The effects of anode and cathode materials on the amount of material transfer, and the transition current are examined for different kinds of materials as anode and cathode electrodes, as shown in Fig. 8.

Figure 8(a) shows a combination of silver and silver-manganese oxide contacts. When silver-manganese oxide is set on the anode and silver on the cathode, the amount of material transfer is similar to that of silver to silver electrodes in the lower current region than the transition amperage. On the other hand, when silver is set on anode and silver-manganese oxide on the cathode, the amount of material transfer is in a good agreement with that of silver-manganese oxide for both electrodes. In a range in which the material
(6) Effect of contact testing machine

The behavior of material transfer may be affected by the switching mechanism of a testing machine. In these experiments the inertia of the switching contact motion is directed from anode to cathode. When the polarity of electrodes is inverted in the same testing machine, the amount of material transfer is measured for silver and silver-15 wt% cadmium oxide contacts as in Fig. 11. The influence of this inertia on the amount of material transfer is estimated as a half of the difference between the two values which are measured in the direct and inverted polarities. These differences are so small that the effect of the switching mechanism in a testing machine on the material transfer is observed very small.

IV. Discussion

When the switching arc generates, the material transfer or erosion occurs as a result of the evaporation of the material in electrodes whose surface is mainly heated up by the arc. Therefore, the amount of material transfer or erosion may be related with the arc energy in contact breaking. The relation between the amount of material transfer or erosion and the arc energy in contact breaking is discussed. The arc energy in the contact breaking of direct current and rectified full sinusoidal wave current at a load of non-inductive resistance are calculated. The methods to obtain the arc length, arc voltage, arc current, and the arc energy in the contact breaking of a direct current and an alternating current have been published in a previous paper. The relation between the arc energy in contact breaking of direct current and the applied voltage or current is shown in Fig. 12. On the other hand, in cases of alternating current and rectified full sinusoidal wave current the phase at which contact breaking occurs is different in each operation, and the arc voltage $e$, the arc current $i$ and their product $ei$ are different in each contact breaking. Figure 13 shows the relation between the product of arc voltage and arc current $ei$ and the phase difference in contact breaking of alternating current and rectified full sinusoidal wave current. The arc energy can be obtained from the integration of this $ei$ curve. In this case, as a frequency is 50 Hz, an angle of $\pi$ radian is equivalent to the time of 10 msec. The relation between the arc energy and the phase difference in contact breaking of alternating current or rectified full sinusoidal wave current is shown in Fig. 14. The effects of
transfer occurs in a direction from cathode to anode, the behavior of the material transfer and erosion depends on the characteristics of the cathode material.

Figure 8(b) shows a combination of silver and silver-12 cadmium oxide contacts. When silver is set on both electrodes in the comparable circuit conditions, the direction of material transfer is from cathode to anode, and when silver-12 cadmium oxide on both electrodes the direction is from anode to cathode. In the case of the combination of the two materials on each electrode which show transfer gains respectively in the corresponding circuit, namely, when silver is set on the anode and silver-12 cadmium oxide on the cathode, the behavior of material transfer shows intermediate characteristics between the two both materials, which is similar to that of silver-8 cadmium oxide on both electrodes. In this case, the behavior of material transfer may depend on the both electrode materials, so that it is related with the difference between the amounts of material transfer on both electrodes. Subsequently, in a combination of both materials where erosion occurs, namely, when silver-12 cadmium oxide is set up on the anode and silver on the cathode, the behavior of material transfer is strongly affected by that of the anode material. The amount of the erosion becomes larger than that of silver-12 cadmium oxide on both electrodes. In this case, it may be related with the sum of the erosion in both electrodes. From these results, it is considered that the behavior of material transfer and erosion depends largely on the characteristics of a electrode material where erosion occurs\(^{1,11}\).

(5) Effect of making and breaking operation speed

The behavior of material transfer is likely to change by the operation speed in contact switching of rectified full sinusoidal wave current and of direct current and alternating current. The relation between the amount of material transfer and the operation speed in a switching contact of rectified full sinusoidal wave current is shown in Fig. 9, which are measured with silver contacts at various operation speeds under an applied voltage of 141 V and testing currents of 23.6 and 31.4 A. The amount and the direction of the material transfer are changed by the operation speed. These results are obviously different from those of direct current and alternating current as shown in Figs. 2 and 4, respectively. In the case of contact breaking of direct current, the arc length is determined from the properties of contact material and the circuit conditions. On the other hand, in the case of alternating current and rectified full sinusoidal wave current, the arc length is limited to half a wave\(^{15}\). From the above considerations and eq. (1), the arc length, the arc voltage and the arc current at each distance between the electrodes are changed by the breaking speed. Therefore, the behavior of material transfer may be changed by the breaking speed. Since the measured amount of material transfer are the sum of those at each distance in contact breaking, its complicated behavior may be found as shown in Fig. 9.

Moreover, the relation between the material transfer and the testing current may change with operation speed. The relation is shown in Fig. 10, as measured for silver contacts at an applied voltage of 141 V with a change of the current under operation speeds of 38, 63 and 84 mm/sec where the chattering does not occur in contact operations. The relation describes that the transition current to change the direction of material transfer varies with the operation speed.
Fig. 14 Arc energy $J$ as a function of phase difference $\phi$ in contact breaking at a.c. and rectified full sinusoidal wave current. Breaking speed is 63 mm/sec.
(a) Various applied voltage. Testing current is 7.85 A.
(b) Various testing current. Applied voltage is 42.4 V.

Fig. 15 Arc energy $J$ in contact breaking at a.c. and rectified full sinusoidal wave current as a function of applied voltage $E$ and testing current $I$. Breaking speed is 63 mm/sec.

Fig. 16 Amount of cathode erosion $W$ as a function of arc energy $J$ in contact breaking for silver contacts.
Subsequently, the transition current to change the direction of material transfer depends on the kind of oxides in rectified full sinusoidal wave current. In the range of lower current than the transition amperage, the rate of the transfer gain on one electrode to the erosion loss on the other electrode is high, and the amount of erosion is very small in alternating current. On the other hand, in the range of higher current than the transition amperage the rate becomes lower, and the amount of the erosion shows a marked increase in alternating current. Therefore, when the oxide, which raises the transition amperage in rectified sinusoidal wave current circuit, is contained the erosion of contacts in alternating current may be small in quantity.

V. Summary

Silver base contacts containing some oxides such as magnesium, aluminium, manganese, zirconium, lanthanum and cadmium oxides are prepared by means of internal oxidation. The behavior of the material transfer or erosion of these contacts is investigated in direct current, alternating current and rectified full sinusoidal wave current circuits with switching arc.

The characteristics of the material transfer or erosion in direct current and the alternating current can be greatly clarified by a switching test of rectified full sinusoidal wave current. In the switching operation of rectified full sinusoidal wave current, the direction of material transfer depends slightly on the applied voltage but largely on the value of the testing current. In the current region lower than the transition current the material transfer occurs in a direction from cathode to anode, and in the higher current region, from anode to cathode. The direction of material transfer and the amount of erosion are remarkably affected by the kind of oxides and particularly by the materials of the erosion side of electrodes.

Moreover, the current in which the amount of erosion increases remarkably is closely related with the transition current to change the direction of material transfer.

In the region of material transfer from cathode to anode in direct current and rectified full sinusoidal wave current, the amount of cathode erosion is approximately proportional to the arc energy in contact breaking at a constant applied voltage. The ratio of the amount of material transfer or erosion to the arc energy varies with the kind of containing oxides.

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REFERENCES