

Metal Migration on Electric Circuit Boards

1. Introduction

Today, many mechanical parts such as those used on electronic circuit boards are made to specifications for providing high reliability and low output at a low current and voltage, which has given rise to more and more stringent requirements for their characteristics. The most important issue may be Galvanic corrosion, in which the electrochemical reactions of heterologous metals are accelerated due to the presence of moisture and electrolytes at boundaries, resulting in metallic corrosion. These phenomena are early symptoms of destruction and peeling of the film of an adhesive or coating agent. In electronic parts, however, it is observed that the diffusion of ions and the like directly affects the characteristics before physical deterioration occurs, which makes theoretical prediction possible.

In recent years there has been a growing shift toward the use of inexpensive metallic materials, e.g., from gold to tin, in order to cut costs. Even with gold, the plating is becoming thinner, to the point that it is actually flashing rather than plating. In terms of the chemical composition of metal, it may be more true that the plated gold is a compound metal. Adhesives and coating agents that contact a metal exhibit pseudo-electrolytic properties at high temperature and high humidity. It is not an exaggeration to say that these materials constitute a multi-ion electrode. That is, if the application or use conditions are incorrect, an insulation disorder may result.

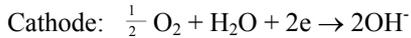
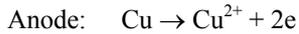
The present report is intended to enable the accelerated evaluation of creepage based on the electrochemical potentials of adhesives and coating agents that contact the metallic materials used in circuit-mounted parts and their peripheries, and to enable determination of the reliability of adhesives and coating agents.

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2. Measurement-system configuration

Adhesives and coating agents contain impurities and low-molecular-weight compounds, which combine to exhibit pseudo-electrolytic properties at high temperature and high humidity. With a voltage applied, an electric current flows through these materials via the electrolytes, thereby accelerating corrosion. In a copper electrode, for instance, the following reaction occurs to develop corrosion.



Thus, those adhesives and coating agents that exhibit such corrosive activity cannot be used for

electric circuit boards.

Chlorine and sodium ions in particular may damage electric and electronic devices, so care should be taken in their use.

The evaluation system for metals, adhesives, and coating agents against this problem consists of A-D and D-A converters, interfaces, an anti-log amplifier, an electrolytic cell, and others. Shown below are a block diagram of the system and a flowchart.

2-1. Evaluation-system block diagram

The system used for the accelerated evaluation can be represented in a block diagram as shown below.

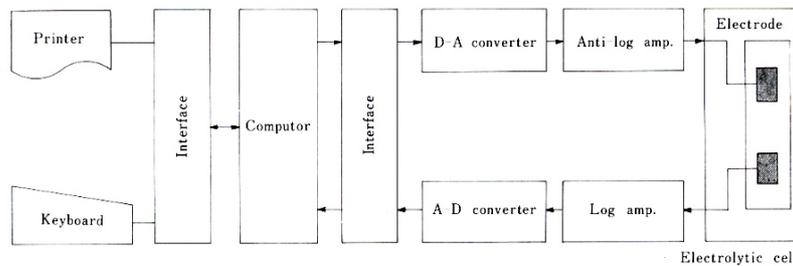


Fig. 1 Block Diagram of the Evaluation System

2-2. Measurement-procedure flowchart

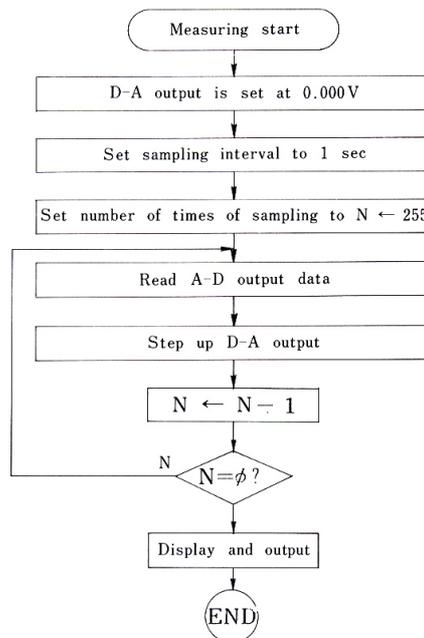


Fig. 2

The procedures for measurement were performed according to the flowchart shown above, producing computed results as output.

3. Experiment

Typically, adhesive manufacturers have no knowledge of the metals that constitute a material to which an adhesive is applied. To them, a metal is a metal. Therefore, they should study how the electric potential on a contact surface affects the characteristics of the metals there. Hence, we decided to investigate the phenomenon of metal migration at high temperature and high humidity, using representative metals as specimens.

In this experiment, the significant difference in leakage current properties between a pair of opposed metallic electrodes consisting of homologous metals and those consisting of heterologous metals, as well as the effect of coating agents that are a factor in that significant difference, were investigated. Comparatively studied in the present report were gold, copper, tin, silver, and zinc.

4. Measurement conditions and results

The experimental test pieces used were opposed electrodes with a creeping distance of 1 mm on a ceramic or glass epoxy-insulated board.

Those test pieces were observed for electric potential or leakage current at high temperature and

high humidity, specifically 70°C and 98% RH.

Silver is considered likely to cause ion migration and thus is not used for important circuits or is surface-treated or alloyed prior to use. Silver is thus a risky metal requiring special care. As a result of our comparison with gold and others with regard to the extent of a leakage current, it was found that silver has very high likelihood of migration and that, when it is used where the creeping distance is small, the user must take special care. In particular, silver reacts with water to be electrolyzed, turning into silver ions. The silver ions react with oxygen to develop AgO, which is unstable and likely to be deoxidized metal silver, which diffuses in the shape of the leaf vein, resulting in a creeping short. Thus it is important to prevent silver from absorbing moisture and turning into metal ions as a result. The phenomenon described above is typically referred to as the "migration" of silver. The creeping current leakage, however, varies in degree with the classification of the metal in contact and the combination of metals, as shown in Figs. 4 and 5. When silver is applied, therefore, careful consideration is required. Gold and silver in particular have only a low contact resistance on their surface, and seem to show stable properties other than corrosive-gas longevity.

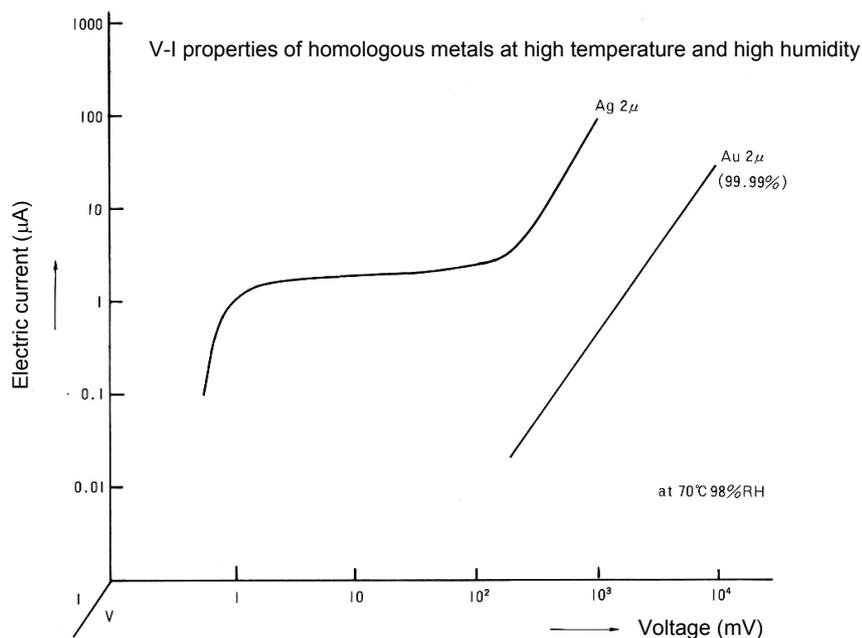


Fig. 3

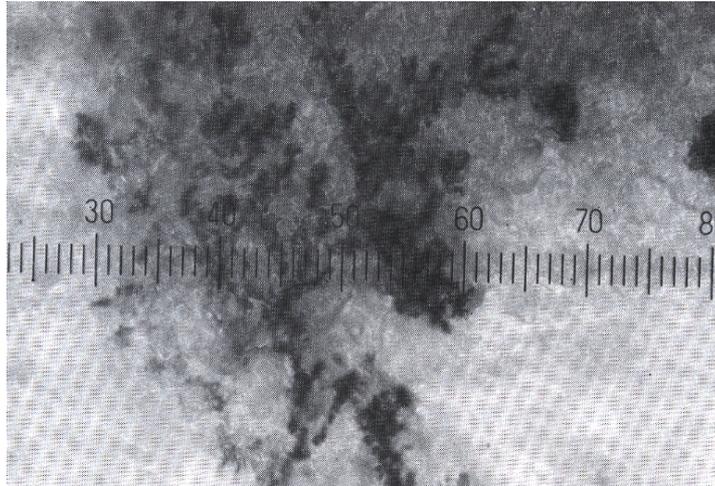


Photo 1. Silver That Diffused in the Shape of the Leaf Vein

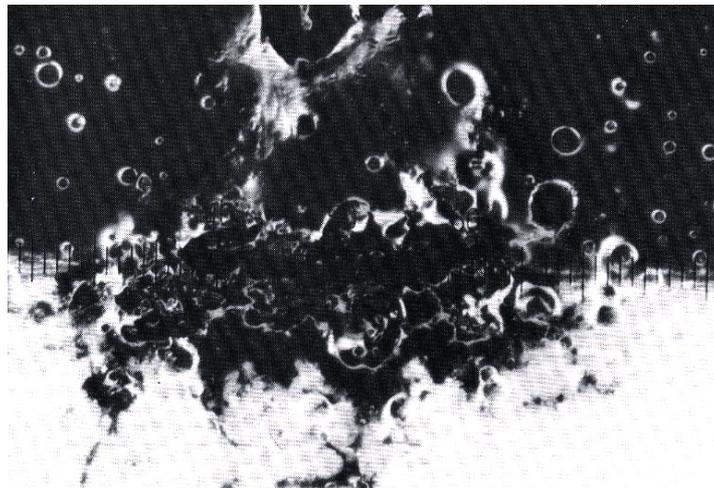


Photo 2. Silver Migration

Zinc and tin, which have a high ionization tendency, in contrast, readily migrate as a result of the absorption of moisture. On the surface of gold, for example, the migrated zinc and tin develop electrolytic plating, causing a creeping short and forming a high-resistance metallic film. The combination of gold and tin, between which the electrode potential difference is great, accelerates the electrochemical reaction toward deterioration, and is therefore risky.

Thus, the metals used on and around electronic circuit boards develop an electric potential in locations subject to changes in temperature and humidity, often causing a creeping short.

For electronic circuit boards for military and space uses in particular, coating with a moisture-proof paint is important. In addition, consideration of the possibility of a short and corrosion due to deteriorated insulation under stringent environmental conditions will be increasingly critical in reducing the size of mechanical parts. The reliability of printed circuit boards needs to be examined in stringent environmental tests, in accordance with the specifications of MIL-E5272, MIL-E16400E, and MIL-STD-202.

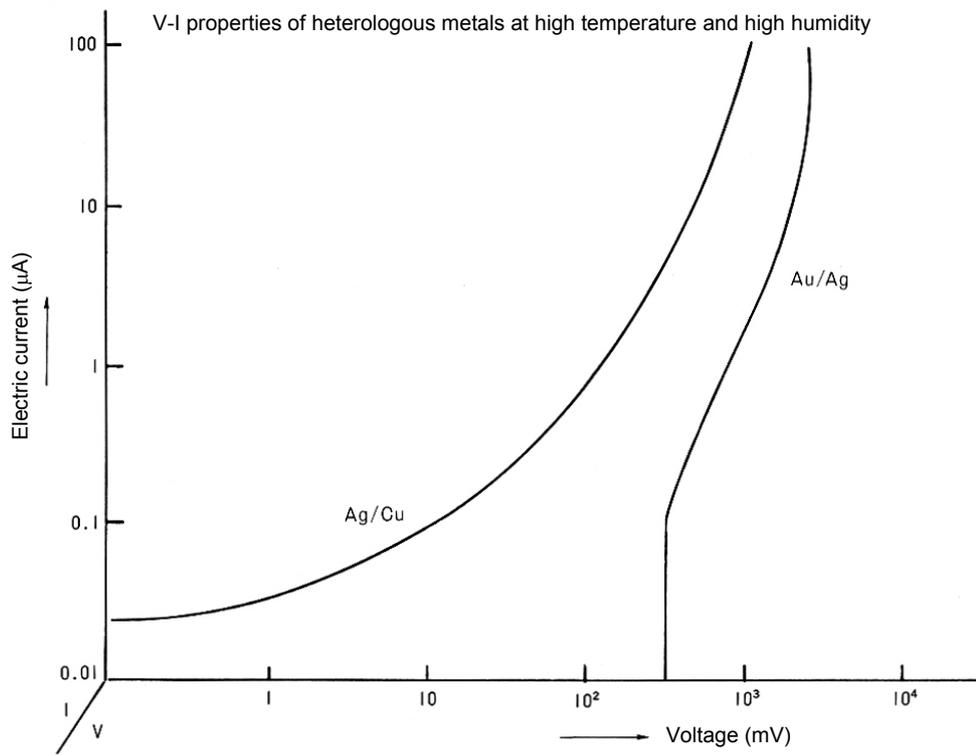


Fig. 4

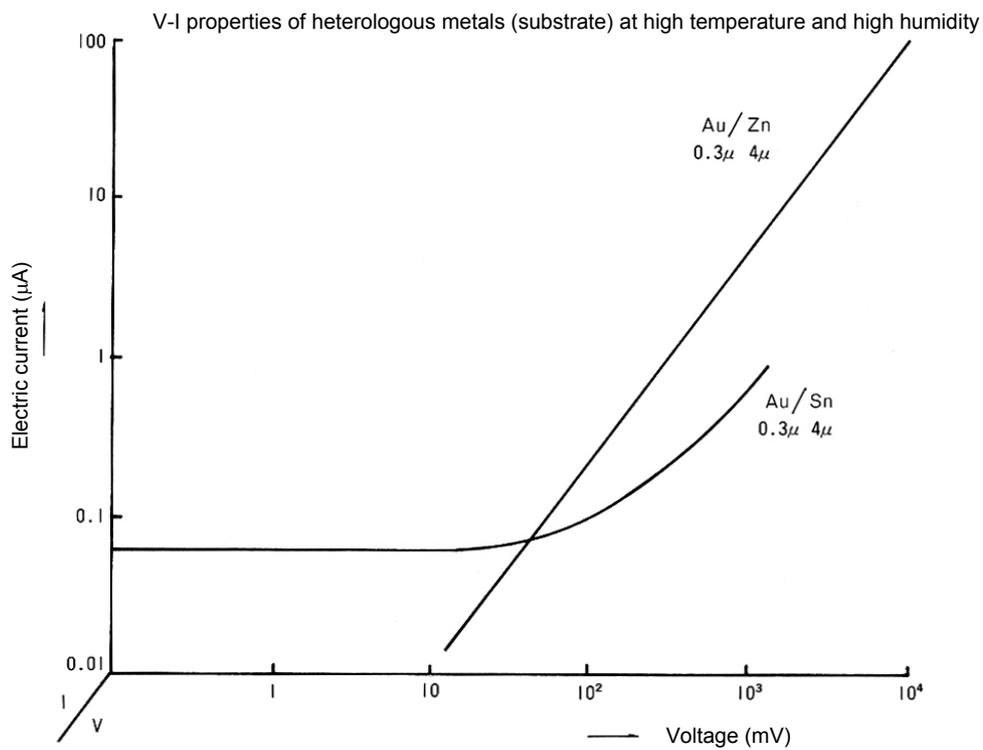


Fig. 5

Recently, bacteriological tests, impact tests, and wear tests were added to the temperature and humidity tests of these specifications. Moisture-proof paints are classified into the following four types in MIL-I-46058:

- 1) ER type: Epoxy
- 2) PUR type: Polyurethane
- 3) SR type: Silicone
- 4) PO type: Polystyrene

Thus far, we have discussed the basic aspects of metal migration. Reported below are the effects of paints that inhibit metal migration.

- 1) Epoxy resin/mercaptan
- 2) Epoxy resin/ denatured polyamine
- 3) Alkyd paint
- 4) De-alcohol type silicone RTV

Sample application 1

Discussed here are the moisture-resistant effects of the mercaptan group produced by the combination of Epicoat 828 of MW390 and a mercaptan-based curing agent.

Molecular structure

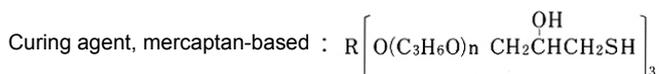
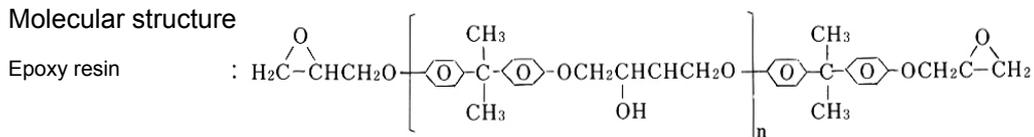


Fig. 6

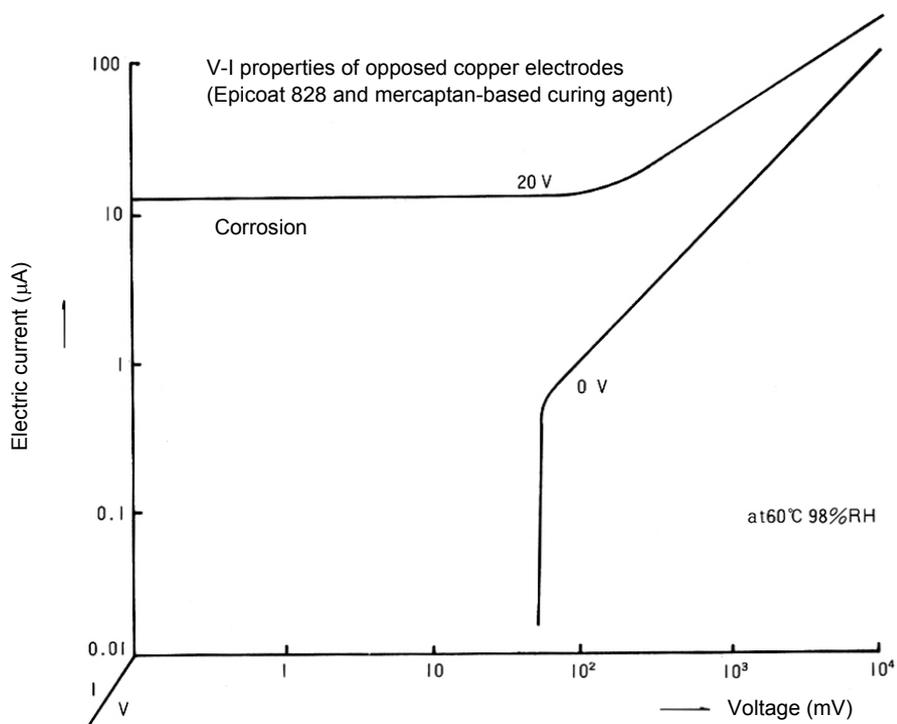


Fig. 7

Judging from the V-I properties shown in Fig. 7, the curing agent having an SH group is highly hygroscopic and non-heat-resistant. The moisture-resistant property of this curing agent is so low that a short occurs even at a low voltage. When it is applied, careful consideration is required, depending on some applications.

Molecular structure

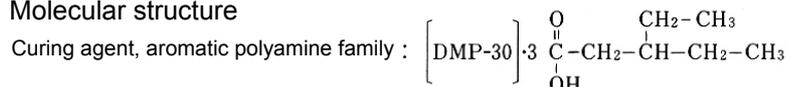


Fig. 8

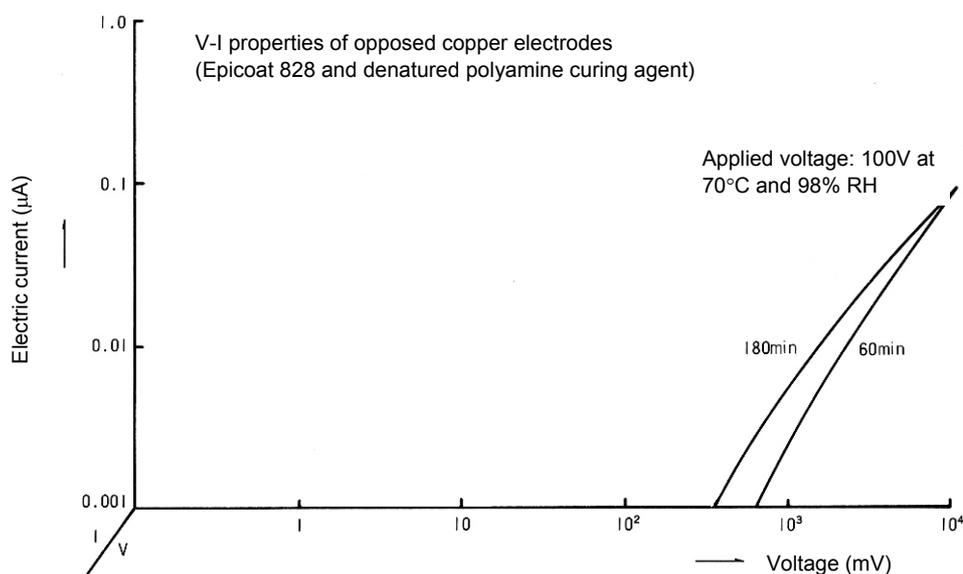


Fig. 9

The V-I properties shown in Fig. 9 indicate that the leakage current was low even at a voltage as high as 100V, and that no corrosion developed. Thus, this combination can be considered to provide a highly moisture-resistant curing agent. To copper in particular, no corrosion was noted.

Sample application 3

The moisture-resistant property of the lacquer-type alkyd paint was evaluated.

Generally, the alkyd paint exhibits excellent adhesion to copper and other metals. Judging from the obtained data, the alkyd paint lacks heat resistance and is therefore likely to cause electrolysis when a voltage is applied. That is, the alkyd paint is concluded to have very weak adhesion to metals at high temperature.

Sample application 2

Regarding the combination of Epicoat 828 of MW390 and the denatured polyamine-based curing agent, the moisture-resistant effect of the aromatic structure was discussed.

Sample application 4

The moisture-resistant property of the de-alcohol type silicone (RTV) was evaluated.

As the main component of silicone RTV is organo-polyoxyloxane, it shows very high heat resistance, moisture resistance, and good electrical properties compared with organic rubber, which consists mainly of carbon-carbon bonds.

Compared with the acetone type, however, the de-alcohol type, which contains active hydrogen, is likely to cause hydrolysis. The de-alcohol type silicone reported to be free from metallic corrosion is characteristic in that the leakage current remains very low from an early stage, whereas under a high voltage at high temperature its creeping leakage appears to increase quickly. That is, it can be judged that hydrolysis developed gradually, turning copper into ions.

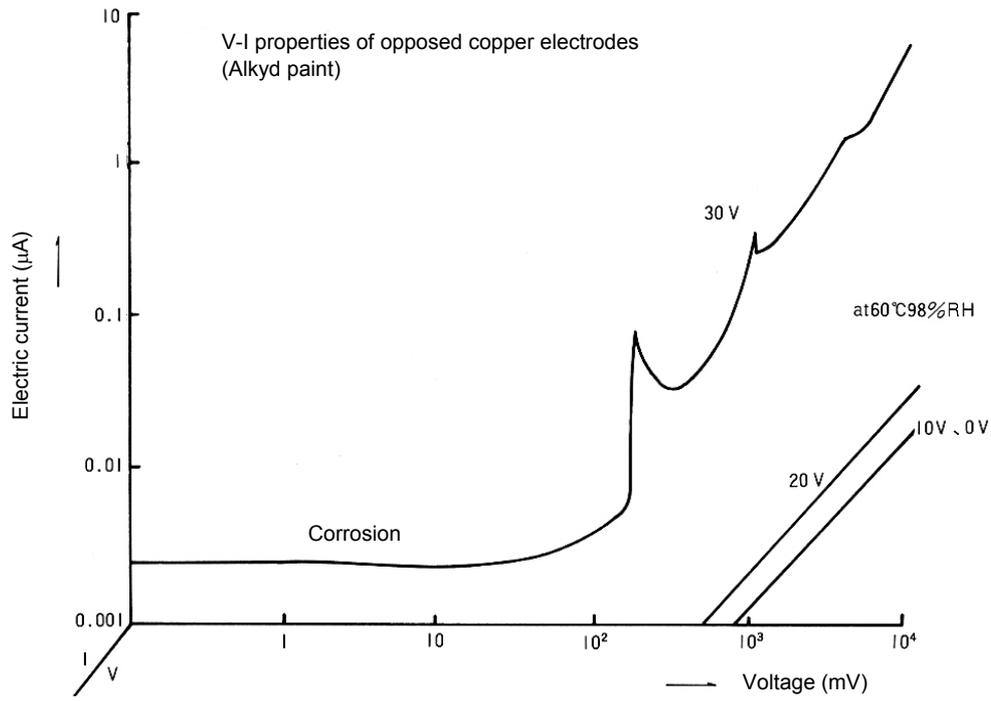


Fig. 10

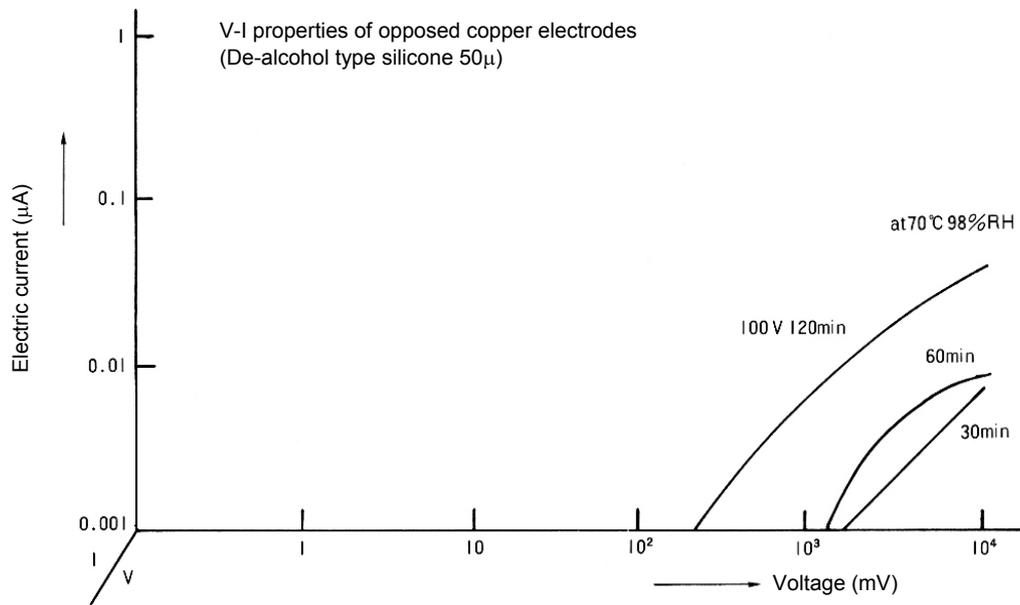
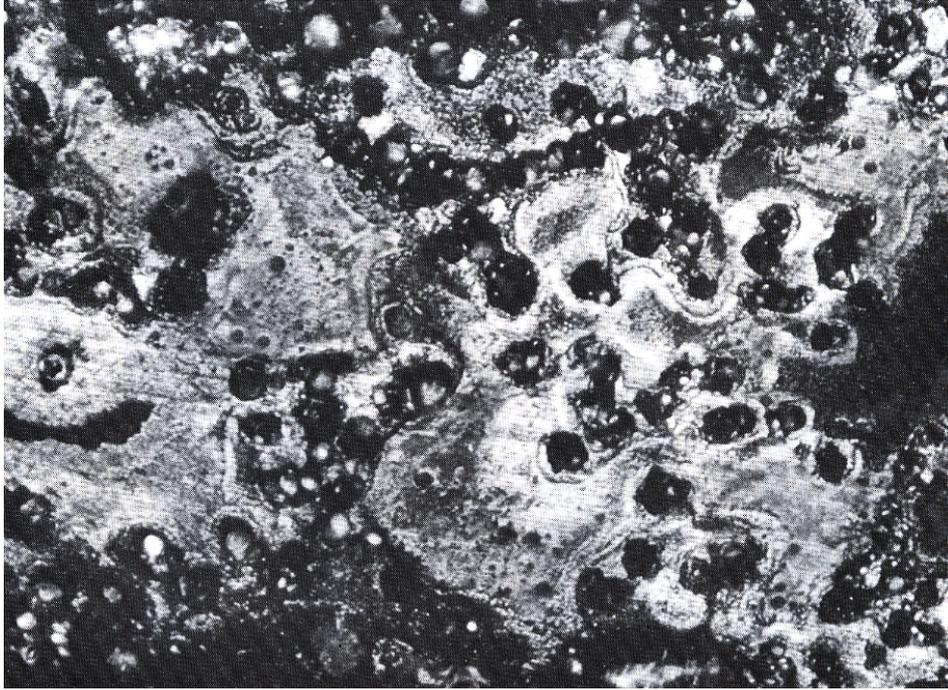


Fig. 11



Microscopic Photograph of Corroded Gold

5. Discussion

The opposed placement of heterologous metals accelerates corrosion due to a great difference in electrode potential. An adhesive and/or a coating agent used on and around the metals may accelerate deterioration, as they act as a semi-electrolytic substance.

6. Conclusions

1. Heterologous opposed tin electrodes exhibited particularly distinct deterioration.
2. Impurities in an adhesive and a coating agent tend to accelerate electrode deterioration, contrary to expectations.
3. When handling electrodes, special care should be taken, as electrodes including organic substances should be assumed to be multiple electrodes.

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● Procedures

1. Remove the cap. Insert the provided needle into the tip of the nozzle to make a small hole. Take care to prevent the contents from jetting out.
2. Fully wipe away all moisture, oil, rust, and other impurities on the surfaces to be bonded.
3. Apply the adhesive sparingly over the areas to be bonded. The more sparingly it is applied, the stronger the adhesion. If the material is absorptive, apply slightly more adhesive than normal.
4. Sparingly and uniformly apply a grinding liquid to the adhered surfaces of the subject areas. Fasten the work piece to a desired spot. The less time is taken to fasten the work piece in place, the stronger the resulting adhesion.
5. The bonding time varies depending on the types of materials to be bonded and the surface condition. Bonding will occur in approximately 5 seconds to 1 minute. In 30 minutes to 2 hours, the bonded area will be sufficiently strong for practical use.
6. For materials that are hard to bond, such as polypropylene, polyethylene, polyacetal, and EPT rubber, apply the instant extra-strength adhesive-dedicated primer, + ThreeBond 1797 in advance.



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