KINETICS OF AGING OF WELDED JOINTS OF GOLD AND ALUMINUM

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Thermocompression microwelding of gold conductors with aluminum contacts may lead to formation of $\text{Au}_x\text{Al}_y$ phase in the weld zone, which impairs the physicomechanical properties [1].

We investigated the effect of thermal aging on the properties of gold-aluminum, gold-gold, and aluminum-aluminum welds. Gold and aluminum wires 40 $\mu$m in diameter were welded by means of thermocompression and ultrasonic microwelding to aluminum or gold surfaces with the MS-41P2-1 apparatus [2].

The mechanical strength of the welds was determined from measurements of the pull strength $P$ of the wire at an angle of 90° to the surface. The electrical resistance of the contacts $R_c$ was also measured by the compensation method.

The samples were aged at 20, 80, 125, 200, and 225°C. The mechanical and electrical properties of the welds were measured at each temperature after 100, 250, 500, 1000, 1250, and 1500 h. Each experimental point is an average of measurements on at least 100 samples.

The results are shown in Fig. 1a, b.

As the temperature is raised to 175°C and higher the outward appearance of the gold-aluminum welds changes. A dark area is formed around the point of the weld, evidently due to growth of intermetallic compound. A similar change in the outward appearance of thermocompression welds was observed in [1].

In aluminum-aluminum and gold-aluminum welds made by ultrasonic microwelding and gold-gold welds made by thermocompression microwelding no changes were observed in the outward appearance at the same temperatures and aging times. No sharp changes in strength or electrical resistance were noted.

Figure 2 shows the logarithm of the relative strength $P_T/P_O$ vs $1/T$K ($P_O$ and $P_T$ are the pull strength before and after aging respectively).

The bends in the curves for gold-aluminum welds indicate a difference in the kinetics of the aging process due to the respective activation energies. At low temperatures (up to 125°C) stress relaxation occurs in the deformed areas resulting from welding [3]. At higher temperatures growth of intermetallic compounds is predominant. Prolonged aging induces a notable increase in the quantity of the intermetallic compound at lower temperatures.

The curves for gold-aluminum and aluminum-aluminum welds made by ultrasonic microwelding and gold-gold welds made by thermocompression microwelding have no inflection, and thus it can be assumed that only the relaxation process occurs. In gold-aluminum welds obtained by ultrasonic microwelding there are evidently no nuclei of intermetallic phase, and at an aging temperature of 225°C there is insufficient energy for their formation. Nuclei of intermetallic phase form in gold-aluminum welds made by thermocompression microwelding [4], growth of which is stimulated by aging, which lowers the strength and increases the electrical resistance of the joint.

If it is assumed that aging occurs by an exponential law in this case then the equation of aging can be written as follows:
Fig. 1. Electrical resistance and mechanical strength of welded joints in relation to testing time at different temperatures of the surrounding medium. a) Gold—aluminum, thermocompression microwelding; b) aluminum—aluminum or gold—aluminum, ultrasonic microwelding.

Fig. 2. Relative pull strength of welds in relation to testing temperature, 1) Aluminum—aluminum and gold—aluminum, ultrasonic microwelding; 2) gold—aluminum, thermocompression microwelding. ——) 500 h; ---) 1500 h.

\[ P_t = P_0 \exp \left( -\frac{\tau}{n} \right) \exp \left[ -\frac{E}{kT} \right] \]

where \( n \) is an empirical factor, equal to 20,000 h; \( E \) is the activation energy, eV; \( \tau \) is the aging time, h.

Since the value of \( \exp(-\tau/n) \) takes into account the stress relaxation time, and \( \exp(-E/kT) \) is associated with thermal stress relaxation processes and with growth of intermetallic phase, the activation energy is the sum

\[ E = E_r + E_i. \]

where \( E_r \) is the activation energy of the relaxation process; \( E_i \) is the activation energy of formation of intermetallic phase.

For ultrasonic microwelding \( E_r = 0.06 \) eV and for thermocompression welding \( E_r = 0.36 \) eV.

The activation energy of phase formation can be written as follows [5]:

\[ E_i = \Sigma \Delta E_f + \Sigma \Delta E_m \]

where \( \Sigma \Delta E_f \) is the sum of the formation of phases of the \( \text{Au}_x\text{Al}_y \) type; \( \Sigma \Delta E_m \) is the sum of the energy of movement of the component during phase formation.

From the test results one obtains \( E_i = 5.16 \) eV (for 500 h of testing) and \( E_i = 1.72 \) eV (for 1500 h of testing). The value of \( E_i \) is determined as the tangent of the slope of the lines in Fig. 2.

It was found in [6] that not only the temperature but also the direction of the electric current affects the value of \( E_i \), since the components of the total energy of movement \( \Sigma \Delta E_m \) increase or decrease under the influence of the latter. However, it is possible for the total energy of formation \( \Sigma \Delta E_f \) to decrease with increasing amounts of \( \text{Au}_x\text{Al}_y \).

CONCLUSIONS

1. Thermocompression microwelding of gold with aluminum leads to formation of nuclei of intermetallic phase that may grow during subsequent aging, leading to a reduction of the strength and higher electrical resistance of the joint.