THE EFFECT ON THERMAL CONTACT RESISTANCE OF THE TIME OF APPLICATION OF THE LOAD

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Problems of the effect of the time at which the load is applied on thermal contact resistance are considered. A relationship permitting a determination of the thermal contact resistance as a function of the time of load application is presented.

The formation of thermal contact resistance is usually considered [1-3] in interrelation with the process of mechanical contact between surfaces. At the same time, the actual contact area and the thickness of the intercontact gap are independent of the duration of the load, which definitely introduces errors into the quantities being sought. Deformation processes during formation of the contact of two surfaces are represented only as viscoelastic. They cannot be considered purely elastic, since it would be impossible to observe an increase of the actual contact area with time or an increase of the static frictional force as a function of the duration of the stationary contact [4]. Nor is it possible to assume that the process of the convergence and formation of a real contact is due purely to plastic flow of the material – this would lead to an infinite increase of convergence and increase of the actual contact area.

If rough surfaces are modeled in the form of a set of spherical projections of radius r arranged with a constant density, we can use the well-known relationships from mechanical contact theory.

An empirical equation which characterizes the change of convergence of the surfaces with time if given in [5]:

$$\varepsilon_\tau = \varepsilon_\infty (1 - e^{-\delta\tau^\rho}). \tag{1}$$

According to the derivations in [4] the solution for ε_∞ is represented in the form

$$\varepsilon_\infty = \left[\frac{P(\nu + \omega)}{bB}\right]^{\frac{1}{\nu+\omega}}. \tag{2}$$

The relative area of actual contact according to the data in [6], obtained by treating a large number of curves of supporting surfaces, is expressed in terms of convergence as

$$\eta_\tau = \alpha b \varepsilon_\tau^\nu. \tag{3}$$

After substituting (2) into (1) and then into (3), the dependence of the relative contact area on time of load application acquires the form

$$\eta_\tau = \alpha b \left[\frac{P(\nu + \omega)}{bB}\right]^{\frac{\nu}{\nu+\omega}} (1 - e^{-\delta\tau^\rho}). \tag{4}$$

The coefficient α figuring in Eq. (4), which takes into account the difference between the actual contact area and the cross-sectional area of the projections during the same convergence, is equal to unity for a plastic contact and to 1/2 for an elastic contact of the surfaces [6].

The total contact conductance is expressed by the sum of the conductances through points of actual contact and through the intercontact environment:

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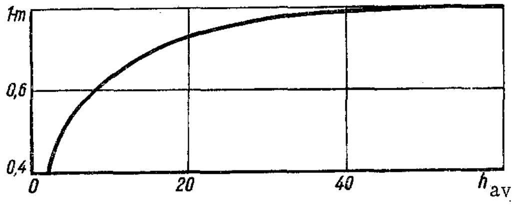

Fig. 1. Dependence $1-m = f(h_{av})$; h, μ.

$$\alpha_c = \alpha_p + \alpha_e \tag{5}$$

or, expressing the conductances by thermal resistances,

$$\frac{1}{R_c} = \frac{1}{R_p} + \frac{1}{R_e}. \tag{6}$$

In [7] the thermal resistance through points of actual contact is defined as

$$R_p = \frac{\varphi S_n}{2a\bar{\lambda}_p n}. \tag{7}$$

The solution for φ according to [8] in terms of the relative actual contact area is equal to:

$$\varphi = 1 - 1.41\eta_\tau^{1/2} + 0.3\eta_\tau^{3/2}. \tag{8}$$

With consideration that $n = S_a/\pi a^2$ and $a = 30 \cdot 10^{-6}$ m [9], Eq. (7) acquires the form

$$R_{p_\tau} = \frac{\varphi}{2.12\bar{\lambda}_p\eta_\tau} \cdot 10^{-4}. \tag{9}$$

The thermal resistance of the intercontact environment is

$$R_m = \delta_{ef}/\lambda_e. \tag{10}$$

The equivalent thickness of the interlayer δ_{eq} with consideration of the discrete character of the arrangement of the cavities of the environment has the form

$$\delta_{ef} = (h_{av_1} + h_{av_2})(1-\eta_\tau)(1-m)(1-\varepsilon_\tau). \tag{11}$$

Treatment of a large number of longitudinal and transverse profilograms of surfaces with a finish from the 3rd to the 10th class for materials with $E > 7 \cdot 10^{10}$ N/m² leads to the dependence $1-m = f(h_{av})$ (Fig. 1).

After combining (6), (9), (10), and (11), we have

$$\frac{1}{R_{c_\tau}} = 2.12 \cdot 10^4 \bar{\lambda}_p \frac{\eta_\tau}{\varphi} + \frac{\lambda_e}{(h_{av_1} + h_{av_2})(1-\eta_\tau)(1-m)(1-\varepsilon_\tau)}. \tag{12}$$

The use of Eq. (12) is complicated by the absence of ready data on the rheological constants δ and ρ. We determined δ and ρ as a function of temperature for alloy D16T and copper M2 according to the method in [10] (Table 1).

Equation (12) is obtained on the basis of numerous assumptions, the correctness of introducing which can be confirmed only experimentally. The experimental data obtained on a rod-type device [11] in the form of the dependence of thermal contact resistance on the time of load application in the presence of different surface finishes for different materials and thermal conditions are presented in Figs. 2 and 3.

An analysis of the character of arrangement of the curves $R_c = f(\tau)$ gives grounds for the following conclusions.

1. A considerable decrease of thermal resistance during prolonged holding under load is observed for materials with a low modulus of elasticity $E > (10-12) \cdot 10^4$ N/m².

TABLE 1. Temperature Dependence of Rheological Constants δ and ρ

Alloy	ρ at temperature, °K			δ at temperature, °K		
	293	373	473	293	373	473
D16T	0,46	0,478	0,491	2,12	2,01	1,87
M2	0,32	0,36	0,384	2,5	2,36	2,14

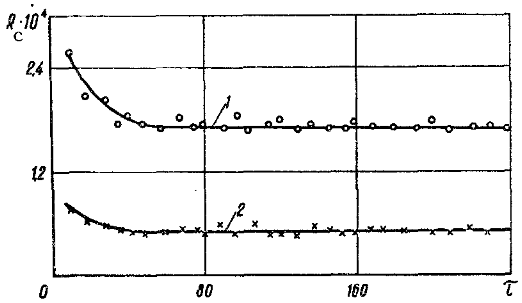

Fig. 2

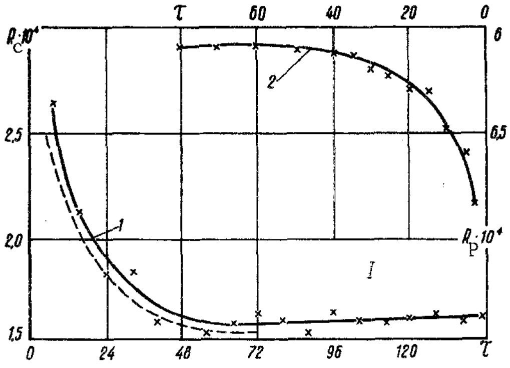

Fig. 3

Fig. 2. Thermal contact resistance (R_c, $m^2 \cdot deg/W$) as a function of the time (τ, h) of load application for a contact pair of steel 2Kh13 at $P = 98 \cdot 10^5$ N/m^2 and $T_c = 470°K$ with contact surfaces machined to finish classes: 1) $\nabla 4/\nabla 7$"a"; 2) $\nabla 7$"a"/$\nabla 9$"b".

Fig. 3. Thermal contact resistance (R_c, $m^2 \cdot deg/W$) as a function of the time (τ, h) of load application for the pair M2–steel 45 at $P = 98 \cdot 10^5$ N/m^2 and $T_c = 468°K$ with surface $\nabla 8$"a"$-\nabla 3$ (1) and thermal resistance of actual (metal) contact (R_p, $m^2 \cdot deg/W$) as a function of the time of load application for a steel 2Kh13 steel at $P = 98 \cdot 10^5$ N/m^2 and $T_c = 473°K$ with surfaces $\nabla 4-\nabla 7$"a" (in vacuo) (2). Dashed lines: calculation. I) Zone of intense growth of oxide film.

2. The thermal contact resistance for a material with $E > 18 \cdot 10^{10}$ N/m^2 at the initial stage of holding under load (to $\tau = 50$ h and less), decreasing slightly (to 15-20%), thereafter remains practically constant.

3. An increase of the surface finish class leads to degeneration of the dependence $R_{c_\tau} = f(\tau)$.

4. The formation of resistance in the contact zone during prolonged holding under load is equally affected by an increase of the actual contact area and decrease of the thickness of the equivalent interlayer (experiment in vacuo).

5. Both with respect to the character of the dependence $R_{c_\tau} = f(\tau)$ and with respect to the absolute value of R_{c_τ} the calculated values obtained from Eq. (12) agree satisfactorily with the experimental data.

NOTATION

ε_τ	is the relative deformation, determined by the time of normal load application;
ε_∞	is the relative deformation, established at the end of the interaction stage;
τ	is the time;
N	is the normal load;
$P = N/S_n$	is the specific load on converging surfaces;
S_n	is the nominal contact area;
S_a	is the actual contact area;
$\eta = S_a/S_n$	is the relative actual contact area;
b and ν	are the parameters of the supporting surface curve;
B	is the coefficient characterizing the properties of the materials;
ω	is the coefficient determined by the character of deformations;
α	is the coefficient of the ratio of converging surfaces;
α_c, α_p, α_e	are the total conductance of contact and conductances through points of actual contact and intercontact environment;
R_c, R_p, R_e	are the total thermal resistance of contact and resistances of points of actual contact and intercontact environment;
φ	is the coefficient of contraction of thermal flux lines at points of actual contact;
a	is the radius of a single contact spot;
$\bar{\lambda}_p = (2\lambda_{p_1}\lambda_{p_2})/(\lambda_{p_1} + \lambda_{p_2})$	is the reduced thermal conductivity;

n	is the number of contact spots;
λ_e	is the thermal conductivity of intercontact environment;
h_{av}	is the average height of microroughness projections;
m	is the space factor of microroughness profile;
E	is Young's modulus.

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