GENERALIZED RELATIONS FOR DETERMINING THERMAL CONTACT RESISTANCE

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By analyzing numerous experimental data dimensionless relations for calculating thermal contact resistance (TCR) over a broad range of thermal contact conditions are obtained.

A large amount of experimental material has been accumulated on the problem of contact heat transfer. Many experimental results were used in a number of investigations to obtain generalized relations for determining thermal contact resistance (TCR). As a rule, however, the relations obtained [1-3] describe a limited range of thermal contact conditions and practically do not take account of the effect of the nature of the deformation of the microroughnesses of the surfaces and the temperature conditions in the contact zone on the TCR.

In the present article we consider heat transfer in the contact zone in a gaseous medium. It is known [4] that in the absence of an oxide film on the contacting surfaces, and for moderate temperatures in the contact zone, the total TCR can be written as

$$\frac{1}{R_c} = \frac{1}{R_a} + \frac{1}{R_m}. \quad (1)$$

Substituting into (1) the value of the TCR of the actual contact from [5], and using the familiar equation for determining the relative area of actual contact from [6], we obtain in general form

$$\frac{1}{R_c} = \frac{1}{R_m} + K\frac{\bar{\lambda}_a}{a}\left(\frac{P}{E}\right)^n\left(\frac{r}{h_{max}}\right)^m. \quad (2)$$

Multiplying both sides of Eq. (2) by $a/\bar{\lambda}_a$ and introducing the dimensionless temperature gives

$$\frac{1/R_c}{\bar{\lambda}_a/a} - \frac{1/R_m}{\bar{\lambda}_a/a} = K\left(\frac{P}{E}\right)^n\left(\frac{r}{h_{max}}\right)^m \beta T_c. \quad (3)$$

We write the terms on the left-hand side of Eq. (3) in the form $(a/\bar{\lambda}_a)/R_c$ and $(a/\bar{\lambda}_a)/R_a$. Analysis of these combinations shows that they explain physically the Biot number Bi_c for contact heat transfer in a heat-conducting medium and Bi_m for heat transfer through an interlayer of the medium. By taking account of the above, Eq. (3) can be written in the form

$$Bi_c - Bi_m = K\left(\frac{P}{E}\right)^n\left(\frac{r}{h_{max}}\right)^m \beta T_c. \quad (4)$$

Analysis of the experimental data by using the equation in this form enables us to find the specific form of the dependence of the Bi_c–Bi_m combination on the unit load, the roughness, the physical and mechanical properties of the materials, and the temperature conditions of the contact.

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By processing 74 experimental points obtained by the author and other investigators for contacts of highly plastic metals in a gaseous medium (Fig. 1a) we can transform Eq. (4) to the form

$$\mathrm{Bi_c} - \mathrm{Bi_m} = 0.89 \cdot 10^2 \left(\frac{P}{E} \beta T_c \varkappa \right)^{0.73} \tag{5}$$

for

$$\frac{P}{E} \beta T_c \varkappa > 3 \cdot 10^{-7},$$

$$\mathrm{Bi_c} - \mathrm{Bi_m} = 1.9 \cdot 10^4 \left(\frac{P}{E} \beta T_c \varkappa \right)^{1.08} \tag{6}$$

for

$$5 \cdot 10^{-8} < \frac{P}{E} \beta T_c \varkappa < (2-3) \cdot 10^{-7}$$

the radius of the area of contact a is taken as $3 \cdot 10^{-5}$ m.

Similar processing of 102 experimental points for contacts of highly elastic metals (Fig. 1b) gives

$$\mathrm{Bi_c} - \mathrm{Bi_m} = 31.6 \left(\frac{P}{E} \beta T_c \varkappa \right)^{0.677} \tag{7}$$

for

$$\frac{P}{E} \beta T_c \varkappa > 1.5 \cdot 10^{-7},$$

$$\mathrm{Bi_c} - \mathrm{Bi_m} = 5 \cdot 10^2 \left(\frac{P}{E} \beta T_c \varkappa \right)^{0.85} \tag{8}$$

for

$$2 \cdot 10^{-8} < \frac{P}{E} \beta T_c \varkappa < (1-1.5) \cdot 10^{-7}.$$

Here $\varkappa$ is a coefficient depending on $h_{max_1} + h_{max_2}$ found from the relations

$$\varkappa = \frac{12}{h_{max1} + h_{max2}} \quad \text{for} \quad 5 \geqslant h_{max1} + h_{max2} \geqslant 1 \ \mu,$$

$$\varkappa = \left(\frac{20}{h_{max1} + h_{max2}} \right)^{0.63} \quad \text{for} \quad 10 \geqslant h_{max1} + h_{max2} \geqslant 5 \ \mu,$$

$$\varkappa = \left(\frac{30}{h_{max1} + h_{max2}} \right)^{0.4} \quad \text{for} \quad 30 \geqslant h_{max1} + h_{max2} \geqslant 10 \ \mu,$$

$$\varkappa = \left(\frac{30}{h_{max1} + h_{max2}} \right)^{0.5} \quad \text{for} \quad 50 \geqslant h_{max1} + h_{max2} \geqslant 30 \ \mu,$$

The correlation coefficients for the two groups of experimental data treated are 0.99 and 0.985. Taking into account the wide diversity of the experimental conditions, the correlation results can be considered quite satisfactory.

By using Eqs. (5)-(8) operational information on TCR can be obtained for specific thermal contact conditions.

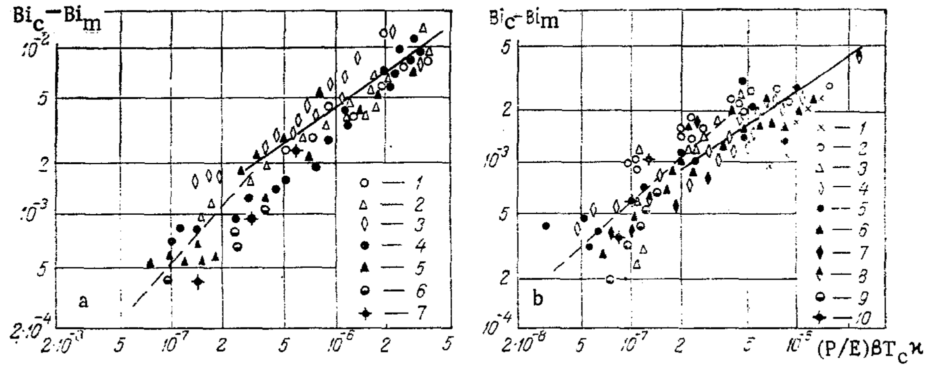

Fig. 1. Results of dimensionsless processing of experimental data for contact of samples of highly plastic (a) and highly elastic (b) metals in air: a: 1) D16T—D16T, D16T—steel 45 [7]; 2) aluminum—aluminum [8]; 3) D16—D16 [9]; 4) D16T—D16T, ZOKhGSA—D16T [10]; 5) D16T—D16T [11]; 6) aluminum—aluminum [12]; 7) bronze—bronze [13]. Solid curve) approximate Eq. (5); open curve) (6). b: 1) steel 30—steel 30 [14]; 2) steel 45—steel 45, ÉZh-1—ÉZh-2, ÉYaIT—ÉYaIT [7]; 3) 1Kh13—1Kh13, steel 45—steel 45 [8]; 4) 1Kh18N9T—1Kh18N9T, steel 3—steel 3 [9], 5) ZOKhGSA—ZOKhGSA [10]; 6) steel 45—steel 45, 1Kh18N9T—1Kh18N9T, 2Kh13—2Kh13—[11]; 7) steel—steel [15]; 8) stainless steel—stainless steel [16]; 9) iron—iron [12]; 10) steel—steel [13]. Solid curve) approximate Eq.(7); open curve) (8).

NOTATION

R_c, R_a, R_m, total contact resistance, actual contact resistance, and resistance of intercontact medium, respectively; $\bar{\lambda}_a = 2\lambda_{a_1}\lambda_{a_2}/(\lambda_{a_1} + \lambda_{a_2})$, reduced thermal conductivity of materials of contacting bodies 1 and 2; P, contact pressure (specific compression load); E, elastic modulus; h_{max}, maximum height of microroughnesses; r, radius of protuberances of microroughnesses; β, volume coefficient of expansion of material; T_c, average temperature in contact zone.

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