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ANALYSIS OF THERMAL CONDUCTANCE OF CONTACTS WITH INTERSTITIAL PLATES

T. N. VEZIROĞLU
University of Miami, Coral Gables, Florida, U.S.A.

and

H. YÜNCÜ and S. KAKAÇ*
Middle East Technical University, Ankara, Turkey

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Abstract—An analytical and experimental analysis has been carried out for the prediction of contact conductance with interstitial plates and an expression has been developed in terms of known properties and parameters. The model assumes that the interface is composed of similar macroscopic and microscopic contact elements. These elements are considered to be made up of two cylindrical solids having a circular contact in the middle of their surfaces facing each other with the gap between them filled with a material of uniform conductance. Theoretical predictions are compared with experimental data in the literature. Good agreement is found between theoretical and experimental values for thermal contact conductance with interstitial plates. The theory shows that thermal contact conductance is a strong function of hardness and thermal conductivity of interstitial plates as well as the surface texture of contact elements and interstitial plates.

NOMENCLATURE

- A, total apparent contact area;
- B, fluid thickness number, δ/a;
- C, constriction number, b/a;
- D, coefficient of series expansion;
- E, modulus of elasticity [kg_f/cm^2];
- J_1, J_2, semiaxes of contact region;
- K, k_f/k_s, conductivity number;
- M, Meyer hardness [kg_f/cm^2];
- P, apparent contact load per unit area [kg_f/cm^2];
- Q, heat flow rate [W];
- S, temperature slope at $z \to \infty$ [K/cm], size number;
- T, temperature [°C];
- U, conductance number, $u\delta/k$;
- a, contact element radius [m];
- b, contact region radius [m];
- h, heat-transfer coefficient [W/cm^2 K];
- k, thermal conductivity [W/cm K];
- l, amplitude [cm];
- p, pressure [kg_f/cm^2];
- r, radius [m];
- t, plate thickness [m];
- u, thermal contact conductance [W/cm^2 K];
- z, r, cylindrical coordinates.

Greek symbols

- β, eigen-values;
- δ, gap thickness, roughness, effective fluid thickness;
- ρ, radius of curvature [m];
- λ, wavelength [μ];
- ν, Poisson's ratio.

Subscripts

- 0, original;
- 1, solid 1;
- 2, solid 2;
- a, actual;
- c, contact;
- f, fluid;
- m, macroscopic, mean;
- p, plate;
- s, mean t.

The meanings of other symbols are given in the text as they occur.

1. INTRODUCTION

THE BASIC cause of interface resistance is unevenness of real surfaces. Surfaces which are said to be flat, in fact are wavy with regular pitch owing to the periodic nature of machining processes. Therefore, when two solid surfaces are brought into contact, they actually touch only at a limited number of spots, the aggregate area of which is usually only a small fraction of the apparent contact area. The remainder of the space between the surfaces may be filled with air or another fluid, or may be in vacuum. When heat flows from one metal to the other, flow lines converge toward the actual contact spots, since the thermal conductivities of metals are so much greater than those of fluids. This converging of the flow lines causes the thermal contact resistance which is usually high compared to the resistances offered to heat flow away from the contact spots.

The importance of the problem of the interfacial conductance (or resistance) has attracted the attention of many researchers [1–5] in the last few decades. One important problem is the controlling (increasing or decreasing) thermal contact conductances by introducing interstitial plates between the contact surfaces.

* Presently, Visiting Professor in the Department of Mechanical Engineering, University of Miami, Coral Gables, Florida, U.S.A.

A method of increasing the thermal contact conductance by filling the interfacial gap with highly conducting materials was investigated by Cunningham [6]. Joints made of aluminum and magnesium with indium foil, silicone vacuum grease and filler grease as interstitial fillers, were tested in vacuum for contact pressures between 1200 and 6720 $N \cdot m^{-2}$. The interstitial materials of indium foil and vacuum grease produced approximately tenfold increases in thermal conductance compared to unfilled joints. James and Barry [7] indicated that the thermal conductance between metal surfaces in contact can be increased by placing metallic foils between the contacting surfaces. Lead, aluminum, indium and copper foils were tested between mild steel surfaces at low contact pressures. Foil softness was found to be more significant than thermal conductivity in reducing contact resistance. A series of experiments were conducted by Fletcher *et al.* [8, 9] to determine the effect of a metallic interstitial plate on thermal contact conductance. They presented thermal conductance data for contacts with interstitial materials in evacuated environments, and the results were categorized with emphasis on the suitability of interstitial materials for thermal control applications. Veziroğlu *et al.* [10] investigated experimentally the effect of very thin plates between mating surfaces and of contact pressure upon the thermal contact conductance, and developed a theory for the prediction of contact conductance by modifying a relationship obtained by Çetinkale (Veziroğlu) and Fishenden [11].

In the work presented herein, an analysis has been carried out for the prediction of the thermal contact conductance with interstitial plates, and a theoretical expression has been developed in terms of the known properties and parameters. The comparison of the experimental results with the theory revealed good agreement for all the test plates—with the exception of mica—and for all test conditions.

2. DESCRIPTION OF MODEL

For the theoretical study, the interface is assumed to be composed of a number of similar "macroscopic" contact elements, each having a load bearing contact region at its center surrounded by a non-contact region (see Fig. 1). Furthermore, each macroscopic contact region can be assumed to be made up of a number of microscopic contacts each having a contact spot at its center surrounded by a non-contact region.

It must also be noted that the macroscopic non-contact region consists of two regions, viz. a region where both sides of the plate are in continuous touch with the interstitial fluid contained within the waviness troughs of the contact surfaces (region A_a, Fig. 2), and a region where on one side, the plate is in continuous touch with the fluid and at the other side is in touch with the roughness asperities of the opposite surface (regions A_{ab} and A_{ba}, Fig. 2). Region A_b of Fig. 2 is the macroscopic contact region. The distances λ_{m1} and λ_{m2} (Fig. 2) are the waviness wavelengths for the surfaces 1 and 2 respectively.

For simplicity both the macroscopic and microscopic contact elements are assumed to be made up of two cylindrical solids having a circular contact in the middle of their surfaces (bases) facing each other (Fig. 3), with the gap between them filled with a material of uniform conductance.

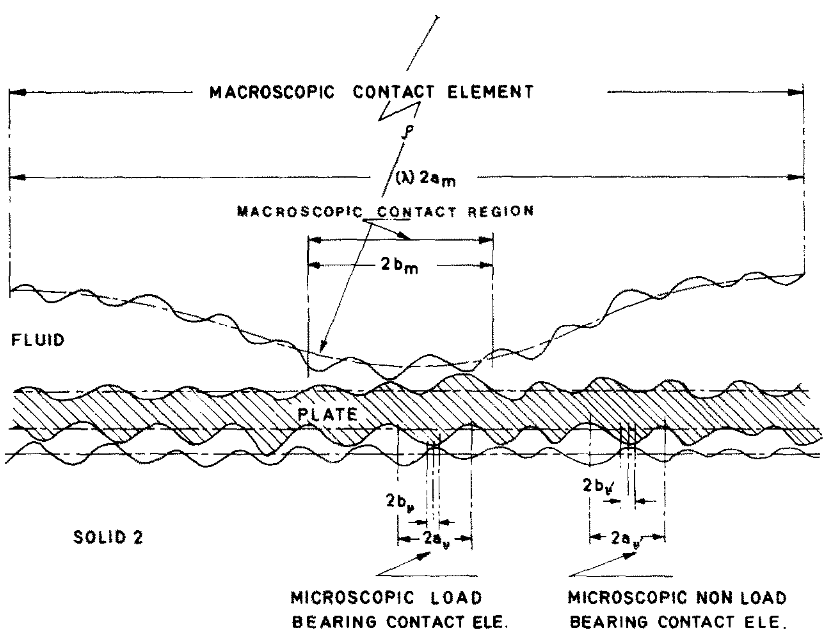

Fig. 1. Schematic diagram of a contact.

3. CONTACT ELEMENT CONDUCTANCE

Let the contact element of Fig. 3 refer to a macroscopic contact element. It will be assumed that the

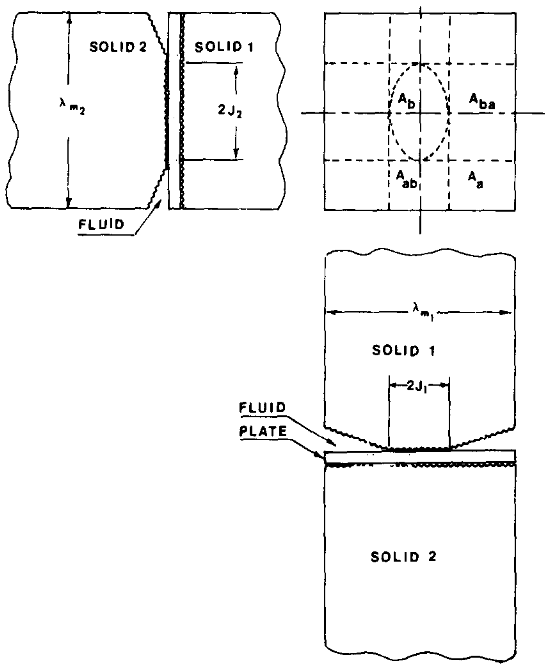

FIG. 2. Macroscopic contact regions.

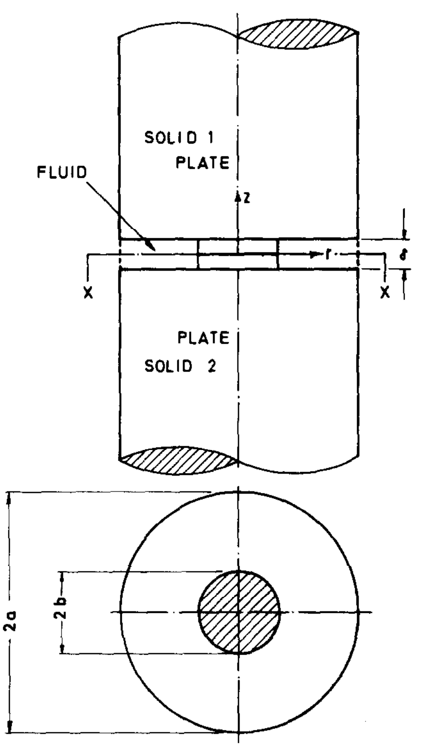

FIG. 3. Contact element.

contact region "c" and the non-contact region "n" consist of materials of uniform conductance or conductivity, including the interstitial plate. Then if the r-axis divides the gap δ_m into two gaps δ_{m1} and δ_{m2} defined as follows

$$\delta_{m1} = \frac{k_2}{k_1+k_2}\delta_m \tag{1}$$

$$\delta_{m2} = \frac{k_1}{k_1+k_2}\delta_m \tag{2}$$

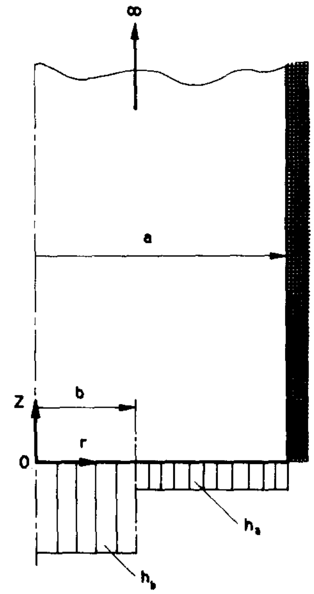

FIG. 4. Geometry of the problem.

the system becomes symmetrical with respect to r-axis from the heat transfer point of view. Since there is an axial symmetry too, it suffices to consider the quarter region, $(Z, 0, r)$, only, Fig. 4.

A dimensionless temperature distribution in solid 1 must satisfy the Laplace's equation

$$\frac{\partial^2 \bar{T}}{\partial \bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial \bar{T}}{\partial \bar{r}} + \frac{\partial^2 \bar{T}}{\partial \bar{Z}^2} = 0 \tag{3}$$

where $\bar{T} = T/Sa, \bar{r} = r/a, \bar{Z} = z/a$, a the contact element radius and S is the temperature slope at $z \to \infty$. The boundary conditions of the problem can be written as follows:

$$\frac{\partial \bar{T}(0,\bar{Z})}{\partial \bar{r}} = 0 \qquad 0 < \bar{Z} < \infty \tag{4a}$$

$$\frac{\partial \bar{T}(1,\bar{Z})}{\partial \bar{r}} = 0 \qquad 0 < \bar{Z} < \infty \tag{4b}$$

$$\frac{\partial \bar{T}(\bar{r},\infty)}{\partial \bar{Z}} = 1 \qquad 0 < \bar{r} < 1 \tag{4c}$$

$$\frac{\partial \bar{T}(\bar{r},0)}{\partial \bar{Z}} = \bar{h}\bar{T} \qquad 0 < \bar{r} < 1 \tag{4d}$$

where the dimensionless heat-transfer coefficient $\bar{h}(=ha/k)$ is defined as $\bar{h} = \bar{h}_b$ when $0 < \bar{r} < C$ and $\bar{h} = \bar{h}_a$ when $C < \bar{r} < 1$.

The temperature distribution which satisfies equation (3) and the boundary conditions (4a, b, c) is given by

$$\bar{T}(\bar{r},\bar{Z}) = \bar{Z} + D_0 - \sum_{n=1}^{\infty}{}' D_n J_0(\beta_n \bar{r}) e^{-\beta_n \bar{Z}} \tag{5}$$

where D_0 and D_n's are constants to be determined; and the eigen-values β_n are given as the roots of the equation

$$J_1(\beta_n) = 0, \qquad n = 1, 2, 3 \ldots. \tag{6}$$

The constant D_0 is found to be

$$D_0 = \frac{1+2C(\bar{h}_b-\bar{h}_a)\sum_{n=1}^{\infty}\frac{D_n}{\beta_n}J_1(\beta_n C)}{C^2(\bar{h}_b-\bar{h}_a)+\bar{h}_a} \quad (7)$$

where D_n's are the solutions of the following set of linear equations which are obtained from the boundary condition (4d).

$$a_m = a_{m1}D_1 + a_{m2}D_2 \ldots + a_{mn}D_n \quad (m = 1,2,3\ldots;\ n = 1,2,3\ldots) \quad (8)$$

where

$$a_m = \frac{J_1(\beta_m C)}{\beta_m(C^2(\bar{h}_b-\bar{h}_a)+\bar{h}_b)} \quad (9)$$

$$a_{mn} = \frac{C^2}{2}\left(J_0^2(\beta_m C)+J_1^2(\beta_m C)\right)+\tfrac{1}{2}\frac{(\beta_m+\bar{h}_a)}{(\bar{h}_b-\bar{h}_a)C}J_0^2(\beta_m) - \frac{2C}{\beta_m^2}\frac{\bar{h}_b-\bar{h}_a}{C^2(\bar{h}_b-\bar{h}_a)+\bar{h}_a}J_1^2(\beta_m C) \quad (10)$$

when $m = n = 1,2,3\ldots$ and

$$a_{mn} = \frac{1}{\beta_m^2-\beta_n^2}\left(\beta_m J_0(\beta_n C)J_1(\beta_m C)\right)-\beta_n J_0(\beta_m C)J_1(\beta_n C) - \frac{2C}{\beta_m\beta_n}\frac{(\bar{h}_b-\bar{h}_a)J_1(\beta_n C)J_1(\beta_m C)}{C^2(\bar{h}_b-\bar{h}_a)+\bar{h}_a} \quad (11)$$

when $m \neq n$.

Thus the temperature distribution in a contact element can be obtained by combining the solution of equation (8) with equations (5) and (7).

The additional dimensionless temperature drop $\Delta\bar{T}$ to overcome the thermal resistance of contact is given by,

$$\Delta\bar{T} = \frac{\Delta T}{Sa} = \lim_{\bar{Z}\to\infty}\left(\bar{T}-\bar{Z}\frac{\partial\bar{T}}{\partial\bar{Z}}\right). \quad (12)$$

The thermal contact conductance per unit area can be obtained from its definition, i.e.

$$u = \frac{Sk}{\Delta T}. \quad (13)$$

From equations (5), (12) and (13), the thermal conductance per unit area of a contact becomes

$$u = \frac{k}{a}\frac{1}{D_0}. \quad (14)$$

Since the conductance components of solid 1 and solid 2 are in series, the overall contact conductance per unit area becomes

$$u_m = \frac{k_s}{2a_m D_0} \quad (15)$$

where the average thermal conductivity k_s is defined as

$$\frac{2}{k_s} = \frac{1}{k_1}+\frac{1}{k_2}. \quad (16)$$

Then the dimensionless contact conductance can be written as

$$U_m = \frac{B_m}{2D_{m0}} \quad (17)$$

where

$$U_m = \frac{u_m\delta_m}{k_s} \quad (18)$$

and

$$B_m = \frac{\delta_m}{a_m} \quad (19)$$

where the subscript "m" refers to the macroscopic contact element. The dimensionless parameter D_{m0} of equation (17) is the same as D_0 given by equation (7).

4. PARAMETERS OF CONDUCTANCE EQUATION

In order to make use of equations (17) and/or (18) and compute the thermal contact conductance of a contact having an interstitial plate, the variables a_m, δ_m, B_m and D_{m0}, and C_m, $\bar{h}_{ma}$ and $\bar{h}_{mb}$ (see equation (7)) must be calculated using the known thermophysical and surface properties.

4.1. *Parameters for overall conductance*

Considering the actual and the assumed shapes of the cross-sections of the macroscopic contact element, we can define an effective macroscopic contact element radius as

$$\lambda_{m1}\lambda_{m2} = \pi a_m^2$$
$$a_m = \sqrt{(\lambda_{m1}\lambda_{m2}/\pi)}. \quad (20)$$

From [12], the effective gap thickness for the macroscopic contact element becomes,

$$\delta_m = 0.46(\delta_{m1}+\delta_{m2})+\delta_t \quad (21)$$

where δ_{m1} and δ_{m2} are the center line averages of the macro-roughness of the surfaces 1 and 2 respectively, and δ_t is the effective plate thickness. Since the fluid thermal conductivity governs the heat flow in the gap, δ_t becomes

$$\delta_t = tk_f/k_t \quad (22)$$

where t is the plate thickness, k_f the effective fluid thermal conductivity, and k_t the plate thermal conductivity.

The constriction number for the macroscopic contact element is given by

$$C_m = b_m/a_m. \quad (23)$$

The effective contact element radius a_m is given by equation (20). The effective contact region radius b_m can be calculated from the contact region area. Since, in general, the radii of curvature of the macro-roughness are large, the deformation causing the contact regions will be elastic and the contact region area will be elliptical with the following semiaxes [13],

$$J_1 = \omega\left[\frac{3P\lambda_{m1}\lambda_{m2}\left(\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right)}{2\left(\frac{1}{\rho_1}+\frac{1}{\rho_2}\right)}\right]^{1/3} \quad (24)$$

and

$$J_2 = \psi\left[\frac{3P\lambda_{m1}\lambda_{m2}\left(\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right)}{2\left(\frac{1}{\rho_1}+\frac{1}{\rho_2}\right)}\right]^{1/3} \quad (25)$$

where P is the apparent contact load per unit area, ν_1 and ν_2 the Poisson's ratios for the solids 1 and 2 respectively, E_1 and E_2 moduli of elasticity for the two solids, ρ_1 and ρ_2 the radii of curvature of the surface waviness for the surfaces 1 and 2, and the coefficients ω and ψ are given in Table 1.

Table 1. Semiaxes coefficients

$\theta = \cos^{-1}\left[\frac{\rho_2-\rho_1}{\rho_2+\rho_1}\right]$	ω	ψ
30°	2.731	0.493
40°	2.136	0.567
50°	1.754	0.641
60°	1.486	0.717
70°	1.284	0.802
80°	1.128	0.893
90°	1.000	1.000

Considering the area of the elliptical contact region and that of the equivalent circle, the effective contact region radius b_m becomes,

$$b_m = \sqrt{(J_1 - J_2)}. \tag{26}$$

As can be seen from Fig. 1, the dimensionless effective heat-transfer coefficient for the macroscopic contact region is the resultant of those produced by microscopic contacts on each side of the interstitial plate plus the interstitial plate itself, viz.

$$\bar{h}_b = \frac{a_m}{k_s} \frac{1}{\frac{1}{u_{\mu 1}} + \frac{t}{k_t} + \frac{1}{u_{\mu 2}}} \tag{27}$$

where $u_{\mu 1}$ and $u_{\mu 2}$ are the thermal contact conductances per unit area for the microscopic contacts on surface 1 and surface 2 sides of the plate respectively.

The dimensionless effective heat-transfer coefficient for the macroscopic no-contact region can be written as the mean of three heat-transfer coefficients as follows (see Fig. 2),

$$\bar{h}_a = \frac{a_m}{k_s} \frac{A_a h_a + A_{ab} h_{ab} + A_{ba} h_{ba}}{A_a + A_{ab} + A_{ba}} \tag{28}$$

where A_a is the total area covered by the region having no microscopic contacts and h_a the corresponding heat-transfer coefficient, A_{ab} the total area covered by the region having microscopic contacts only at the surface 1 side of the plate and h_{ab} the corresponding heat-transfer coefficient, and A_{ba} the total area covered by the region having microscopic contacts only at the surface 2 side of the plate and h_{ba} the corresponding heat-transfer coefficient.

From a study of Fig. 2, the three areas included in equation (28) can be calculated from

$$A_a = (\lambda_{m1} - 2J_1)(\lambda_{m2} - 2J_2) \tag{29}$$

$$A_{ab} = J_1(2\lambda_{m2} - \pi J_2) \tag{30}$$

and

$$A_{ba} = J_2(2\lambda_{m1} - \pi J_1) \tag{31}$$

From a study of Fig. 1, the three heat-transfer coefficients included in equation (28) becomes,

$$h_a = \left(\frac{\delta_1}{k_f} + \frac{t}{k_t} + \frac{\delta_2}{k_f}\right)^{-1} \tag{32}$$

$$h_{ab} = \left(\frac{1}{u^1_{\mu 1}} + \frac{t}{k_t} + \frac{\delta_2}{k_f}\right)^{-1} \tag{33}$$

and

$$h_{ba} = \left(\frac{\delta_1}{k_f} + \frac{t}{k_t} + \frac{1}{u^1_{\mu 2}}\right)^{-1} \tag{34}$$

where $u^1_{\mu 1}$ and $u^1_{\mu 2}$ are the thermal contact conductances of the microscopic contact elements in regions of A_{ab} and A_{ba} respectively.

4.2. *Parameters for microscopic conductances*

Using the subscript μ for the microscopic contacts, from equations (17) and (18), the thermal contact conductance per unit area for a given microscopic contact element becomes,

$$u_\mu = \frac{B_\mu k_\mu}{2D_{\mu 0}\delta_\mu}. \tag{35}$$

The relationships needed to calculate the various parameters in equations (7) and (35) will now be given. From equation (16), the relationships for the effective solid thermal conductivities becomes,

$$k_\mu = \frac{2}{\frac{1}{k_1} + \frac{1}{k_t}}, \quad (\text{for } u_{\mu 1} \text{ and } u^1_{\mu 1}) \tag{36}$$

or

$$k_\mu = \frac{2}{\frac{1}{k_2} + \frac{1}{k_t}}, \quad (\text{for } u_{\mu 2} \text{ and } u^1_{\mu 2}) \tag{37}$$

From [11], the effective gap thicknesses for the microscopic contact elements become,

$$\delta_\mu = 3.56(\delta_{\mu 1} + \delta_t), (\text{for } u_{\mu 1} \text{ and } u^1_{\mu 1}) \tag{38}$$

and

$$\delta_\mu = 3.56(\delta_{\mu 2} + \delta_t), (\text{for } u_{\mu 2} \text{ and } u^1_{\mu 2}) \tag{39}$$

where $\delta_{\mu 1}$ and $\delta_{\mu 2}$ are the centerline averages of the micro-roughness of the surfaces 1 and 2, and δ_t is the centerline average of the micro-roughness of the plate.

Since the micro-roughness asperities have small radii of curvature, they yield by means of plastic flow under load. The load between the surfaces 1 and 2 is supported within the macroscopic contact region. Hence the constriction number for the conductances $u_{\mu 1}$ and $u_{\mu 2}$ becomes,

$$C_\mu = \sqrt{(P/M)} \tag{40}$$

where P is the contact load per unit area and M the Meyer hardness of the softer of the solids 1 or 2.

For the microscopic contacts in the non-contact region, the constriction number would change from C_μ near the contact region to almost zero at the point half a wavelength away from the center of the contact region. Hence, for the conductances $u^1_{\mu 1}$ and $u^1_{\mu 2}$, the

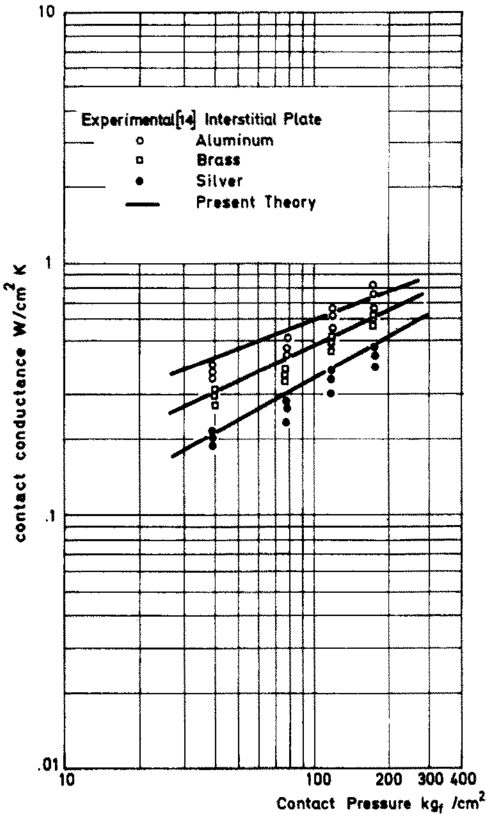

FIG. 5. Thermal contact conductance of interstitial materials.

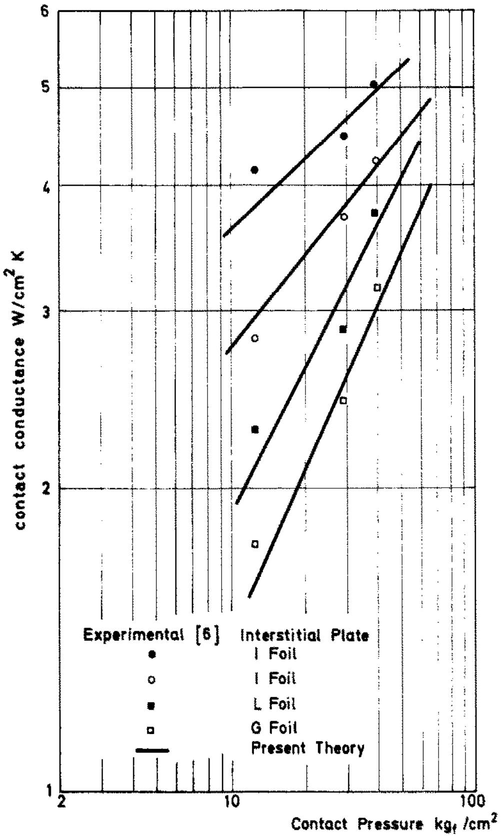

FIG. 7. Thermal contact conductance of interstitial materials.

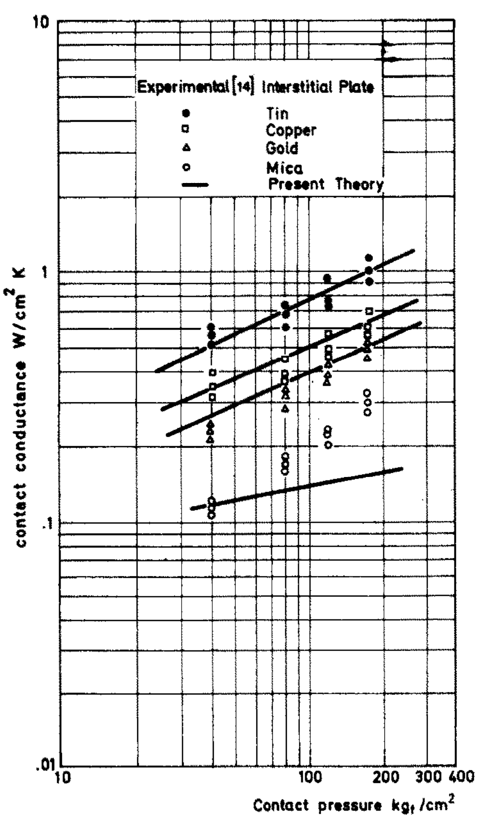

FIG. 6. Thermal contact conductance of interstitial materials.

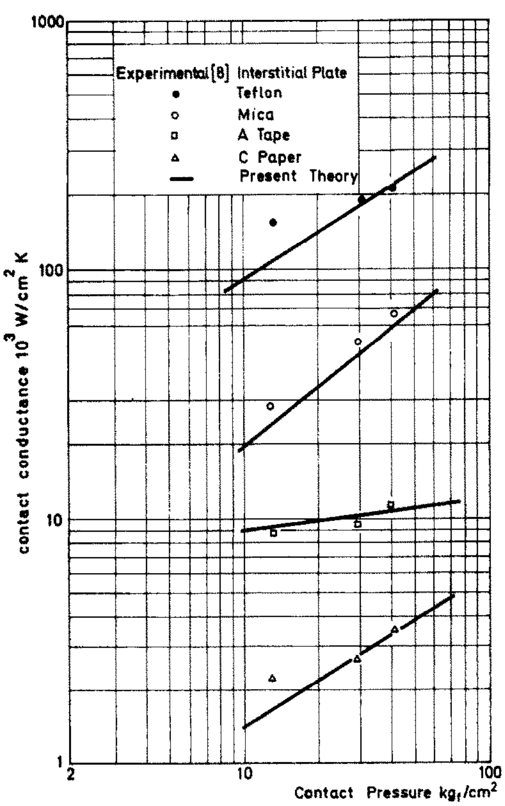

FIG. 8. Thermal contact conductance of interstitial materials.

mean constriction number can be taken as,

$$C_u^1 = 0.5C_u$$

or

$$C_u^1 = 0.5\sqrt{(P/M)}. \quad (41)$$

The gap numbers for the thermal conductances of the microscopic contact elements can be calculated from [11],

$$B_u = 0.335C_u^{0.315}S_u^{0.137} \quad (42)$$

where $C_u = C_u$ for u_{u1} and u_{u2}, $C_u = C_u^1$ for u_{u1}^1 and u_{u2}^1, and the size number S_u can be computed from

$$S_u = \sqrt{(A)}/\delta_u \quad (43)$$

where A is the total apparent contact area.

Considering that the components of the heat-transfer coefficients in the actual contact are in series, the heat-transfer coefficients for the actual contact becomes,

$$h_{ub} = \left(\frac{\delta_t}{k_t}+\frac{\delta_{u1}}{k_1}\right)^{-1} \quad (\text{for } u_{u1} \text{ and } u_{u1}^1) \quad (44)$$

and

$$h_{ub} = \left(\frac{\delta_t}{k_t}+\frac{\delta_{u2}}{k_2}\right)^{-1}, \quad (\text{for } u_{u2} \text{ and } u_{u2}^1) \quad (45)$$

For the microscopic contact elements, only the interstitial fluid has to be considered with regard to the heat-transfer coefficients of the non-contact region. Consequently, they become,

$$h_{ua} = \frac{k_f}{\delta_u} \quad (46)$$

where δ_u is given by equation (38) for u_{u1} and u_{u1}^1, and by equation (39) for u_{u2} and u_{u2}^1.

5. COMPARISON OF THEORY WITH EXPERIMENTS

The variation of thermal conductance with plates between contact surfaces and apparent contact pressure, for ST-42 steel having surface roughness in the form of parallel grooves has been investigated. The details of this study are given in [14]. Experimental data have been obtained for seven different test plates (viz. aluminum, brass, silver, tin, copper, gold and mica) by varying the contact loads. The experimental results are shown on Figs. 5 and 6 together with the theoretical results of contact conductance as a function of interface pressure for different interstitial plates. It can be seen that a good agreement is obtained between theory and the experimental results, with the exception of the results for mica. Visual inspection of the interface, after testing the mica, revealed that the contact load caused the mica to crack permitting metal-to-metal bridges to be formed thus resulting in higher conductances.

In the literature a limited amount of contact conductance data with interstitial plates has been published. These data have been reviewed and only those which satisfy the underlying assumptions for the model (i.e. those presented in [6, 8, 9]) have been compared with the theory. The comparisons are given in Figs. 7 and 8. As seen from the figures, there is a good agreement between the theory and the experimental result of various investigators.

CONCLUSION

The assumed model for the study of the thermal conductance of contacts having interstitial plates, and the theory developed therefrom agree well with the experimental results for many materials with the exception of mica.

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ETUDE DE LA CONDUCTANCE THERMIQUE DE CONTACT AVEC PLAQUES INTERSTICIELLES

Résumé—On a effectué une étude analytique et expérimentale en vue d'évaluer la conductance de contact de plaques intersticielles et une expression de la conductance a été obtenue en fonction des paramètres et des propriétés connues. Le modèle suppose que l'interface est constitué d'éléments de contact macroscopiques et microscopiques de constitution similaires. Ces éléments comprennent deux solides cylindriques présentant un contact circulaire en leur milieu, les surfaces en regard étant séparées par un intervalle rempli d'un matériau de conductance uniforme. Les prévisions théoriques sont comparées avec les données expérimentales disponibles. Un bon accord a été trouvé entre valeurs théoriques et expérimentales pour la conductance thermique de contact avec plaques interticielles. La théorie montre que la conductance thermique de contact dépend fortement de la dureté et de la conductivité thermique des plaques intersticielles ainsi que de la texture de la surface des éléments de contact et des plaques intersticielles.

ANALYSIS DES THERMISCHEN LEITUNGSWIDERSTANDES VON KONTAKTPLATTEN

Zusammenfassung—Es wurde eine analytische und experimentelle Analyse durchgeführt für die Bestimmung des thermischen Leitungswiderstandes von Kontaktplatten, und aus bekannten Eigenschaften und Parametern wird eine Beziehung formuliert. Im Modell wird angenommen, daß die Kontaktflächen aus ähnlichen makroskopischen und mikroskopischen Kontaktelementen zusammengesetzt sind. Diese Elemente sollen aus zwei zylindrischen Festkörpern bestehen, die kreisförmigen Kontakt aufweisen im Mittelpunkt ihrer einander zugewandten Oberflächen und einem Zwischenraum, der mit einem Material einheitlicher Wärmeleitfähigkeit ausgefüllt ist. Die theoretischen Ergebnisse wurden mit experimentellen Werten aus der Literatur verglichen. Es ergab sich gute Übereinstimmung zwischen den theoretischen und experimentellen Werten für den thermischen Leitungswiderstand. Die Theorie zeigt, daß der Leitungswiderstand eine ausgeprägte Funktion der Härte und der thermischen Leitfähigkeit der Kontaktplatten ist, sowie auch der Oberflächenform der Kontaktelemente und der Platten.

АНАЛИЗ ТЕПЛОПРОВОДНОСТИ КОНТАКТОВ СО ВСТАВКАМИ

Аннотация — Проведено теоретическое и экспериментальное исследование с целью определения теплопроводности контактов с промежуточными пластинами и получено выражение для известных свойств и параметров. В принятой модели предполагается, что поверхность раздела состоит из одинаковых макроскопических и микроскопических контактных элементов. Считают, что эти элементы состоят из двух цилиндрических твёрдых тел с круговым контактом в середине их обращенных друг к другу поверхностей, промежуток между которыми заполнен материалом с постоянной теплопроводностью. Теоретические расчеты сравнивались с имеющимися в литературе данными. Обнаружено хорошее соответствие между теоретическими и экспериментальными значениями теплопроводности контактов со вставками. Теоретический анализ показывает, что теплопроводность контактов сильно зависит от твёрдости и теплопроводности промежуточных пластин, а также от поверхностной структуры контактных элементов и промежуточных пластин.