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The parameters affecting on Thermal contact conductance-A Review

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Abstract - *Thermal contact conductance is involved in many practical applications. To understand the transfer of heat between two surfaces having interface material as it affects the mode of heat transfer, is very essential in design of different heat transfer equipment. Here Thermal contact conductance is the property which indicates the thermal conductivity, or ability to conduct heat between two Solid bodies when they are in thermal contact. It is also defined as the ratio of heat flux to the additional temperature drop incurred at the contact. And Inverse property of thermal contact conductance is called thermal contact resistance Here an objective is comprehensive review of thermal contact conductance across different composite material pair using different interface material. Also, summarized are the parameter influences on thermal contact conductance.*

Keywords: *Thermal contact conductance, Interfacial pressure and temperature, Interface material, Geometry of solid, Hardness*

1. Introduction

When two surfaces are in contact with each other, the actual area of contact is much smaller than the apparent area of contact. This area of actual contact occurs where the asperities of one surface are in contact with the asperities of the other surface. The number of these contact spots is further reduced when surface waviness and errors in form are taken onto account. Typically, there is some material or fluid filled in the interstitial spaces between the contacting surfaces, and heat is transferred through this interstitial material.

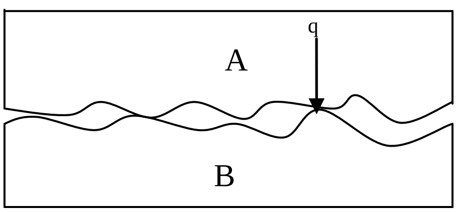

Figure 1.1 Heat flow in solids

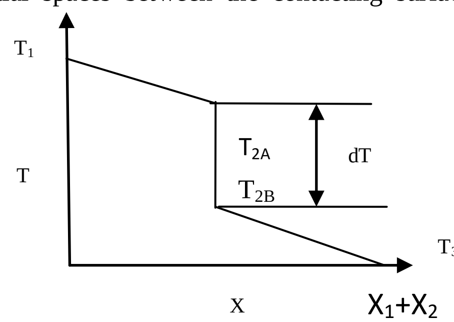

Figure1.2 Temperature distribution

$$q = \frac{T1 - T3}{R_{th}}$$

$$R_{th} = \frac{\Delta x_A}{k_A A} + \frac{1}{h_C A} + \frac{\Delta x_B}{k_B B}$$

Here, Rth = Resistance of solid ($℃/W$)
X = Thickness of Solid (m)
k = Thermal conductivity of Solid (W/m K)
A= Area of solid (m2)

$$h_c = \frac{q}{\Delta T}\left(\frac{w}{m^2 ℃}\right)$$

Thermal Contact conductance is depends on various parameter geometry of surface and hardness
Thermal contact conductance is increases by decreasing contact resistance and to reduce this resistance pressure is applied on the contacting surface to reduce contact gap. When contact gap is reduces then contact area is rise and due to that contact conductance is rises.
Other method to increase thermal contact conductance between solid contacts is filling conductive material between gaps of solid then thermal contact conductance is increases.

2. LITERATURE RIVIEW

Whenever there is a contact between two solids or mechanical joints there is always temperature drop placed because of interface of material. Thermal contact conductance is the function of temperature pressure and geometry of surfaces. In this literature review it consist number of experimental and analytical study of thermal contact conductance has been for different combination of material by different researcher and scientists.

S. Sunil Kumar, K. Ramamurthi(2004)[1] Experimental investigation were carried out in a closed loop cryostat and interface temperature in the range 50–300 K on the thermal contact conductance between aluminium and stainless steel joints was determined Both elastic and plastic deformation was considered,. A reduction of the interface temperature resulted in a smaller value of thermal contact conductance.

Majid Bahrami, M. Michael Yovanovich, J. Richard Culham (2005) [2] This study is carried out at low pressure. The effect of elastic deformations was determined beneath the plastically deformed microcontacts is determined by superimposing normal deformations due to self and neighboring contact spots in an elastic half-space.

C.L.Yeh, C.Y. Wen, Y.F. Chen, S.H. Yeh, C.H. Wu (2001)[3]This experimental study of thermal contact cconductance was conducted with pairs of aluminum alloy (6061-T6) specimens jointed by bolts the samples have a square cross-section (63.5mmX63.5mm) and a height of 50mm. Three different bolt patterns were adopted in this study, including single bolt, 4-bolt, and 8-bolt configuration and with diameter of bolt 3, 5 and 8mm and the torque applied on each bolt were between 1 and 10Nm.Results show that the interfacial contact pressure increases with an increase of either the applied torque or the number of bolts.

Ju Liu, Han Feng, Xiaobing Luo, Run Hu, Sheng Liu(2010)[4] In this paper, a simple and easy setup was built to test the thermal contact resistance in a solid/solid interface. The setup is built at room temperature and normal pressure environment, which is different from the conventional methods that the thermal contact resistance was measured in ultrahigh vacuum or high vacuum environment. By this test apparatus, several kinds of materials were tested. The results were compared with the existing results obtained by other methods. The comparison demonstrated that the proposed measuring method can realize good measurement of thermal contact resistance. This study shows that thermal contact resistance decreases with the increase of interfacial pressure, thermal contact resistance almost does not change with the increase of input voltage of heater, and the thermal contact resistance for the experiments with temperature compensation is lower than that without temperature compensation.

M. G. Cooper, B. B. Mikic and M. M. Yovanovich (1969)[5] In this paper considered the resistance of the flow of heat between two thick solid bodies in contact in a vacuum. Reconsideration of the theory of interaction between randomly rough surfaces shows how the parameters required to predicting heat transfer can be determined in principle by simple manipulation of typical profiles of the mating surface, together with an approximation from deformation theory This paper is concerned with the temperature distribution near an interface between two solid bodies in contact when heat flows normally from one body to the other.

Yeau-Ren Jenga, Jen-Tin Chena and Ching-Yang Cheng (2003)[6] In this work aims to investigate contact heat conduction from the viewpoint of interface contact and to develop a conductance model considering elastic, elastoplastic and fully plastic deformation. When measuring the thermal contact conductance with contact load being increased or decreased, he found that increasing the load tends to increase the real contact area, thus increasing the surface contact heat conduction rate.

Fernando H. Milanez, J. Richard Culham, M. Michael Yovanovich(2002)[7] In this paper they compared the models against SS 304, Ni 200, Al 6061, Zr-Nb and Zr-4 data collected by other researchers and concluded that the Cooper. Plastic model and the Mikic elastic model are accurate to predict the experimental data, especially for high contact pressures. The main objective of this work is to verify the deviation between experiments and theory at light loads. According to the author, the deformation mode depends on the geometry of the asperities and the mechanical properties of the contacting solids and does not depend on the magnitude of the contact pressure.

C. Merrill, S V. Garimella (2011)[8] In this literature three substrates (copper, brass, and aluminum) and three coatings (silver, nickel and tin) are considered with a variety of coating thicknesses and substrate roughness's. The contact load is also varied. The experimental measurements show that the best choice of a coating for contact resistance mitigation depends on the substrate material and roughness, and cannot be prescribed in general. A regression equation developed for the experimental results offers a useful tool for the design of coated contacts.

M.H. Shojaefard and K. Goudarzi(2008)[9] In this investigation a new transient method and measurement apparatus are used in which the measurements are conducted on specimens, which are retained under pressure Measurements of the thermal contact resistance have been carried out while heat transfer was either in steady-state or transient condition experiments were conducted using devices that contained two specimens or two tools with a specimen sandwiched between them. These experiments were followed by an assessment of the thermal contact resistance while the test specimen was deformed plastically.

Mr. Bipin G. Vyas, Prof. Nilesh R. Sheth, and Prof. Mukesh P. Keshwani(2015)[10] This Practical study of heat transfer through surface contact resistance is very essential for advancement of thermal applications. According to this study it is required to understand the heat transfer between composite pair having same as well as different interface material.

M. M. Yovanovich (2005)[11] This Paper reviews and highlights over 40 years of research on solutions for steady-state and transient thermal constriction and spreading resistances, and thermo mechanical models for contact, gap and joint resistances of joints formed by conforming rough surfaces, nonconforming smooth surfaces, and nonconforming rough surfaces.In this study Contact microhardness, determined by Vickers indenters, are correlated and incorporated into the contact model for conforming rough surfaces. Microhardness parameters are correlated with Brinell hardness values. Elastoplastic contact models for joints formed by smooth sphere-smooth flat and conforming rough surfaces are presented.

Ruiping Xu, Haidong Feng, Lanping Zha, Lie Xu(2004)[12] In this literature an experimental investigation of thermal contact conductance was conducted with pressed pairs of aluminum alloy 5052 and stainless steel 304 over the low temperature range from 155 to 210 K, with nominal contact pressure from 1 to 7 MPa. From the measured results, thermal contact conductance over this temperature range (155–210 K) is less than that near or above room temperature (T>300 K). The load sensitivity at low temperature is less than that at room temperature.

E.M. Burghold*, Y. Frekers, R. Kneer (2015)[13] This paper presents a method to measure contact heat transfer coefficients by means of transient temperature measurements, which are conducted using a high-speed infrared camera. Time-dependent contact heat transfer mechanisms can be visualized and quantified. This enables the technique to be utilized for describing transient heat transfer phenomena, which, among others, emerge within the field of thermo-energetic management of machine tools. Within this work, the experimental method and setup is explained. Subsequently, results of transient measurements are presented, showing a direct relation between the instantaneous load and contact heat transfer coefficient.

Ruifeng Dou, Tianran Ge, Xunliang Liu, Zhi Wen(2015)[14]In this investigation Specimens were prepared using SUS 304 stainless steel, the interface temperature was in the region of 360–640^{o}C, the contact pressure was between 2.39 and 15.17 MPa, and the surface roughness ranged from 0.25 lm to 2.00 µm. All experiments were conducted in ambient atmosphere. Results indicated that TCC presents a power law relationship with contact pressure and interface temperature. While the contact pressure exponent varied between 0.20 and 0.46 at different surface roughness, the interface temperature exponent showed a much wider range of 0.45–2.36. TCC increased more rapidly with temperature in specimens with higher surface roughness than in lower surface roughness.

Reji Joseph, Jophy Peter, S. Sunil Kumar ,N. Asok Kumar(2016)[15] In this work, experimental investigation of dissimilar metallic joints with temperature and load cycles was taken up. Joints formed by titanium alloy, stainless steel and aluminum alloy were considered for the study. Variation in thermal contact conductance across different joints with thermal and load cycles were investigated. The hysteresis associated with thermal contact conductance after load and temperature cycling was evaluated. The hysteresis effects are more for aluminum alloy joints which is known to have low hardness and high conductivity.

Ricardo S. Padilha, Marcelo J. Colaço, Helcio R.B. Orlande, Luiz A.S. Abreu (2016)[16] In this investigation the author proposed an analytical, non-iterative and Non-intrusive method to solve an inverse heat transfer problem in order to estimate a one dimensional steady-state distribution of the thermal contact conductance, combining the reciprocity functional and the Classical Integral Transform Technique (CITT).

Jiang Zheng, Yanzhong Li, Pengwei Chen, Geyuan Yin, Huaihua Luo(2016)[17] In this paper thermal contact conductance of a pair of stainless steel specimens is obtained in the interface temperature range of 135–245 K and in the contact pressure range of 1–9 MPa. The results show that the contact conductance increases with the decrease of surface roughness, the increase of interface temperature and contact pressure. The temperature dependence of thermal conductivity and mechanical properties and these results are regressed as a power function of temperature and load. Thermal conductance is also obtained between aluminums as well as between stainless steel and aluminum. The load exponents of the regressed relations for different contacts are compared.

Mahendrakumar Maisuria(2013)[18] In this paper an investigation is carried out to measure heat conductance at the interface of metal plates of known surface finish. A known energy source is applied to one of the plates, induced a measurable temperature difference between the plates. Other variable that affect interface heat transfer such as type of material ,contact area, pressure, environmental factors inside insulating box and surface finish are documented and held constant for each test configuration. The film heat was energy source for these tests. The results quantify the effect of flatness variation on heat transfer across the interface.

Tang Qingyun, Zhang Weifang(2016)[19] In this study the experimental procedure tested TCC between GH4169/K417 interfaces under high temperature of 600 ^{o}C using compensation heating technique, and the optimal size of the compensation heater was determined by finite element analysis. A constrained optimization problem is constructed to determine the temperature at the interface, taking into consideration the temperature-dependent thermal conductivity of test specimens. The results show that thermal contact conductance is almost directly proportional to interface pressure.

Wang Zongren, Yang Jun, Yang Mingyuan, Zhang Weifang(2012)[20] In this experimental investigation An experimental apparatus with the compensation heater to test the TCC is introduced. By using a statistical regression model along with experimental data obtained from the interfaces of the structural materials GH4169 and K417 used in aero-engine, the estimate values and the confidence level of TCC and RTCC (reliability thermal contact conductance) values are studied and compared The results show that the testing values of TCC increase with interface pressure and the proposed RTCC model matches the test results better at high interface pressure.

Chavan N.L and Sarje S.H(2016)[21] In this paper Results shows that the variation of thermal contact conductance as a function applied interface pressure for aluminium. Various interstitial materials investigated include indium foil, silver foil, and liquid eutectic, as expected, thermal contact resistance decreases as interface pressure increases, except in case of the eutectic, in which it was nearly constant. The softer the interstitial material, the lower the thermal contact resistance. Liquid metal provides the lowest thermal contact resistance across the aluminium interface, followed by the indium foil, and then silver foil.

M. Grujicic, C.L. Zhao, E.C. Dusel(2005)[22] In this study a finite element analysis is carried out in order to investigate the role of thermal contact resistance on heat management within a simple central processing unit (CPU)/heat sink assembly The results clearly reveal that plastic deformation of micro-contacts (promoted by high contact pressures and lower micro-hardness levels) and the use of thermal interface materials which eliminate (high thermal resistance) micro-gaps can significantly lower the overall CPU/heat sink thermal contact resistance and facilitate heat management.

A.M. Khounsary, D. Chojnowski, and L. Assoufid(1997)[23] In this investigation Results show the variation of thermal contact conductance as a function of applied interface pressure for a Cu-Si Interface Various interstitial materials investigated include indium foil, silver foil and a liquid eutectic (Ga-In-Sn) thermal contact resistance decreases as interface pressure increases, except in the case of the eutectic, in which it was nearly constant The softer the interstitial material, the lower the thermal contact resistance. Liquid metal provides the lowest thermal contact resistance across the Cu-Si interface, followed by the indium foil, and then the silver foil.

M. Paggi, J.R. Barber(2011) [24] In this paper to compute the exponent b of the power-law, and relate it to the morphological properties of the surfaces, we numerically test self-affine rough surfaces composed of random midpoint displacement (RMD) patches and Such patches are generated using a modified RMD algorithm in order to decouple the effect of the long wavelength cut-off from that due to microscale roughness. Numerical results show that the long wavelength cut-off has an important effect on the contact conductance, whereas the sampling interval and the fractal dimension are less important.

E.G.Wolff, D.A.Schneider(1998)[25] In this study guarded hot plate method for thermal conductivity measurements was choosen to determine temperature drops across interfaces. It was shown that a general theory can be modified to give a good estimation of the thermal resistance with a variety of interface materials. The effects of pressure, material hardness, surface roughness, and thermal properties of the interface material on thermal resistance between two smooth steel surfaces were studied.

M. A. Lambert, L. S. Fletcher(1997)[26] In this paper Empirical and Semi empirical Correlations for Nominally Flat, Rough Metals are used author reviews that Theoretical models have been developed that accurately predict contact conductance for the two bounding cases of at rough surfaces and non• at (spherical), smooth surfaces. However, these do not agree with most results for arbitrarily non• at, rough surfaces, those usually obtained from common manufacturing processes.

M.M. Yovanovich, A. Hegazy(1983)[27] In this study Thermal contact conductance models incarporatkg surface micro-hardness distributions were resented shown that the conventional mechanical mdel which assumes uniform hardness equal to the bulk value (BHM) gives an upper bound on contact conductances. On the other hand the integrated hardness model (INM) *gives* a lower bound on contact conductances, and the direct approximate model (DAM) predicts contact conductances nearly equal to those of the INM. The iterated hardness model (ITM) predicts contact conductances between the upper and lower bounds.

Syed M.S. Wahid, C.V. Madhusudana(2003)[28] In this paper an experimental investigation is carried out to study the effects on joint conductance of progressive loading and unloading, cyclic loading and overloading to a predetermined value. The test pair used is AISI 304 stainless steel, bead blasted to an effective rms surface roughness of 7.55 µm and a slope of 0.36 rad. In all cases a hysteresis loop is seen to exist for the loading unloading cycle and is seen to decrease with increasing number of cycles. The conductance values eventually appear to settle down to values higher than those obtained during first loading. Enhancement of contact conductance by cyclic loading is found to be rather small. On the other hand overloading the test pairs to a predetermined contact pressure is found to be promising.

Y. Z. Li. C. V. Madhusudana, E. Leonardi(2000)[29] The present experimental work investigated the effect of loading history; in particular the number of load cycles and overloading pressure, on the thermal contact conductance. It was found that the value of the thermal contact conductance might be enhanced by up to 51 percent.

M. Clausing, B. T. Chao(1965)[30] in this investigation Extensive results are given for brass, magnesium, stainless steel, and aluminum surfaces which show the effects of material properties and the degree of conformity of mating surfaces under load. Limited results are presented to show the influence of surface films, surface roughness, creep, additional interstitial material, mean interface temperature, etc. Good agreement between the measured and predicted values of the thermal contact resistance was found over wide ranges of the applied load and other system variables.

K. C. Toh , K. K. Ng (1997)[31] Tests are conducted for a mold compound FP4450 held in contact with A1 6061 having various surface finishes, under lightly loaded conditions, in a vacuum environment. They are found to be adequately represented even by the early simple metal-to-metal models, and not significantly affected by minor flatness deviations. However, with a thin (10µm) anodised coat on the aluminium surface, correlations that are derived primarily for metal-coating-metal surfaces would seriously overpredict the mold compound - anodised A1 6061 contact conductance. In general, the anodising process degrades the contact conductance due to an increase in roughness and hardness.

M. R. Sridhar, M. M. Yovanovich(1994)[32] In this paper normally, data were compared with either the elastic model or the plastic model assuming a type of deformation a priori. The relative merits of different models and the surface factors influencing the mode of deformation are still not clear. Hence, the aim of the present work was to compare most of the models available in the literature with themselves as well as with isotropic data. Comparison showed that generally smoother surfaces deform elastically, and rougher ones plastically. However, there are some data sets that compare well with both the elastic as well as the plastic models.

L.J. Salemo, P.Kittel, A.L. Spivak (1994)[33] In this paper sample pairs were fabricated from OFHC copper,6061-T6 aluminium, free machining brass and 304 stainless steel. And thermal contact conductance was found to increase with increasing applied force and the addition of indium foil or apiezon grease between the contact surfaces resulted in an improvement over uncoated surfaces ranging from approximately a factor of 3 for stainless steel to an order of magnitude for copper contacts.

3. CONCLUSION

Following are the inference of literature study

From the literature study One can characterize a surface that has undergone certain finishing operations by three properties: roughness, waviness and flatness. Among these, roughness is of most importance, and is usually indicated by an rms value σ .When two surfaces are in contact; the presence of surface roughness produces imperfect contact at their interface. In many applications involving rough surface contact, it is important to know the thermal contact resistance through real contact areas.

-When the two bodies come in contact, surface deformation may occur on both bodies. This deformation may either be plastic or elastic, depending on the material properties and the contact pressure. When a surface undergoes plastic deformation, contact resistance is lowered, since the deformation causes the actual contact area to increase

-The presence of dust particles, acids, etc., can also influence the contact conductance.

-No truly smooth surfaces really exist, and surface imperfections are visible under a microscope. As a result, when two bodies are pressed together, contact is only performed in a finite number of points, separated by relatively large gaps. Since the actual contact area is reduced, another resistance for heat flow exists. The gases/fluids filling these gaps may largely influence the total heat flow across the interface. The thermal conductivity of the interstitial material and its pressure are the two properties governing its influence on contact conductance. In the absence of interstitial materials, as in a vacuum, the contact resistance will be much larger, since flow through the intimate contact points is dominant.

-The contact pressure is the factor of most influence on contact conductance. As contact pressure grows, contact conductance grows (And consequentially, contact resistance becomes smaller). This is attributed to the fact that the contact surface between the bodies grows as the contact pressure grows. Since the contact pressure is the most important factor, most studies, correlations and mathematical models for measurement of contact conductance are done as a function of this factor. As pressure increase a greater asperity deformation happens and the thermal contact resistance reduces.

-Thermo physical properties of contacting materials like's high values of thermal conductivity and thermal expansion coefficients have favorable effect on the resistance. As thermal conductivity and thermal coefficient vary with the temperature, the thermal contact resistance depends on the temperature at the interface.

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