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Abdullah, M. Z.

Yau, Y. C.

Alauddin And, Z. A. Zainal

Seetharamu K. N.

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EFFECTS OF PRESSURE ON THERMAL CONTACT RESISTANCE FOR ROUGH MATING SURFACES

M. Z. Abdullah, Y. C. Yau, Z. A. Zainal Alauddin and K. N. Seetharamu

School of Mechanical Engineering, Universiti Sains Malaysia
Transkrian Engineering Campus, Penang, Malaysia

ABSTRACT

Thermal contact resistance has been studied experimentally to investigate the effect of pressure between two aluminium or two brass rough surfaces at three different heat flux levels. Three different rough surfaces are considered in the range of 2.63 to 40.69μm. It is demonstrated that the thermal contact resistance reduces significantly with pressure for both materials, the harder material gives higher thermal contact resistance as expected.

1. INTRODUCTION

Thermal contact resistance is of interest in many fields including internal combustion engineering, bearings with lubrication, heat transfer across granular solids, microelectronics, superconductors, aerospace structures, and biomedical prosthetics[1]. Whenever heat flow or energy transfer at the interface of two materials are to be estimated or controlled, then the conductance data must be available either from experiments or predictions. Thermal conductance data is also required in the measurement of the thermal conductivity of solids. Heat transfer through two contacting bodies is characterised by a temperature drop across the interface. Thermal contact resistance is defined as the ratio of the temperature drop to the heat flow across the interface:

$$R = \frac{\Delta T}{Q}\left[KW^{-1}\right]$$

Resistance values based on the heat flux allow the comparison of data obtained by using different geometric configurations, and for the estimation of the resistance across given mating surfaces. It is sometimes more convenient to express the contact resistance across a pressed contact in terms of contact conductance. The contact conductance has been defined as the ratio of the heat flux to the temperature drop across an interface[3,5,9]. In general, the conductance equals the reciprocal of the resistance.

A number of theories and experimental investigations have been made in order to estimate the thermal contact resistance[1-8]. However, the agreement between theory and experiment needed further improvement due to the complicated pattern of surface roughness. The theoretical method of correlation to determine the thermal contact resistance is important and it depends on the characteristics of the interface surface. The thermal contact resistance depends on the thermal conductivity, surface finish, contact pressure, and both the size and shape of the contacting irregularities. In order to correlate the analytical and measured contact resistance, it is first necessary to measure and quantify the surface finish of the mating surfaces.

The general theory correlated the data from numerous investigations based on stainless steel and aluminium contact surfaces, contact pressures of 0.0035-0.3kg/mm^2 and RMS surface roughness of 0.25 to 3μm. For such case, the theory has been established and available in the handbooks[12]. However, agreement with experiments has been variable, especially when the relatively rough mating surfaces are involved. The surface roughness is varied from machined, ground, sand blasted and bead blasted to high polish (up to 0.2μm). In general, the bead blasted surface results matched more closely the analytical models and have low contact resistance compared to the sand blasted, ground or machined surfaces. This is because the bead blasted surface has homogeneous distribution of asperities. However, the ground, sand blasted and machined surfaces have a directionally dependent roughness causing long wave-length undulations which makes it more difficult to predict the actual contact ratio i.e. the true contact area of the asperity tips divided by the nominal area; thus leading to increase in the thermal contact resistance.

The present investigation provides thermal contact resistance data for soft mating materials i.e. aluminium and brass; at different contact pressures, and for relatively rough mating surfaces as shown in Table 1. Interface temperatures varied between 4.79 – 23.97°C and detailed surface roughness measurements are made for all contacting surfaces.

Table 1: Specimen roughness values and heat rates used in experiment.

Type	**A1**	**B1**	**C1**
Aluminum: Roughness R_q (μm) (RMS value)	5.59	15.04	25.65
Type	**A2**	**B2**	**C2**
Brass: Roughness R_q (μm) (RMS value)	7.11	14.85	15.74
Heat Rate (W)	3.24	7.98	12.5

2. EXPERIMENTAL SET-UP

Figure 1 shows a schematic view of the experimental apparatus used in the present study. The apparatus consists of two mating bars with different roughness. A bar heater is used as a heat source in the right bar and the cooling water flow is used as a heat sink in the left bar, in order to maintain a steady state heat flow along the longitudinal axis of the test specimen. Several rough surfaces are made on the end of aluminium and brass bars. Thus, three sets of aluminium and brass bars are used as specimens in the experiment. The heat supplied is varied in the experiment using a controlled power supply unit.

Table 2: Combination of roughness (RMS values) for aluminum and brass.

Combination	Sum of Rq (μm)
Aluminum	
A1+B1	20.63
A1+C1	31.24
B1+C1	40.69
Brass	
A2+B2	21.96
A2+C2	22.85
B2+C2	30.59

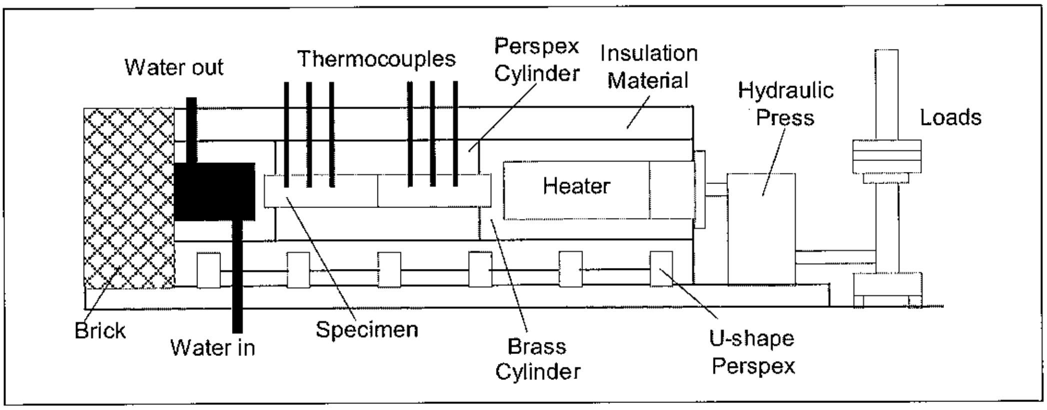

Figure 1: Experimental apparatus.

The surface roughness on the mating surface is measured using a calibrated roughness meter (Mitutoyo Surftest 301). The aluminium and brass surfaces are machined on the lathe machine in order to provide rough surface for the specimens. These resulted in surface roughness in the range of 5.56 to 25.65μm (RMS) as shown in Table 1. In order to measure the temperature and the heat flux across the mating surfaces, six standard thermocouples (K-type) are used in the specimens at various axial locations. The output of the thermocouples are measured using a digital thermocouple meter.

The hydraulic press is designed to bring two rough surfaces of the specimens in contact at different pressures. It consists of a cylindrical body, a connecting conduit, large and small pistons. The hydraulic press converts the vertical load to the horizontal force exerted by the horizontal pressing rod and to the test specimens. The loads used are varied from 0 to 15.64kg in the experiment that provide the contact pressure in the range of 0 to 868.0kPa. A hollow cylindrical portion made of perspex is used as casing for the specimens in order to make sure that two mating surfaces are contacted properly.

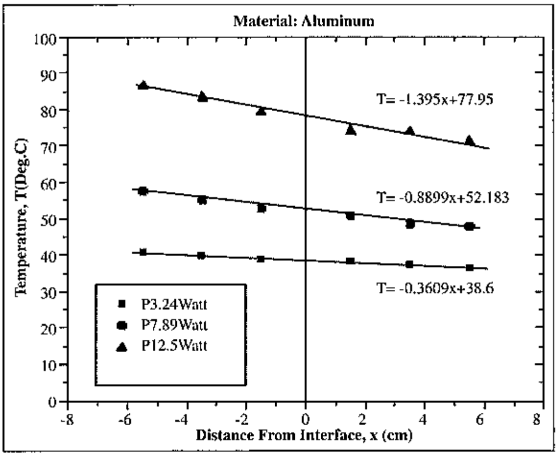

Figure 2: Temperature profiles for aluminium specimen without interface at different heat rates.

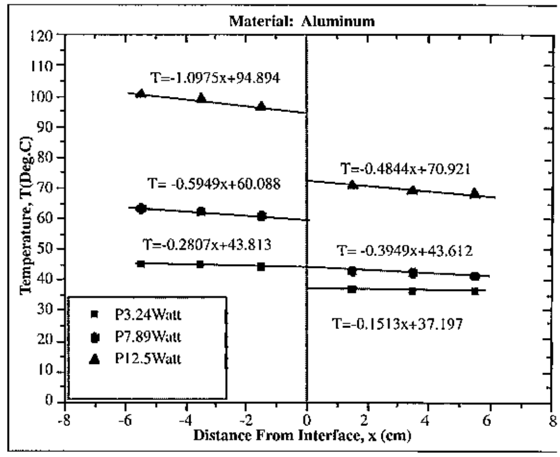

Figure 3: Temperature profiles for aluminium specimen A1+B1 at different heat rates.

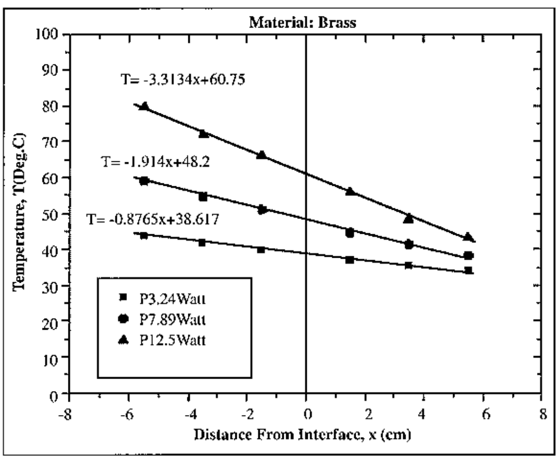

Figure 4: Temperature profiles for brass specimens without interface at different heat rates.

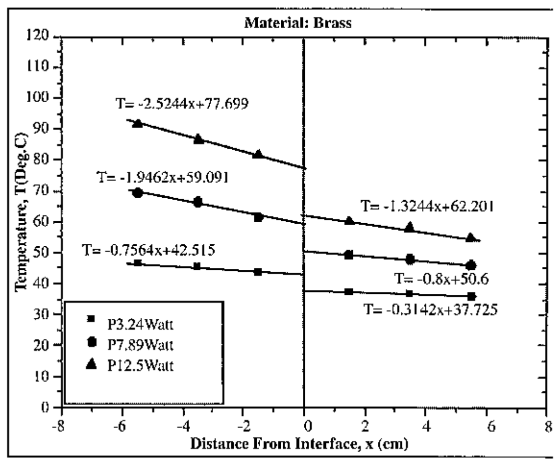

Figure 5: Temperature profiles for brass specimens A2+B2 at different heat rates.

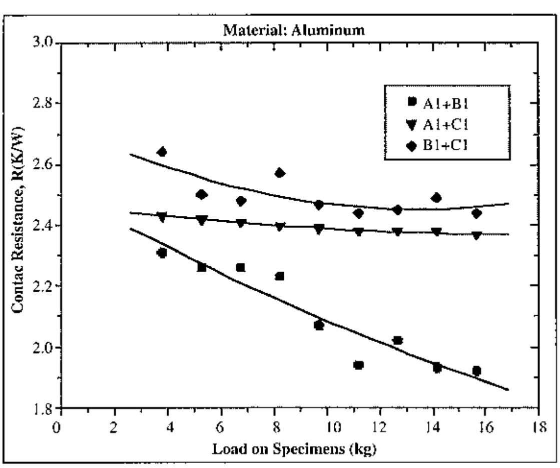

Figure 6: Thermal contact resistances at various loads and roughness combination for aluminium.

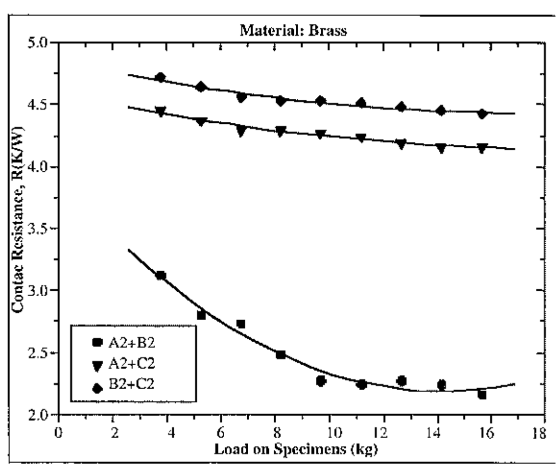

Figure 7: Thermal contact resistances at various loads and roughness combination for brass.

3. TEST PROCEDURE

The specimen without interface or with different combinations are inserted in the cylindrical perspex which is covered by external silicate insulation. The desired load is applied by the hydraulic press as shown in Figure 1 and the power supply is switched ON. At the same time, the water is allowed to flow through the heat sink section. The loads applied on the hydraulic press are varied from 0.5kg to 4.5kg with the increment of 0.5kg for the heat input of 7.98W, whereas a fixed load of 2.5kg is applied for the heat input of 3.24W and 12.5W.

The temperature reading at six axial locations in the specimens are taken after it reached the steady state condition i.e. approximately 8 hours after starting the test run. The flow rate of the water is measured to make sure a constant flow rate used for every test. The heat rate, Q across the interface is taken to be equal to the electrical energy input to the heater, which assumes that there is no heat loss to the surrounding.

4. RESULTS AND DISCUSSION

Figures 2 and 4 show the temperature profiles for the specimens without interface at different power inputs (3.24W, 7.98W and 12.5W) for aluminium and brass respectively. The results illustrate the temperature gradients, dT/dx are linear and increases with the heat input as expected. At the same heat input, the temperature gradient for brass bar is higher than the aluminium bar in view of lower thermal conductivity coefficient, k, of brass compared to aluminium.

Figures 3 and 5 show the temperature drop across the contact surfaces as a function of several roughness and at different power input for aluminium and brass respectively. The temperature drops at the contact surface for given two rough surfaces for both aluminium and brass are at a contact loading of 9.7kg. It is observed from Figures 3 and 5 that as roughness increases, the temperature drop across the contact surfaces increases for a given heat flow and for a given combination of the two surfaces i.e. type A1+B1, as indicated in the abscissa by the sum of the RMS roughness values (e.g. for aluminium 5.59 + 15.04 = 20.63 as given in Table 2). In Figure 3, for a heat rate of 12.5W, the temperature drop is 23.97°C where as for a heat input of 7.98W, the temperature drop is 16.48°C. However, when the heat input is decreased to 3.24W, the temperature drop is only 6.61°C. Figure 5 shows a similar trend where for a heat input of 12.5W, the temperature drop is 15.50°C where as for a heat input of 7.98W, the temperature drop is 8.50°C. However, when the heat input is decreased to 3.24W, the temperature drop is only 4.79°C. The results illustrate that the lower the heat input, the smaller will be the temperature drop at the mating surface.

Figures 6 and 7 show the effects of pressure on the contact resistance for both aluminium and brass specimens at a heat input of 7.98W. The results show similar trends where the contact resistance reduces with the increase of the contact pressure. Figure 6 shows that for the aluminium specimens with the combination of roughness A1+B1, the contact resistance, R is in the range of 1.92 to 2.32K/W whereas for higher combination of roughness i.e. A1+C1 and B1+C1, the contact resistances are increased in the range of 2.37 to 2.47K/W (for A1+C1) and 2.44 to 2.62K/W (for B1+C1). It is also observed from Figure 6 that the effect of pressure on the combination A1+B1 is more than the other two combinations.

Figure 7 shows the results for the brass specimens at different roughness combination and contact pressure. The results also show that at lower roughness such as for combination of A2+B2, the contact resistance is in the range of 2.16 to 3.12K/W, whereas for the combination of A2+C2 and B2+C2 the contact resistances are significantly higher in the range of 4.16 to 4.45K/W and 4.43 to 4.72K/W respectively compared to A2+B2. The effect of pressure on the combination A2+B2 is more than the other two combinations.

Thus, these results illustrate that the contact resistances, R are lower for the aluminium compared to brass for all combinations. It is also known that the brass is the harder material with the hardness of 178kg/mm^2 (Meyer's hardness) compared to aluminium (with Meyer hardness of 30kg/mm^2). This also shows that aluminium, as a softer material, might deform plastically more at the mating surfaces and give a larger contact surface compared to the brass which has much higher hardness value.

5. CONCLUSION

The problems of contact resistance between two aluminium and brass surfaces of different relatively rough surfaces have been studied. From the studies it is concluded that as the roughness increases, the thermal contact resistance increases. The higher contact pressure significantly reduced the contact resistance. Heat flow across the contact resistance does have an influence on contact resistance.

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