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ABSTRACT

The thermal conductance of oxygen-free high conductivity (OFHC) copper sample pairs with surface finishes ranging from 0.1 to 1.6-μm rms roughness has been investigated over the range of 1.6 to 6.0-K under applied contact forces up to 670 N. The thermal conductance increases with increasing contact force; however, no correlation can be drawn with respect to surface finish.

INTRODUCTION

To optimize performance of cryogenic instruments, a knowledge of the thermal conductance of pressed contacts is necessary. This is especially true for instruments whose performance is temperature-dependent, as is the case with many infrared astronomical instruments. Facilities such as the Infrared Astronomical Satellite (IRAS), Shuttle Infrared Telescope Facility (SIRTF), and the Large Deployable Reflector (LDR) depend on accurate knowledge of the behavior of pressed contacts at liquid helium temperatures.

Whereas estimates of the thermal conductance can be derived from measurements of the electrical conductance from the Weidemann-Franz law, it has been shown that such estimates may deviate from the actual values by a factor of 10 E + 5.[1]

Several theoretical models have been developed to account for the thermal resistance of pressed contact pairs[2-8]; however, most usable data in the field are empirical. Previous work has shown that the thermal conductance is independent of contact area, and is dependent on applied contact force.[1,9] At liquid helium temperatures, conductance follows a T^2-temperature dependence. Whereas surface finish effects have been studied, most data available deal with specific contact geometries, such as cup and cone, copper rods, etc., and often correspond to particular applications. A need exists for more general data covering a variety of sample pairs over a wide range of temperatures and applied contact forces.

Method

The present work examines the thermal conductance of pressed contact OFHC copper sample pairs as a function of temperature from 1.6 to 6.0 K with applied force up to 670 N as a parameter. An apparatus has been fabricated and tested and is pictured in Figs. 1 and 2. Several sample pairs have been prepared, with surface finishes ranging from 0.1-μm surface roughness to 1.6-μm surface roughness.

The general form of the relation involving thermal conductance is given as

$$\dot{Q} = \int k \, dT$$

Although the method and theory have been covered in a previous paper,[10] the equation of condition which is applicable in the present case

$$\dot{Q} = \int_{T_L}^{T_u} \alpha \, T^n \, dT$$

is employed where:

$\dot{Q}$ = the applied heater power

T_L = the lower sample temperature

T_u = the upper sample temperature

α = the constant of proportionality

n = the exponent

In this case, the thermal conductance is assumed to follow a power law function of temperature, where $k = \alpha T^n$. The values of α and n are obtained by using a computer program and by linearizing the equation of condition. A Gauss-Jordan elimination is performed to

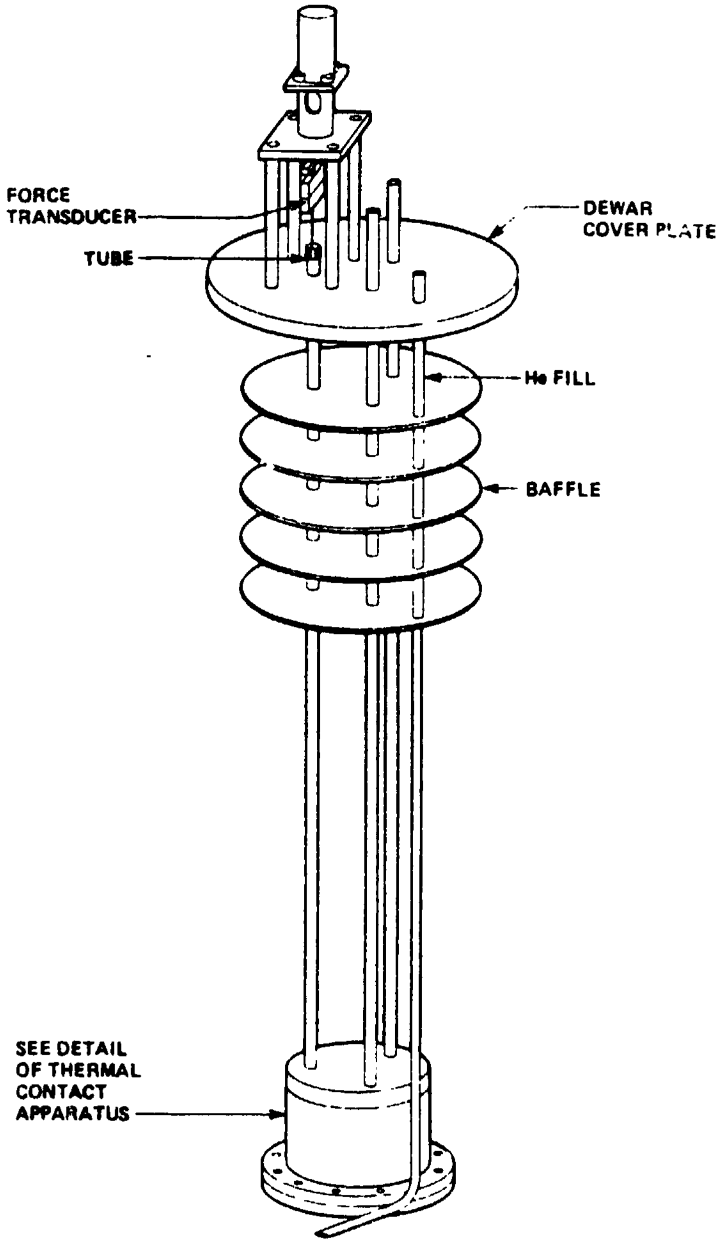

Fig. 1. Overall view of thermal contact apparatus.

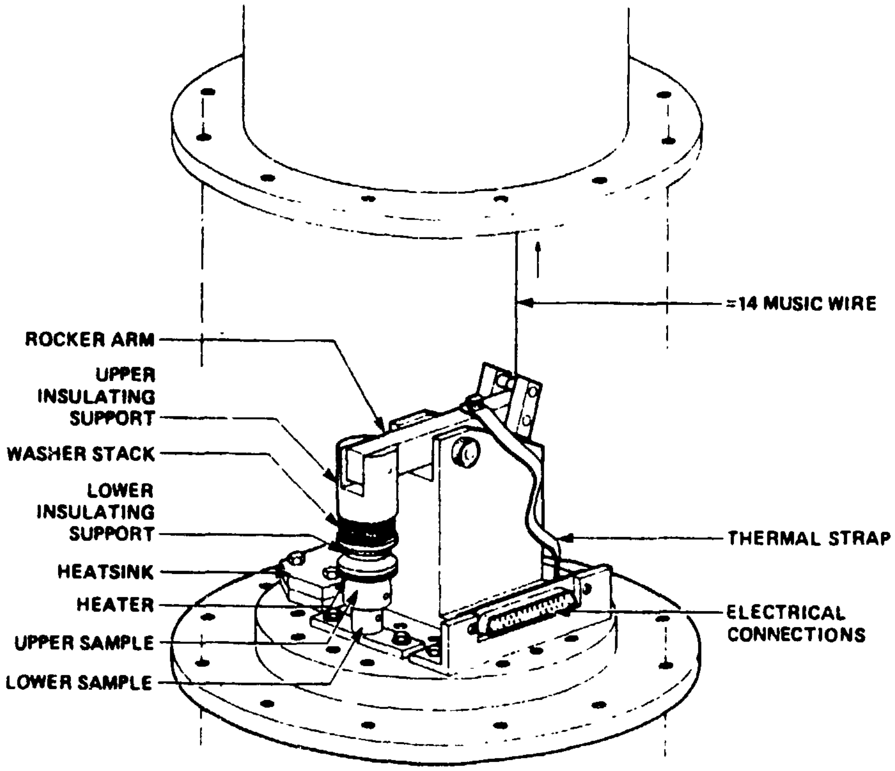

Fig. 2. Cold plate detail.

solve a set of linear equations representing the sum of the squares of the deviations between the measured and the computed values and n-normal equations, so that the deviation can be minimized. The computer program also performs a perturbation of the input parameters according to the standard deviation of the known measurement tolerances including instrument accuracies, roundoff, and truncation errors. By means of a random number generator, 99 replications are performed with the result that the output values of α and n are averages of the replications representing the error as a result of the input uncertainties.

Results

Figures 3-7 plot thermal contact conductance vs temperature with applied force as a parameter for each of the surface finishes. Curves were obtained by calculating αT^n from the program output parameters for a given temperature over the measured range from the lowest sample temperature to the highest. The errors obtained in α and in n from the program are on the order of 10 e-3,

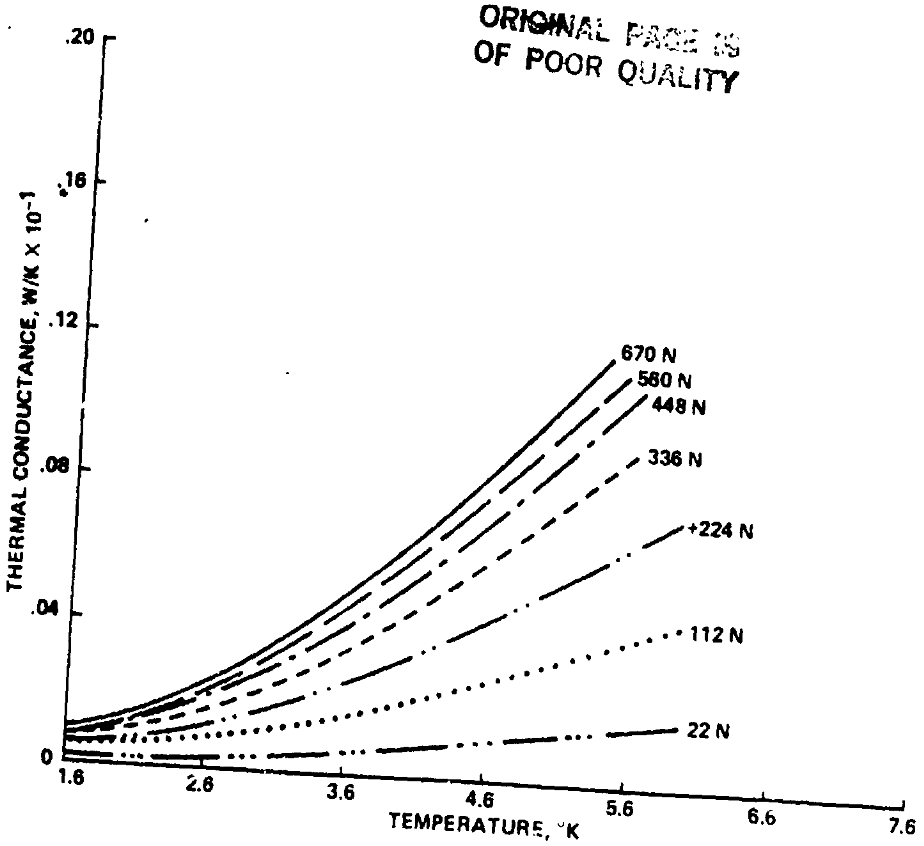

Fig. 3. Results for 0.1 μm surface sample pair.

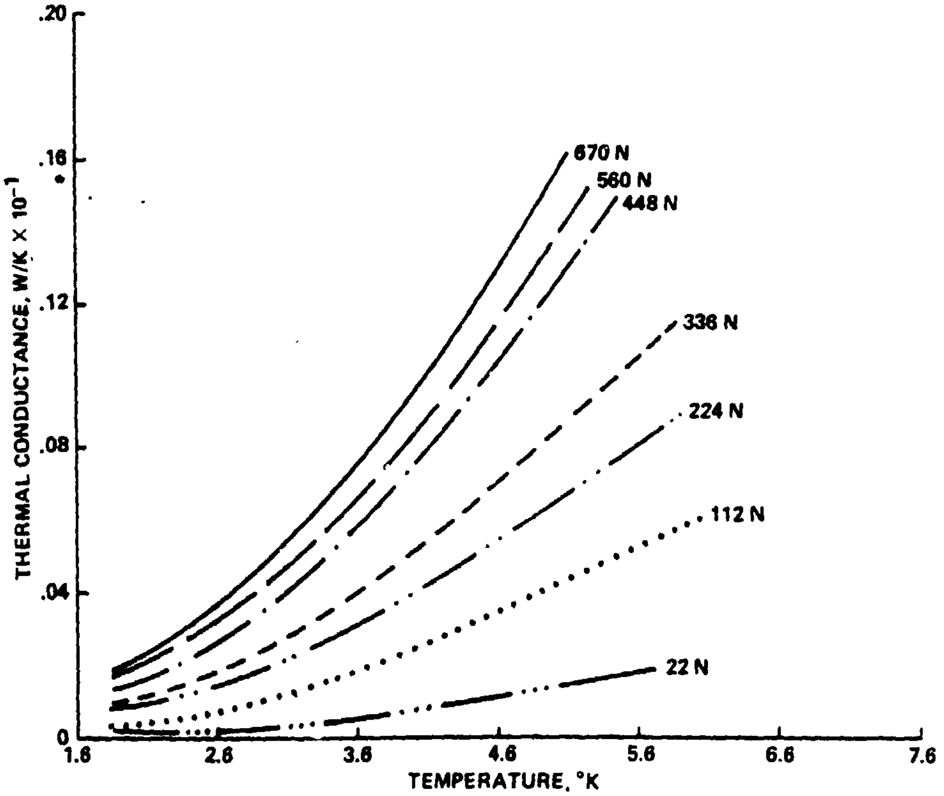

Fig. 4. Results for 0.2 μm surface sample pair.

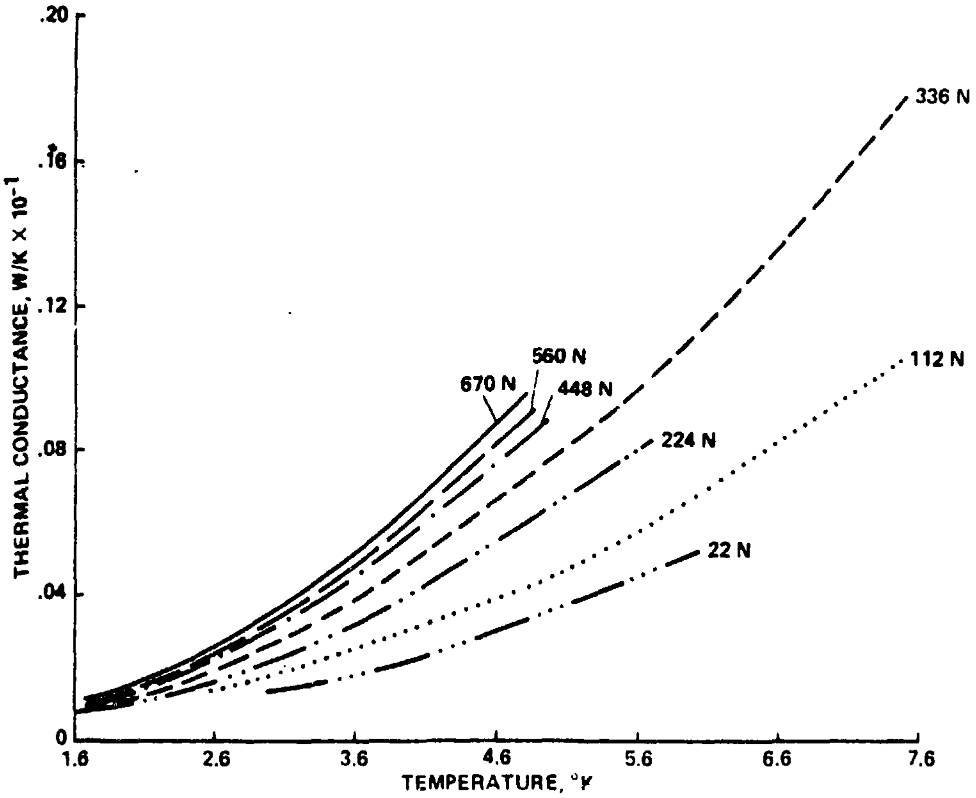

Fig. 5. Results for 0.4 μm surface sample pair.

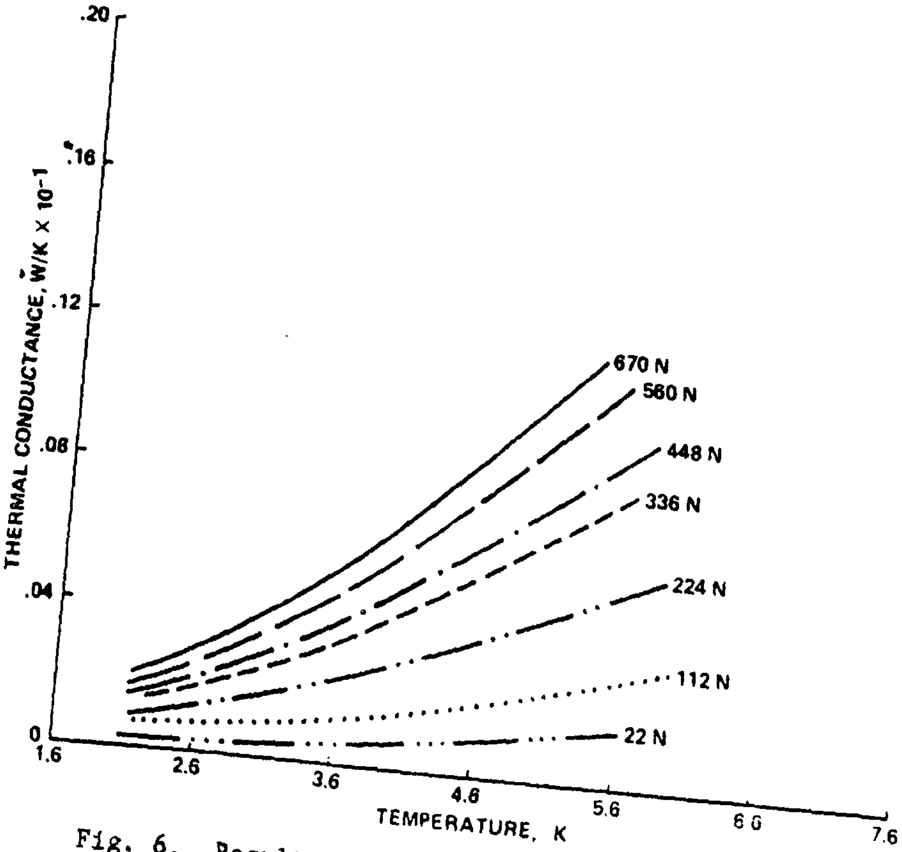

Fig. 6. Results for 0.8 μm surface sample pair.

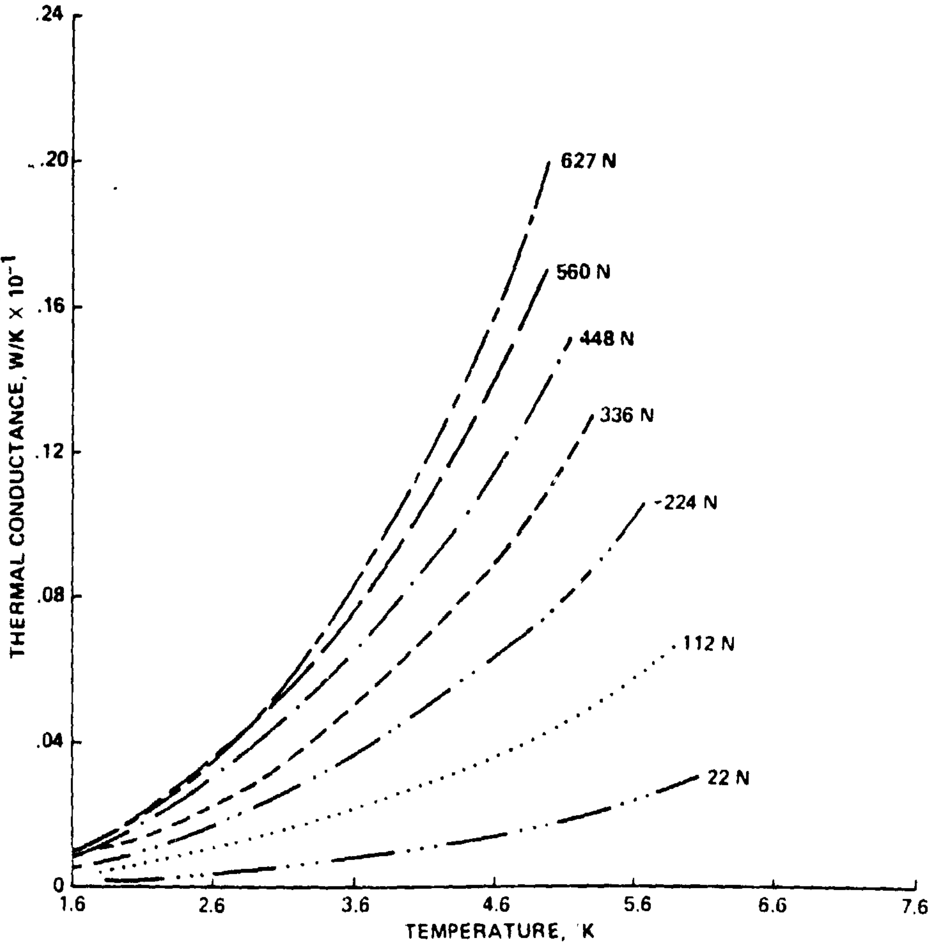

Fig. 7. Results for 1.6 μm surface sample pair.

which indicates little effect on the curves, since the values of α and n are on the order of 0.1 and 2.0, respectively. Figure 8 compares the overall performance of the surface finishes with respect to thermal contact conductance.

DISCUSSION

In examining Figs. 3-7, it can readily be seen that thermal conductance very definitely increases with the increasing contact force, thus confirming earlier work. To ensure repeatability, the 0.2-μm sample pair was tested twice over a 90-day period. The obtained results were within the range of experimental error as defined previously. The thermal conductance obtained appears to be

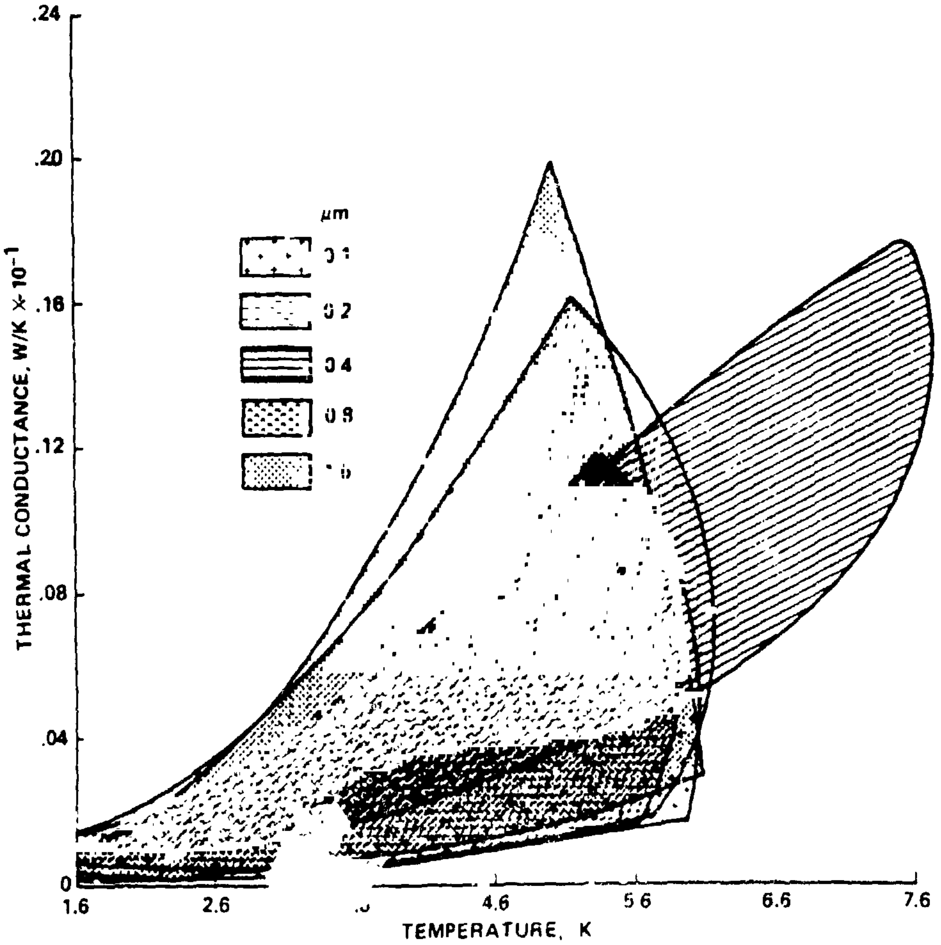

Fig. 8. Surface finish comparison.

a function of temperature to the second power, again as found in previous work. Although no precise quantitative correlations can be drawn from Fig 8, it appears that the surface finishes tested are essentially equivalent in terms of thermal conductance, with the exception of the 1.6-µm and 0.2-µm surfaces. If indeed the thermal conductance is dependent only upon the applied contact force and independent of area as earlier work would suggest, the observed results are not surprising. The reason is that the energy transfer is thought to occur only at a few discrete points which represent the asperities of the surfaces. In this case, the higher roughness of the 1.6-µm surface would explain the increased conductance shown in Fig. 8, since the points would provide elastically deformable contact areas. It would be expected that conductance would increase because of the effect of cold welding of the surfaces as the surfaces became very fine (in particular, highly polished surfaces).

CONCLUSION

At the present time it appears that the thermal contact conductance of OFHC copper sample pairs increases with increasing applied force, which is supported by earlier work; however, no correlation can be drawn with respect to surface finishes. Future work examining the contact conductance of brass, stainless steel, and aluminum may provide further insight into the phenomenon of surface finish effects.

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