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THERMAL CONDUCTANCE OF PRESSED ALUMINUM AND STAINLESS STEEL CONTACTS AT LIQUID HELIUM TEMPERATURES

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ABSTRACT

The thermal conductance of aluminum and stainless steel 304 sample pairs with surface finishes ranging from 0.1 to 1.6 μm rms roughness has been investigated over a temperature range from 1.6 to 6.0 K. The thermal conductance follows a simple power law function of temperature, with the exponent ranging from 0.5 to 2.25, increases asymptotically with increasing applied force, and exhibits an anomaly for surface finishes in the 0.4-μm region.

INTRODUCTION

Accurate thermal models are crucial for optimum cryogenic instrument design, particularly concerning infrared instruments and focal planes whose performance is temperature-dependent. Instruments aboard space projects such as the infrared Astronomical Satellite (IRAS), The Space Infrared Telescope Facility (SIRTF), and the Large Deployable Reflector (LDR) fall into this category. Present models are limited by a lack of cryogenic temperature data to allow one to predict the thermal conductance of the bolted joints typically used in the instrument-to-system interface. The performance of OFHC copper and brass contact pairs has already been characterized,[1-3] and the theory, apparatus, and experimental method have been examined in detail.[3] The present work examines the thermal contact

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conductance of pressed pure aluminum and stainless steel 304 contact pairs having surface finishes of 0.1, 0.2, 0.4, 0.8, and 1.6 µm rms at temperatures from 1.6 to 6.0 K, under applied contact forces up to 670 N.

RESULTS

The experimental data were fitted to a simple power law where the thermal conductance is given by

$$k = \alpha T^n$$

where k is the thermal conductance, and α and n are constants which are determined empirically.

Figures 1-9 present results obtained for aluminum sample pairs. In Figures 1-5, the thermal conductance is plotted versus temperature for each of the tested surface finishes, with applied force as a parameter. It should be noted that thermal conductance is given in units of mW/K, in keeping with the finding of Berman[4] that thermal conductance is independent of the contact area, and dependent on the applied force. The reason for this is that the actual contact area between two surfaces is dependent on the applied force, rather than the apparent surface area. Some work-hardening of the surface occurs, which determines the contact area.

Figure 6 shows the relation between thermal conductance and applied force for the different finishes. The dependence of thermal conductance, and n on surface finish for the range of applied forces is shown in Figures 7, 8, and 9, respectively.

Figures 10-18 represent the same relations as Figures 1-9 but pertain to the stainless steel samples. Figures 19 and 20 for brass samples tested previously[3] correspond to Figures 8 and 9 for aluminum and Figures 17 and 18 for stainless steel.

DISCUSSION

When Figures 1-5 and 10-14 are examined it can be seen that, as verified earlier with copper[1,2] and brass[3] samples, the thermal conductance of the aluminum and stainless steel sample pairs increases according to a power law relation with increasing applied force. The variation of conductance with applied force appears to be asymptotic, as shown in Figures 6 and 15 for data at 4.2 K, and consistent with effects observed by Berman.[4] Figures 7 and 16 show the anomalous thermal conductance peak of the 0.4-µm surface finish sample pair at an applied force of 670 N, a behavior which was observed earlier.[1-3] Of particular interest is the fact that for the aluminum, the thermal conductance, instead of peaking at 0.4 µm, is actually lowest at that finish, an effect opposite to that observed in the other materials.

Figures 8, 9, 17, 18, and 19 show that for the most part, the anomaly is also apparent in both the values of α and n, the exception being Figure 20, suggesting that thermal energy transport is altered at the 0.4-µm boundary. Since the samples were lapped to achieve the required surface finish, it was thought that the 0.4-µm sample pairs could have been prepared differently. All contact surfaces were examined under a 10X microscope to determine whether any particular characteristic of the preparation (e.g., lap mark orientation) was different for the samples in question. Specifically, it was hypothesized that if the two samples were lapped such that when they were in contact the direction of lapping coincided, the thermal conductance would be higher for this particular pair than for others. Alignment of the pairs, with respect to microscratches was examined as well. All contact surfaces showed that visible surface effects had no observable correlation with measured thermal conductance.

Since thermal energy transport is by phonons, the effect could possibly be related to the vibrational energy. It was thought that the frequency of vibration could be related to the surface roughness. If the wavelength corresponded to the wavelength of the surface asperities (i.e., the finish), perhaps this phenomenon would account for the increase in thermal conductance, an effect similar to the relative ease of driving a mechanical system at its natural frequency. An attempt was made to correlate the vibrational energy to the thermal energy, but again no causal relationship was established. In this case, the wavelength of the surface asperities would shift downward with increasing temperature, an effect which was not observed within the range of experimental error.

Since the problem of thermal contact conductance is basically one of a mismatch of the acoustic impedance between two solids, Kapitza conductance may offer some explanation of the effects observed.[5]

CONCLUSION

As found earlier with copper and brass samples, the thermal conductance of pressed aluminum and stainless steel sample pairs increases according to a simple power law function of temperature. Thermal conductance also increases asymptotically with increasing applied contact force and is related to the surface finish of the sample. The maximum contact conductance for materials other than aluminum is obtained for samples having an rms surface roughness of 0.4 μm. For aluminum, the conductance is lowest for this surface finish. Reasons for this anomalous behavior are not understood at this time. Further work is needed to identify the exact mechanism of conductance at the contact interfaces.

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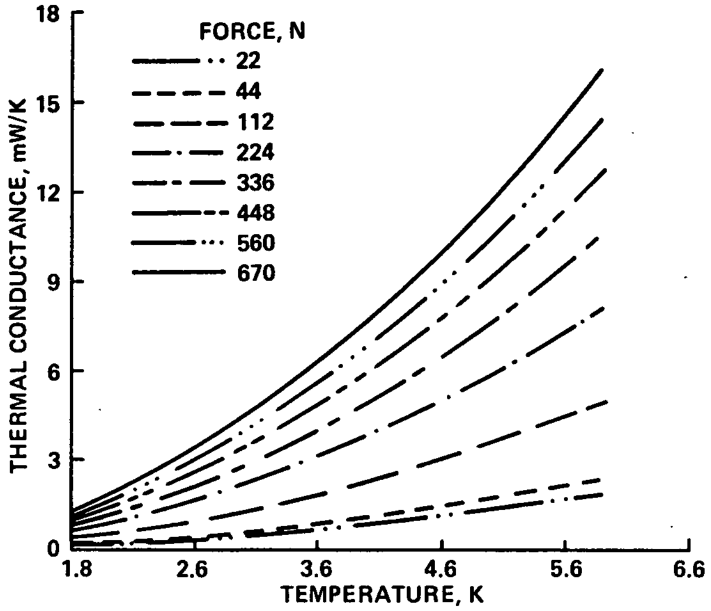

Fig. 1. Aluminum, 0.1-μm surface finish.

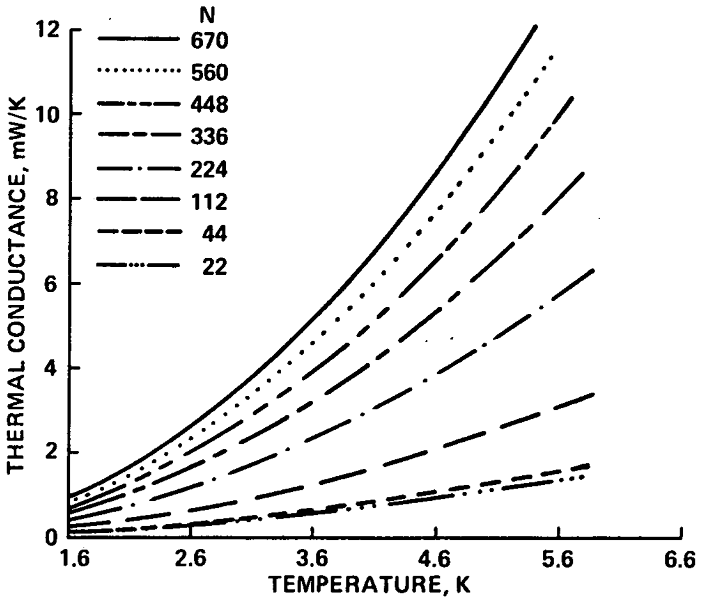

Fig. 2. Aluminum, 0.2-μm surface finish.

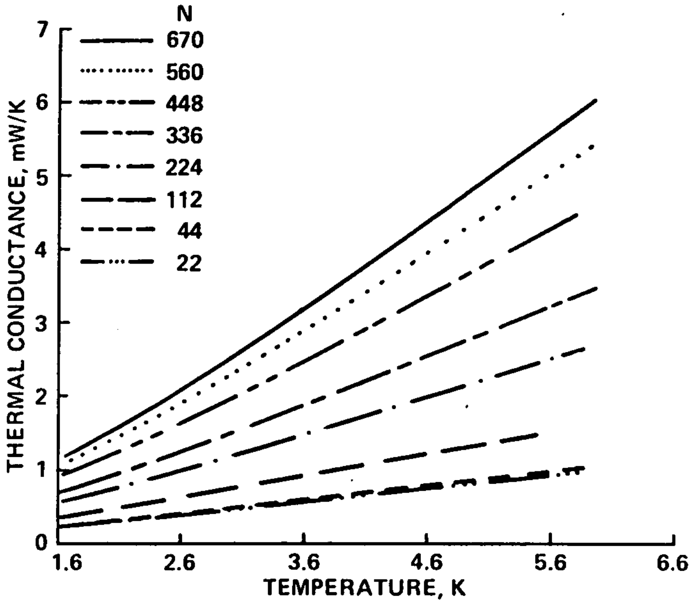

Fig. 3. Aluminum, 0.4-μm surface finish.

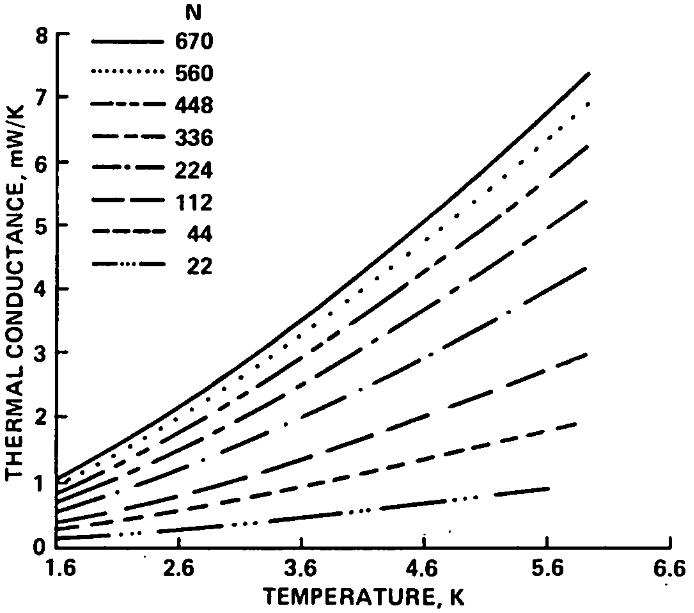

Fig. 4. Aluminum, 0.8-μm surface finish.

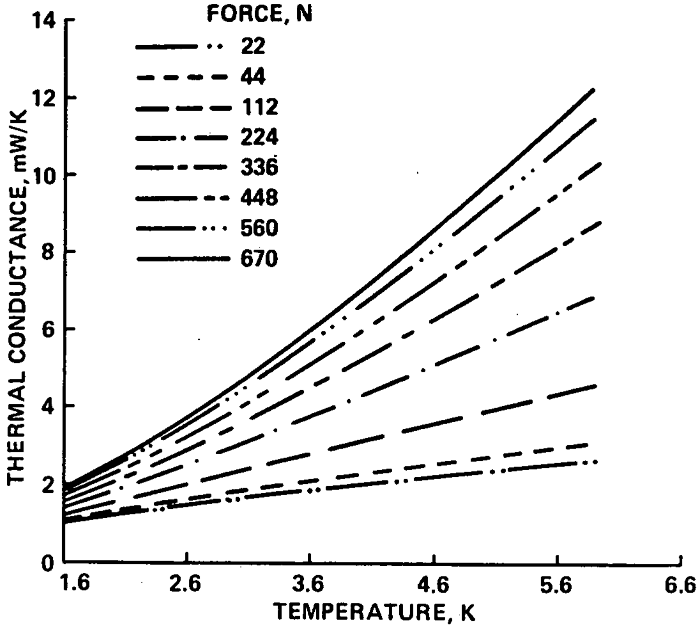

Fig. 5. Aluminum, 1.6-μm surface finish.

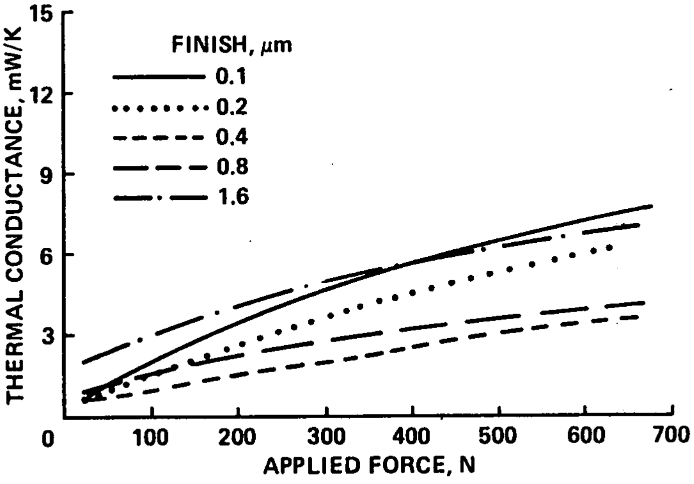

Fig. 6. Aluminum, T = 4.2 K.

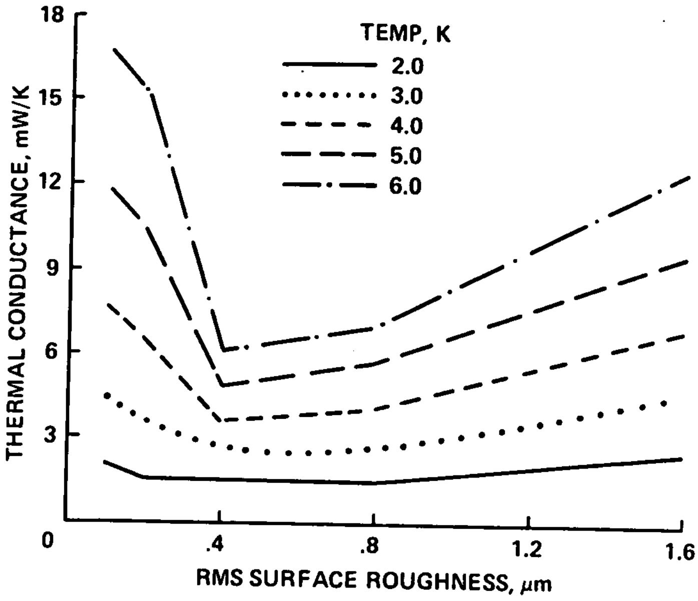

Fig. 7. Aluminum, F = 670 N.

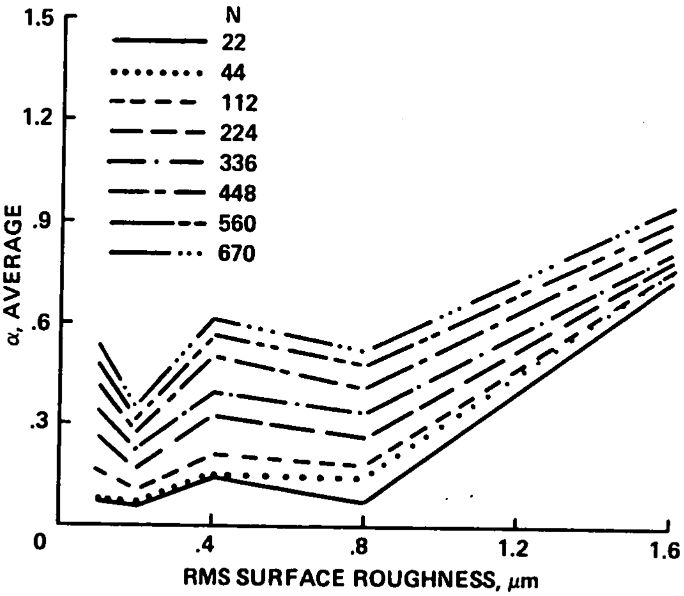

Fig. 8. Aluminum, T = 4.2 K.

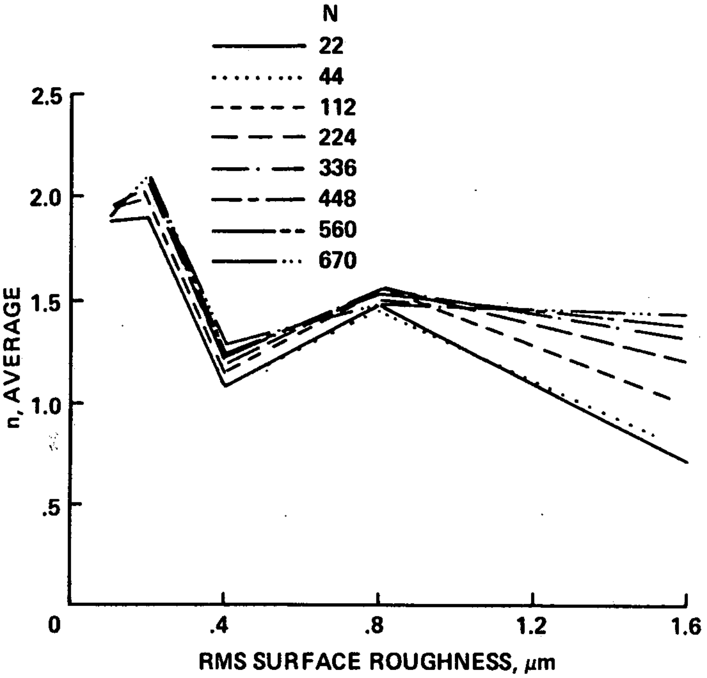

Fig. 9. Aluminum, T = 4.2 k.

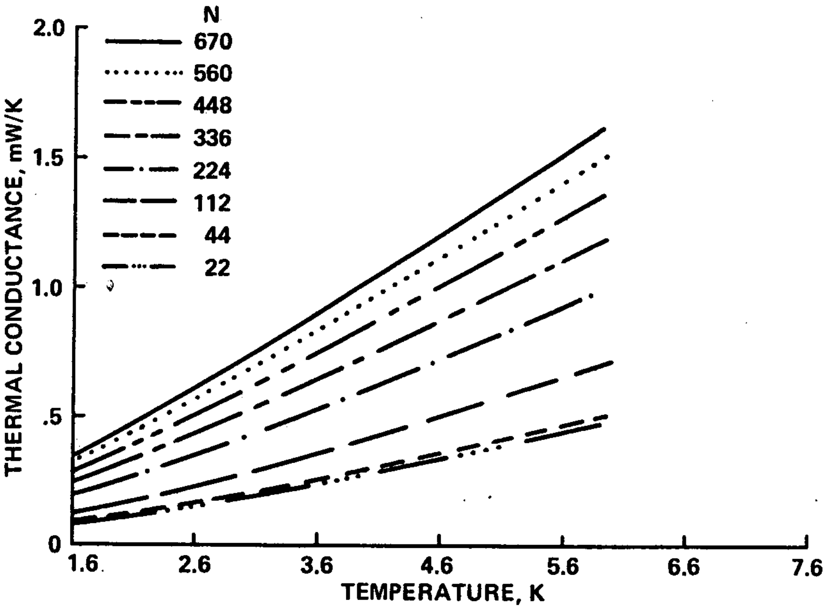

Fig. 10. Stainless steel, 0.1-μm surface finish.

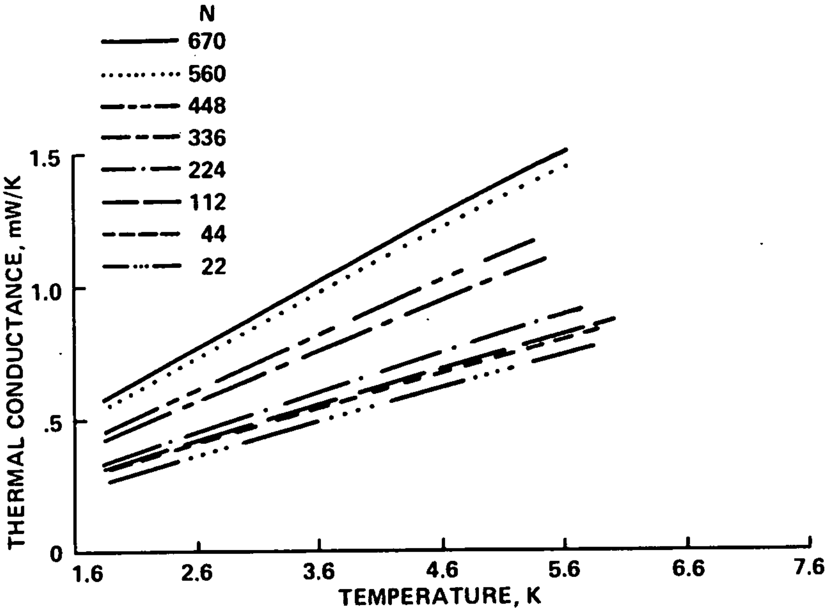

Fig. 11. Stainless steel, 0.2-µm surface finish.

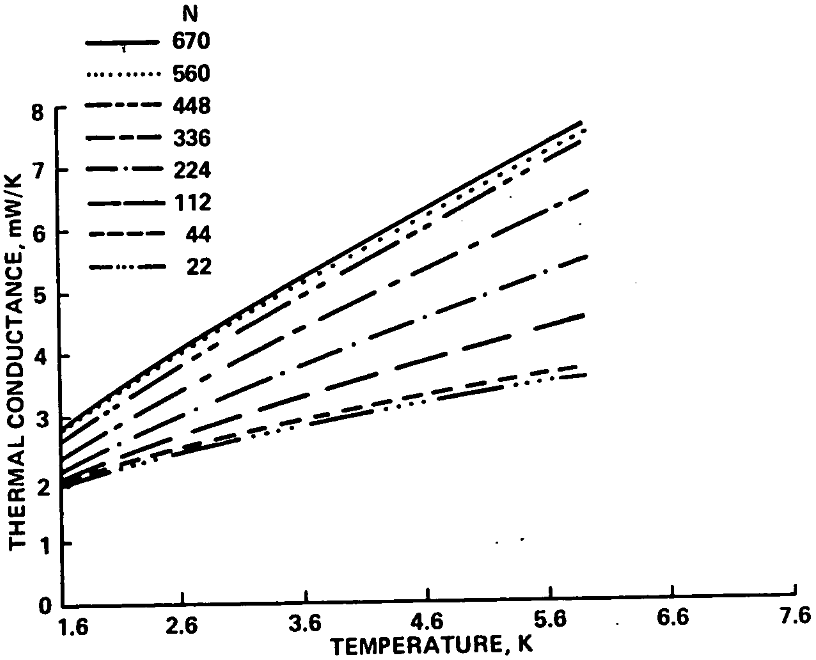

Fig. 12. Stainless steel, 0.4-µm surface finish.

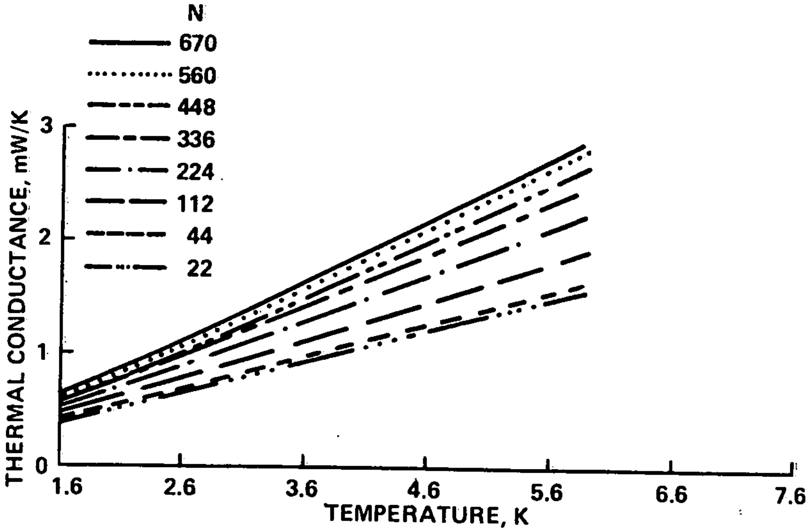

Fig. 13. Stainless steel, 0.8-μm surface finish.

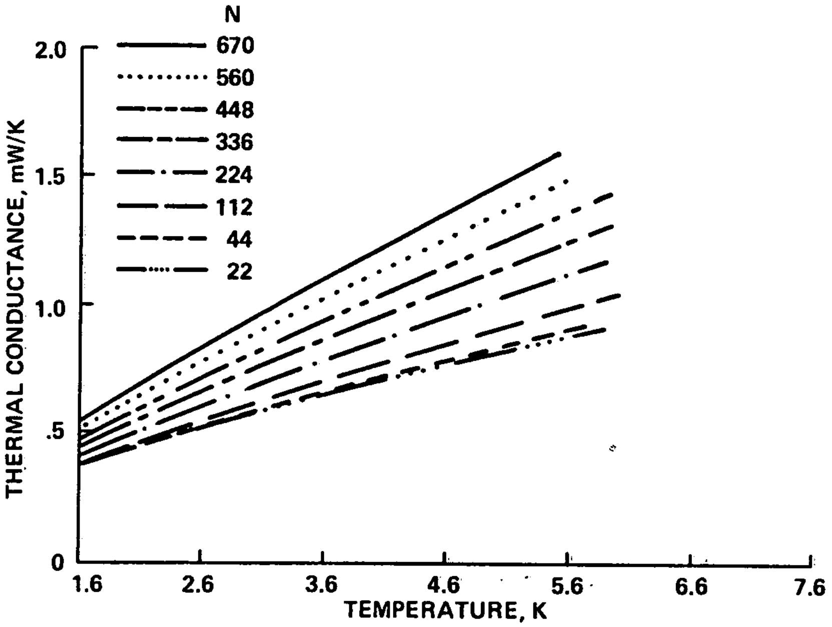

Fig. 14. Stainless steel, 1.6-μm surface finish.

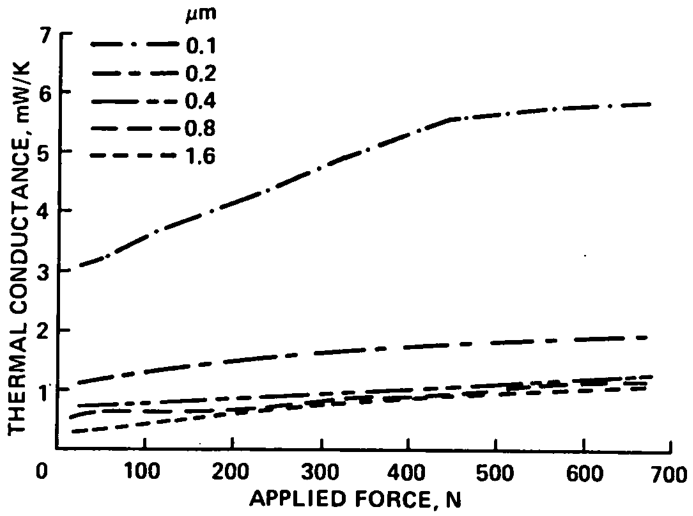

Fig. 15. Stainless steel, T = 4.2 K.

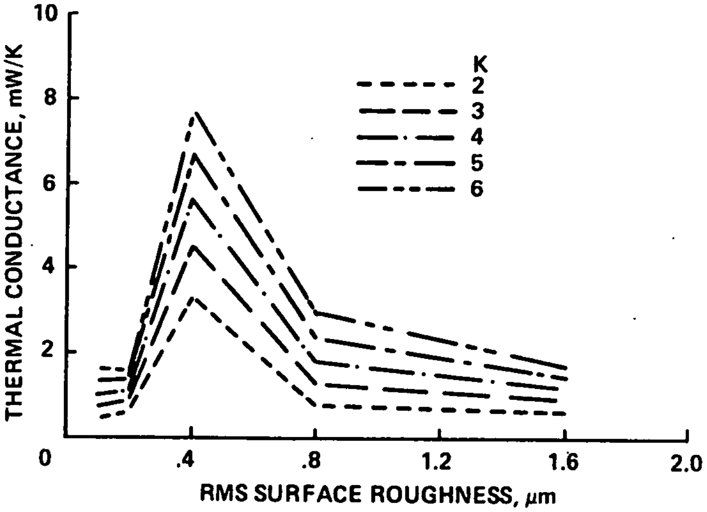

Fig. 16. Stainless steel, F = 670 N.

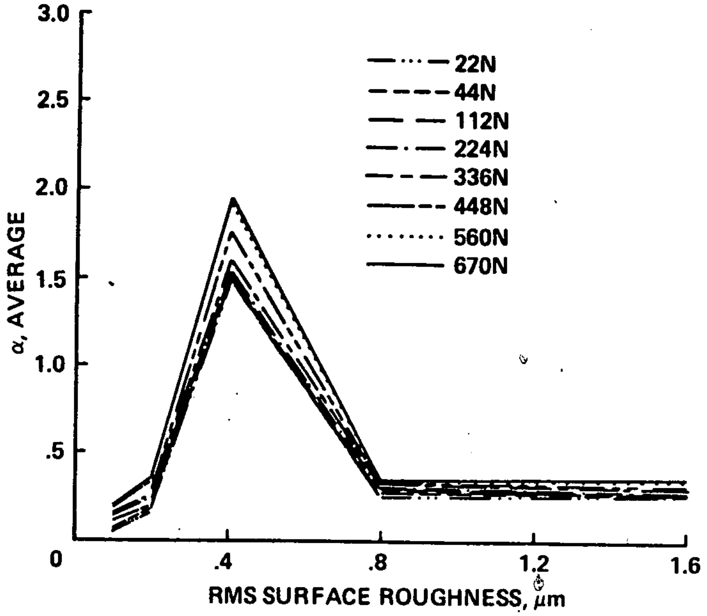

Fig. 17. Stainless steel, T = 4.2 K.

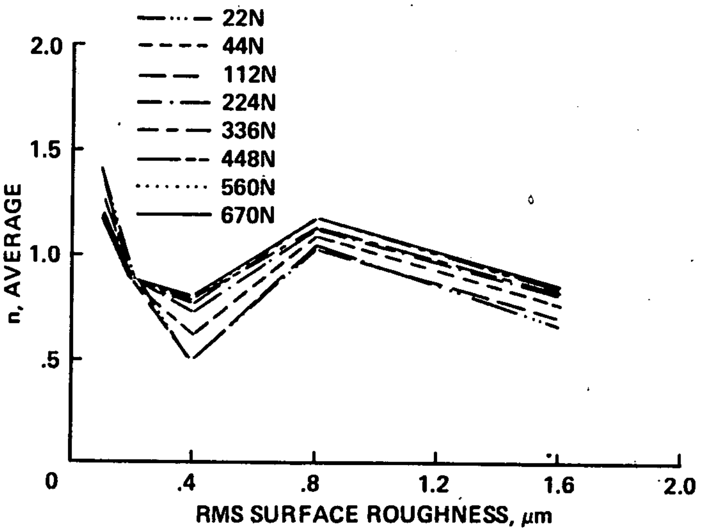

Fig. 18. Stainless steel, T = 4.2 K.

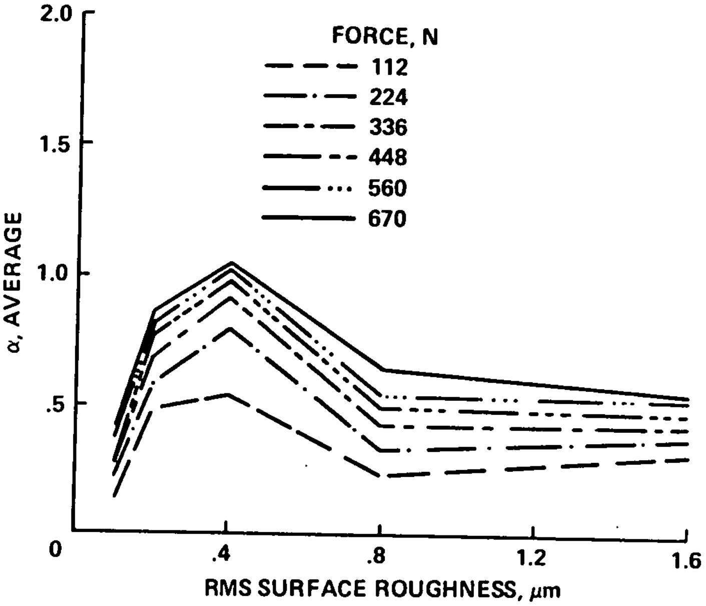

Fig. 19. Brass, T = 4.2 K.

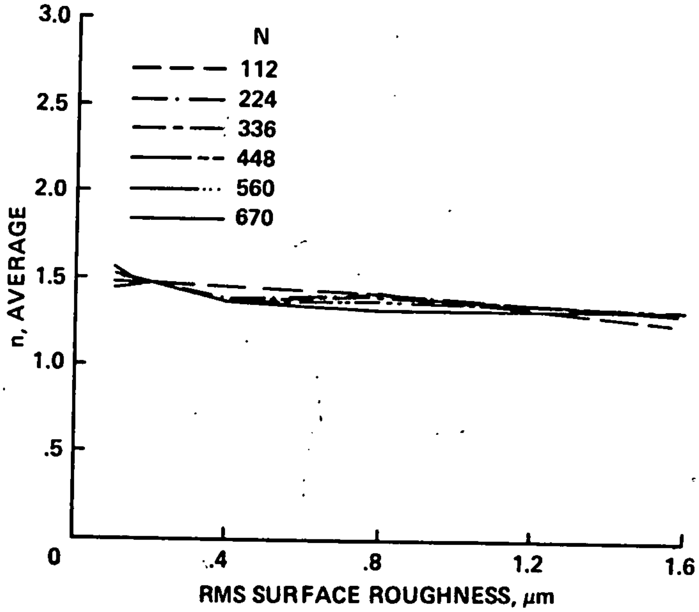

Fig. 20. Brass, T = 4.2 K.

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16. Abstract

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