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EFFECT OF PLASTIC SET ON THERMAL CONDUCTANCE AT LIGHT LOADING

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1971

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-2385		

4. Title and Subtitle	5. Report Date
EFFECT OF PLASTIC SET ON THERMAL CONDUCTANCE AT LIGHT LOADING	September 1971
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Daniel J. McKinzie, Jr.	E-6402
	10. Work Unit No.
9. Performing Organization Name and Address	124-09
Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Smooth metal surfaces joined together (e.g., by rivets, bolts, etc.) are commonly encountered in spacecraft. To predict the heat-transfer rates for high-vacuum conditions across such surfaces, the theories of A. M. Clausing and B. T. Chao and B. B. Mikic and W. M. Rohsenow are often used. Experimental data presented in this report indicate that the assumption of elastic deformation made in these theories is inadequate for accurate prediction of heat transfer with light loads.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Heat transfer Thermodynamics	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	5	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

Smooth metal surfaces joined together (e.g., by rivets, bolts, etc.) are commonly encountered in spacecraft. To predict the heat-transfer rates for high-vacuum conditions across such surfaces, theories such as those of A. M. Clausing and B. T. Chao and B. B. Mikic and W. M. Rohsenow are often used. These theories assume that macroscopic elastic deformation occurs during the formation of such joints with an associated effect on the heat-transfer rates. Experimental data presented in this report indicate that this assumption is inadequate for accurate prediction of heat transfer with light loads.

INTRODUCTION

The prediction of heat-transfer rates across smooth metal surfaces joined together by fasteners is required for spacecraft thermal design. The theories of references 1 and 2 are frequently used to predict the thermal balance across such surfaces under high-vacuum conditions and light loads. These theories assume that macroscopic elastic deformation occurs during the formation of such joints with an associated effect on the heat-transfer rates. Experimental data obtained from two Armco iron cylindrical specimens are presented in this report which provide new physical insight into the thermal contact conductance phenomenon at vacuum conditions of 1.2×10^{-7} torr and contact pressures which range from 0.45×10^{6} to 3.44×10^{6} newtons per square meter.

EXPERIMENTAL PROCEDURE

The contact surfaces of the two specimens investigated had arithmetic average roughness heights ranging from 0.01 to 0.1 micrometer. Both were 2.54-centimeter-diameter Armco iron cylinders, the ends of which were placed in contact. The contacting surfaces were analyzed with a stylus type of surface analyzer before the tests were conducted and were found to approximate convex spherical segments. The tests were conducted in the facility described in reference 3.

After the outgassed surfaces of a specimen were placed in contact at a loading pressure of 4.48×10^5 newtons per square meter, the interface temperature was raised to approximately 367 K. The contact pressure was then varied through two monotonically increasing then decreasing loading cycles while a constant interface temperature was maintained. At each test point, a minimum of 50 hours of data were taken to assure that steady-state conditions were achieved. Both specimens were instrumented as described in reference 3.

RESULTS AND DISCUSSION

Figure 1 shows the cyclic thermal contact conductance as a function of apparent contact pressure for specimen 1. The specimen was loaded through two cycles. The mean interface temperature of the specimen was kept at 369 K with one exception noted at the end of the first loading, where it was raised at constant pressure (350 N/m^2) to 477 K. It remained at this temperature for 50 hours. While still at this pressure, the interface temperature was then lowered to 369 K and the pressure cycling was continued. The data obtained for the first loading followed the generally recognized trend exhibited when macroscopic elastic deformation of contacting surfaces takes place. However, a comparison with the theoretical predictions from references 1 and 2 has shown the data obtained here to be low by several factors. All data following the first loading fell reproducibly very nearly on a curve having a slope of approximately 1, which is characteristic for a specimen as moderate loading pressures are reached (ref. 4). For the smallest apparent contact pressures these thermal conductance coefficients were consistently lower than those obrained initially. Therefore, it may be surmised that the specimen took a permanent set after the initial loading.

The results from the second specimen, under almost identical experimental conditions, are shown in figure 2. This specimen, however, was not exposed to a temperature excursion. In this case, all the data appear to follow the accepted trend for elastic deformation. However, closer examination of the data obtained at the lowest loading pressures shows a consistent and reproducible decrease in the conductance, perhaps indicating an increasing permanent set.

The contacting surfaces were reexamined with a surface analyzer after each test was completed. Table I presents the surface half-wave height d of each specimen obtained before and after the tests. The half-wave height of the top of specimen 1 increased by 3.35 micrometers and that of the bottom by 2.10 micrometers. The top of specimen 2 increased by 1.49 micrometers and that of the bottom by 1.22 micrometers. Thus, both specimens deformed plastically with the attendant changes in the coefficient of thermal contact conductance noted in the experimental data. The interface temperature excursion apparently caused specimen 1 to deform more than did specimen 2.

Changes in the half-wave surface heights of specimens during tests may explain why the experimental data of references 1 and 5, to mention two, were not in good agreement with such macrostructural elastic deformation theories as those of references 1 and 2. If macrostructural plastic deformation occurs during a test, a basic assumption of these theories is violated, and disagreement between experiment and theory is to be expected.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 8, 1971,
124-09.

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TABLE I. - HALF-WAVE SURFACE HEIGHT

FOR ARMCO IRON SPECIMENS

Speci-men	Specimen surface	Half-wave surface height, d, μm	
		Before test	After test
1	Top Bottom	0.46 0.53	3.81 2.63
2	Top Bottom	1.33 0.51	2.82 1.73

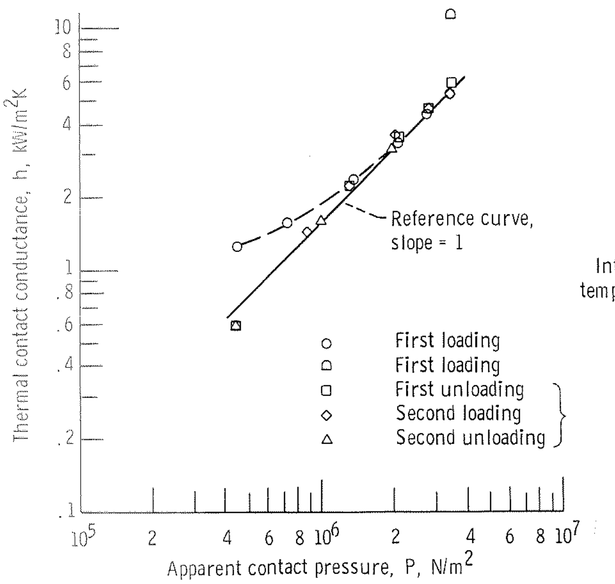

Figure 1. - Thermal contact conductance as function of pressure for Armco iron specimen 1. Arithmetic average roughness height of surface; top, 0.02 micrometer; bottom, 0.014 micrometer.

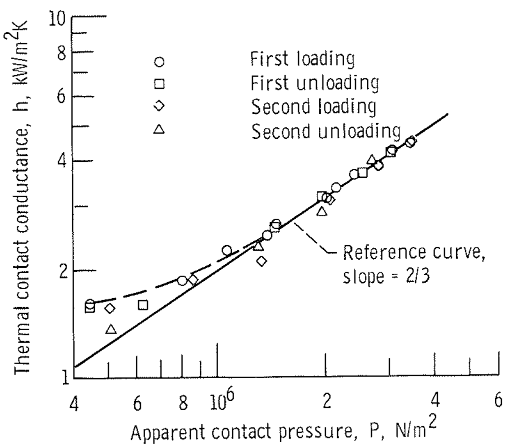

Figure 2. - Thermal contact conductance as function of pressure for Armco iron specimen 2. Interface temperature, 367 K; arithmetic average roughness height of surface; top, 0.038 micrometer; bottom, 0.102 micrometer.

NASA-Langley, 1971 —— 33 E-6402

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