39. ✓ Rover Rocket Materials

R. E. Clausing

We continued to provide materials support to the AEC-NASA Space Nuclear Propulsion Office on the Rover Nuclear Rocket Program.¹ We are providing technical liaison between NASA and some contractors and performing experimental work in certain areas. We concluded the thermal fatigue testing of nozzle tube configurations and the elevated-temperature testing of tubing materials reported in progress last year. More recent effort has been directed mostly toward materials problems that may arise as the result of exposure to the space environment.

THERMAL FATIGUE PROPERTIES OF NOZZLE COOLANT TUBES

D. G. Harman A. E. Carden²

The nozzles for nuclear rockets are typical of most regeneratively cooled rocket nozzles in that the inner surface that contacts the hot exhaust gas is formed by brazing together large numbers of suitably shaped thin-walled tubes. The cryogenic propellant (liquid hydrogen) is forced into these tubes and is vaporized to keep the nozzle from melting. The propellant is then fed into the reactor. The thin-walled tubes are supported externally by relatively heavy sections and are firmly joined to them. These heavy sections remain at low temperatures while the interior nozzle surfaces become quite hot. Thermal expansions of up to 2% may be produced in the tubes, and thermal cycling may produce low-cycle thermal fatigue failures. Apparatus was developed to permit simulation of the thermal and mechanical constraints operating in an actual nozzle,³

and the results of tests have been reported⁴ and are abstracted below.

Multiple-tube specimens of type 347 stainless steel and Hastelloy X were cycled from -200 to 1600, 1800, and 1900°F. Fatigue failures in the form of intergranular cracks were observed through the tube crowns after 23 to 87 thermal cycles. The number of thermal cycles to failure was decreased by increasing the test temperature, holding at this temperature for longer times, or denting the tube crowns before test. Fatigue life increased with decreasing tube diameters, and this was applied to the analysis of a typical nozzle configuration. No appreciable difference was noted between the type 347 stainless steel and the Hastelloy X test specimens.

Simplified single-tube specimens were tested in a specialized low-cycle fatigue apparatus developed under the direction of A. E. Carden at the University of Alabama. Thermal and mechanical effects can be programmed and controlled independently. This apparatus was used specifically to determine the effect of the minimum in the tensile ductility of Hastelloy X near 1300°F on the low-cycle fatigue of the alloy and to provide other data for correlation with the simulated service tests. The fatigue data have been reported elsewhere⁵ and only the abstract is included here.

The low cycle fatigue of Hastelloy X at elevated temperature is presented. Isothermal data at 800, 1300, 1500, and 1800°F are presented with cyclic thermal fatigue data for 600 to 1800°F, 800 to 1300°F, and 1300 to 1800°F. These tests were performed in an Instron machine with separate temperature control. The purpose was to determine the effect of a minimum tensile ductility at or near 1300°F, the effect of the stress-temperature arrangement, and the effect of temperature and frequency. Based on a correlation of strain range with life, the results show no significant deterioration to the fatigue properties at 1300°F; increasing the temperature lowers the strain fatigue curve; and the stress-temperature arrangement shows no adverse effect on this alloy. In general, the thermal fatigue data agree with the isothermal data at the maximum temperature. Only a few tests were performed to investigate the frequency effect, but no significant change could be seen for the 360 and 420 cycles per hour as compared to the base-line data at 36

¹E. A. Franco-Ferreira, *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1967*, ORNL-4170, pp. 238-44.

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³A. E. Carden, D. G. Harman, and E. A. Franco-Ferreira, "Thermal Fatigue Analysis of a Cryogenically Cooled Rocket Nozzle," pp. 102-1-102-12 in *Southeastern Symposium on Missiles & Aerospace Vehicles Sciences*, Vol. II, American Astronautical Society, Southeast Section, Huntsville, Ala., 1966.

⁴D. G. Harman, *Thermal Fatigue of Rocket Nozzle Cooling Tubes*, ORNL-TM-2089 (in preparation).

⁵A. E. Carden and T. B. Slade, "Low-Cycle Fatigue of Hastelloy X," presented at the ASTM Annual Meeting, June 1968, San Francisco.

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cycles per hour. Although the tests included appreciable creep strains, the results agreed with those of the other 36-cycles per hour sawtooth extension cycle data.

Correlation of the results^{4,5} is in progress and will be the subject of a topical report.

EFFECTS OF SPACE ENVIRONMENT ON NERVA MATERIALS

R. E. Clausing

Exposure of the NERVA engine to the environment of space may produce some materials problems not encountered in ground tests. A committee composed of representatives from the NASA Space Nuclear Propulsion Office at Cleveland, Aerojet General Corporation, Westinghouse Astronuclear Laboratory, Oak Ridge National Laboratory, and Thompson-Ramo-Wooldridge attempts to define such problem areas and to ensure that the NERVA design and fabrication are consistent with reliable operation in the space environment.

The tendency of atomically clean surfaces to adhere strongly is one of the most important space-related phenomena to be considered. Adhesion and friction of clean surfaces are not well understood, but it has been demonstrated that the presence or absence of adsorbed gases on otherwise atomically clean surfaces can completely alter adhesional and frictional properties of both pure materials and engineering alloys. To better assess the importance of these effects on the materials in the NERVA system it is necessary to know (1) the specific environment at the location of particular components in the engine and (2) how this environment will influence adhesion and friction. We provide information on both of these subjects by implementing the two experimental studies described briefly below.

Outgassing of NERVA Fuel Elements

The gaseous atmosphere at any point in the NERVA engine will depend upon the temperature and history of the entire engine system; however, in the present design it will be determined primarily by the outgassing of the graphite reactor. This outgassing cannot be accurately estimated because of the special nature of the core material, its configuration, and its coating. Experimental data must be sought for the actual core elements at temperatures and pressures similar to those expected in space operation. We have designed and are assembling an experiment to obtain such measurements.

The data obtained will include both the quantity and species of gases released from fuel elements as a function of configuration, temperature, and pretreat-

ment. Measurements will be made on both single elements and a cluster of seven. Temperatures from room temperature to 2000°R will be used for outgassing, and pretreatments will be provided to produce conditions similar to those encountered (1) after launching but before the first firing in space and (2) after the engine has been fired once and subjected to the postfiring cool-down procedure but not restarted. The tests are to be conducted using quarter-length fuel element sections; however, several full-length single-element tests will be made to confirm the extrapolation of the data from partial elements to full-length elements. The gases evolved will be measured quantitatively in a specially designed ultrahigh-vacuum system.

Adhesion of NERVA Materials

This program is being conducted through an ORNL subcontract with the Syracuse University Research Corporation. Dr. R. G. Aldrich is the principal investigator, and R. E. Clausing of the ORNL Metals and Ceramics Division is the project monitor. The program is providing information on the adhesion of graphites and metals to themselves and to other materials in various controlled environments. Special emphasis is placed on the effect of surface contamination from the gaseous environment on adhesion.

The technique used in these experiments is based upon that developed by D. V. Keller of Syracuse University.⁶ The experimental plan is to (1) produce an initial surface that is atomically clean, (2) measure its adhesion properties, (3) provide a known gaseous contamination, and (4) measure the change in adhesion produced by the contamination with hydrogen and oxygen. The results of the tests are given in Table 39.1. They indicate that for some materials it is not possible to produce surfaces that will adhere by any of the usual cleaning procedures, including thermal cleaning or electron or ion bombardment. Others have shown that engineering alloys can be made to adhere if mechanical shearing occurs or if mechanical rubbing motions are permitted. Our apparatus has now been modified to permit a controlled rubbing action. This has produced adhesion without the need for other surface cleaning in the case of the only alloy tested thus far. Table 39.1 also shows that oxygen is more effective than hydrogen in inhibiting adhesion for materials that could be compared.

⁶K. I. Johnson and D. V. Keller, *J. Appl. Phys.* 38, 1896-1904 (1967).

Table 39.1. Summary of Adhesion Tests

Couple	Adhesion Obtained	Result for Various Conditions ^a								Pressure (torr) to Inhibit Adhesion	
		1	2	3	4	5	6	7	8	H ₂	O ₂
Type 440 stainless steel ^b	No	—	—	—	—	—	—	—	c	c	c
PO-3 graphite ^b	No	—	—	—	—	—	—	—	c	c	c
Pyrolytic graphite ^b	No	—	—	—	—	—	—	—	c	c	c
Pyrolytic graphite } ZTA graphite }	Yes	+	c	+	+	+	+	+	c	70	10 ⁻⁵
Pure titanium ^b	Yes	—	—	—	—	+	c	c	c	70	10 ⁻⁶
Ti-5% Al-2.5% Sn ^{b,d}	Yes	—	—	—	c	e	e	e	+	e	e

^aSpecimen conditions: (1) As received, laboratory air; (2) as received, 10⁻⁶ torr; (3) as received, 10⁻⁹ torr; (4) vacuum baked to 250°C; (5) degassed at higher temperatures; (6) argon ion bombarded; (7) cleaned by electron bombardment; (8) mechanically rubbed. Results: +, adhesion observed; —, adhesion not observed.

^bBoth specimens of same material.

^cNot tested.

^dAlloy in the EL1 condition.

^eBeing tested.