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BELL AEROSYSTEMS COMPANY
DIVISION OF BELL AEROSPACE CORPORATION

Bell Laboratory Report 63-13(M)
March 1963

MODULUS OF RUPTURE, THERMAL CONDUCTIVITY, AND
THERMAL EXPOSURE TESTS ON FOAMED
ALUMINUM OXIDE AND FOAMED ZIRCONIUM OXIDE

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ALUMINUM OXIDE AND FOAMED ZIRCONIUM OXIDE

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ABSTRACT

Physical property data at room temperature and at high temperatures are presented on foamed aluminum oxide and foamed zirconium oxide materials. Tests conducted were modulus of rupture, thermal conductivity, and thermal exposure. The data in the report are based on tests conducted in the Bell Aerosystems Company Engineering Laboratories in 1961.

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I. INTRODUCTION

Physical property data at room temperature and at high temperatures are presented on foamed aluminum oxide and foamed zirconium oxide materials. Tests conducted were modulus of rupture, thermal conductivity, and thermal exposure. Hard, smooth ceramic surface coatings were applied to simulate service conditions. Only thermal exposure tests were conducted on the coated specimens. The coatings used were Astroceram A and Astroceram B, manufactured by the American Thermocatalytic Corporation, Mineola, New York. The data are based on tests* conducted by the Bell Aerosystems Company Engineering Laboratories.

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This report represents only a relatively small part of the test and development efforts of the laboratories. Other test data have been forwarded under this contract in the form of individual Bell laboratory reports. Reports containing proprietary and/or classified information are not included.

* Based on tests conducted in 1961.

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II. X-RAY INSPECTION

X-ray photographs were taken of the specimen before testing. The specimens were homogenous and free of internal voids. No cracks or other failures were observable.

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III. TEST METHODS

A. Modulus of Rupture

Modulus of rupture determinations were made with a Baldwin Tate Emery testing machine using a two point load method. Specimen size was nominally 4-1/2" x 1/2" x 1/2". The edges upon which the specimen rested were three inches apart. The loading edges were one inch apart. A dial gauge was used to measure deflection at regular loading increments.

B. Thermal Exposure

An oxy-acetylene crucible-type furnace was used for the thermal exposure tests. Specimen size is given in Table II. A firebrick framework was fitted over the opening in the top of the furnace so that one face of the test specimen could be exposed to temperature. The sides and cold face of the specimen were insulated with a blanket insulation. Thermocouples were introduced through holes in the back of the specimen so that hot face and midpoint temperatures could be measured. A third thermocouple was bonded on the back (cold) face. The hot face thermocouple hole was terminated just under the coating so that hot gases would not contact the thermocouple bead directly. Iridium-60 iridium 40 rhodium thermocouples were used for the hot face measurements; platinum-90 platinum 10 rhodium thermocouples were used for the midpoint and the cold face measurements.

C. Thermal Conductivity

The thermal conductivity values were determined by a comparative axial heat flow method. The alumina foam specimen was mounted on an Inconel slug which was heated by a silicon carbide plate. The plate was heated by silicon carbide heating elements. An Inconel rod of known thermal conductivity was placed on top of the alumina. A water-cooled heat sink removed heat from the other end of the Inconel rod. Temperature measurements were made at the hot and cold surfaces of the alumina specimen and at two points on the standard rod. Radial heat losses were minimized by insulation between the test and standard specimens and the chamber walls. The system was operated for 18 hours to insure equilibrium conditions. Periodic temperature measurements were made to ascertain this equilibrium. The thermal conductivity was calculated as follows:

$$K_1 = \frac{A_2 \Delta t_2 L_1 K_2}{A_1 \Delta t_1 L_2}$$

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where:

- K_1 = thermal conductivity of alumina foam
- K_2 = thermal conductivity of standard rod
- A_1 = cross sectional area of alumina foam
- A_2 = cross sectional area of standard rod
- Δt_1 = temperature differential between thermocouple attachments on alumina foam
- Δt_2 = temperature differential between thermocouple attachments in standard rod
- L_1 = distance between thermocouple attachments on alumina foam
- L_2 = distance between thermocouple attachments in standard rod

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IV. TEST RESULTS

A. Modulus of Rupture

The foam aluminum oxide test bars were nominally 4-1/2" x 1/2" x 1/2". Three specimens were tested at room temperature. The test results are as follows:

<u>Specimen No.</u>	<u>Dimensions (in)</u> ⁽¹⁾	<u>Modulus of Rupture (psi)</u>	<u>Deflection Maximum (in)</u>
a	0.510 wide x 0.536 thick	373	0.0050
b	0.524 wide x 0.527 thick	381	0.0100
c	0.517 wide x 0.5225 thick	408	0.0085

- (1) All test bars are 4-1/2" long. The width dimension is the dimension in contact with the edges of the loading bar.

Table I gives the complete load (lbs) vs deflection (in) data for the three specimens.

B. Thermal Exposure

Figures 1 and 2 are photographs of the coated sirconia foam and the coated alumina foam before testing. Figures 3 and 4 are photographs of the specimens after testing. Table II gives dimensional and weight data for all test specimens before and after testing.

The sirconia specimen with the Astroceram B coating was very weak after the 2200°F (1/2 hour) cure of its coating. The specimen broke into pieces as a result of normal handling and could not be tested.

Tables III and IV present thermal gradient data for the foam alumina with Astroceram A and foam sirconia with Astroceram A.

The sirconia foam with the Astroceram A coating was tested for a total of 40 minutes. The hot surface temperature was 3100°F to 3300°F for the final 15 minutes. Prior to that the temperature ranged from 1600°F to 3000°F. The specimen cracked across the cold face after six minutes of exposure. The crack had extended through the specimen to the hot face after 16 minutes of exposure.

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The crack did not develop through the thermocouple holes. Upon cooling the specimen developed a second crack, this time through the thermocouple hole locations. The specimen was quite weak after testing and broke under normal handling.

The alumina specimen with the Astroceram A coating was subjected to two different thermal exposure cycles. The first exposure, which was conducted for 25 minutes, failed to reach temperatures above 2100°F. Upon cooling, the alumina specimen was found to have a single crack which extended over the coated face. The second exposure continued for a total of 1 hour 40 minutes. The hot surface temperature was at 3100°F to 3300°F for the final 15 minutes. Prior to that, the temperature ranged from 1200°F to 3000°F. After the second exposure, when the temperature reached approximately 3200°F, the hard coated surface exhibited multiple cracks but none appeared to extend deep into the foam. The surface crack from the original exposure did not increase but rather seemed to be partially healed. The Astroceram A coating still remained on the areas which were not cracked open. A small amount of fusing of the alumina was visible at the open cracked areas. As compared with the other specimens tested during this program, this specimen was quite strong after testing.

The alumina specimen with Astroceram B broke in half immediately after it was placed on the holding fixture over the furnace opening. Half of the specimen dropped into the furnace. The remaining piece was tested for 15 minutes. Hot face and midpoint temperatures could not be measured since the section which fell into the furnace contained the thermocouple holes.

C. Thermal Conductivity

The table below gives the results of the thermal conductivity determinations for alumina foam.

<u>Hot Surface Temperature</u> (F)	<u>Mean Temperature</u> (F)	<u>Thermal Conductivity</u> BTU/hr·ft ² (°F/in)
870	660	9.8
1160	885	10.0

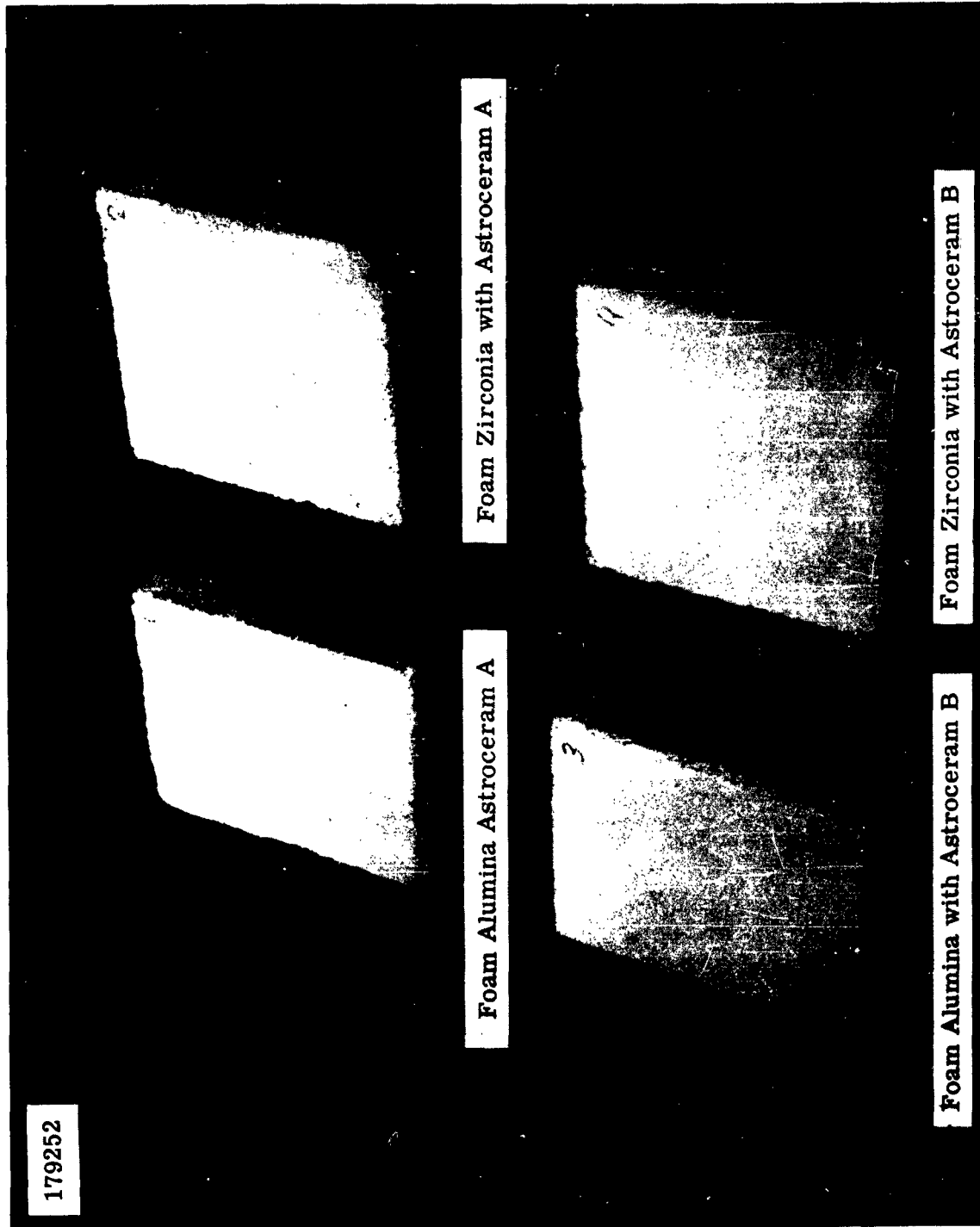


Figure 1. Hard Faced Surface of Foam Ceramics Before Testing

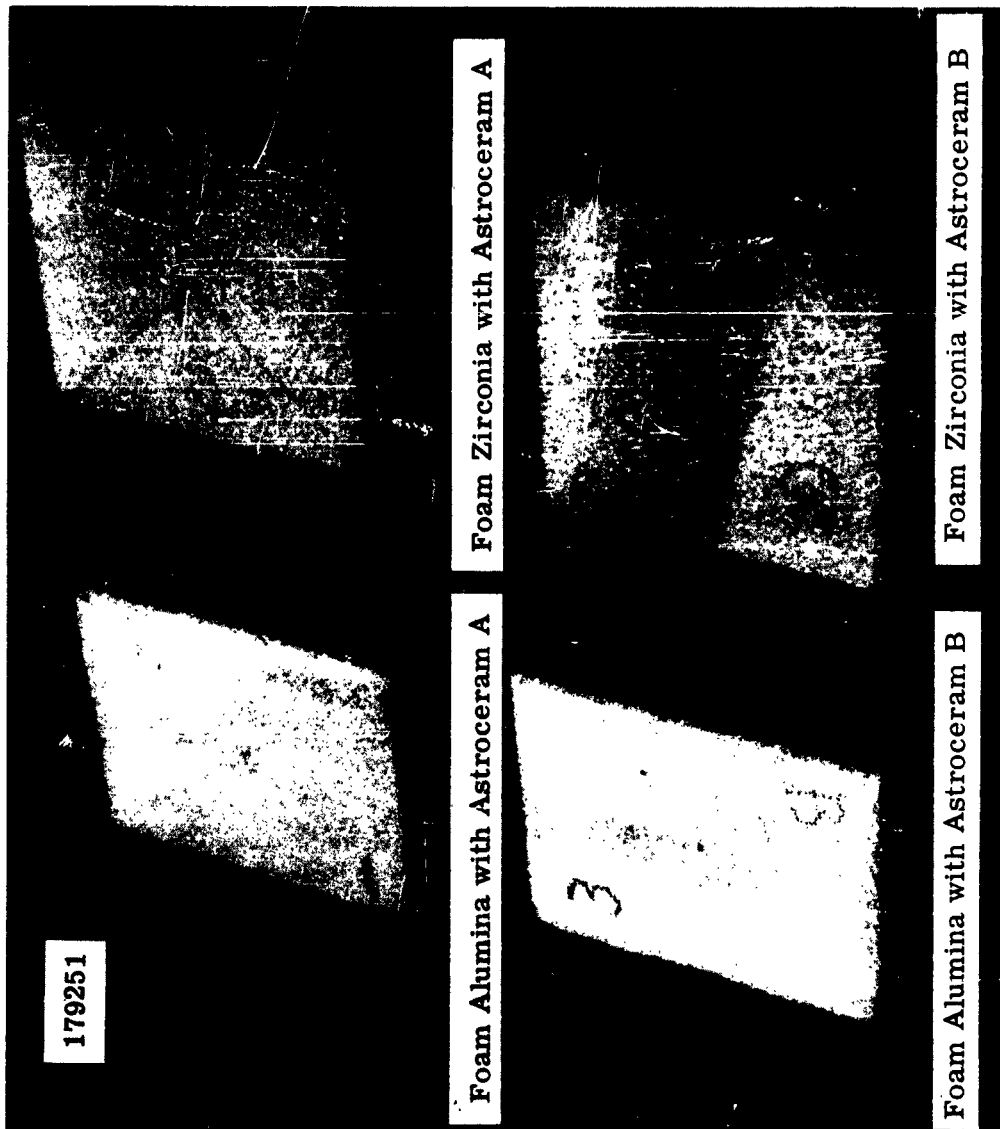


Figure 2. Uncoated Surfaces of Foam Ceramics Before Testing

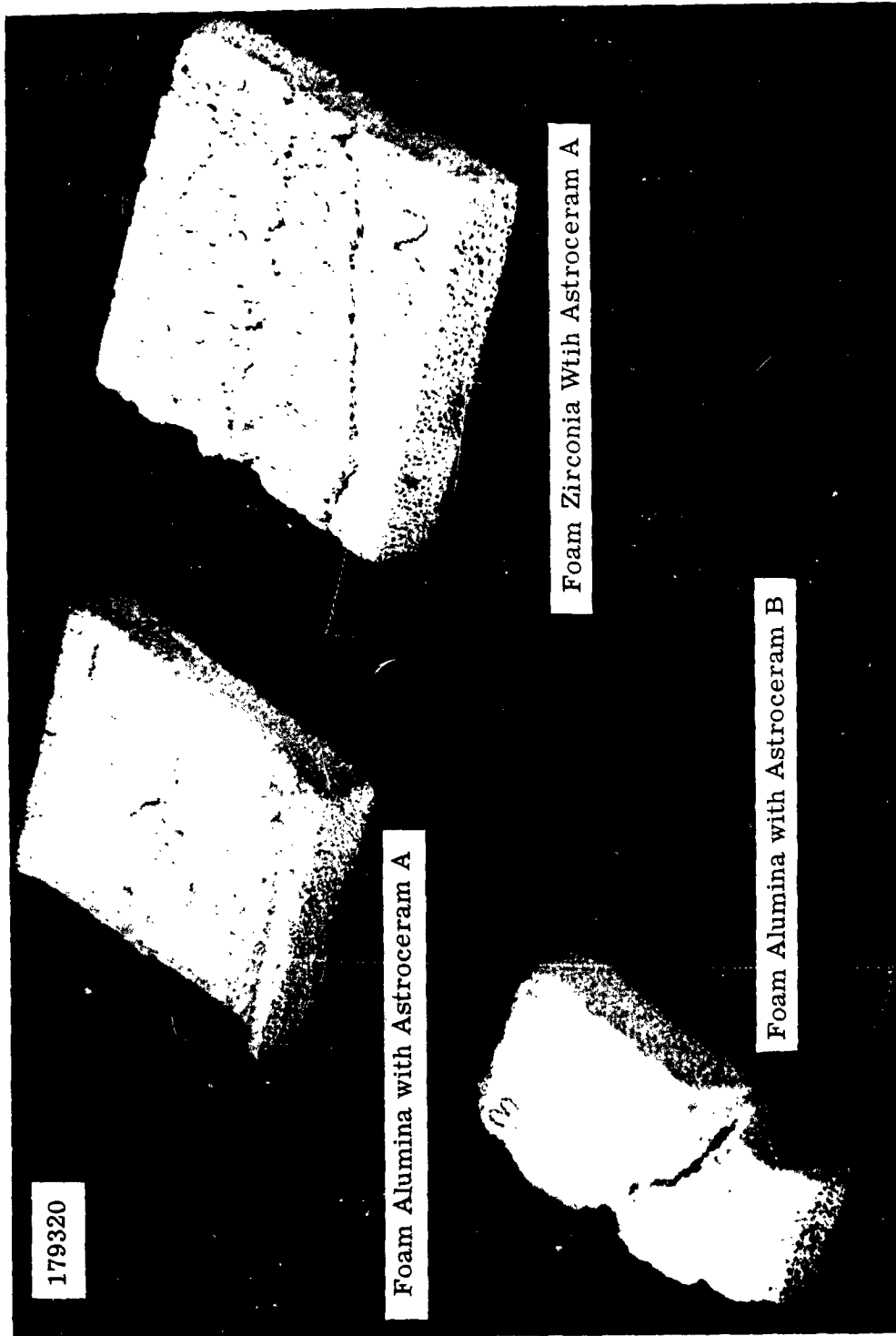


Figure 3. Hard Faced Surface of Foam Ceramics After Testing

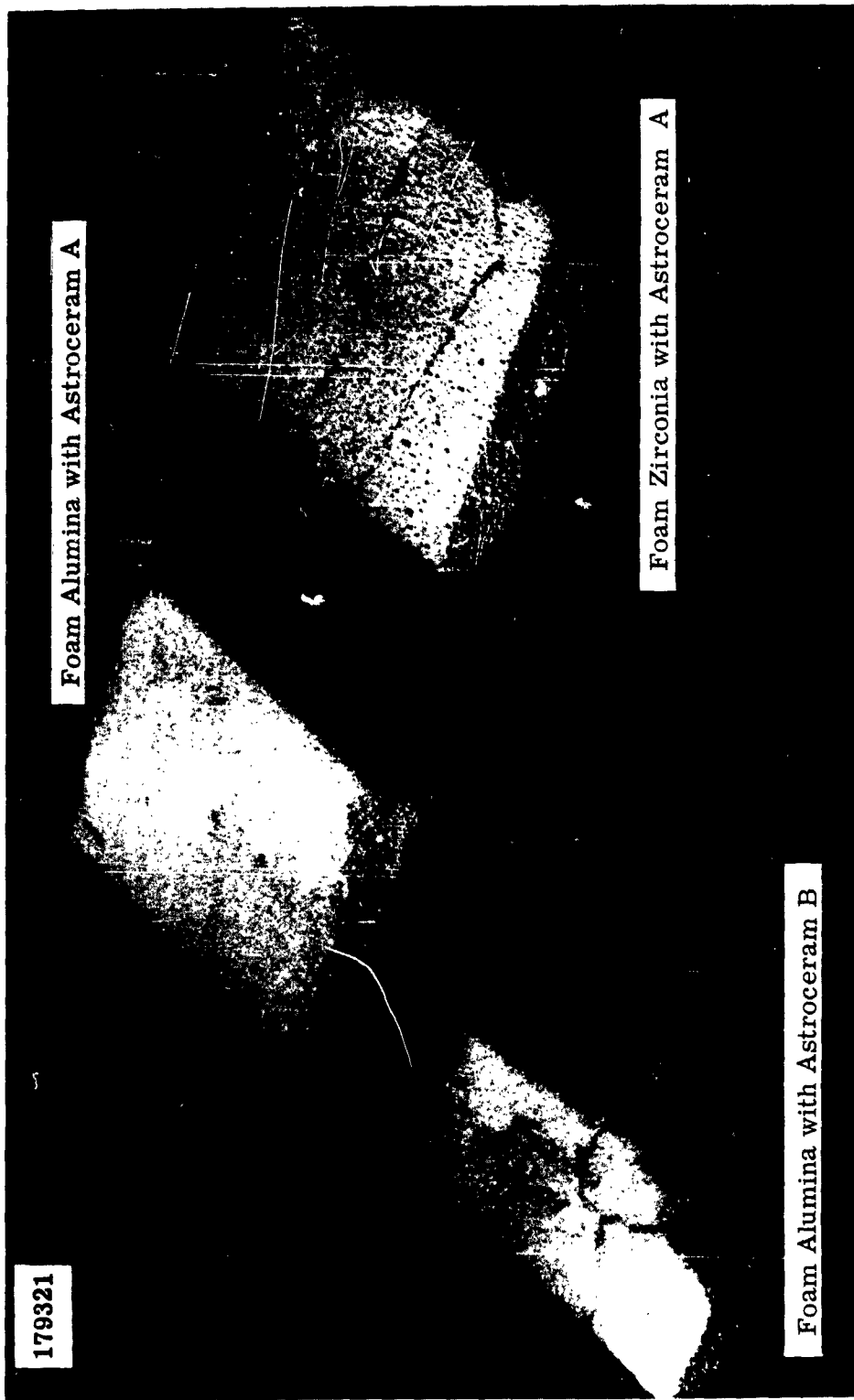


Figure 4. Uncoated Surface of Foam Ceramics After Testing

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TABLE I

Load vs Deflection for Foam Aluminum Oxide
Specimens Tested at Room Temperature

<u>Specimen No.</u>	<u>Dimensions (in)</u>	<u>Load (lbs)</u>	<u>Deflection (in)</u>
a	0.510 wide x 0.536 thick	0	0
		10.0	0.0035
		13.0	0.005
b	0.524 wide x 0.527 thick	0	0
		2.5	0.0001
		5.0	0.0025
		7.5	0.0030
		10.0	0.0050
		12.5	0.0070
c	0.517 wide x 0.522 thick	14.8	0.0100
		0	0
		1.2	0
		5.0	0.0030
		7.5	0.0040
		10.0	0.0050
		12.5	0.0065
		13.95	0.0085

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TABLE II Thermal Exposure Tests on Alumina Foam and Zirconia Foam									
Spe No.	Material	Coating	Test Temp (F)	Test Time (minutes)	Dimensions Before Test (inches)	Wt. Before Test (g)	Dimensions After Test (inches)	Wt. After Test (g)	Remarks
1	Al ₂ O ₃	Astrocera A	3200	15 min at test temp + thermal exposure given on Page 5	$2\frac{17}{32} \times 2\frac{3}{16} \times \frac{1}{2}$	28.1572	$2\frac{17}{32} \times 2\frac{3}{16}$ Note (1)	27.8591	of un-coated material = 31 lbs/ft ³
2	ZrO ₂	Astrocera A	3200	15	$2\frac{3}{8} \times 2\frac{5}{16} \times \frac{1}{2}$	42.2315	$2\frac{3}{8} \times 2\frac{5}{8} \times \frac{1}{2}$	41.3590	of un-coated material = 51 lbs/ft ³
3	Al ₂ O ₃	Astrocera B	3200	15	$2\frac{3}{16} \times 2\frac{1}{2} \times \frac{1}{2}$	29.2534			Specimen broke up when placed on test fixture for thermal exposure. Two-thirds of specimen fell in furnace. Remainder was tested to determine the effects of temperature on the coating.
4	ZrO ₂	Astrocera B				41.4026			
Specimen broke up after 2200°F cure of coating.									
Note (1): Thickness measurement not possible due to irregular shrinkage.									

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TABLE III

Temperature Gradient Data for Alumina Foam with Astroceram A Coating

<u>Exposure Time</u> <u>(minutes)</u>	<u>Hot⁽¹⁾</u> <u>(F)</u>	<u>Middle⁽²⁾</u> <u>(F)</u>	<u>Cold⁽³⁾</u> <u>(F)</u>
Back of panel insulated			
70	Low Output	2080	2075
75	2700	2230	2200
77	2700	2300	2250
85	3250	2500	2425
88	3200	2585	2540
93	3200	2550	2510
97	3200	2550	2510

Note (1) The hot surface thermocouple was immediately below the Astroceram A coating.

(2) The middle thermocouple was half way between the hot and cold surfaces. These surfaces were 1/2 inch apart.

(3) The cold surface thermocouple was bonded on the cold surface of the panel.

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TABLE IV

Temperature Gradient Data for Zirconia Foam with Astroceram A Coating

<u>Exposure Time</u> <u>(minutes)</u>	<u>Hot⁽¹⁾</u> <u>(F)</u>	<u>Middle⁽²⁾</u> <u>(F)</u>	<u>Cold⁽³⁾</u> <u>(F)</u>
5	T.C. Shorted	1355	1100
15	Low Output	1575	1175
17	2550	1860	1290

Insulation placed on back of specimen.

21	3300	2305	2225
23	3200	2305	2190

Temperature dropped off. Gas adjustments made.

37	2800	2125	2115
39	3200	2260	2225
40	3250	2295	2265

- Note: (1) The hot surface thermocouple was immediately below the Astroceram A coating.
- (2) The middle thermocouple was half way between the hot and cold surfaces. These surfaces were 1/2 inch apart.
- (3) The cold surface thermocouple was bonded on the cold surface of the panel.