MODULUS OF RUPTURE MEASUREMENTS ON BERYLLIUM OXIDE AT ELEVATED TEMPERATURES

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Lawrence Radiation Laboratory P.O. 3951607

Report No. 1777
(Final)
March 1960

THE SPACE TECHNOLOGY DIVISION

Aerojet-General
CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY
AZUSA, CALIFORNIA SACRAMENTO, CALIFORNIA

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Written by:

Melvin L. Stehsel
Robert M. Hale
Cecil E. Waller

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Approved by:

Y. C. Lee, Director
Space Technology Division

AEROJET-GENERAL CORPORATION

Azusa, California

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CONTRACT FULFILLMENT STATEMENT

This final report completes fulfillment of the contract.

ABSTRACT

A bend-test furnace is described for measuring the modulus of rupture on beryllium oxide at elevated temperatures. Test beams are subjected to three-point loading by utilizing a conventional Instron tensile-testing machine. These tests are performed in a helium atmosphere at temperatures ranging to 3000°F.

Comparative data are presented for hot-pressed, cold-pressed, and slip-cast specimens supplied by several manufacturers. Preliminary results indicate that, in general, the hot-pressed specimens have the highest modulus at all temperatures which have been investigated.

I. INTRODUCTION

Beryllium oxide (BeO) possesses many characteristics such as chemical stability, nuclear properties, and reduction of brittleness at high temperatures which make it attractive for consideration as a structural material at elevated temperatures. The degree to which brittleness may limit the usefulness of a refractory material ordinarily depends on the mechanical requirements to maintain structural integrity at the temperature of operation. At lower temperatures it may be necessary to use other materials but, as the temperature increases, brittleness becomes less important.

At temperatures to 3090°F, BeO is stable in air, hydrogen, carbon monoxide, argon, nitrogen, and vacuo. It is not stable at these temperatures in atmospheres containing water vapor, halogens, or sulphur. In addition to chemical inertness at elevated temperatures, BeO has nuclear properties similar to those of graphite. Such a combination of properties makes BeO a likely candidate as a moderator material in reactors.

Many of the physical properties of BeO and other refractories depend on chemical composition and method of fabrication. The best high-temperature chemical inertness and strength occurs in dense, single-phase crystalline solids or single crystals and, therefore, can be influenced by the method of manufacture. In order to evaluate the effect which various processing routines may have, the value for modulus of rupture at several temperatures ranging from ambient to 3000°F was selected for investigation. These measurements could be made with some precision by means of the standard bend-test, using three-point loading. In this manner, a comparison was made between methods of manufacture, i.e., hot-pressed, cold-pressed and slip-cast, and, where possible, between manufacturers. Some data has been presented[1,2] on the modulus of rupture of BeO at elevated temperatures, but little comparative information is available.

In this preliminary investigation, it was not possible to control chemical composition or density of the specimens received from the various sources. However, in most cases the BeO content was approximately 95%, and densities approximated 95% of theory.

II. DESCRIPTION OF EXPERIMENT

A. MATERIALS

Rectangular BeO test blocks 1/4 x 1/2 x 3 in. were fabricated by various manufacturers. Where possible, 25 specimens from any given source, and fabricated by any particular procedure, were obtained for testing. Quality control and inspection of the specimens were maintained throughout this investigation by the Lawrence Radiation Laboratory (LRL). The origin of samples used in this study is indicated in Table 1.

B. EQUIPMENT AND TESTING PROCEDURE

The equipment used for performing modulus of rupture measurements consisted of a furnace mounted in an Instron tensile tester. Details of the furnace design are shown in Figure 1, together with the method for holding and applying loads to the specimen. The mounting of the furnace in the Instron machine is shown in Figures 2 and 3. This type of tensile tester permits accurate control of the rate of load application by means of a servo-controlled mechanism. In this manner, the load may be applied at a constant rate, ranging from 0.02 to 2.0 in./min. For this investigation, a rate of 0.02 in./min was selected. The load was measured with a compression cell designed for use with this machine. The output was measured on a self-contained strip-chart recorder. The paper in this recorder moved at a constant speed of 20 in./min, thus resulting in a plot which can be interpreted as either load vs deflection or load vs time.

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1. R. E. Long and H. Z. Shofield, "Beryllia," Reactor Handbook V. 3.
2. R. D. Chipman, "Stress-Strain-Temperature-Time Relationships for Refractory Materials," NAA-SR-3205, 1958.

The specimen was supported on two molybdenum knife-edges and the load was applied to the specimen by means of another knife-edge, located exactly in the center and parallel to the two supports. The loading point was firmly attached through a baked-carbon gripper to the moving platen of the testing machine. Another rigid pedestal was used under the two-point support to transmit the load to the compression cell. It is necessary to use baked carbon so the rate of heat transfer to various components outside the furnace is reduced. In order to maintain a controlled, inert, helium atmosphere in the furnace, each end of the furnace was closed with a plastic-bag seal. Such precautions to seal off the furnace are necessary for several reasons, especially when BeO is the material undergoing testing. First of all, an inert atmosphere must be maintained to prevent oxidation of the molybdenum supports and carbon or graphite furnace parts. Secondly, BeO is a toxic material and any dust generated during testing must be contained. For this reason, when the furnace was opened to change specimens, a blower was used to maintain a reduced pressure inside the furnace. This was attached to the equipment, as shown in Figure 3. The exhaust from this blower passed through a filtering system capable of removing particles down to 5 microns before the air was released outside the laboratory. The blower was operated only after the test had been completed and the furnace was relatively cool.

Specimens were heated by radiation from an encircling self-resistance graphite heating element of spiral design. Power to the heater was supplied by an ac-dc motor-generator unit of 35-kw capacity. This arrangement provided such a stable source of power that, after the desired specimen temperature had been attained and equilibrium established, the temperature remained constant for the duration of the test. A series of graphite radiation shields were used to reduce the heat losses to the water-cooled shell. Such a furnace configuration closely approximates a theoretical blackbody cavity, and as long as the temperature differential between the specimen and inner wall of the heating element is less than $75^{\circ}F$, it is not necessary to apply an emissivity correction to temperatures measured by optical pyrometry. In this manner, all specimen temperatures were determined with an accuracy of $\pm 10^{\circ}F$. A Leeds & Northrup disappearing filament optical pyrometer was used to make these measurements. It was calibrated by viewing a NBS standard lamp through the window actually used in the furnace. In order to maintain the calibration during testing, this window must be kept clean. This was done by directing the helium gas entering the furnace against the window. Thus, contaminants and other materials which might interfere with temperature measurements were swept toward the center of the furnace and out through the exhaust system.

Prior to a series of tests, deflection in the system caused by the compression cell and pedestals was determined by placing a thick (1.5 in.) stainless-steel bar on the supporting knife-edges, and applying a load over the several ranges used in this investigation. The small deflections which were detected were used to correct the considerably larger ones observed in the actual test specimens.

The heating rate for the specimens did not exceed 750°F/min. However, a total time of 5 to 10 min was required to reach a given temperature and attain equilibrium.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Modulus of rupture was calculated by using the classical equation for a rectangular beam undergoing three-point loading.

$$S = \frac{M}{I/c} = \frac{Pl/4}{1/6\ bh^2} = 132P$$

Where S is modulus of rupture, M is the moment of the system for this particular geometry, P is the load applied to the beam, l is the length of the beam between supports for center loading (2-3/4 in.), and, since the beam is rectangular, the section modulus, I/c becomes $1/6\ bh^2$, where b and h are the base and height of the beam respectively. For the particular specimen configuration used in this investigation, this equation reduces to 132P, where P is the applied load in pounds at failure. Since the relationship between ultimate breaking load, or strength, and modulus of rupture is linear, the data have been presented graphically, using dual ordinates. Because of this relationship, the terms above have been used interchangeably in the following discussion.

In Figures 4, 5, and 6 a comparison can be made between BeO derived from various sources and that obtained by use of several manufacturing procedures. As might be expected, the hot-pressed specimens generally are stronger and consequently have the highest modulus of rupture at most temperatures. Although only one slip-cast series of specimens was included for examination, its behavior was similar to those which had been formed by cold-pressing. Maximum strength usually occurred in the specimens, particularly those made by cold-pressing and slip-casting, in the 1470 ±180°F range. For Coors cold-pressed specimens, this increase in strength was 30% greater than that at ambient temperatures. Insufficient samples were available to carry out an investigation of the range between ambient and 1470°F. Above 2910°F the strength of the cold-pressed and slip-cast specimens rapidly converged toward the same level. However, several groups of hot-pressed samples still possessed much higher moduli at this temperature. Thus, it is evident that the modulus of rupture varies considerably in BeO made by different processes and supplied from several sources. Large differences exist even between samples prepared by similar methods but by different manufacturers.

In order to obtain information on the scatter of data, 80% of the specimens were tested at approximately 2200 and 2400°F. Such a detailed examination of other temperature ranges was not possible with the number of specimens that were available. Although all specimens were carefully examined by LRL for quality control purposes, there was extensive scatter of strength data from specimen to specimen within the same group. If the extreme values are used, this amounted to approximately ±25% of the average strength at these temperatures. In an attempt to determine if this variation in strength could be correlated with density, LRL measured the density of each test block. No clear-cut correlation was found between the minor density changes and the strength.

All specimens exhibited normal brittle fracture at ambient temperature. This was typified by a clean break, with separation of the specimen at the point of load application. At elevated temperatures, this mode of failure predominated in most specimens made by hot-pressing. However, at these temperatures cold-pressed and slip-cast specimens failed by a mechanism best described as stress-relieving crack formation. The crack started over the width of the specimen directly beneath the loading knife-edge, i.e., the line of highest stress, and propagated upward at a rate which is temperature dependent. The formation of this crack ceases at a point just beneath the upper surface, and the specimen bends plastically, with little measurable resistance (less than 2 lb applied load) to the advance of the loading point. Upon return to ambient temperature, such specimens broke with applied loads of about 5 lb. All specimens, regardless of processing method, manufacturer or temperature failed by brittle fracture when the modulus of rupture was greater than 10,000 psi. If the modulus was below this value, failure consistently occurred by stress-relieving crack formation. Little, if any, creep occurred in any specimen that did not fail in this manner. At 2910°F, where creep was prevalent, the specimen still showed crack formation accompanying the creep. This might be expected, since stress builds up in the outer layer of the beam at an increasing rate as the load is applied. If this stress is not relieved fast enough by creep, this layer will rupture to relieve the stress. The resulting crack will propagate at a rate dependent on the amount of creep which can occur in the next layer before it too builds up stresses to a level which can cause fracture. The higher the temperature, the longer it takes for such stresses to develop. It is then necessary to increase the rate of load application until stress builds up at a rate faster than the creep rate can compensate.

IV. CONCLUSION

The modulus of rupture for BeO was measured at temperatures ranging to 3000°F. A comparison was made between specimens supplied by several manufacturers and between those fabricated by hot- and cold-pressing, and slip-casting techniques. Extensive variations in strength were observed in BeO samples prepared by these procedures, and also in those obtained from several sources even if they had been made by similar methods. The hot-pressed samples had the highest modulus at most of the temperatures investigated. Two modes of failure were observed in these specimens. Brittle fracture occurred in all specimens when the modulus of rupture was greater than 10,000 psi. Below this level, cold-pressed and slip-cast specimens fractured by a stress-relieving phenomena.

V. RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

The foregoing discussion has described the results of modulus of rupture measurements on BeO at elevated temperatures. Several observations were made which indicate that the following studies could well be the subject for a continuing investigation.

A. Determine the modulus of rupture for a group of specimens in which densities vary widely, and which have been fabricated from a single batch of high purity BeO. All three methods of fabrication, hot- and cold-pressed and slip-cast, should be investigated because one group of specimens may demonstrate more sensitivity to density variations.

B. Investigate more thoroughly the variation of modulus of rupture over a complete temperature range.

C. Evaluate the effect of controlled impurity additions on the modulus of rupture of BeO at various temperatures.

D. Compare modulus of rupture data obtained from specimens of varying dimensions and loaded at several rates. Such an investigation would determine if stress-relieving crack formation is influenced by size of specimen or loading rate.

TABLE 1

SOURCE AND METHOD OF MANUFACTURING BeO SPECIMENS

Source	Method of Manufacture
National Beryllia	Other sources (cold-pressed)
National Beryllia	Cold-pressed
National Beryllia	Hot-pressed
National Beryllia	Slip-cast
Brush	Cold-pressed
Brush	Hot-pressed
Beryllium Corporation	Hot-pressed
UCNC-Y-12 (Oak Ridge)	Hot-pressed
Coors	Cold-pressed

TABLE 2

DATA FROM TESTS ON BeO SPECIMENS

(National Beryllia - Other Sources)

Specimen No.	Temperature ^{o}F	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
21	75	110	14.5×10^3	2.00	2.86	brittle
23	75	120	15.8	2.00	2.86	
30	75	101	13.3	1.85	2.85	
33	75	115	15.2	2.00	2.84	
43	75	109	14.4	1.40	2.86	
80	75	108	14.3	2.26	2.86	
76	1455	124	16.4	3.29	2.86	
24	1830	100	13.2	1.80	2.86	
26	1830	80	10.6	2.00	2.87	
32	1830	116	15.3	2.10	2.87	
48	1830	128	16.9	1.95	2.84	brittle
29	1880	63.5	8.4	1.45	2.85	crack
50	1880	85	11.2	1.85	2.86	
72	2180	47	6.2	2.51	2.87	
49	2190	48	6.3	1.67	2.86	
51	2190	42.5	5.6	1.80	2.86	
60	2200	46	6.1	3.27	2.85	
82	2200	43	5.7	2.71	2.84	
87	2200	38	5.0	2.30	2.85	
88	2200	54.5	7.2	1.70	2.85	
89	2200	35	4.6	2.23	2.85	
90	2200	43	5.7	3.52	2.85	
92	2200	63	8.3	2.27	2.86	crack
52	2210	45	5.9	2.07	2.87	crack creep
78	2235	32	4.2	1.68	2.85	crack
25	2400	31	4.1×10^3	2.25	2.87	crack creep

TABLE 2 (cont.)

Specimen No.	Temperature °F	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm³	Mode of Fracture*
37	2400	29.5	3.9×10^3	2.56	2.84	crack creep
71	2400	43	5.7 ↓	1.90	2.84	↓
73	2400	30.5	4.0	2.61	2.85	
77	2400	22	2.9	3.38	2.85	
85	2400	23	3.0	2.25	2.86	
35	2435	17	2.2	2.63	2.85	
47	2445	44	5.8	2.10	2.86	
38	2445	21.5	2.8	2.68	2.87	
39	2445	17.5	2.3	3.25	2.85	
40	2445	15.6	2.1	3.05	2.84	
41**	2445	26.5	3.5	1.97	2.87	
45**	2700	7.2	0.95	5.85	2.85	
34	2820	9.0	1.2×10^3	3.57	2.85	crack creep
27	--	wrong load cell, 1st test		--	2.86	
31	--	unreliable temperature		--	2.85	

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

**Platen rate was 0.05 in./min these runs.

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TABLE 3

DATA FROM TESTS ON BeO SPECIMENS

(National Beryllia, Cold-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
1	75	117	15.4×10^3	2.49	2.764	brittle
24	75	122	16.1	3.08	2.769	
5	1475	143	18.9	2.92	2.738	
19	2180	85.5	11.3	2.49	2.718	brittle
13	2190	79	10.4	1.42	2.735	crack
23	2190	74	9.8	3.07	2.771	crack
2	2200	110	14.5	1.43	2.747	brittle
3	2200	91	12.0	2.30	2.675	brittle
10	2200	87	11.5	2.16	2.661	brittle
15	2200	74	9.8	1.42	2.760	crack
17	2200	92	12.1	1.46	2.749	brittle
8	2220	80	10.6	1.74	2.756	crack
12	2220	76	10.0	2.15	2.696	brittle
11	2380	47	6.2	2.18	2.734	crack
14	2380	55	7.3	1.71	2.714	
4	2400	59.5	7.9	1.58	2.734	
6	2400	51.5	6.8	1.88	2.735	
9	2400	33	4.4	1.56	2.735	
16	2400	48.5	6.4	1.82	2.715	
18	2400	47.5	6.3	1.95	2.765	
21	2420	51	6.7	1.55	2.792	
7	2435	60.5	8.0	1.45	2.736	
20	2435	54	7.1	2.38	2.713	crack
25	2640	43	5.7	2.68	2.678	creep crack
22	2975	12.5	1.7×10^3	5.75	2.715	creep crack

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

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TABLE 4

DATA FROM TESTS ON BeO SPECIMENS

(National Beryllia, Hot-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
1	75	232	30.6×10^3	3.15	3.009	brittle
2	75	248	32.7	4.19	2.956	brittle
5	1475	149	19.7	2.58	3.008	brittle
20	2155	55	7.3	3.32	2.972	crack
4	2165	36.5	4.8	2.61	2.972	
10	2165	35.5	4.7	3.28	2.966	
8	2190	51	6.7	3.31	2.992	
3	2200	78	10.3	2.41	2.990	
13	2200	65	8.6	2.63	3.004	
15	2200	70	9.2	2.67	3.003	
21	2200	43	5.7	3.82	2.959	
23	2380	87	11.5	2.49	3.007	crack
11	2380	24	3.2	4.97	2.946	crack creep
19	2400	33	4.4	6.27	2.967	
6	2400	45	5.9	5.22	2.996	
7	2400	61	8.1	5.55	3.003	
9	2400	29	3.8	6.08	2.937	
12	2400	36.5	4.8	5.80	2.992	
14	2400	70	9.2	5.02	3.004	
16	2400	60	7.9	5.28	3.008	
22	2400	50	6.6	4.37	2.993	
24	2400	38.5	5.1	5.15	2.975	
17	2730	21	2.8	8.35	2.985	crack creep
18	3130	4.0	0.53×10^3	15.0	2.943	creep rate same as load rate
25	Broken by accident				2.961	

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 5

DATA FROM TESTS ON BeO SPECIMENS
(National Beryllia, Slip-Cast)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
26	75	154	20.3×10^3	2.60	2.717	brittle
33	75	123	16.2	3.45	2.680	
34	1465	131	17.3	4.63	2.577	
45	2180	97	12.8	2.80	2.763	
47	2180	102	13.5	2.59	2.793	
37	2190	81.5	10.8	2.59	2.642	
39	2190	73	9.6	1.98	2.709	
28	2200	91	12.0	2.35	2.775	brittle
30	2200	70.5	9.3	2.40	2.752	crack
32	2200	57.5	7.6	2.67	2.733	
35	2200	81	10.7	1.92	2.767	
41	2200	71	9.4	1.70	2.652	crack
50	2230	74	9.8	1.93	2.758	brittle
48	2380	78.5	10.4	1.93	2.729	brittle
29	2400	39.5	5.2	2.27	2.691	creep crack
31	2400	40	5.3	1.88	2.641	crack
42	2400	62	8.2	2.95	2.710	crack
46	2400	78	10.3	3.26	2.786	brittle
27	2410	50	6.6	2.83	2.623	creep crack
44	2410	52	6.9	1.86	2.637	crack
40	2420	40	5.3	2.74	2.747	
43	2420	62	8.2	2.33	2.568	
49	2435	81	10.7	3.06	2.655	
38	2615	51	6.7	1.92	2.626	
36	2995	20.5	2.7×10^3	3.55	2.654	crack

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 6

DATA FROM TESTS ON BeO SPECIMENS

(Brush, Cold-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
1	75	95	12.5×10^3	1.91	2.855	brittle
4	75	127	16.8	1.65	2.877	brittle
8	1285	110	14.5	1.75	2.872	crack
7	2190	62	8.2	1.90	2.871	
2	2200	66	8.7	1.39	2.875	
5	2200	76	10.0	1.23	2.845	
17	2200	73	9.6	1.68	2.852	
9	2210	55.5	7.3	1.15	2.850	
19	2210	66	8.7	1.71	2.825	
10	2220	66.5	8.8	1.47	2.833	
11	2220	63	8.3	1.32	2.846	
12	2220	76	10.0	1.32	2.861	
21	2220	52	6.9	2.50	2.863	
3	2400	55	7.3	1.86	2.874	
6	2400	59	7.8	1.51	2.850	
13	2400	42	5.5	1.90	2.836	
15	2400	61	8.1	1.80	2.857	
23	2400	57.5	7.6	2.09	2.868	
25	2410	55	7.3	1.81	2.869	
16	2420	64	8.4	1.65	2.846	
20	2420	47	6.2	1.77	2.843	
14	2430	74.5	9.8	1.15	2.854	
18	2435	63	8.3	2.02	2.840	crack
22	2645	54	7.1	4.32	2.864	crack creep
24	2985	28.5	3.8×10^3	7.87	2.868	crack creep

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 7

DATA FROM TESTS ON BeO SPECIMENS
(Brush, Hot-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
26	75	124	16.4×10^3	2.01	2.865	brittle
29	75	139	18.3	1.87	2.878	
37	1265	149	19.7	2.75	2.869	
40	2165	125	16.5	1.60	2.865	
35	2190	120	15.9	1.56	2.871	
27	2200	127	16.8	2.72	2.852	
30	2200	141	18.6	1.99	2.883	
34	2200	136	17.9	2.65	2.859	
39	2200	141	18.6	2.51	2.873	
41	2200	127	16.8	2.05	2.858	
38	2210	140	18.5	1.98	2.882	
36	2240	109	14.4	1.70	2.854	
33	2255	140	18.5	2.05	2.896	
45	2390	114	15.1	2.35	2.881	
28	2400	107	14.1	2.55	2.864	
32	2400	122	16.1	2.64	2.872	
43	2400	101	13.3	2.13	2.855	
46	2400	100	13.2	2.31	2.861	
47	2400	125	16.5	3.42	2.892	
48	2400	101	13.3	1.71	2.891	
42	2420	112	14.8	2.03	2.882	
44	2435	98	12.9	2.41	2.851	
49	2465	122	16.1	2.45	2.897	brittle
50	2865	90	12.9×10^3	3.11	2.884	crack
31	No data (broken by accident)				2.847	

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 8

DATA FROM TESTS ON BeO SPECIMENS

(Beryllium Corporation, Hot-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
4	75	190	25.1×10^3	2.30	2.961	brittle
13	75	219	28.9	3.24	2.919	
5	2200	186	24.6	3.12	2.944	
7	2200	176	23.3	3.22	2.939	
14	2200	180	23.8	3.53	2.932	
15	2200	190	25.1	3.85	2.957	
16	2200	198	26.1	5.90	2.934	
17	2200	189	25.0	4.01	2.929	
1	2200	189	25.0	4.00	2.938	
6	2200	159	21.0	2.72	2.936	
2	2240	140	18.4	2.30	2.919	
3	2275	164	21.7	3.40	2.934	
19	2390	164	21.7	3.70	2.929	
8	2400	150	19.8	2.57	2.924	
9	2400	146	19.3	2.72	2.928	
10	2400	151	19.9	5.16	2.929	
18	2400	158	20.9	2.54	2.916	
20	2400	156	20.6	2.66	2.904	
21	2400	147	19.4	4.28	2.946	
25	2410	147	19.4	3.62	2.952	
22	2445	129	17.0	2.47	2.910	
23	2445	153	20.2	3.70	2.939	
11	2600	111	14.7	3.11	2.965	
12	2600	120	15.8	3.05	2.942	
24	2795	92	12.1×10^3	2.05	2.929	brittle

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 9

DATA FROM TESTS ON BeO SPECIMENS
(UCNC-Y-12, Hot-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm³	Mode of Fracture*
1	75	133	17.6×10^3	1.40	2.908	brittle
2	75	154	20.3	0.83	2.934	
5	1555	126	16.6	2.11	2.936	
9	2150	85	11.2	1.13	2.949	
12	2150	104	13.7	2.02	2.930	
3	2165	102	13.5	1.79	2.880	
4	2200	104	13.7	1.84	2.957	
6	2200	99	13.1	0.97	2.918	
7	2200	73	9.6	1.59	2.892	
14	2200	78.5	10.4	1.86	2.930	
18	2200	99	13.1	2.08	2.951	
25	2200	92	12.1	1.70	2.959	
8	2240	60	7.9	1.16	2.888	
23	2375	74	9.8	1.67	2.916	
13	2380	91	12.0	1.85	2.922	brittle
11	2400	71	9.4	1.52	2.939	crack
17	2400	71	9.4	2.06	2.949	crack
19	2400	92	12.1	1.83	2.915	brittle
20	2400	65	8.6	1.64	2.925	crack
22	2400	97	12.8	2.67	2.950	brittle
24	2400	77.5	10.2	1.94	2.962	brittle
10	2435	104	13.7	2.87	2.941	brittle
16	2435	69	9.1	1.75	2.926	crack
21	2600	81	10.7	2.03	2.910	crack
26	3110	35.5	4.7×10^3	6.50	2.904	crack creep

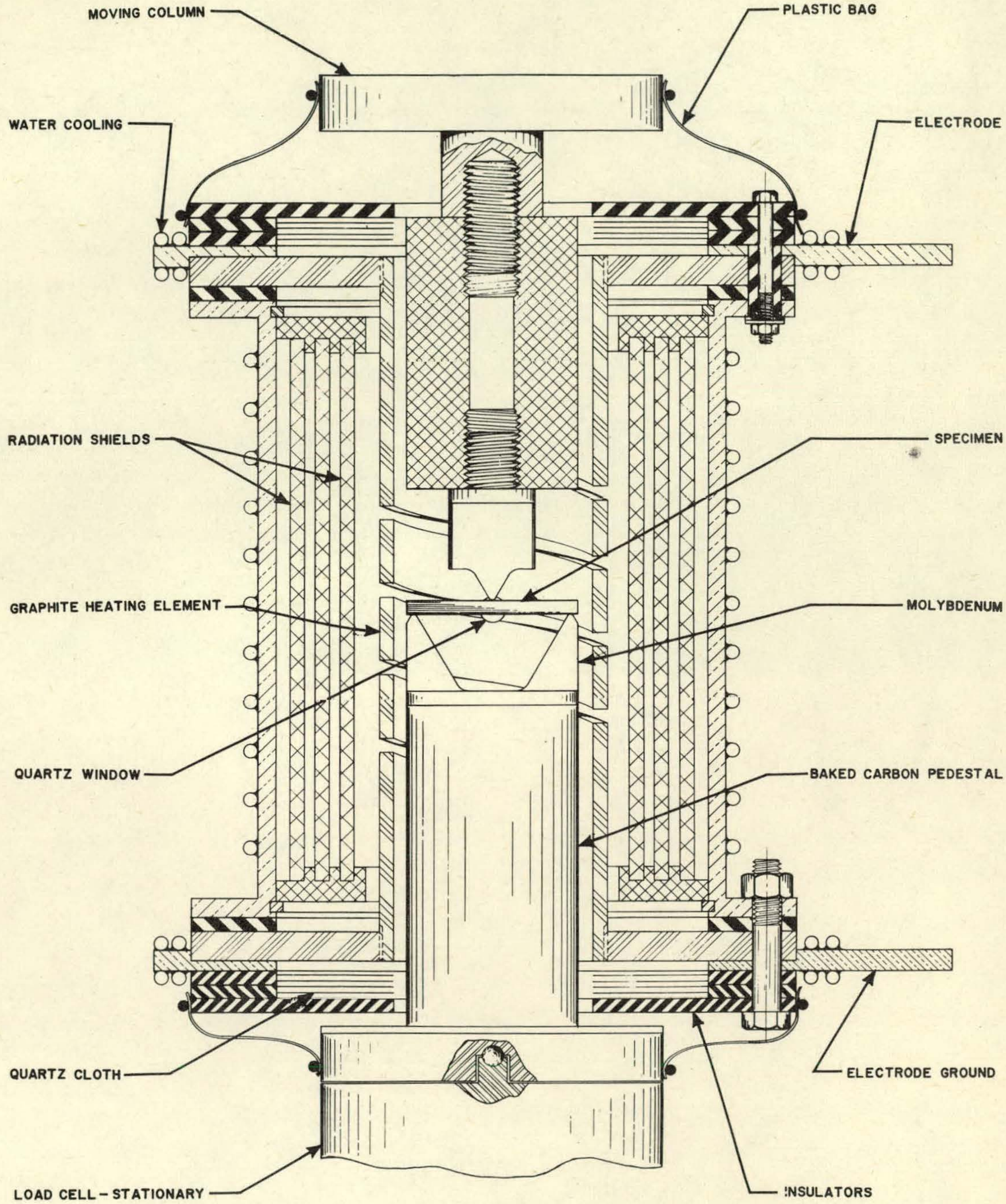
*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."

TABLE 10

DATA FROM TESTS ON BeO SPECIMENS
(Coors, Cold-Pressed)

Specimen No.	Temperature (°F)	Ultimate Load (lb)	Modulus of Rupture (psi)	Corrected Deflection (mils)	Density gm/cm^3	Mode of Fracture*
51	75	152	20.0 x 10^3	2.48	2.895	brittle
54	75	157	20.7	2.98	2.896	brittle
55	1475	236	31.2	4.35	2.894	brittle
71	2180	62	8.2	1.85	2.897	crack
52	2200	76	10.0	2.30	2.896	crack
53	2200	79	10.4	3.26	2.895	crack
59	2200	67	8.8	2.65	2.894	brittle
61	2200	71	9.4	2.38	2.896	crack
63	2200	70	9.2	1.92	2.896	↓
65	2200	65.5	8.6	2.28	2.895	↓
67	2200	66.5	8.8	2.04	2.896	↓
69	2200	72.5	9.6	4.48	2.935	↓
73	2200	61	8.0	2.17	2.896	↓
56	2400	45	5.9	3.57	2.894	crack
58	2400	43	5.7	3.12	2.896	creep crack
60	2400	54	7.1	2.27	2.896	↓
64	2400	43	5.7	2.50	2.895	↓
66	2400	42.5	5.6	3.09	2.897	↓
68	2400	39	5.1	2.87	2.896	↓
70	2400	48.5	6.4	2.50	2.895	↓
62	2430	50	6.6	3.32	2.895	↓
74	2445	48.5	6.4 ↓	2.14	2.896	↓
72	2455	34.5	4.6 x 10^3	3.64	2.895	creep crack
57	2200	(Broken by accident)			2.895	

*Normal brittle fracture is denoted by "brittle."
Stress-relieving crack formation is denoted by "crack."



659-1557

Diagram of Bend-Test Furnace

234 024

Figure 1

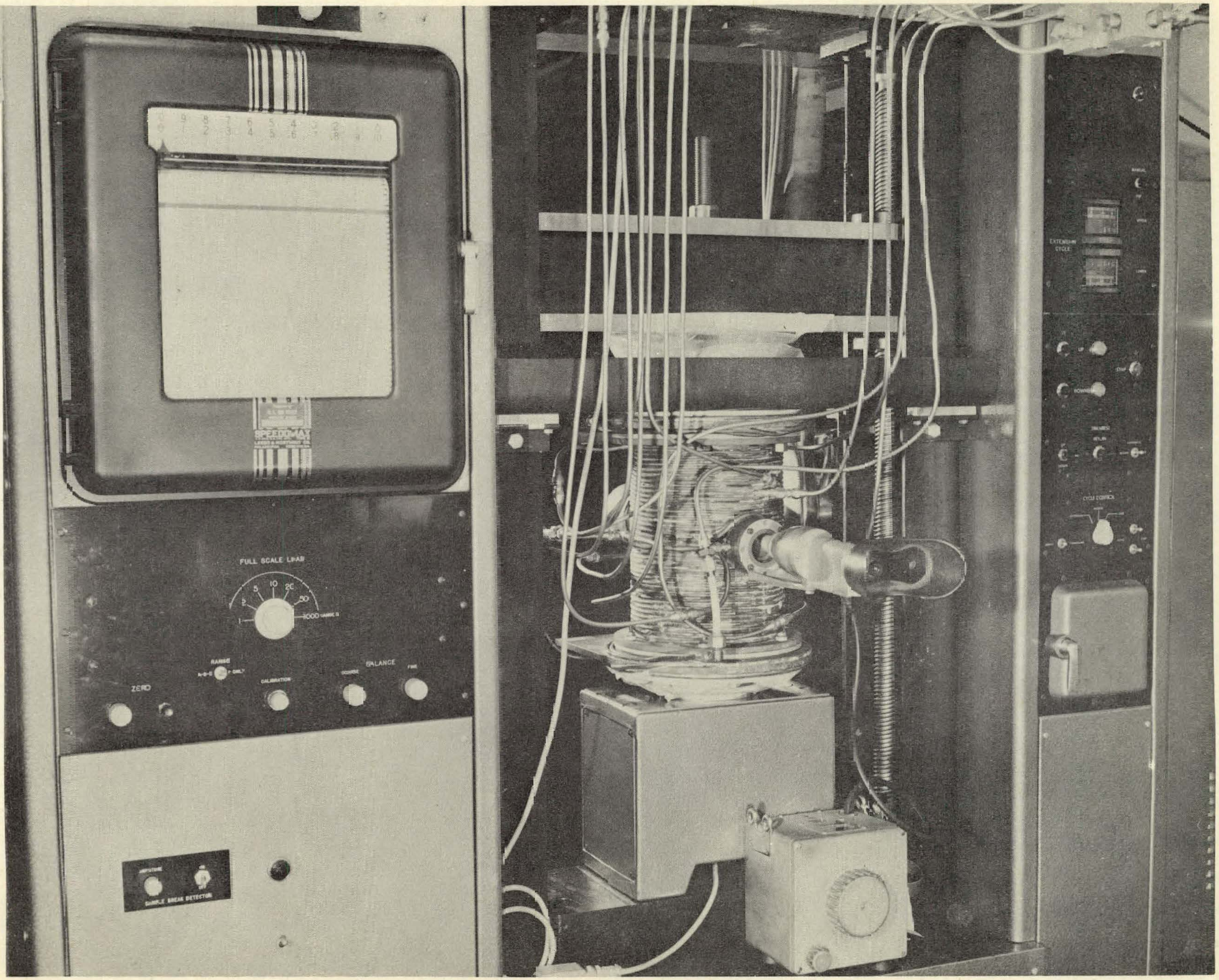
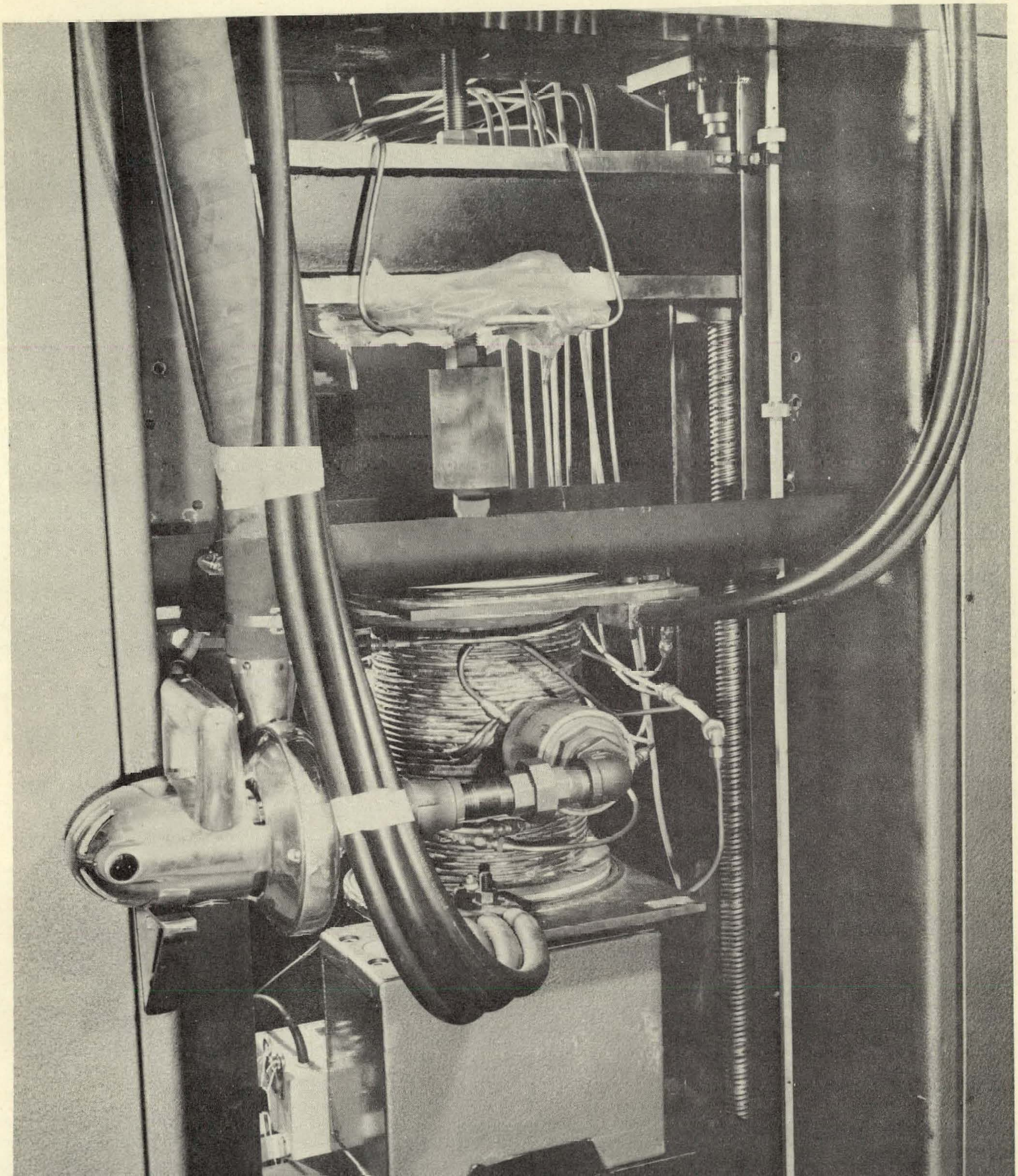


Figure 2

Bend-Test Furnace, Front View



Bend-Test Furnace, Rear View

234 026

Figure 3

234 027

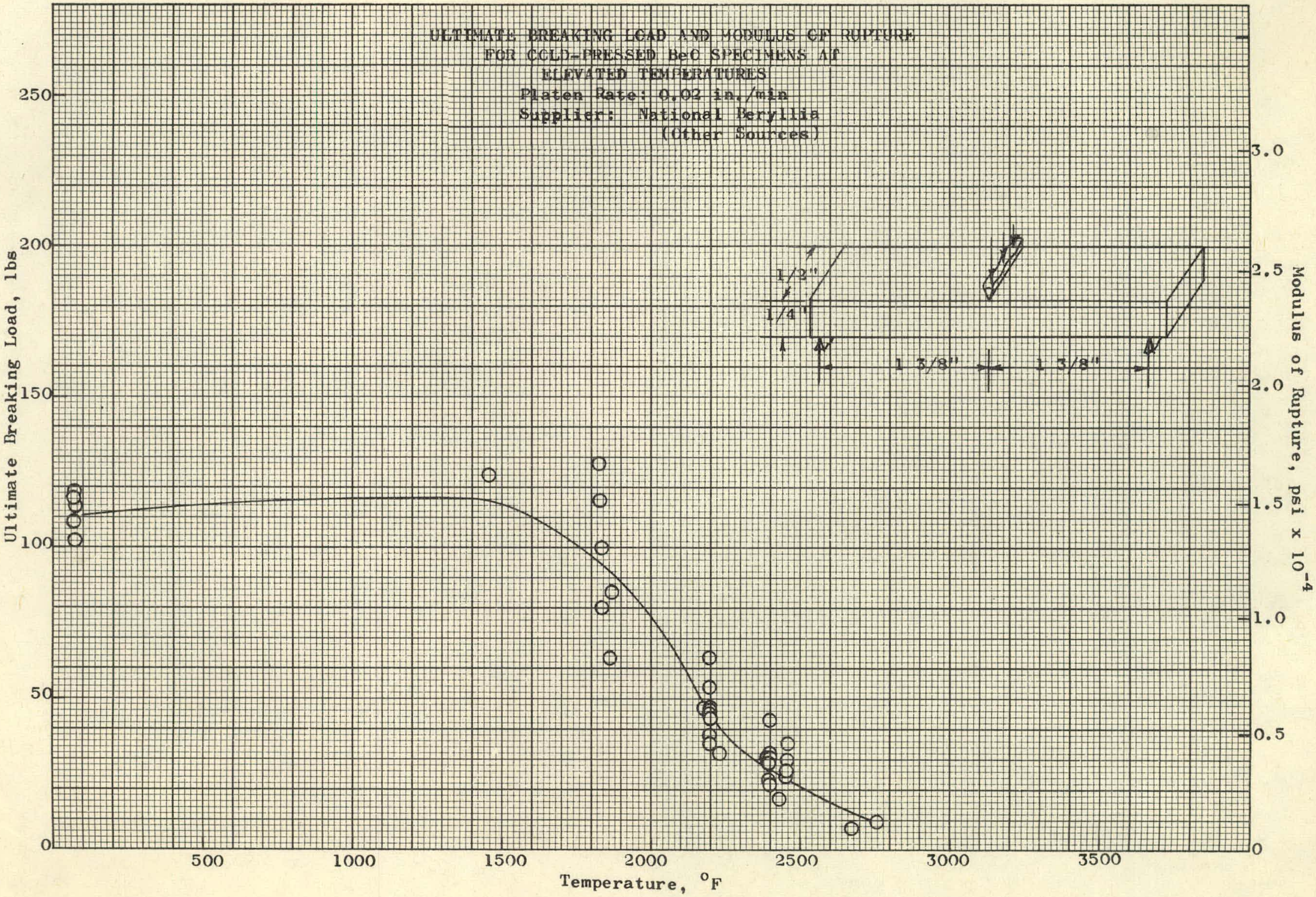


Figure 4

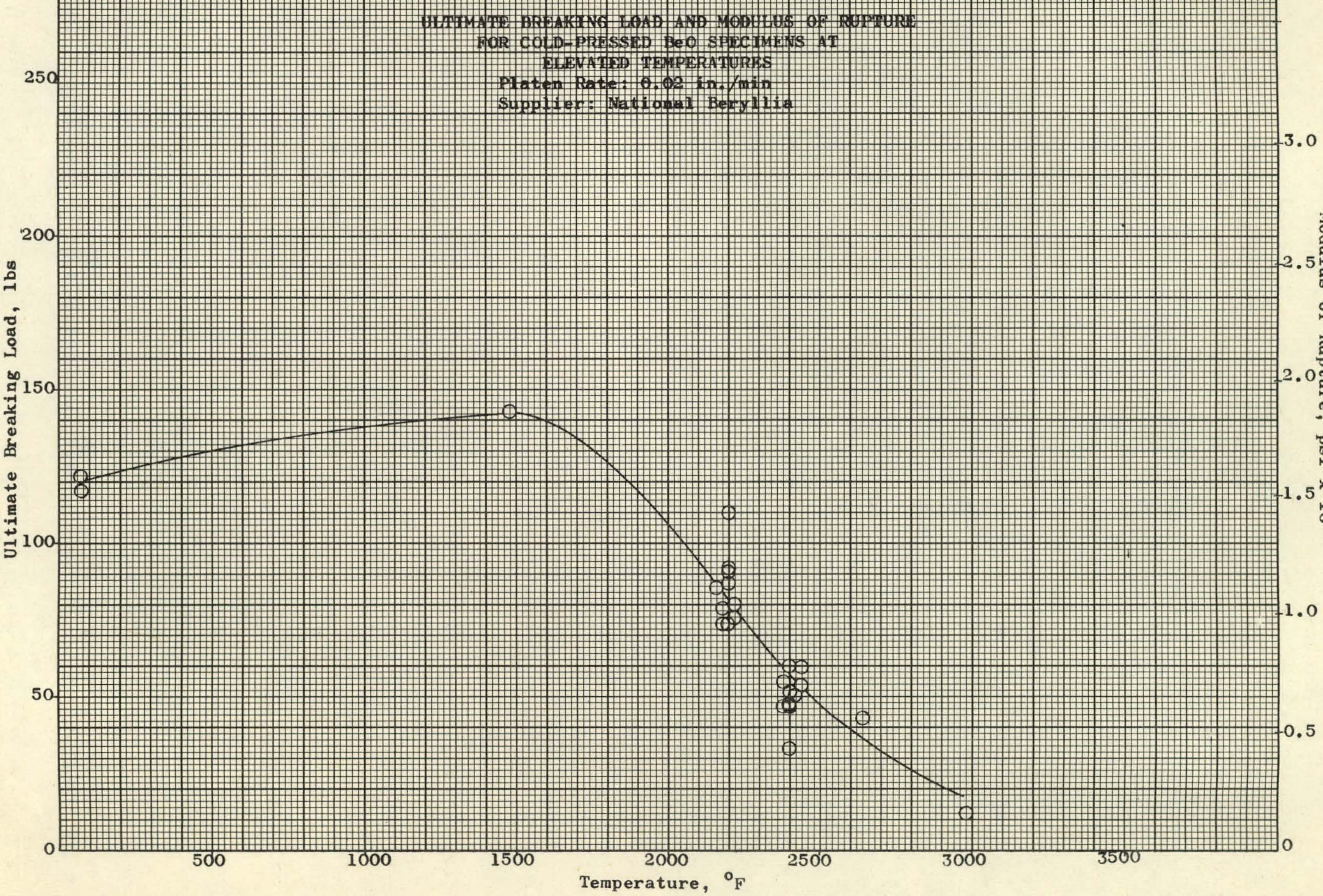
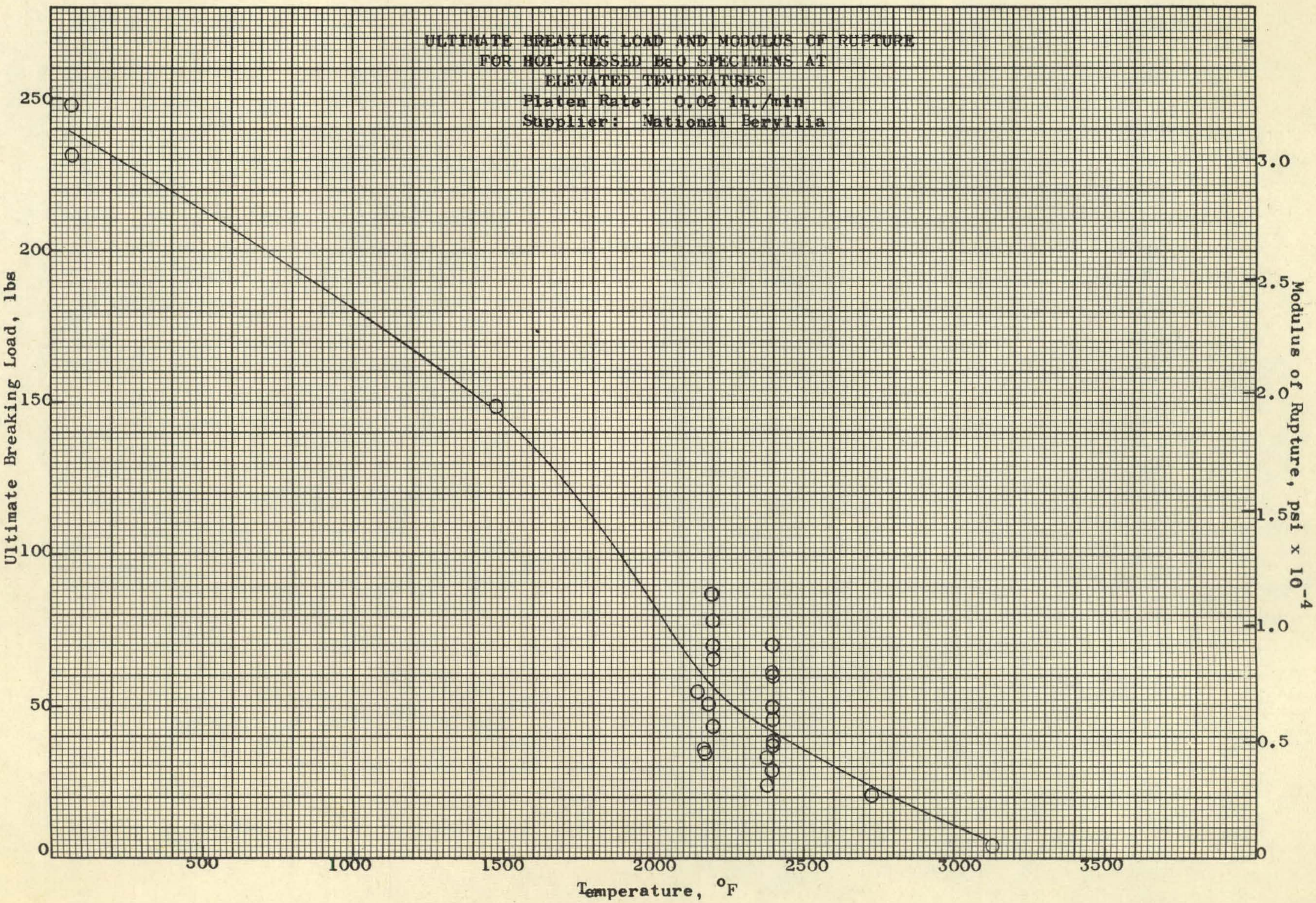


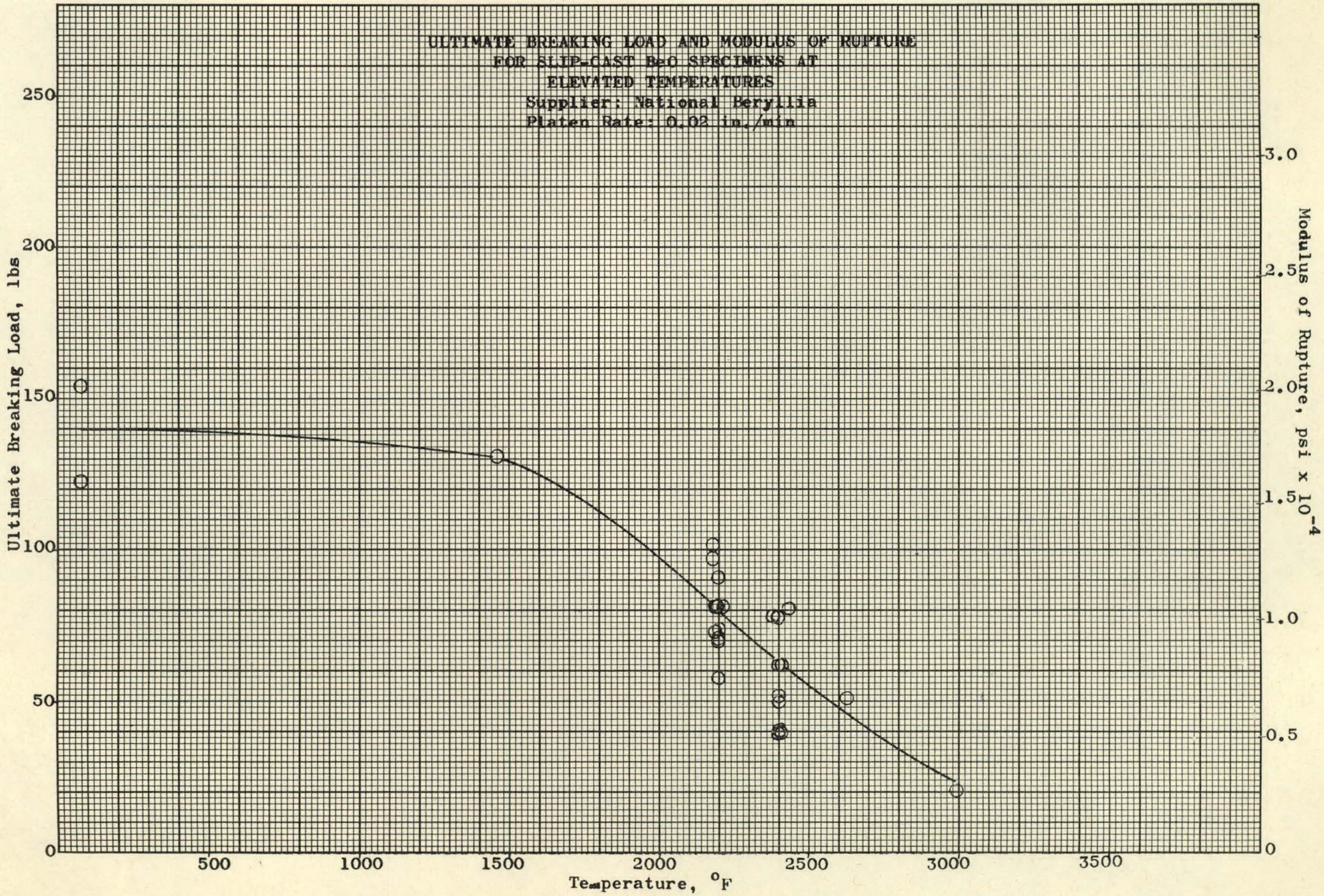
Figure 5

234 028



234 029

Figure 6



234 030

Figure 7

Report No. 1777

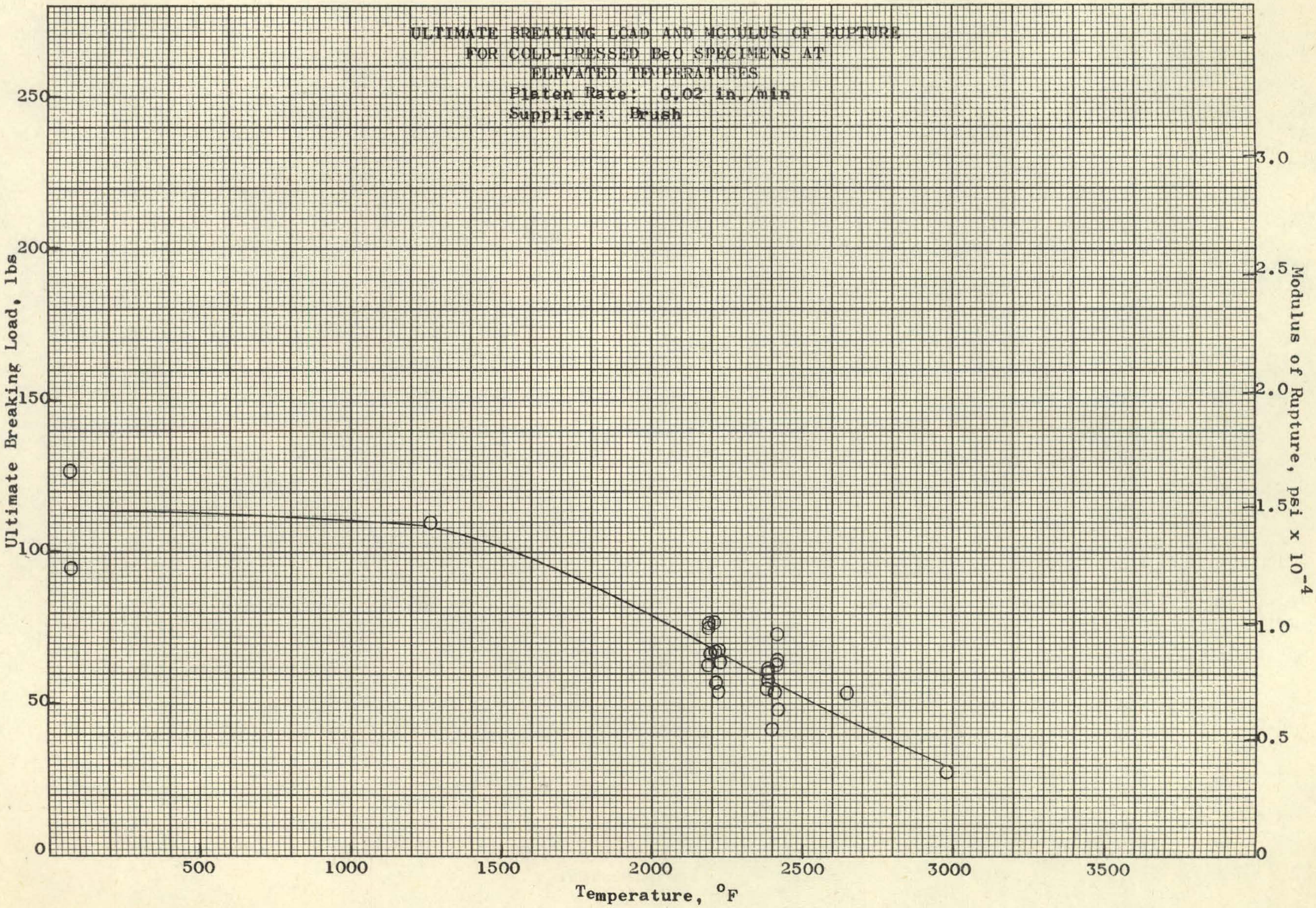
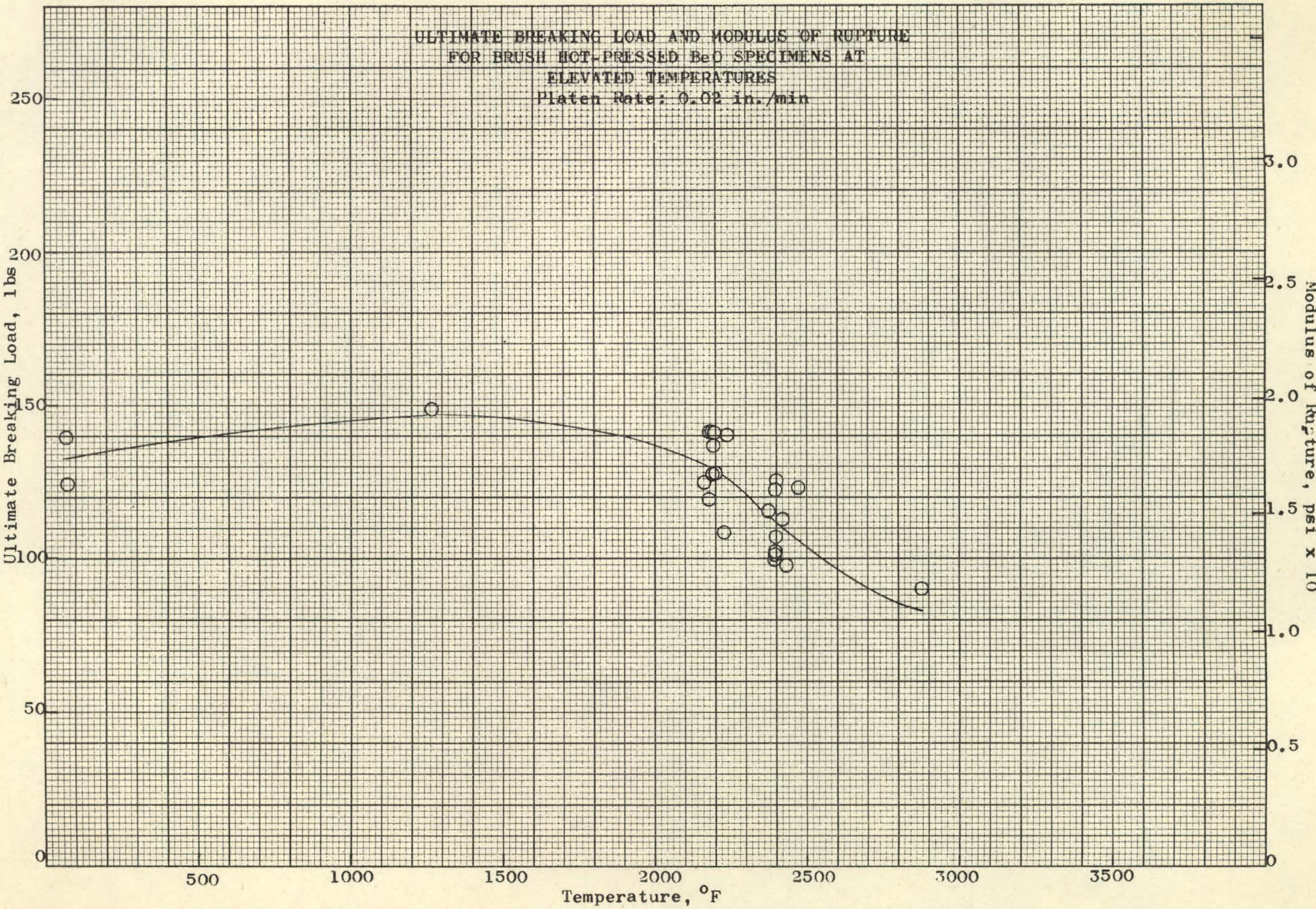


Figure 8

234 031

Report No. 1777



ULTIMATE BREAKING LOAD AND MODULUS OF RUPTURE
FOR BRUSH HOT-PRESSED BeO SPECIMENS AT
ELEVATED TEMPERATURES
Platen Rate: 0.02 in./min
Ultimate Breaking Load, lbs
0
50
100
150
200
250
Temperature, °F
500
1000
1500
2000
2500
3000
3500
Modulus of Rupture, psi x 10^-4
0
0.5
1.0
1.5
2.0
2.5
3.0

Figure 9

234 033

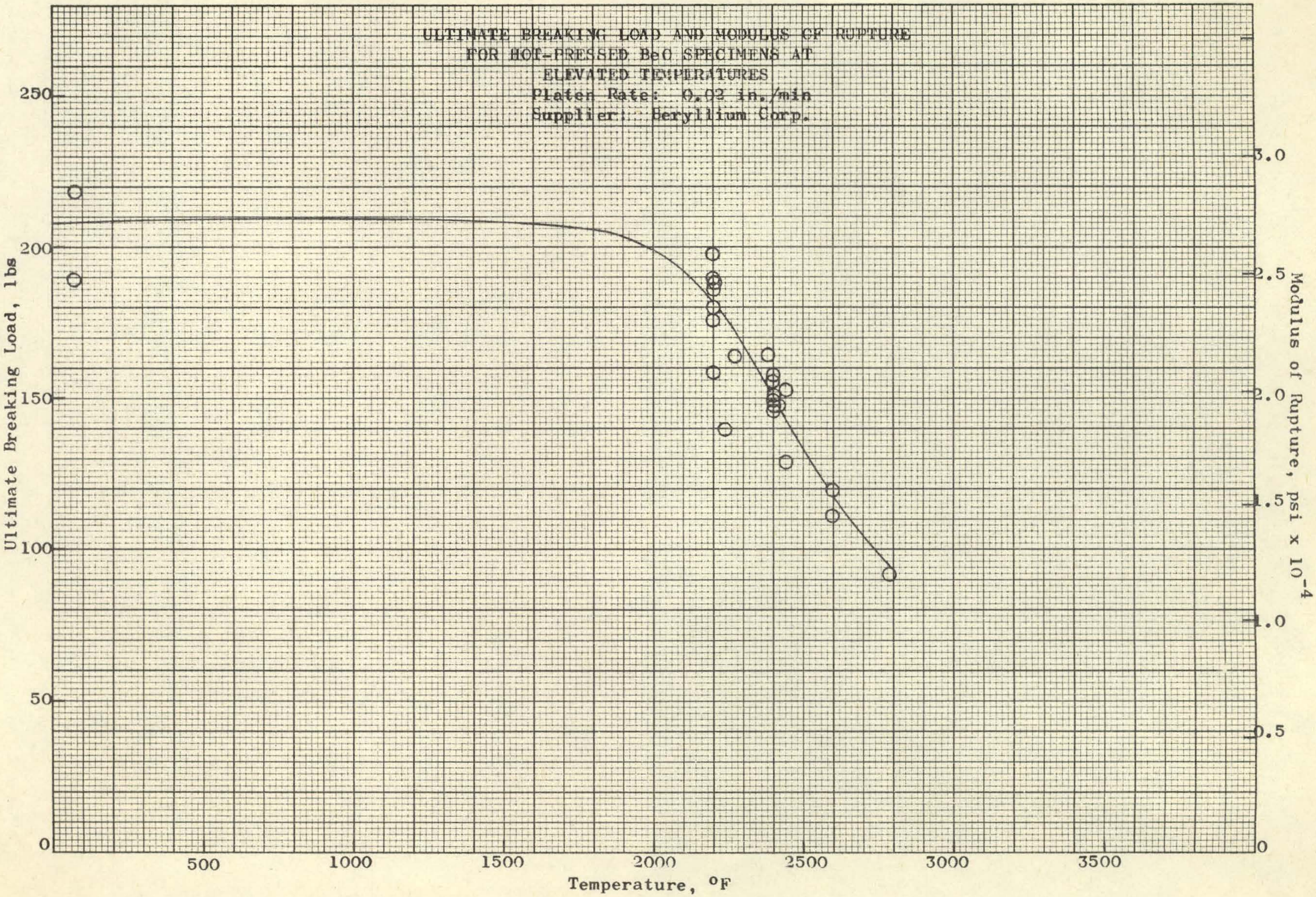


Figure 10

Report No. 1777

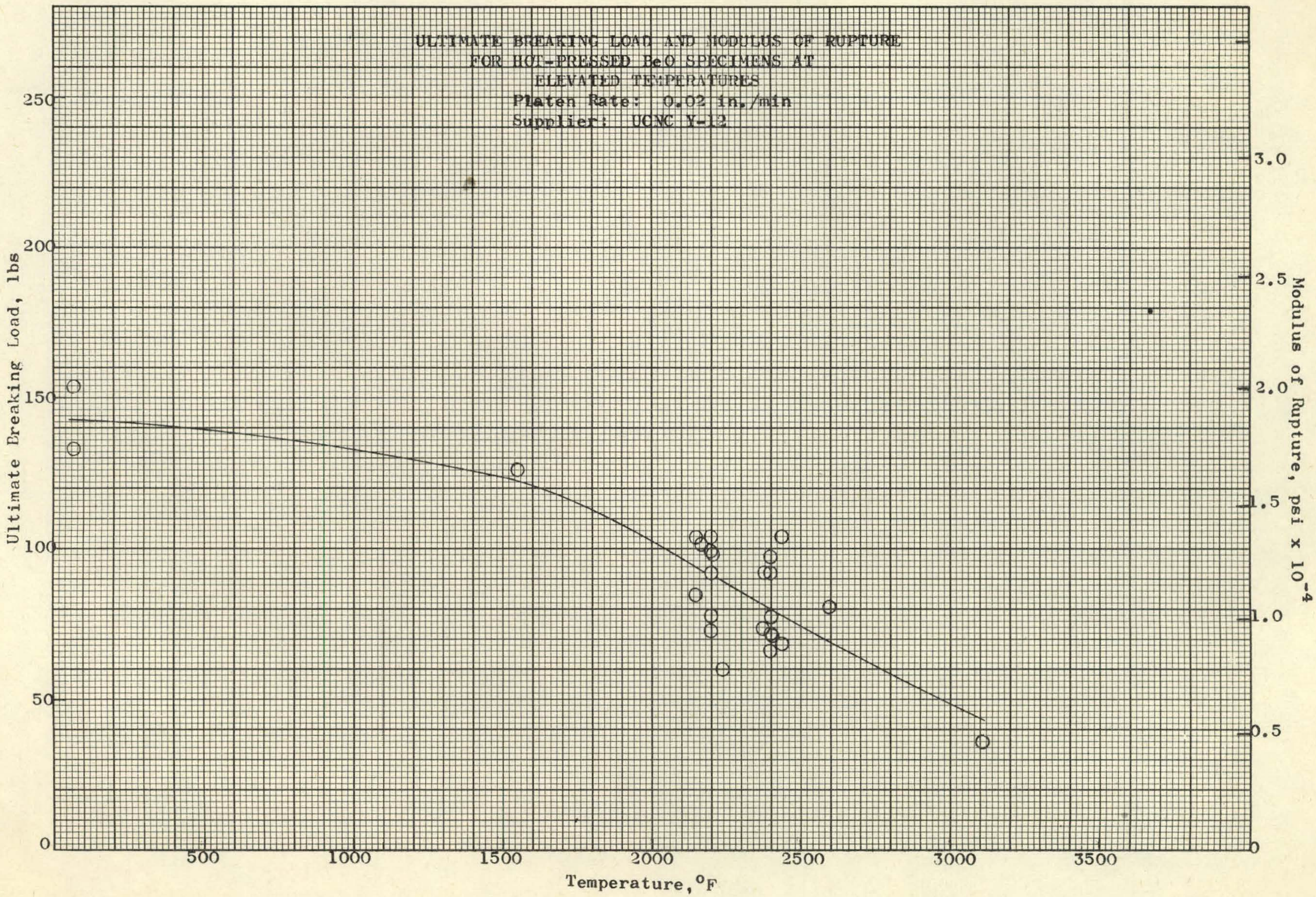
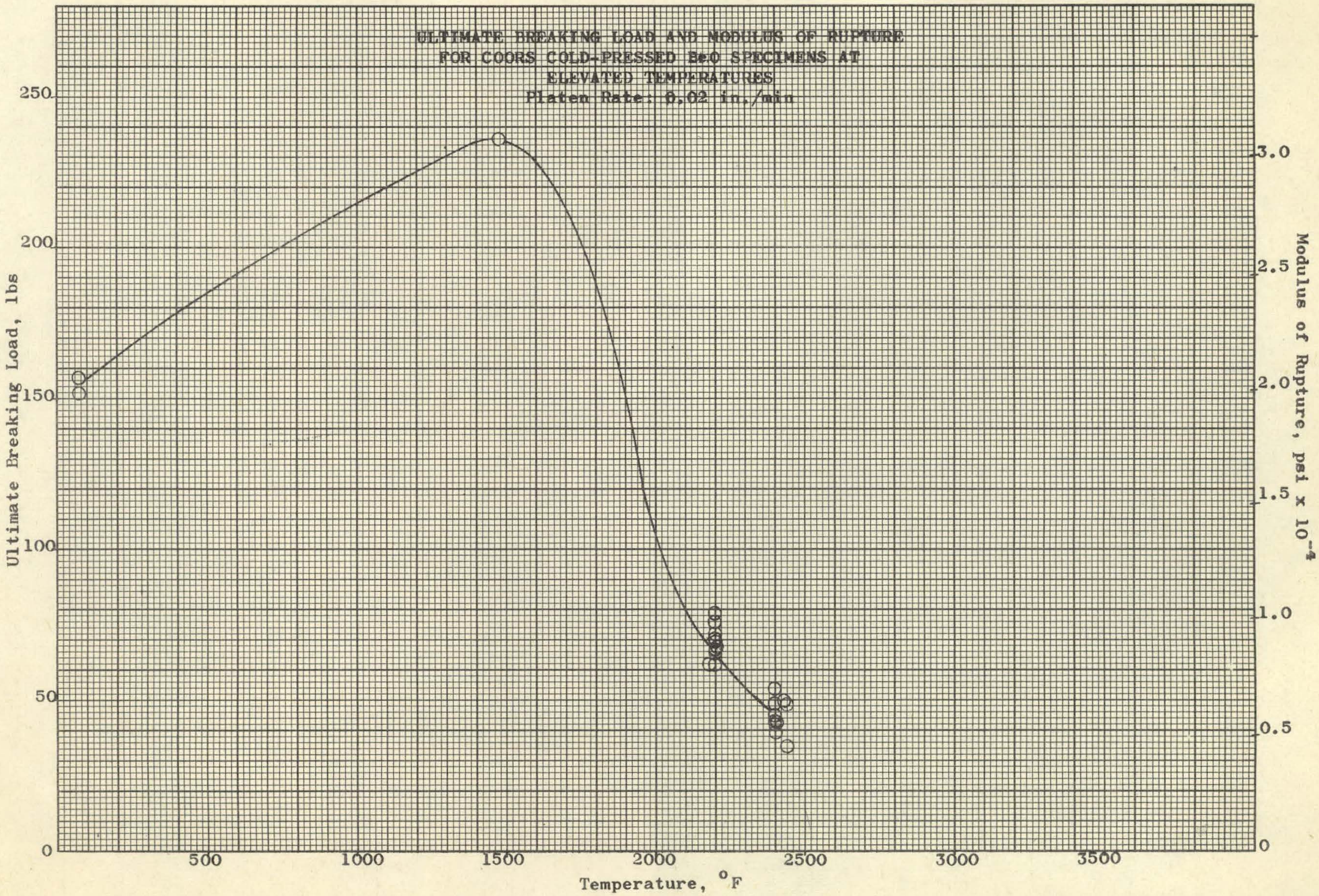

ULTIMATE BREAKING LOAD AND MODULUS OF RUPTURE
FOR HOT-PRESSED BeO SPECIMENS AT
ELEVATED TEMPERATURES
Platen Rate: 0.02 in./min
Supplier: UCNC Y-12
Ultimate Breaking Load, lbs
0
50
100
150
200
250
Modulus of Rupture, psi x 10^-4
0
0.5
1.0
1.5
2.0
2.5
3.0
Temperature, °F
500
1000
1500
2000
2500
3000
3500

Figure 11



234 035

Figure 12

Report No. 1777