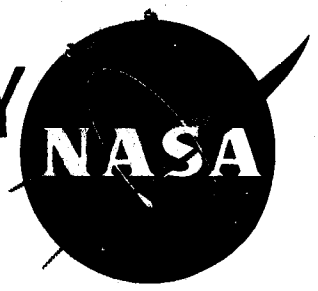

TECHNICAL NOTE

D-644

A STUDY OF THE OXIDATION OF MATERIALS

IN AN ARC-IMAGE FURNACE

By R. Gale Wilson, Roger W. Peters,
and Arthur J. McEvily, Jr.

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
January 1961

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SUMMARY

A series of tests on silicon carbide, graphite, nylon, Bakelite, Fiberglas phenolic, and ammonium chloride has been conducted in an arc-image furnace, with radiant heat fluxes at the specimen surfaces ranging from 100 to 1,000 Btu/ft^2-sec. The effects of radiant heat flux and concentration of oxygen in the specimen environment on the rate of material loss were determined. It was found that for the upper half of the heat-flux range the rate-controlling process for materials that oxidize was the diffusion rate of oxygen to the specimen surface.

INTRODUCTION

The behavior of materials subjected to heat fluxes in the range from 100 to 1,000 Btu/ft^2-sec is a matter of concern in the design of rocket nozzles, high-speed aircraft structures, and reentry vehicles. In order to study the behavior of materials under such heat fluxes a variety of laboratory facilities have been developed. Some of these, such as the electric arc jets, attempt to simulate as many of the environmental factors as possible in order to obtain an integrated response to the combined effects of heating rate, velocity, chemical composition, and enthalpy of the environmental air. Other facilities, such as the arc-image furnace used in the present investigation, provide less complete simulation but have the advantage of allowing the isolation and study of certain factors of the environment and their effects on materials. For example, the present paper gives the results of a study of the effect of oxygen concentration on the behavior of several materials subjected to a range of radiant heat fluxes. The materials investigated were selected because of their potential use in ablation or high-temperature applications.

EQUIPMENT AND SPECIMENS

The Arc-Image Furnace

The oxidation tests reported in this paper were conducted in the 60-inch arc-image furnace at the Langley Research Center. The furnace comprises a high-intensity carbon arc operating at the focal point of a 60-inch paraboloidal mirror, a second mirror of the same geometry to collect and refocus the radiant energy received from the first mirror, a solenoid-operated shutter interposed between the mirrors to provide a controlled heat pulse at the focal point of the receiving mirror, and a specimen support to hold material models in the image of the anode crater at the second focal point. A complete description of the arc-image furnace is presented in reference 1.

The specimen support utilized in the oxidation tests consists of a manually-controlled feed mechanism and a water-cooled shield (fig. 1). The material specimen is fed by manual control through a 5/16-inch-diameter hole in the shield so that the exposed face of the specimen is kept at the focal plane as the specimen surface is varporized, melted, or oxidized. The shield limits the area of exposure to one end of the specimen by shielding the walls of the specimen from the radiation.

In line with the test specimen and the longitudinal axis of the furnace is a 3/4-inch-diameter gas flow tube. The open end of the tube is so located that low-velocity air, oxygen, or inert gases may be directed at the exposed surface of the material specimen at the focal plane.

Radiant heat fluxes in the arc image are determined from the rate of temperature rise of a 1/4-inch-diameter, 1/16-inch-thick copper disk whose blackened surface is assumed to have an emissivity of 0.9.

Specimens and Materials

The type of specimen used for studying the oxidation behavior of materials exposed to uniform high heat fluxes produced by the arc image was a flat-faced cylinder of 1/4-inch diameter. Clearance between the specimen and the 5/16-inch hole in the shield was therefore 1/32 inch. The materials studied were graphite (AGX), silicon carbide (self-bonded), nylon, Bakelite, Fiberglas phenolic, and ammonium chloride. Some thermophysical properties of these materials are listed in table 1. The Fiberglas phenolic specimens were flat laminates cut to expose the fiber ends to the radiation. The lengths of the test specimens were determined by the intended time of exposure and by preliminary observation of the rate of material loss under high heat fluxes. Lengths of Bakelite, nylon,

Fiberglas phenolic, and ammonium chloride specimens varied from 1 to 3 inches. Specimens of graphite and silicon carbide, more slowly ablating materials, were 1/4 inch long.

TEST PROCEDURE

In general, the materials specimens tested in this investigation were exposed to high thermal fluxes in four different environments: ambient air, air flow at 47 ft/sec, argon flow at 47 ft/sec, and oxygen flow at 47 ft/sec. The air, argon, or oxygen flow was directed toward the end of the specimen exposed to the high thermal flux. Gas velocity was measured by a flowmeter in the gas supply line; prior to a test this flowmeter was calibrated directly against a velocity meter placed at the focal plane, where the irradiated end of the specimen is located in a test.

It has been shown that radiant heat flux at the focal spot of the arc-image furnace is a function of the arc current (fig. 6 of ref. 1). After the desired heat flux for a particular test was selected, the corresponding arc current was taken from the curve in reference 1, which gives the relationship between radiant heat flux and arc current in ambient air. For those tests which were to be made in ambient air, the radiant heat-flux value in reference 1 was verified by means of the blackened-copper-disk calorimeter each time a change in current was made. For those tests which were to be made in a moving gas environment, heat-flux values were obtained by exposing the calorimeter in an air stream of 47 ft/sec velocity, with resulting values 5 to 10 percent lower than those in reference 1. The values of radiant heat flux used in these tests were in the range from 100 to 1,000 Btu/ft^2-sec.

The sequence for performing the tests after the thermal flux had been verified was as follows:

1. The material specimen was installed and carefully centered so that the surface to be irradiated was located at the center of the focal spot.

2. The high-intensity arc was struck and its operation stabilized.

3. The gas flow, directed at the specimen surface, was initiated.

4. The specimen was exposed to the high thermal flux for the desired time by control of the shutter.

5. The gas flow was terminated immediately after the shutter had been closed.

The exposure times for this series of tests varied from 10 seconds to 4 minutes. The test technique varied, depending on the behavior of the material being tested. The techniques used are delineated in the paragraphs which follow.

Silicon Carbide and Graphite

Each specimen of silicon carbide and graphite was mounted on a tungsten wire of 0.027-inch diameter, which in turn was inserted in an insulating ceramic cylinder. The ceramic cylinder was supported inside the water-cooled shield, as illustrated in figure 2. These specimens were kept stationary during exposure and the time of exposure was limited to prevent enough recession of the exposed end to cause appreciable change in the incident heat flux. Apparent surface temperatures of the exposed ends of the specimens tested in ambient air were determined with a disappearing-filament optical pyrometer.

Nylon, Bakelite, and Fiberglas Phenolic

The specimens of nylon, Bakelite, and Fiberglas phenolic were 2 to 3 inches long and were mounted in an insulating block which was fed forward by manual control to keep the exposed ends of the specimens continuously at the focal point.

Ammonium Chloride

Specimens of ammonium chloride were exposed in three environments - ambient air, air at 47 ft/sec, and oxygen at 47 ft/sec. They were not exposed in argon as were all other materials since lack of oxidation made the chemical composition of the environment relatively unimportant. Ammonium chloride specimens were mounted and tested similarly to the specimens of nylon, Bakelite, and Fiberglas. The lengths of the specimens varied from about 1 to 3 inches.

TEST RESULTS

The results of the oxidation tests on the six materials considered in this investigation are presented in tables 2 to 7 and are plotted as curves of rate of weight loss against radiant heat flux in figures 3 to 9. Each test point represents one specimen. A comparison of the results for the six different materials in air flow only is presented in figure 9.

Silicon Carbide and Graphite

The optical pyrometer readings on silicon carbide varied from 4,000° F at a radiant heat flux of 300 Btu/ft^2-sec to about 5,200° F at 950 Btu/ft^2-sec. For graphite they varied from 3,100° F at 130 Btu/ft^2-sec to 4,500° F at 950 Btu/ft^2-sec. The values are not corrected for absence of black-body conditions and absorption losses through gas products of reaction, and therefore should be considered as only approximate. The pyrometer measurement on each specimen is given in figures 3 and 4. The temperature was constant for essentially the entire duration of each test.

No equipment was provided in the arc-image furnace for collecting volatile products. During the tests on silicon carbide a dense white smoke was liberated from the reaction surface in all the tests except those in argon flow. Except for the tests in argon flow, oxidation products recovered were a glassy material in the form of a loose peripheral ring at the exposed end of the specimen and a white powdery substance deposited on the specimen shield. For tests in argon flow a brownish substance was deposited on the specimen shield.

There were no recovered products from the tests on graphite.

Nylon, Bakelite, and Fiberglas Phenolic

Nylon weight loss in argon flow seemed to be due mainly to melting and vaporization. In still air nylon ignited and burned with a visible flame emanating from the exposed end of the specimen. In oxygen flow the specimen was engulfed by flame, which was swept back from the exposed end by the oxygen flow. This resulted in burning along the cylindrical surface of the specimen. Melting occurred in all the tests and the melt charred upon cooling. The amount of resolidified nylon decreased with increasing concentration of oxygen, and for tests in oxygen flow no such residue remained.

The behavior of Bakelite was very similar to that of nylon with the exception that melting was not observed. Specimens exposed in argon flow and still air became charred at the exposed end and somewhat beyond. Specimens exposed in air flow and in oxygen flow ignited and burned along their cylindrical surfaces as well as at their exposed ends.

The test results for Fiberglas phenolic differed from those for nylon and Bakelite in that weight loss in all the tests occurred entirely from the exposed ends of the specimens. A flame at the exposed ends of the specimens was visible only in still air. Oxidation products left from these tests were white and grayish powders and a greenish glass melt.

Ammonium Chloride

Ammonium chloride sublimes at about 640° F and decomposes into NH_3 and HCl, and therefore oxidation does not play a significant role in determining the rate of material loss. In these tests a white powder was deposited on the shield, indicating that partial recombination of the vapor products had occurred. Weight loss occurred only from the exposed ends of the specimens.

DISCUSSION

Silicon Carbide and Graphite

Two processes could be involved in the material loss in the tests on silicon carbide and graphite, namely, the formation of volatile oxides and sublimation. If sublimation is involved at all, it is probably only for silicon carbide at the highest heating rates where the temperature may approach the sublimation temperature. The pronounced effect of increasing oxygen concentration on the rate of material loss indicates that oxidation is primarily responsible for the material loss in these tests.

A characteristic phenomenon is the leveling off of the curves with increasing heat fluxes. Figures 3 and 4 indicate that temperatures continue to increase concurrently with the leveling off of the curves. Since reaction rates are generally exponential functions of temperature, on this basis alone the rate of weight loss should increase at higher heat fluxes, rather than level off as observed.

A possible explanation for the leveling off of the weight-loss curves is that the oxygen supply to the heated surface is insufficient to maintain the increasing rate of formation of volatile oxides. This would mean that the available oxygen is being fully utilized at the region of the curve where the slope is decreasing most rapidly, and the heat fluxes in excess of those in that region have little additional influence. Oxygen supply to the specimen is limited by the rate of diffusion through the protective shielding layer of volatile reaction products at the specimen surface. Increasing the supply of oxygen increases the rate of diffusion and, consequently, the rate of formation of volatile oxides. This type of diffusion-controlled reaction has been discussed in references 2, 3, and 4, and is considered to be primarily responsible for the observed behavior in the arc-image-furnace tests of graphite and silicon carbide.

The fact that silicon carbide is a compound and each of its elements forms two oxides complicates interpretation of test results. References 5, 6, and 7 indicate that the glassy material and the white powdery substance

formed as oxidation products in the arc-image furnace were forms of SiO_2. An X-ray diffraction analysis of the white powdery substances and the brownish deposits formed in these tests showed the presence of SiO_2 in both. According to reference 7, weight losses resulting from the reaction of SiO_2 formed on the surface of SiC with the SiC itself are important above 3,000° F, the reaction products being Si, SiO_2, and CO. A particular type of reaction appeared to be the controlling factor for weight loss in argon flow for the range of heat fluxes used.

In these tests on SiC, the temperature of the exposed end was always in the region of volatile oxide formation, that is, above 3,000° F, so that a weight loss always occurred. It is expected that for temperatures below 3,000° F a weight gain would occur as a result of the formation of an adherent SiO_2 coating at such low temperatures.

Because of the high thermal conductivity and low-temperature oxidation characteristics of graphite, weight loss occurred from the entire surface area of the specimens, in contrast to weight-loss occurrence only from the exposed ends of silicon carbide. However, the rate of weight loss was greatest at the end of the specimen exposed to the thermal flux of the furnace.

Nylon, Bakelite, and Fiberglas Phenolic

The increasing rate of weight loss with increasing concentration of oxygen in the tests on nylon, Bakelite, and Fiberglas phenolic indicates that oxidation is an important factor in material loss.

For nylon there is little difference in the rate of weight loss for exposures in argon flow, ambient air, and air flow, but oxygen flow increases the rate of weight loss greatly. Weight loss results from a combination of melting, vaporization, and oxidation.

There is little difference in the rate of weight loss for Bakelite in argon flow and still air. The rate increases significantly for air flow and much more for oxygen flow.

The Fiberglas phenolic is not as greatly affected by the concentration of oxygen as are nylon and Bakelite, although the rate of weight loss is considerably greater for exposures in oxygen flow than for those in the other three environments. Some of the oxidation products were similar to those from tests on silicon carbide.

Ammonium Chloride

Oxidation is not a factor in weight loss for ammonium chloride, as shown by the fact that varying the oxygen concentration did not affect weight loss. The curve of radiant heat flux against rate of weight loss exhibits a decrease in slope in the region of the highest heat fluxes. This may be accounted for by the radiation-shielding effect of the rapidly escaping vapors.

General Discussion of Test Data

It should be pointed out that the values of radiant heat flux used for figures 3 to 9 do not represent the rate of absorption of radiant energy by the specimen or the rate of consumption of radiant energy in the weight-loss processes. The latter would be the case only if the specimen were a black body, if weight loss occurred uniformly only from the exposed end, if there were no shielding effects by gaseous products, and if there were no heat losses by conduction and convection. All these conditions do not exist in any of the tests, and the degree to which they exist varies with the different materials tested, and in some cases with the oxygen concentration.. Optical pyrometer measurements were made only on graphite and silicon carbide because they were the only ones of the six materials on which meaningful pyrometer readings could be expected.

The literature indicates that the emissivity of graphite in its oxidizing state is 0.90 to 0.95, or possibly higher, and that the emissivity of silicon carbide is lower and varies much more than that of graphite. The relationship of actual temperature to the apparent temperature measured with the optical pyrometer depends upon the emissivity of the specimen surface, the amount of incident radiation reflected diffusely from the specimen surface into the pyrometer, and the amount of absorption of radiation by gases between the specimen and the pyrometer. The emissivity correction at 3,600° F would result in an addition to the apparent temperature of about 100° F for an emissivity of 0.85. The correction for reflection would result in a subtraction from the apparent temperature, and would serve to offset the emissivity correction. Because of the geometry of the arc-image-furnace setup, this would be small, but the exact magnitude for either material is not known. Correction for absorption would result in an addition to the apparent temperature, but again the magnitude is unknown. However, no correction for absorption is necessary for the invisible gases released by graphite (refs. 8 and 9). All three of these corrections would be applicable to the pyrometer measurements on silicon carbide, but their respective magnitudes are undetermined.

Another factor that enters into the heat energy at the exposed end of the test specimen is the exothermic nature of part, or maybe all, of the oxidation processes. For example, the oxidation of graphite, if it forms CO_2, adds 1,095 Btu/ft^2-sec in the test in oxygen flow at an arc-image heating rate of 950 Btu/ft^2-sec. If only CO is formed, the addition is 340 Btu/ft^2-sec. (These values were computed by using values of 377 and 117 Btu/mole for the heat of formation of CO_2 and CO, respectively.)

The nature of the distribution of weight loss affects both coordinates of the curves. The radiant heat-flux values are determined for a flat area, and the value of radiant flux on a specimen deviates slightly from that obtained for a flat area when the exposed end of the specimen loses its flat face. Specimens of ammonium chloride became somewhat pointed at the exposed ends during the tests. Specimens of Bakelite and nylon became pointed and diminished in cross-sectional area in tests in which burning of the cylindrical surface occurred. The ordinate values are determined by using the original cross-sectional area of the specimen (1/4-inch-diameter circle) in all cases as the basis of calculations of rate of weight loss per unit area.

The comparison of curves in figure 9 indicates that if heating rates were the sole criterion for selection, graphite and silicon carbide might be considered to be superior to the other materials because of their low weight losses. However, other factors must also be taken into consideration. For example, the high surface temperatures and high thermal conductivities of graphite and silicon carbide would easily lead to an unsatisfactory situation if it were necessary to keep the temperature level of a structure at some low value.

CONCLUDING REMARKS

Study of the effects of radiant heat flux on silicon carbide, graphite, nylon, Bakelite, and Fiberglas phenolic has revealed that the rate of oxidation is the dominant factor in determining the extent of material loss for the range of radiant heat fluxes from 100 to 1,000 Btu/ft^2-sec. Increasing the concentration of oxygen for a given radiant heat flux can have a marked effect on rate of material loss. For example, in tests on nylon and Bakelite, ignition of the specimen occurred in some cases. Weight loss in ammonium chloride, a nonoxidizable material, was independent of oxygen concentration. In these experiments it has been found that oxidation at the higher radiant heat fluxes involved is a diffusion-controlled reaction, with the result that oxidation in general is much more strongly a function of oxygen concentration at the specimen surface than of radiant heat flux. These results point out that beneficial effects might be derived from protective gas blankets at high heating

rates. Although the comparative behavior of materials can be determined in the arc-image furnace, it is pointed out that other factors, such as thermal conductivity, actual environment, and maximum permissible surface temperature must be considered in order to arrive at an overall evaluation of a particular material for a specific application.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 7, 1960.

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TABLE 1

THERMOPHYSICAL CHARACTERISTICS OF MATERIALS

Material	Density, lb/cu ft	Melting temperature, ^{o}F	Sublimation temperature, ^{o}F
Silicon carbide	187	---	5,160
Graphite	105	---	6,600
Nylon	72	480	-----
Bakelite	85	---	-----
Fiberglas phenolic	118	---	-----
Ammonium chloride	86	---	635

TABLE 2

RESULTS OF OXIDATION TESTS OF SILICON CARBIDE IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec	Temperature, °F
				47 ft/sec argon flow				
1	0.247	1.30×10^{-3}	1.29×10^{-3}	0.01×10^{-3}	30	1.0×10^{-3}	590	
2	.253	1.34	1.31	.03	60	1.5	590	
3	.252	1.35	1.33	.02	40	1.5	730	
4	.253	1.34	1.30	.04	45	2.6	730	
5	.264	1.40	1.36	.04	45	2.6	730	
6	.247	1.33	1.27	.06	40	4.4	940	
7	.249	1.25	1.17	.08	40	5.9	940	
8	.257	1.36	1.27	.09	30	8.8	940	
9	.247	1.31	1.24	.07	30	6.9	945	
				Ambient air				
10	0.253	1.36×10^{-3}	1.36×10^{-3}	0.00×10^{-3}	60	0.0×10^{-3}	300	3,970
11	.254	1.34	1.28	.06	60	2.9	480	4,630
12	.246	1.31	1.29	.02	60	1.0	480	-----
13	.254	1.29	1.21	.08	60	3.9	590	4,880
14	.254	1.36	1.29	.07	60	3.4	590	5,000
15	.248	1.26	1.18	.08	60	3.9	780	5,040
16	.253	1.26	1.18	.08	60	3.9	790	5,200
17	.250	1.25	1.17	.08	60	3.9	955	5,200
18	.251	1.35	1.26	.09	60	4.4	970	5,200
19	.248	1.29	1.18	.11	60	5.4	970	5,200
				47 ft/sec air flow				
20	0.250	1.32×10^{-3}	1.32×10^{-3}	0.00×10^{-3}	60	0.0×10^{-3}	275	
21	.253	1.30	1.24	.06	60	2.9	450	
22	.246	1.32	1.20	.12	25	14.1	590	
23	.245	1.30	1.16	.14	25	16.4	730	
24	.250	1.32	1.17	.15	25	17.6	950	
25	.251	1.36	1.20	.16	25	18.8	940	
				47 ft/sec oxygen flow				
26	0.250	1.26×10^{-3}	1.26×10^{-3}	0.00×10^{-3}	30	0.0×10^{-3}	450	
27	.252	1.38	1.01	.37	31	35.0	575	
28	.242	1.35	.97	.38	30	37.2	700	
29	.254	1.38	1.16	.22	15	43.0	710	
30	.249	1.39	1.27	.12	10	35.2	730	
31	.250	1.42	1.07	.35	30	34.2	800	
32	.254	1.41	1.26	.15	10	44.0	970	
33	.253	1.38	1.01	.37	30	36.2	1,000	

TABLE 3

RESULTS OF OXIDATION TESTS OF GRAPHITE IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec	Temperature, ^oF
47 ft/sec argon flow								
1	0.263	0.778×10^{-3}	0.775×10^{-3}	0.003×10^{-3}	60	0.14×10^{-3}	100	
2	.270	.780	.775	.005	60	.24	275	
3	.259	.755	.749	.006	40	.44	450	
4	.284	.835	.830	.005	35	.42	590	
5	.258	.755	.751	.004	40	.29	730	
6	.265	.759	.755	.004	35	.33	940	
Ambient air								
7	0.329	0.970×10^{-3}	0.949×10^{-3}	$.021 \times 10^{-3}$	60	1.03×10^{-3}	130	3135
8	.344	.922	.881	.041	60	2.00	300	3475
9	.315	1.011	.965	.046	60	2.24	480	3885
10	.332	.974	.921	.053	68	2.29	480	3995
11	.331	.954	.904	.050	60	2.44	640	4280
12	.330	.977	.928	.049	60	2.40	780	4385
13	.334	.984	.929	.055	60	2.69	780	4440
14	.325	.955	.903	.052	60	2.54	930	4500
15	.324	.944	.893	.051	60	2.49	950	4495
47 ft/sec air flow								
16	0.321	0.948×10^{-3}	0.826×10^{-3}	$.122 \times 10^{-3}$	60	5.96×10^{-3}	100	
17	.321	.961	.788	.173	60	8.45	275	
18	.320	.950	.701	.249	60	12.2	450	
19	.336	.998	.760	.238	60	11.6	590	
20	.337	.990	.775	.215	60	10.5	730	
21	.330	.962	.733	.229	60	11.2	730	
22	.338	.995	.760	.235	60	11.5	940	
47 ft/sec O_2 flow								
23	0.264	0.772×10^{-3}	0.560×10^{-3}	$.212 \times 10^{-3}$	27	23.0×10^{-3}	100	
24	.280	.833	.502	.331	18	54.0	275	
25	.279	.820	.540	.280	15	54.7	450	
26	.255	.744	.445	.299	13	67.6	590	
27	.272	.793	.507	.286	12	70.0	590	
28	.273	.803	.507	.296	13	66.9	730	
29	.258	.765	.502	.263	10	77.1	940	
30	.250	.739	.511	.228	10	66.2	970	

TABLE 4

RESULTS OF OXIDATION TESTS OF NYLON IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec
47 ft/sec argon flow							
1	2.089	4.27×10^{-3}	2.65×10^{-3}	1.62×10^{-3}	50	0.095	175
2	1.994	4.08	2.39	1.69	24	.206	450
3	1.945	3.98	2.20	1.78	16	.326	1,000
Ambient air							
4	2.007	4.11×10^{-3}	2.17×10^{-3}	1.94×10^{-3}	66	0.086	225
5	2.000	4.10	2.30	1.80	25	.210	510
6	1.982	4.05	2.14	1.91	22	.255	1,010
47 ft/sec air flow							
7	2.022	4.15×10^{-3}	2.98×10^{-3}	1.17×10^{-3}	39	0.087	175
8	1.962	4.01	2.09	1.92	23	.244	450
9	1.989	4.07	1.98	2.09	18	.340	1,000
47 ft/sec O_2 flow							
10	2.937	3.96×10^{-3}	1.43×10^{-3}	2.53×10^{-3}	38	0.195	175
11	2.160	4.43	0	4.43	19	.685	450
12	2.003	4.10	0	4.10	14	.859	1,000

TABLE 5

RESULTS OF OXIDATION TESTS OF BAKELITE IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec
47 ft/sec argon flow							
1	3.012	7.17×10^{-3}	6.35×10^{-3}	0.82×10^{-3}	120	0.020	175
2	2.927	7.00	5.79	1.21	150	.024	450
3	2.964	7.08	6.32	.76	30	.075	1,000
Ambient air							
4	2.979	7.07×10^{-3}	6.34×10^{-3}	0.73×10^{-3}	120	0.018	225
5	3.021	7.23	5.74	1.49	149	.029	510
6	2.940	7.03	5.96	1.07	55	.057	1,010
47 ft/sec air flow							
7	2.950	7.03×10^{-3}	5.48×10^{-3}	1.55×10^{-3}	120	0.037	175
8	3.004	7.14	.48	6.66	106	.184	450
9	2.927	6.99	2.31	4.68	54	.254	1,000
47 ft/sec O_2 flow							
10	2.899	6.88×10^{-3}	0.47×10^{-3}	6.41×10^{-3}	44	0.427	175
11	2.927	7.00	.86	6.14	39	.462	450
12	2.979	7.08	.13	6.95	41	.497	1,000

TABLE 6

RESULTS OF OXIDATION TESTS OF FIBERGLAS PHENOLIC IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec
47 ft/sec argon flow							
1	2.057	6.85×10^{-3}	6.62×10^{-3}	0.23×10^{-3}	199	0.003	175
2	2.110	6.98	5.85	1.13	52	.064	450
3	2.066	6.75	4.83	1.92	42	.134	1,000
Ambient air							
4	2.053	6.85×10^{-3}	6.29×10^{-3}	0.56×10^{-3}	202	0.008	225
5	2.057	6.85	4.78	2.07	94	.065	510
6	2.055	6.74	4.56	2.18	47	.136	1,010
47 ft/sec air flow							
7	1.998	6.76×10^{-3}	5.20×10^{-3}	1.56×10^{-3}	120	0.038	175
8	1.955	6.50	3.35	3.15	113	.081	450
9	2.063	6.82	4.36	2.46	44	.164	1,000
47 ft/sec O_2 flow							
10	2.083	6.99×10^{-3}	4.60×10^{-3}	2.39×10^{-3}	58	0.121	175
11	2.066	7.12	3.68	3.44	69	.146	450
12	2.077	7.08	3.43	3.65	44	.243	1,000

TABLE 7

RESULTS OF OXIDATION TESTS OF AMMONIUM CHLORIDE IN ARC-IMAGE FURNACE

Specimen	Original length, in.	Weight before test, lb	Weight after test, lb	Weight loss, lb	Time of exposure, sec	Rate of weight loss, lb/ft^2-sec	Radiant heat flux, Btu/ft^2-sec
Ambient air							
1	2.054	4.96×10^{-3}	2.75×10^{-3}	2.21×10^{-3}	250	0.026	130
2	2.067	5.25	2.60	2.65	110	.071	300
3	1.050	2.58	.58	2.00	29	.203	980
4	1.079	2.63	.71	1.92	28	.201	980
5	1.031	2.52	.65	1.87	31	.177	980
47 ft/sec air flow							
6	2.066	5.21×10^{-3}	3.40×10^{-3}	1.81×10^{-3}	110	0.048	100
7	1.789	4.25	2.58	1.67	71	.069	275
8	2.043	5.30	3.75	1.55	62	.074	275
9	2.040	4.96	2.50	2.46	61	.118	450
10	2.025	4.74	3.05	1.69	37	.134	450
11	1.900	4.65	3.54	1.11	31	.105	450
12	2.345	5.74	3.00	2.74	72	.112	450
13	2.105	5.15	2.51	2.64	37	.210	590
14	2.097	5.13	2.93	2.20	37	.175	590
15	1.824	4.43	1.66	2.77	46	.177	590
16	1.529	3.73	1.84	1.89	32	.174	590
17	1.439	3.52	1.13	2.39	41	.171	590
18	1.180	2.88	0.98	1.90	33	.169	590
19	1.049	2.57	.89	1.68	32	.154	590
20	.934	2.28	.59	1.69	26	.191	940
21	2.118	5.18	2.60	2.58	43	.176	940
22	.896	2.19	1.14	1.05	14	.220	940
23	.855	2.09	1.08	1.01	12	.246	940
24	1.030	2.52	.72	1.80	28	.188	945
25	1.023	2.51	1.18	1.33	16	.244	945
26	.850	2.09	1.25	.84	11	.224	945
27	1.108	2.70	0.89	1.81	28	.190	950
28	2.715	6.63	5.04	1.59	24	.194	970
29	2.460	5.96	4.33	1.63	30	.160	970
47 ft/sec O_2 flow							
30	2.536	6.24×10^{-3}	3.80×10^{-3}	2.44×10^{-3}	50	0.143	590
31	2.435	5.58	2.81	2.77	36	.226	940

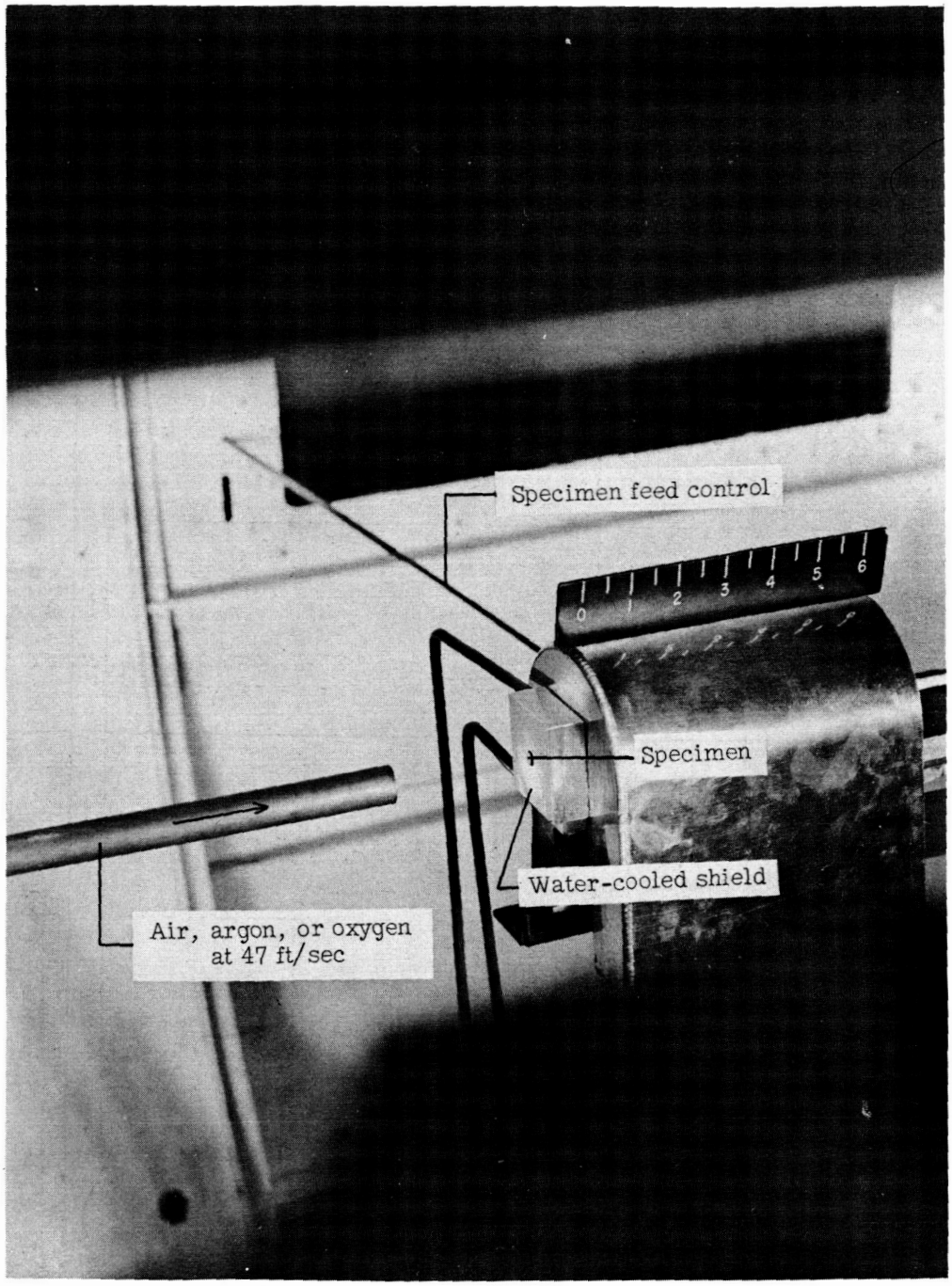

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Figure 1.- Specimen support used for oxidation tests in the 60-inch arc-image furnace.

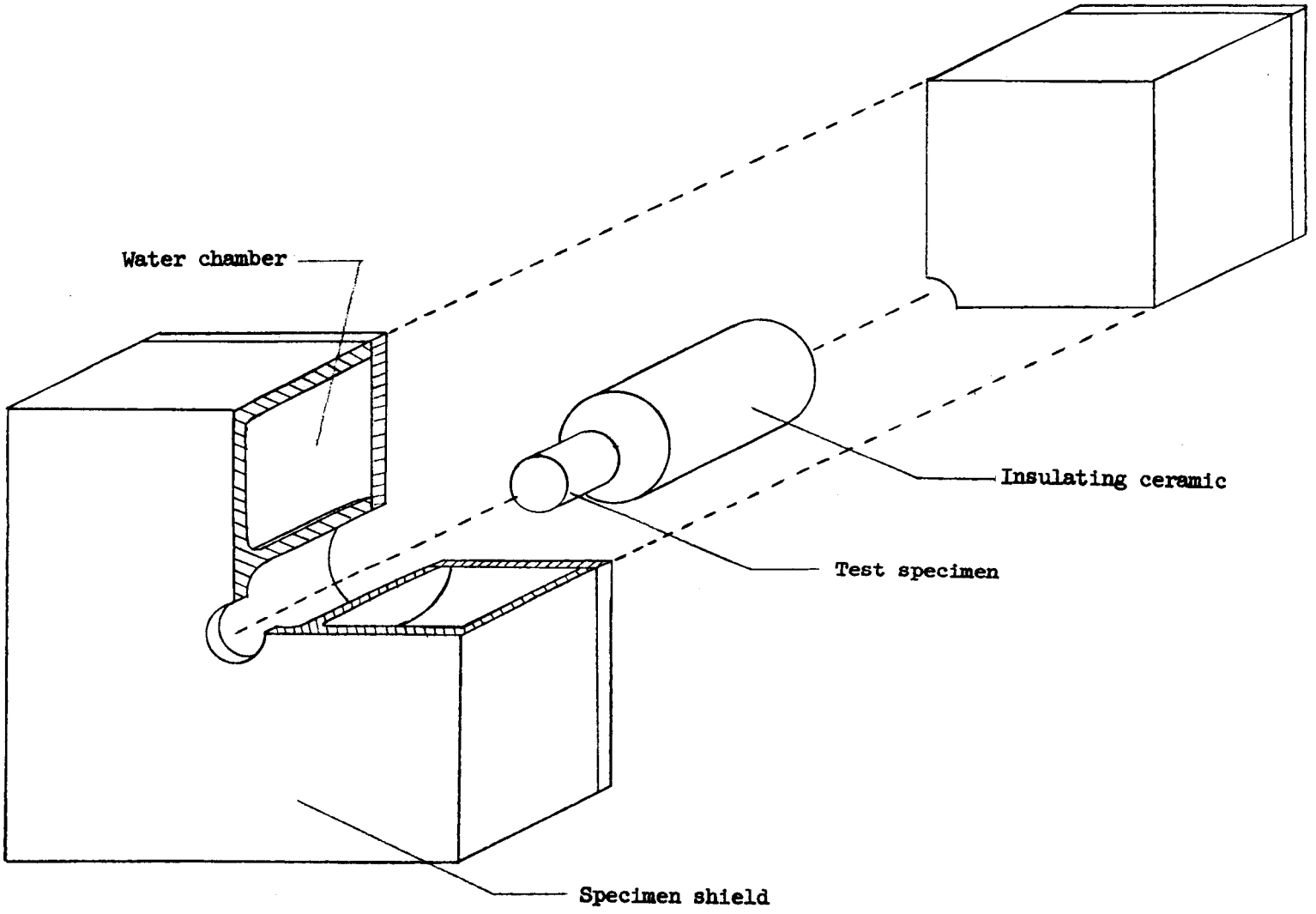

Figure 2.- Specimen mounting for graphite and silicon carbide.

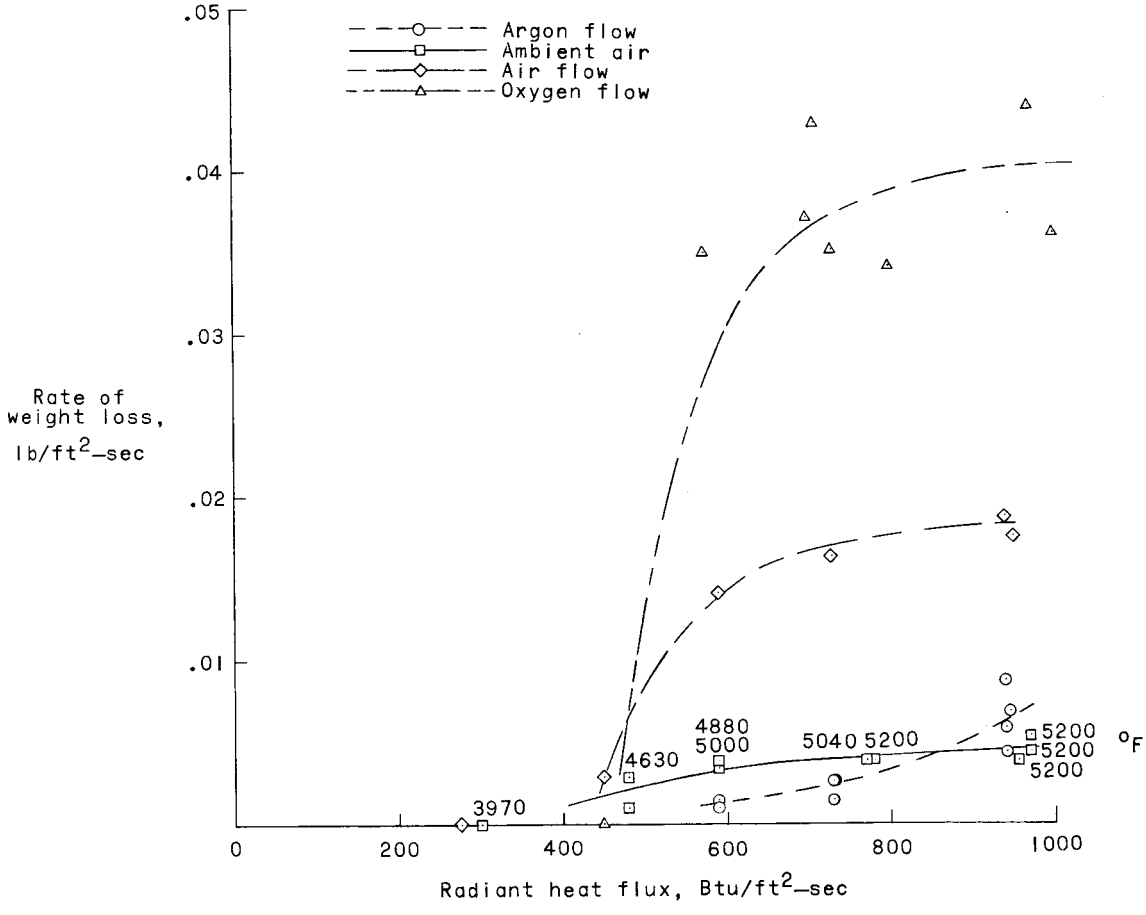

Figure 3.- Oxidation tests of silicon carbide in arc-image furnace.

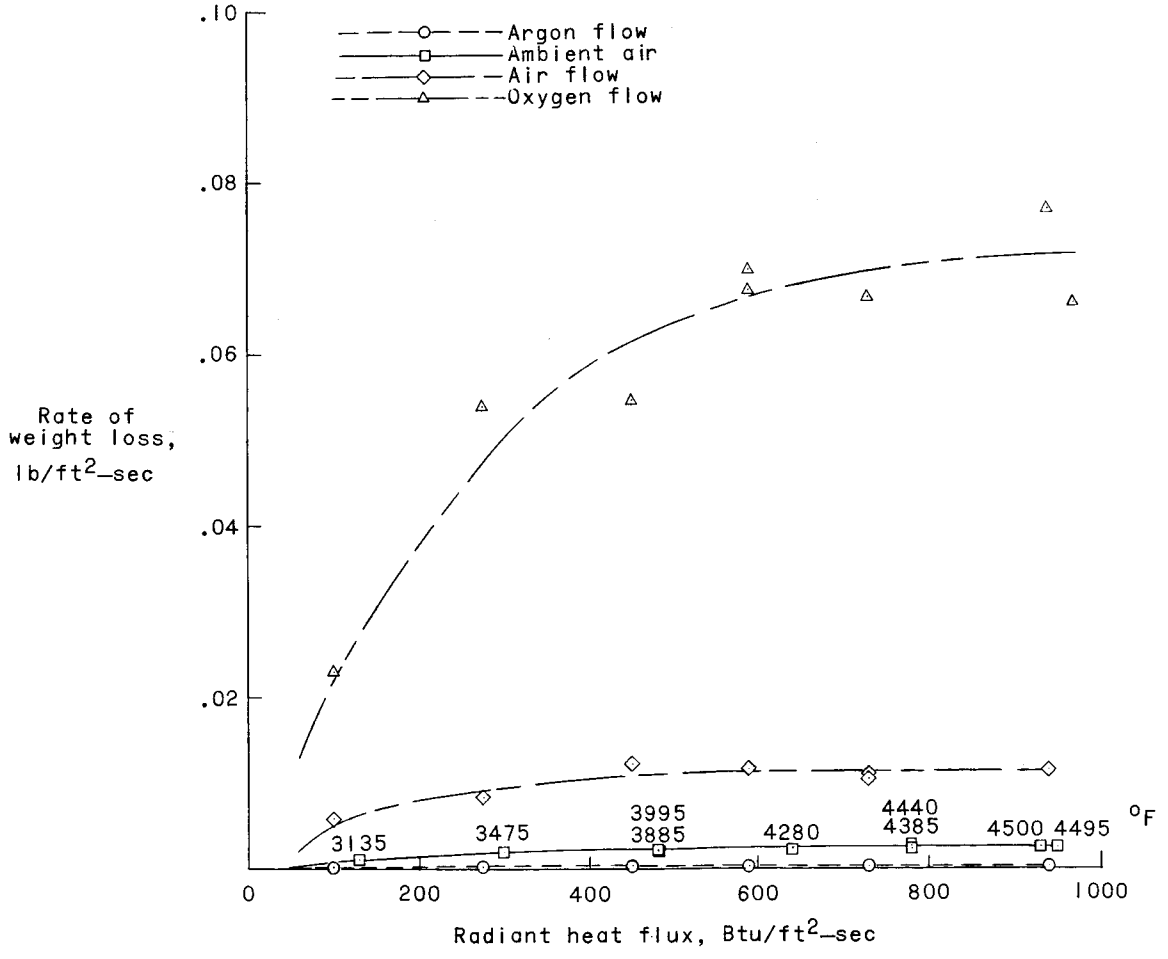

Figure 4.- Oxidation tests of graphite in arc-image furnace.

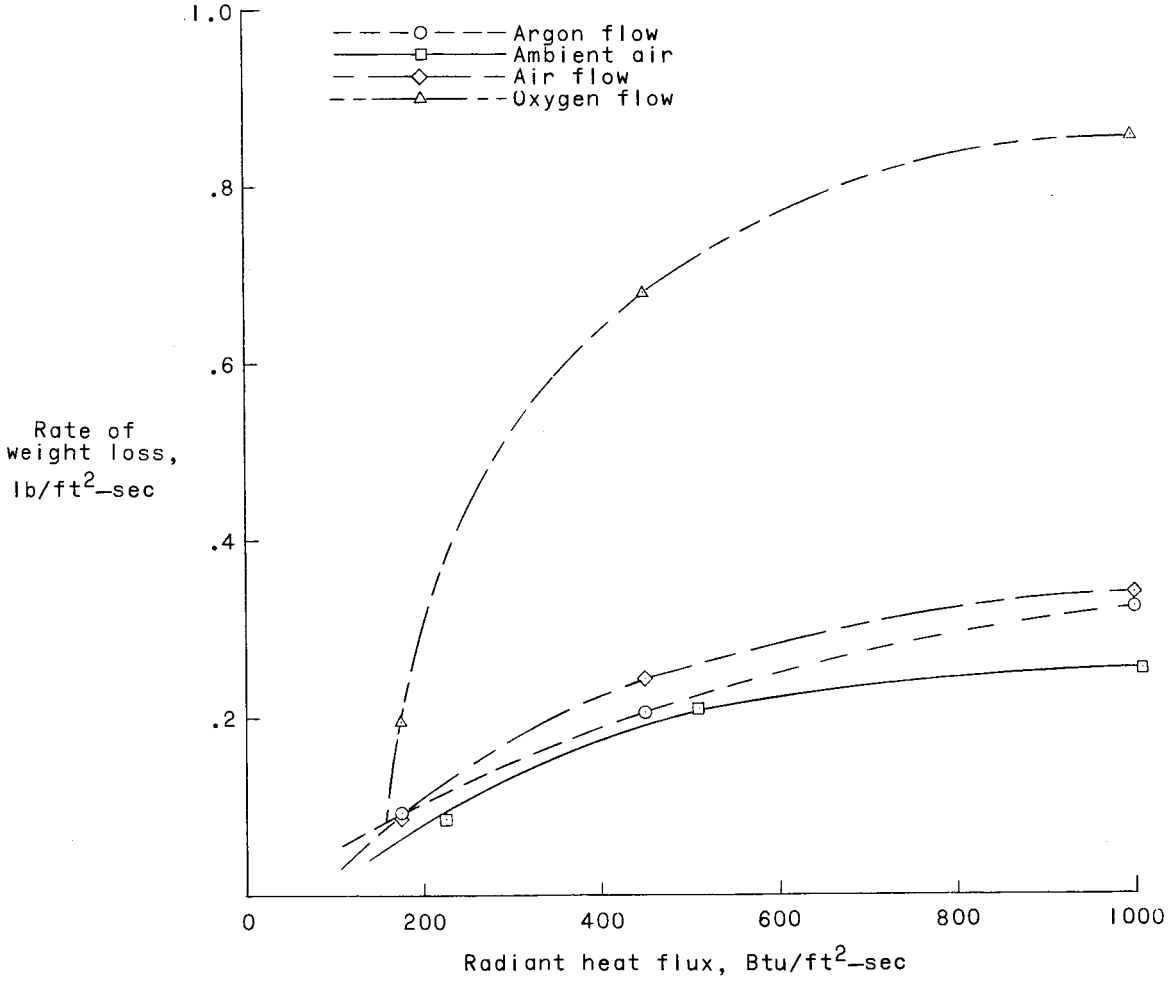

Figure 5.- Oxidation tests of nylon in arc-image furnace.

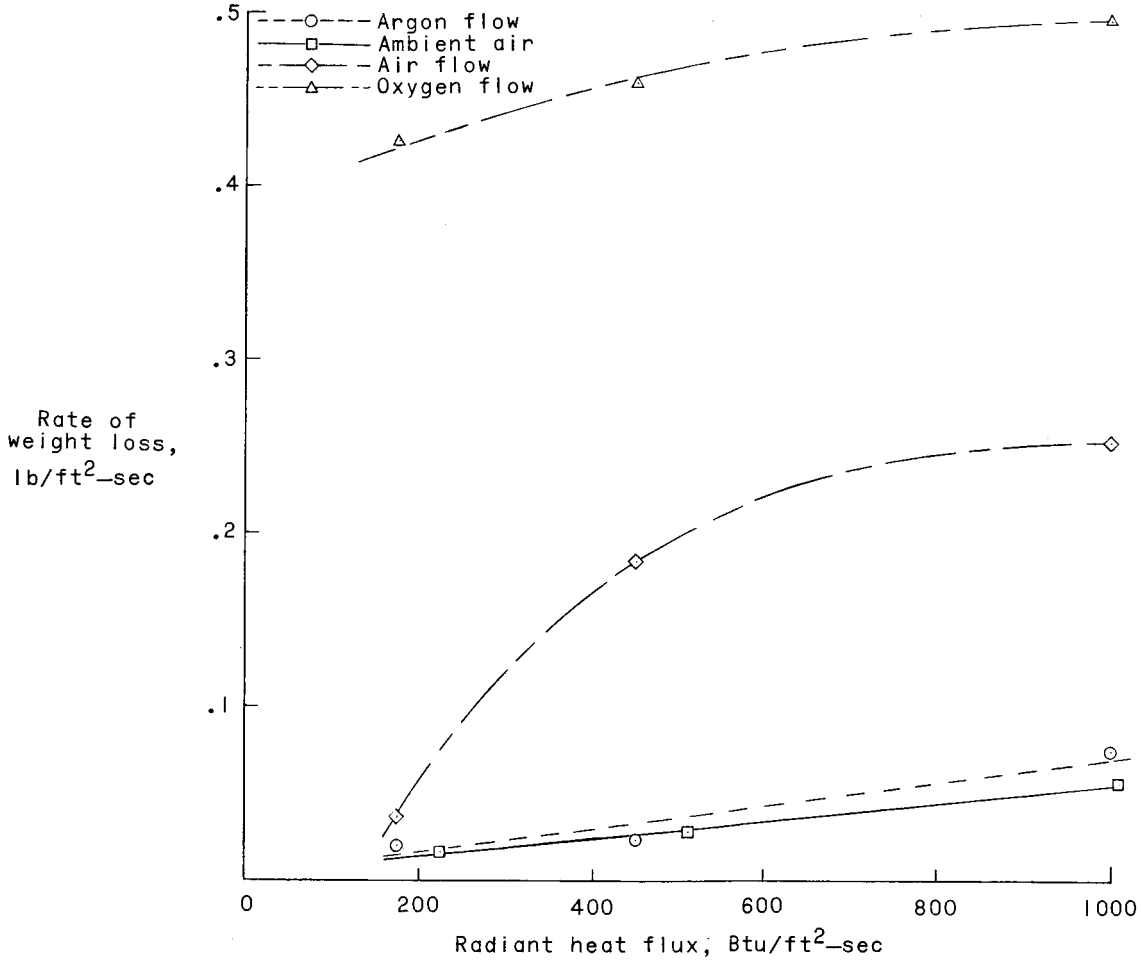

Figure 6.- Oxidation tests of Bakelite in arc-image furnace.

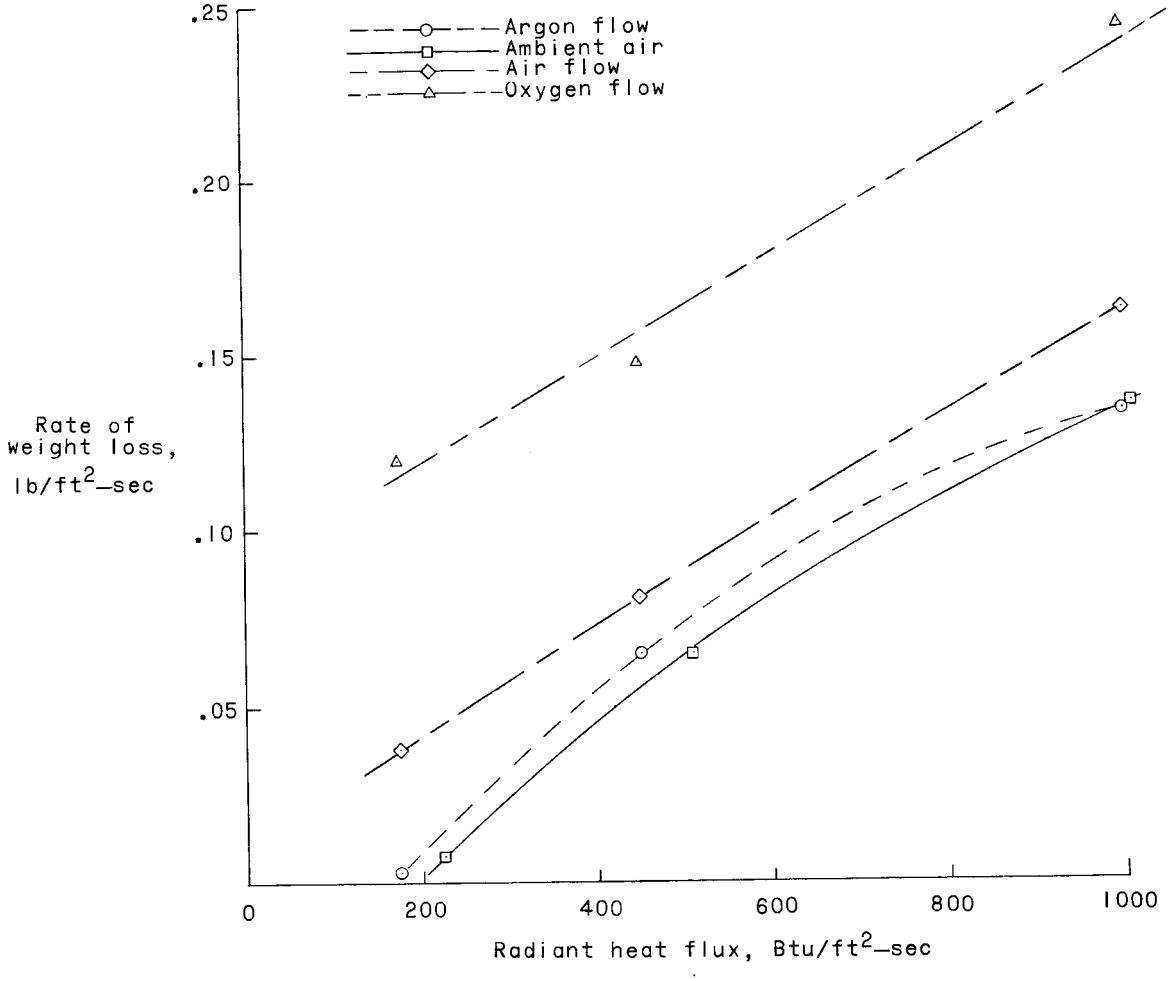

Figure 7.- Oxidation tests of Fiberglas phenolic in arc-image furnace.

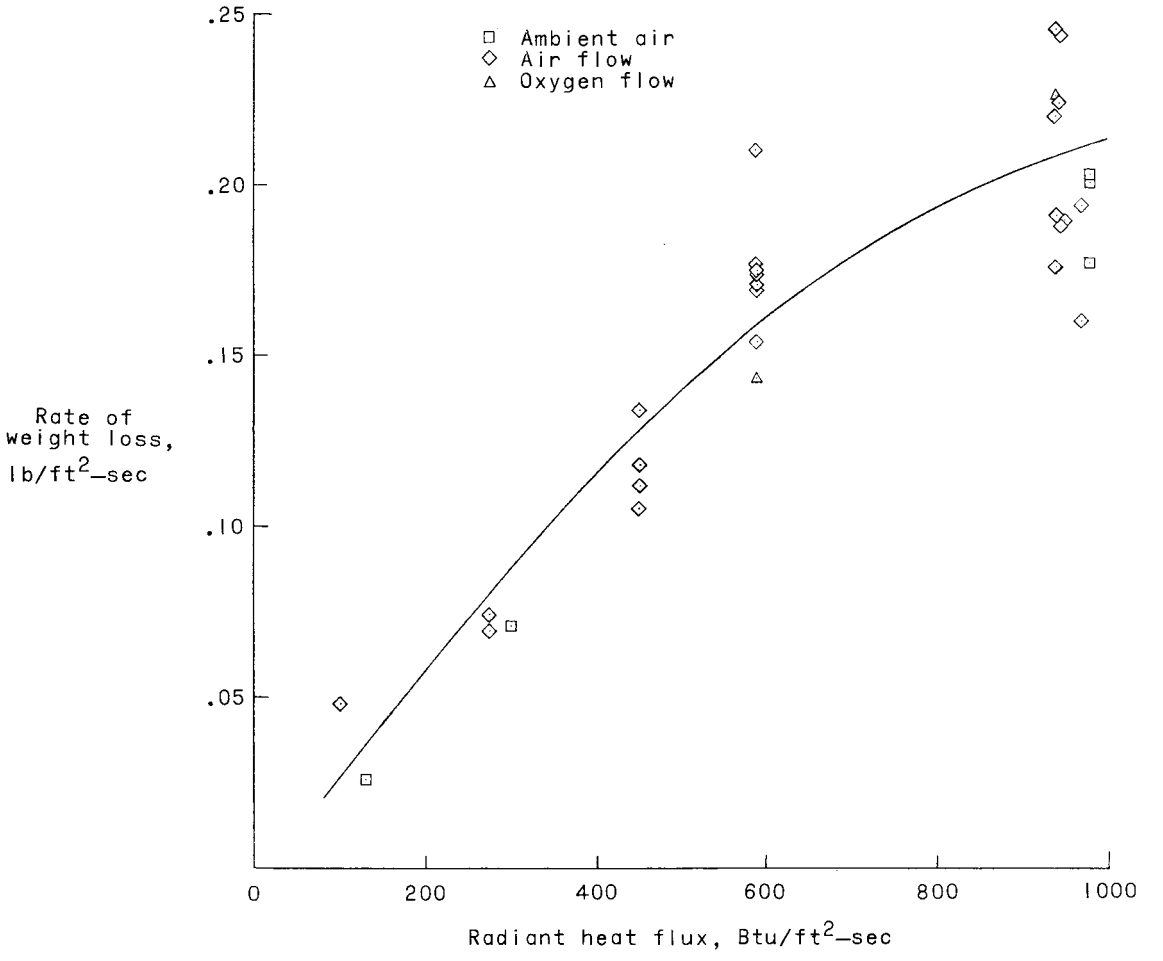

Figure 8.- Oxidation tests of ammonium chloride in arc-image furnace.

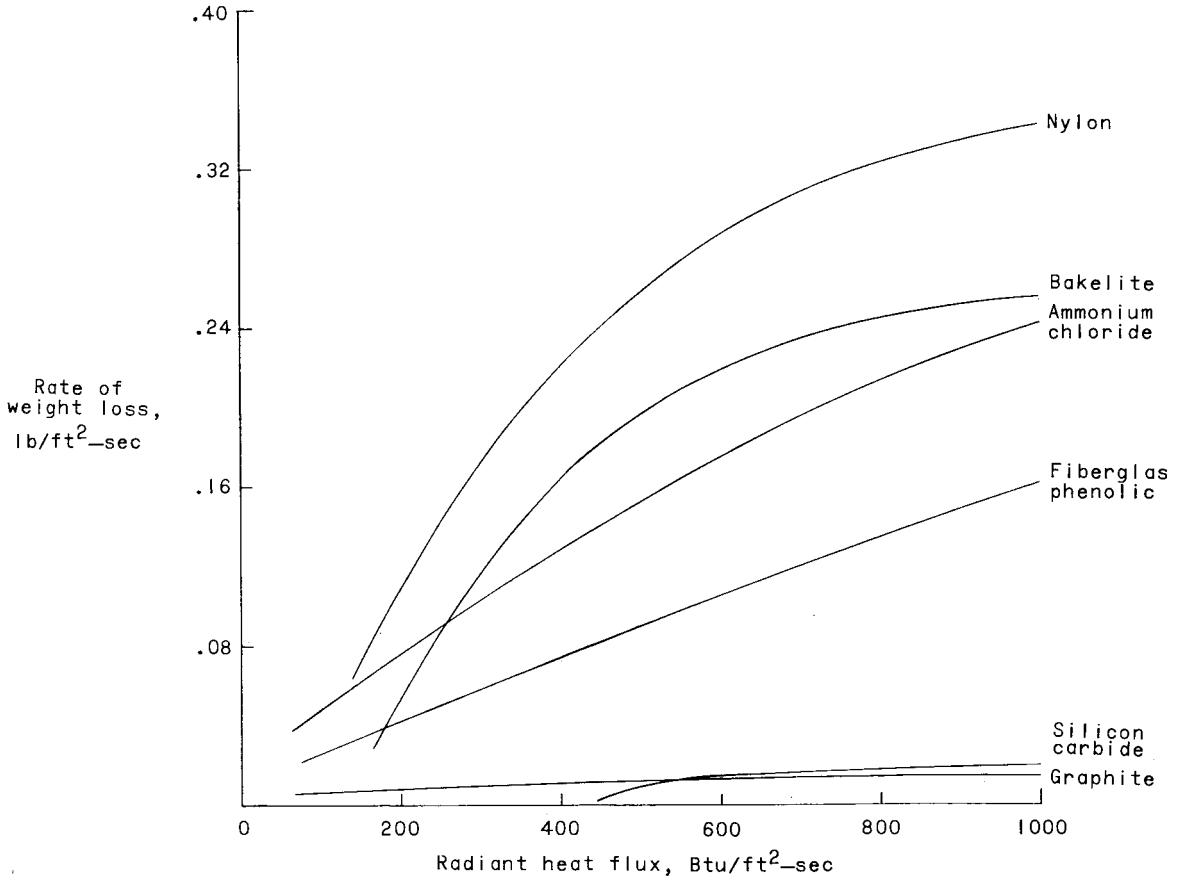

Figure 9.- Comparison of results of oxidation tests of various materials in arc-image furnace with 47 ft/sec air flow.