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WADC TECHNICAL REPORT 54-109
PART 2

SCALING OF TITANIUM AND TITANIUM ALLOYS

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FOREWORD

This report was prepared by the University of Kentucky, in cooperation with the Kentucky Research Foundation, under USAF Contract No. AF 18(600)-60. The contract was initiated under Project No. 7351, "Metallic Materials", Task No. 73510, "Titanium Metal and Alloys", formerly RDO615-11, "Titanium Metal and Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with H. J. Middendorp acting as project engineer.

Acknowledgement is given to the Department of Mining and Metallurgical Engineering of the University of Kentucky for laboratory facilities, to Charles S. Crouse for his interest and direction, to Joseph P. Hammond for suggestions, to Donald F. Clifton for the X-ray studies on scales, to Cullie J. Sparks, Douglas W. Cox and Fritz Mangelsen for their work on this contract, and to Ernest G. Kendall for his assistance in the compilation of this final report.

Howard J. Siegel and Robert C. Duncan are Research Associate and Research Assistant, respectively. Roy E. Swift is immediate supervisor of the activities in connection with Contract No. AF 18(600)-60.

The research covered in this report is for the period January 1, 1954 to June 1, 1955.

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ABSTRACT

A preliminary study of the scaling characteristics in air of experimentally produced titanium and titanium-base alloys was conducted at temperatures of 1200°, 1400°, 1600°, and 1800°F (650°, 760°, 870°, 980°C) in the time range of approximately four to three hundred hours. A total of thirty-six titanium-base alloys were scaled at each of these temperatures. Scales formed on all of the alloys at 1600°F were studied using x-ray diffraction. Scaling propensity of titanium-base alloys relative to unalloyed titanium were evaluated on the basis of weight gain with time. Isothermal transitions were noted for many of the alloys but were not studied in detail. An investigation of gaseous penetration in the commercial materials RC-70, RC-130A, and RC-130B was made at 1600° and 1800°F.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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I. INTRODUCTION

The entrance of titanium into the field of commercial engineering materials has stimulated a considerable amount of research. The possibility of utilizing this non-strategic, corrosion resistant, medium weight material for components in aviation gas turbine engines required research to determine the scaling resistance of various titanium-base alloys at high temperatures. During this investigation a reasonably comprehensive survey of the high temperature scaling resistance of many titanium-base alloys was made.

The objectives of this research were to investigate the scaling phenomena of titanium-base alloys and to develop alloys of high scaling resistance. The alloying elements investigated include: aluminum, cerium, cobalt, copper, chromium, lanthanum, manganese, molybdenum, neodymium, silicon, tantalum, thorium, tungsten, and vanadium in binary, ternary, and quaternary systems.

The investigation also included an x-ray diffraction study of the scales produced on many of the alloys and a study of the depth of gaseous penetration into the base metal for the commercial materials RC-70, RC-130A, and RC-130B.

II. PREPARATION OF TEST SPECIMENS

A. Arc Melting

The arc-melting furnace consists of the following components: a jacket, head, electrode (tungsten), and a copper crucible, all of which are water cooled. Power is supplied to the furnace by three Hobart 400 ampere motor-generator units.

The arc-melting procedure being utilized is as follows:

1. 0.15 lb. of the initial charge is placed in the crucible; the balance of the charge is placed in the charging bottle.

2. The system is sealed and evacuated to a pressure of approximately 10 to 5 microns.

3. The system is flushed with argon for five minutes.

4. The system is again evacuated to approximately 10 to 5 microns pressure.

5. The system is flushed with argon for about two minutes.

6. The motor-generators are started and the arc is struck by lowering the electrode; a potential of 25 to 30 volts and a current of 480 to 540 amperes is used for melting.

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7. The charge is added over a period of from 10 to 25 minutes.

8. The ingot is allowed to cool for ten minutes before the system is opened to the atmosphere and the ingot removed.

B. Fabrication of Ti and Ti Alloy Specimens

The operations which are employed in producing finally prepared specimens of titanium and titanium-base alloys are as follows:

1. Arc melt sponge plus alloy addition.

2. Forge ingot (upsetting in three directions) at temperatures ranging from 1750° to 2300° F.

3. Sand blast forging.

4. Shear forging to approximately 1/8 inch cubes (the forging is usually about 1/8 inch thick).

5. Remelt.

6. Reforge in same manner as previously.

7. Radiograph. (If the radiograph indicates that the forging is not homogenous, it is remelted and forged until homogeneous before processing further.)

8. Machine sides and bottom of ingot if necessary (in order to remove any cold shuts and unmelted particles which otherwise would contribute to surface defects and discontinuities in the forged product).

9. Reforge in same manner as previously.

10. Sand blast and grind faces and edges of forging.

11. Cut forging (approximate dimensions 10"x3"x1/8") into strips of approximate dimensions 1-1/16"x3"x1/8" with a radial cut-off wheel (using a soluble oil type coolant).

12. Roll strips (at 1450° F.) to approximate dimensions 8"x1-1/16"x0.060".

13. Cut strips to a length slightly in excess of 2" and precision grind to final specimen dimensions of 1"x2"x approximately 0.050".

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Considerable difficulty was encountered in the processing of some of the alloys containing rare earth additions. This was particularly true in some cases with additions of 2% Cerium. Difficulty was also encountered in one case with 1% Neodymium and in another instance with 1.5% mixed rare earths. In attempting to forge these alloys after the initial melt they were found to be unworkable, and the ingots broke apart and were badly oxidized. In the case of the 4% Cr - 2% Ce-Ti composition after the first ingot broke apart during forging it was decided to remake this alloy by melting the sponge first, forging the unalloyed ingot, and then make the alloy additions during the remelting of the ingot. This attempt proved to be fruitless for during the forging of the ingot after remelting the same difficulty was encountered and the ingot had to be discarded (Fig. 1). An attempt to produce a titanium ingot of approximate composition 4% Al - 4% Mn - 1.5% mixed rare earths using a 39.4% aluminum - 47.1% manganese - 13.5% mixed rare earth master alloy (furnished by the Materials Laboratory, W.A.D.C.) failed when the ingot broke apart and oxidized during forging. Five compositions were found to be unworkable and the ingots were of necessity discarded. The alloys in this group are the 4% Cr - 2% Ce-Ti alloy mentioned above and the 4% W - 1%Si - 2%Ce-Ti, 2%Ni - 1%Cu - 2%Ce-Ti, 2%Ni - 1%Cu - 1%Nd - Ti, and 4%Al - 4%Mn - 1.5% mixed rare earth alloys.

In rolling the 2% Ce-Ti alloy, at 2000° F. severe cracking occurred and a temperature of 2400° F. was required to successfully roll this alloy.

Considerable difficulty was encountered in the fabrication of specimens, particularly from the alloys in the second and third groups. Many of the alloys were extremely hard and brittle and cracked during fabrication, necessitating the use of sub-sized specimens. Two alloys (4%W - 1%Si - 1%Nd-Ti and 4%Si - 1%Th-Ti) were so brittle that they shattered while being surface ground and were, therefore, discarded. Many of the alloys were so hard that a tungsten carbide drill bit was required to drill the hole in the specimens by which they are suspended in the scaling furnace. Data on the difficulty of fabrication of the alloys are included in Table 1.

C. Analytical Results

The concentration of alloying elements in the binary, ternary, and commercial alloys employed in the scaling tests is given in Table I.

Considerable difficulty was encountered in attempts to determine the amount of tungsten contamination in the arc-melted ingots. Analyses were run by a commercial laboratory using a chemical semi-quantitative method in conjunction with spectrographic data. Results of the tungsten analyses made by two different laboratories varied as much as one per cent, causing some doubt as to the accuracy of the results. Since all the determinations did show considerable amounts of tungsten present, the variation in amount is either due to the sampling or

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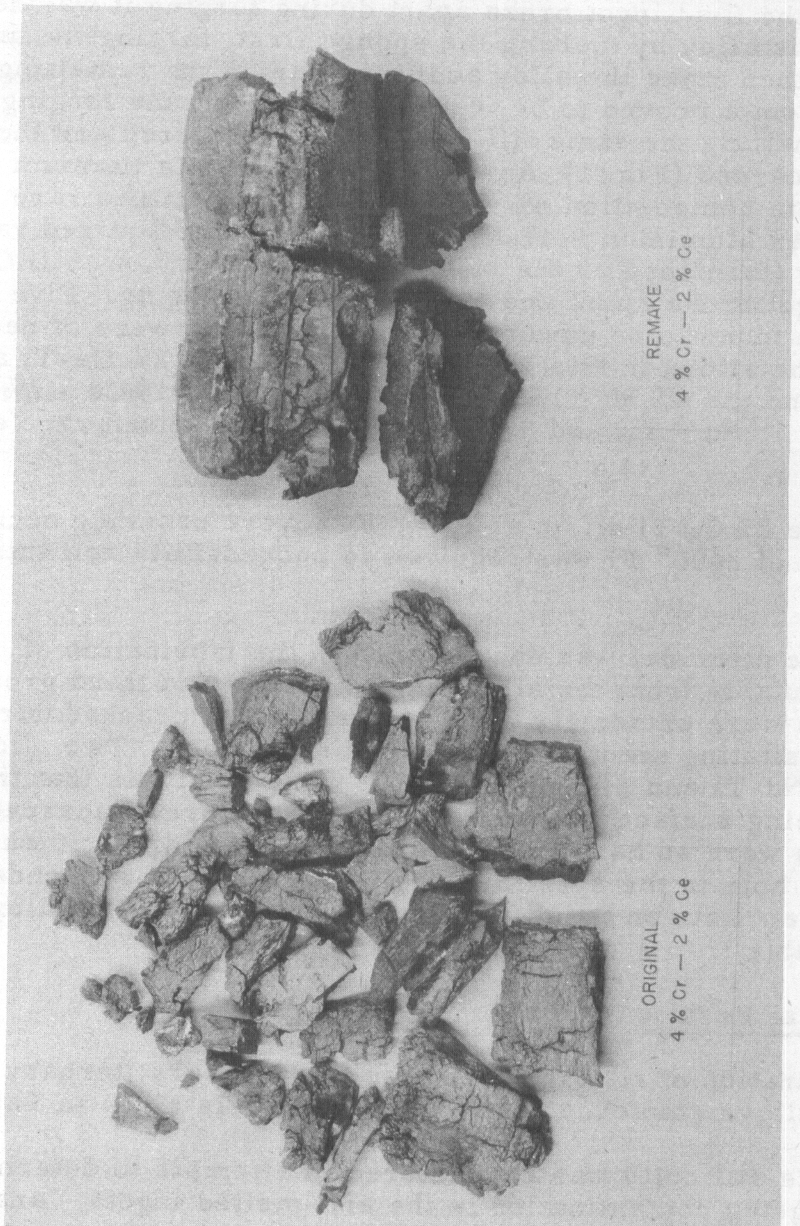

Fig. 1 Photograph of Discarded 4% Cr - 2% Ce - Ti Ingots

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TABLE I

INTENDED COMPOSITION, ANALYSIS, AND WORKABILITY DATA ON TITANIUM ALLOYS

Group	Melt No.	Intended Composition	Actual Composition	Tungsten Contamination	Times# Melted & Forged	Fabrication Workability
Group I	120	1%Ta - 1%Si	1.10%Ta - 0.96%Si	0.37%	6	VD
	121	2%Ta - 1%Si	2.33%Ta - 0.98%Si	0.68%	7	VD
	122	3%Ta - 1%Si	3.00%Ta - 0.90%Si	0.25%	7	VD
	123	4%Al - 1%Si	4.20%Al - 0.93%Si	0.08%	3	D
	124	6%Al - 0.5% Si	6.03%Al - 0.48%Si	0.12%	3	D
	125	4%Al - 0.5% Si	4.17%Al - 0.47%Si	0.08%	3	D
	126	0.5%Co	0.42%Co	0.08%	3	N
	127	1%Co	0.91%Co	0.93%	5	N
	128	2%Co	2.65%Co	0.25%	6	N
	129	0.5%Co - 0.5%Si	0.43%Co - 0.72%Si	0.23%	3	D
	130	1%Co - 0.5%Si	1.08%Co - 0.90%Si	0.12%	4	D
	134	1%Al - 3%Mn	0.93%Al - 2.92%Mn	0.28%	3	N
Group II	133	1%Al - 3%Mo	0.83%Al - 3.00%Mo	0.62%	6	D
	135	6%Al - 3% Mo	6.06%Al - 2.88%Mo	0.88%	6	VD
	136	2%Ce	1.56%Ce	0.55%	2	D
	137	1%La	0.85%La	1.50%	3	D
	138	1%Nd	0.77%Nd	0.32%	3	D
	139	2%Ce - 1%Mo	1.62%Ce - 1.00%Mo	1.90%	4	ED
	140	1%La - 4%Si	0.65%La - 1.83%Si	1.08%	3	VD
	141	1%Nd - 1%Mo	0.64%Nd - 1.00%Mo	2.10%	4	VD
	147	1%La - 1%V	0.63%La - 1.00%V	0.65%	3	D
	148	4%Cr - 1%Nd	3.93%Cr - 0.80%Nd	0.83%	3	D
	158	2%Co - 0.5%Si	1.70%Co - 0.50%Si	2.13%	3	D
	159	6%Al - 4%V	6.03%Al - 4.08%V	1.08%	5	D
Group III	143	4%Ta - 1%Si - 1%La	3.52%Ta - 0.84%Si - 0.82%La	1.45%	7	VD
	144*	4%W - 1%Si - 1%Nd	*-----------------#	Too brittle	2	I
	150	4%Cr - 1%Mn - 1%La	4.06%Cr - 0.97% Mn 1.30%La	3.16%	3	ED
	152	1%Th	0.78%Th	3.66%	5	VD
	153	4%Ta - 1%Si - 1%Th	1.90%Ta - 0.56%Si - 1.08%Th	2.12%	7	VD
	154	4%Cr - 1%Mn - 1%Th	3.84%Cr - 0.75%Mn - 1.25%Th	3.50%	4	ED
	155*	4%Si - 1%Th	*-----------------#	Too brittle	1	I
	156	1%V - 1%Th	0.94%V - 1.15%Th	0.71%	3	VD
	157	0.5%Ce	0.56%Ce	3.33%	4	VD
	160	2%Al - 4%V	2.20%Al - 4.00%V	3.58%	4	VD
	161	6%Al - 2%Mo - 0.5%Si	6.05%Al - 1.97%Mo - 0.48%Si	1.75%	6	VD
	162	4%W - 1%La	5.95%W - 0.66%La	1.95% Min	6	ED
	BV	120AV (6Al-4V)				N
	AS	110AT (5Al-2.5Sn)				N

*Alloy extremely brittle, shattered during finish grinding.
#Alloy radiographically homogeneous.
N - Normal, D - Difficult, VD - Very Difficult, I - Impossible, ED - Extremely Difficult.

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analytical technique and tungsten must be present in approximately the amounts shown in Table I.

No appreciable change has been made in the arc-melting technique which could account for this increase in tungsten contamination over that found in alloys produced previously. A change in the source of the tungsten electrode material was made during the past year and this might possibly be responsible for the increased contamination found in the alloys.

III. TEST EQUIPMENT

Scaling Furnace

The description of the scaling furnace, based on a furnace used by Day and Smith[1], is as follows:

An annular muffle comprises two concentrically positioned refractory cores on which are mounted Nichrome-V windings. The cores with their windings facing the heating chamber constitute the vertical walls of the muffle. (The top and bottom of the heating chamber are bounded by refractory material which constitute the horizontal walls of the muffle.) The specimens to be scaled are suspended from the furnace top by Nichrome ribbons. The top is mounted on a vertical shaft located in the center of the furnace and is slowly rotated by means of a gear arrangement and an electric motor. This rotation of the furnace top insures that the specimens will be maintained at reasonably constant temperatures, up to a maximum of 2000° F., for sustained periods of operation.

Desiccated and metered air is furnished to the heating chamber by a variable capacity blower. Prior to its introduction to the heating chamber the air is preheated to approximately 500° F. Preheating is accomplished by passing the air through about 35 feet of resistance heated Nichrome-V tubing.

The temperature of the furnace is regulated by a thermocouple included in the circuit of a controlling-recording potentiometer. Several symmetrically positioned thermocouples also are included in the circuit and serve as a check on temperature distribution throughout the furnace as a whole.

An analytical balance mounted above the furnace provides a means of determining the weight change of specimens without entailing their removal from the furnace. The furnace top is indexed in order to facilitate rapid identification of the specimens just prior to weighing.

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IV. EXPERIMENTAL RESULTS

A. Scaling Data and Results

Scaling data, of the weight increase versus time type, obtained at 1200°, 1400°, 1600°, and 1800° F. is presented in tabulated form in Tables 12 - 15*, 17 - 20*, and 21 - 24*; and graphically in Figures 3-5 and 30-41*.

Scaling data of the weight increase versus temperature type (at constant exposure time) is presented in tabulated form in Tables 25*, 26*, and 27* and graphically in Figures 5, 6, and 7.

Short time scaling data and data on the gaseous penetration and inches penetration are presented in tabulated form in Tables 28* to 36* and graphically in Figures 10-15 for the commercial materials RC-70, RC-130A, and RC-130B.

1. Experimental Alloys of Group I

The composition of the experimental titanium-base alloys included in this group is given in Table I. Alloys in this group include binary compositions containing cobalt; ternary compositions containing silicon with tantalum, aluminum or cobalt; and one ternary containing aluminum and manganese.

Of the alloys investigated in this group those ternary alloys containing additions of tantalum and silicon, cobalt and silicon, and aluminum and silicon, were generally more resistant to scaling than unalloyed titanium. Binary alloys containing cobalt, and ternary alloys containing aluminum and manganese were generally less resistant to scaling than unalloyed titanium. (See Figs. 2 and 30 to 33* and Tables 2, 3, and 12 to 15*).

Discontinuities in the scaling rate of many of these alloys were observed at 1400°, 1600°, and 1800° F. (Fig. 2). Tabulated data on the adherence of the scale when air cooled from the scaling temperature to room temperature for the alloys in this group are given in Table 16*. There is a general correlation between the scaling rate and the adherence to the base metal of the scale formed. The adherence of the scale seems to be completely dependent upon scale thickness. This may possibly be explained as follows: For extremely thin scales the compressive stress developed in the scale by differences in specific volume of the scale and base metal and differences in thermal expansion is not sufficient to rupture the scale and cause spalling. For scales of intermediate thickness the compressive stress developed in the scales by differences in specific volume and thermal expansion is sufficient to cause buckling and subsequent spalling of the scale. For scales of great thickness, however, the stiffness or rigidity of the scale is sufficiently high to withstand any buckling which would be caused by the compressive stress developed and no spalling occurs. Therefore, the scale formed on an alloy which is either extremely resistant to, or

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very poorly resistant to scaling will or will not spall, depending upon the thickness of the scale developed.

The relative scaling resistance of those alloys more resistant to scaling than unalloyed titanium generally increased with increasing temperature (Tables 2 and 3). The effect of increasing comparative scaling resistance of the alloys with increasing temperature is also shown in Table 25* and Figure 5 where the weight increase at 48 hours at each temperature is compared.

Increasing tantalum content from 1 to 3 per cent with silicon content held constant at approximately 1 per cent slightly increased the scaling resistance, particularly at the higher exposure temperatures. Increasing aluminum content from 4 to 6 per cent with silicon content held constant at one-half of one per cent was slightly detrimental to scaling resistance; however, increasing the silicon content from one-half to one per cent while holding the aluminum content constant at four per cent improved the scaling resistance of the alloy.

Cobalt additions from one-half to two per cent did not appear to be particularly beneficial so far as scaling resistance is concerned; however, the optimum amount appears to be approximately one per cent.

It should be noted that the tungsten contamination in some of the alloys in this group is extremely high, and this will necessarily influence the scaling resistance. The data obtained may, therefore, be in error to some extent.

*An asterisk following a Figure or Table Number denotes that those Figures or Tables are located in the appendix.

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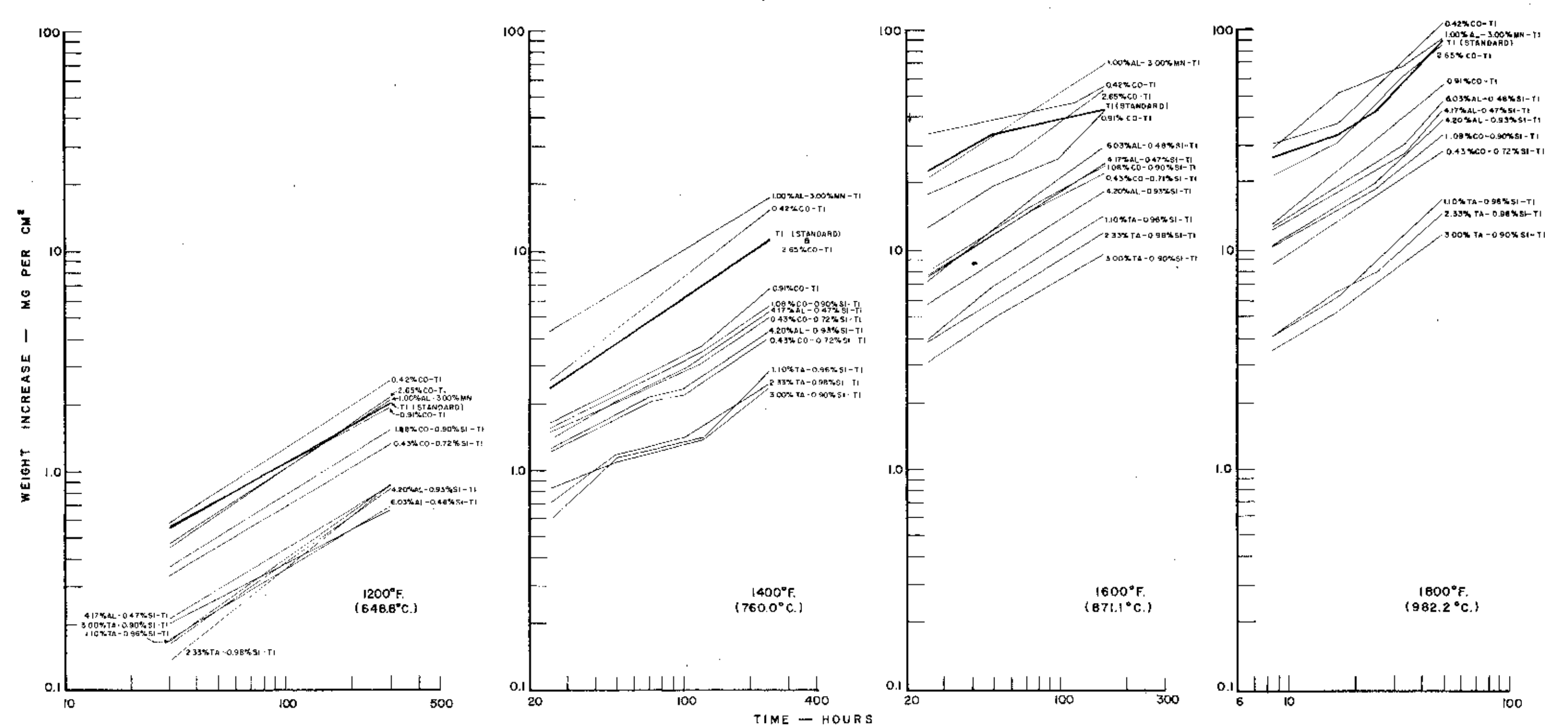
GROUP I ALLOYS



WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME FOR TITANIUM ALLOYS AT 1200, 1400, 1600, 1800°F.

FIG. 2

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TABLE 2

SCALING PROPENSITY RELATIVE TO TITANIUM

FOR GROUP I ALLOYS

Data Obtained from Scaling Tests at 1200°F. and 1400°F.
Exposure Period 48 Hours

1200°F.		1400°F.	
Composition of Alloy	Average Total Weight Increase (mg) Per Average Original Unit Area (cm^2) Relative to Ti = 100%	Composition of Alloy	Average Total Weight Increase (mg) Per Average Original Unit Area (cm^2) Relative to Ti = 100%
2.33% Ta-0.98% Si	31.7	3.00% Ta-0.90% Si	29.4
4.20% Al-0.93% Si	31.7	1.10% Ta-0.96% Si	30.0
6.03% Al-0.48% Si	34.9	2.33% Ta-0.98% Si	31.7
1.10% Ta-0.96% Si	36.5	6.03% Al-0.48% Si	45.6
3.00% Ta-0.90% Si	41.3	4.20% Al-0.93% Si	47.8
4.17% Al-0.47% Si	42.9	4.17% Al-0.47% Si	54.7
0.43% Co-0.72% Si	69.8	0.43% Co-0.72% Si	54.7
1.08% Co-0.90% Si	76.2	1.08% Co-0.90% Si	57.8
0.93% Al-2.92% Mn	97.8	0.91% Co	61.7
Ti Standard	100.0	Ti Standard	100.0
2.65% Co	111.1	2.65% Co	100.0
0.91% Co	112.7	0.42% Co	115.0
0.42% Co	122.2	0.93% Al-2.92% Mn	172.5

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TABLE 3

SCALING PROPENSITY RELATIVE TO TITANIUM

FOR GROUP I ALLOYS

**Data Obtained from Scaling Tests at 1600°F. and 1800°F.
Exposure Period 48 Hours**

1600°F.		1800°F.	
Composition of Alloy	Average Total Weight Increase (mg) Per Average Original Unit Area (cm^2) Relative to Ti = 100%	Composition of Alloy	Average Total Weight Increase (mg) Per Average Original Unit Area (cm^2) Relative to Ti = 100%
3.00% Ta-0.90% Si	14.7	3.00% Ta-0.90% Si	13.1
2.33% Ta-0.98% Si	17.6	2.33% Ta-0.98% Si	16.5
1.10% Ta-0.96% Si	20.5	1.10% Ta-0.96% Si	19.0
4.20% Al-0.93% Si	26.5	0.43% Co-0.72% Si	31.1
4.17% Al-0.47% Si	35.2	1.08% Co-0.90% Si	36.9
0.43% Co-0.72% Si	35.5	4.20% Al-0.93% Si	43.3
1.08% Co-0.90% Si	37.0	4.17% Al-0.47% Si	47.6
6.03% Al-0.48% Si	37.3	6.03% Al-0.48% Si	52.8
0.91% Co	58.8	0.91% Co	63.6
2.65% Co	73.2	2.65% Co	95.3
0.93% Al-2.92% Mn	99.4	Ti Standard	100.0
Ti Standard	100.0	0.93% Al-2.92% Mn	101.7
0.42% Co	118.7	0.42% Co	118.4

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2. Experimental Alloys of Group II

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The composition of the titanium-base alloys to be considered in this group is given in Table I. Alloys in this group include binary compositions containing cerium, lanthanum, and neodymium and ternary compositions containing molybdenum with aluminum, cerium or neodymium; silicon with lanthanum or cobalt; vanadium with aluminum or lanthanum; and one alloy containing chromium and neodymium.

Of the alloys in this group those containing cerium, neodymium, aluminum with molybdenum or vanadium, cobalt and silicon, and lanthanum with silicon or vanadium were generally more resistant to scaling than unalloyed titanium; alloys containing chromium and neodymium, and cerium and molybdenum were consistently less resistant to scaling than unalloyed titanium. (See Figs. 3 and 34 to 37* and Tables 4, 5 and 17 to 20*.)

Discontinuities in the scaling rate of many of these alloys were observed at 1400°, 1600°, and 1800°F. (Fig. 3). As was noted previously the relative scaling resistance of those alloys more resistant to scaling than unalloyed titanium generally increased with increasing temperature (Tables 4 and 5 and Fig. 6).

The addition of cerium and neodymium to titanium gave increasing scaling resistance, compared to unalloyed titanium, with increasing temperature. The addition of lanthanum to titanium increased the scaling resistance, compared to unalloyed titanium, up to 1600°F., at 1800°F., however lanthanum was found to be extremely detrimental.

The addition of one per cent neodymium to a four per cent chromium - titanium binary alloy was particularly effective at the higher temperatures in increasing the scaling resistance of this relatively poor alloy. The addition of one per cent neodymium or two per cent cerium to the binary composition of one per cent molybdenum - titanium had no beneficial effect on the scaling resistance. The addition of lanthanum to a one per cent silicon - titanium binary alloy was generally beneficial up to 1600°F. The addition of one per cent lanthanum to a one per cent vanadium - titanium binary alloy was generally beneficial.

Increasing the aluminum content from one to six per cent with molybdenum held constant at three per cent produced a beneficial effect on the scaling resistance of the alloy. Holding the aluminum content constant at six per cent and replacing three per cent molybdenum with four per cent vanadium was detrimental to the scaling resistance of the alloy, particularly at 1200° and 1400°F.

As was stated previously, tungsten contamination in some of these alloys was extremely high and the above data may be in error to some extent.

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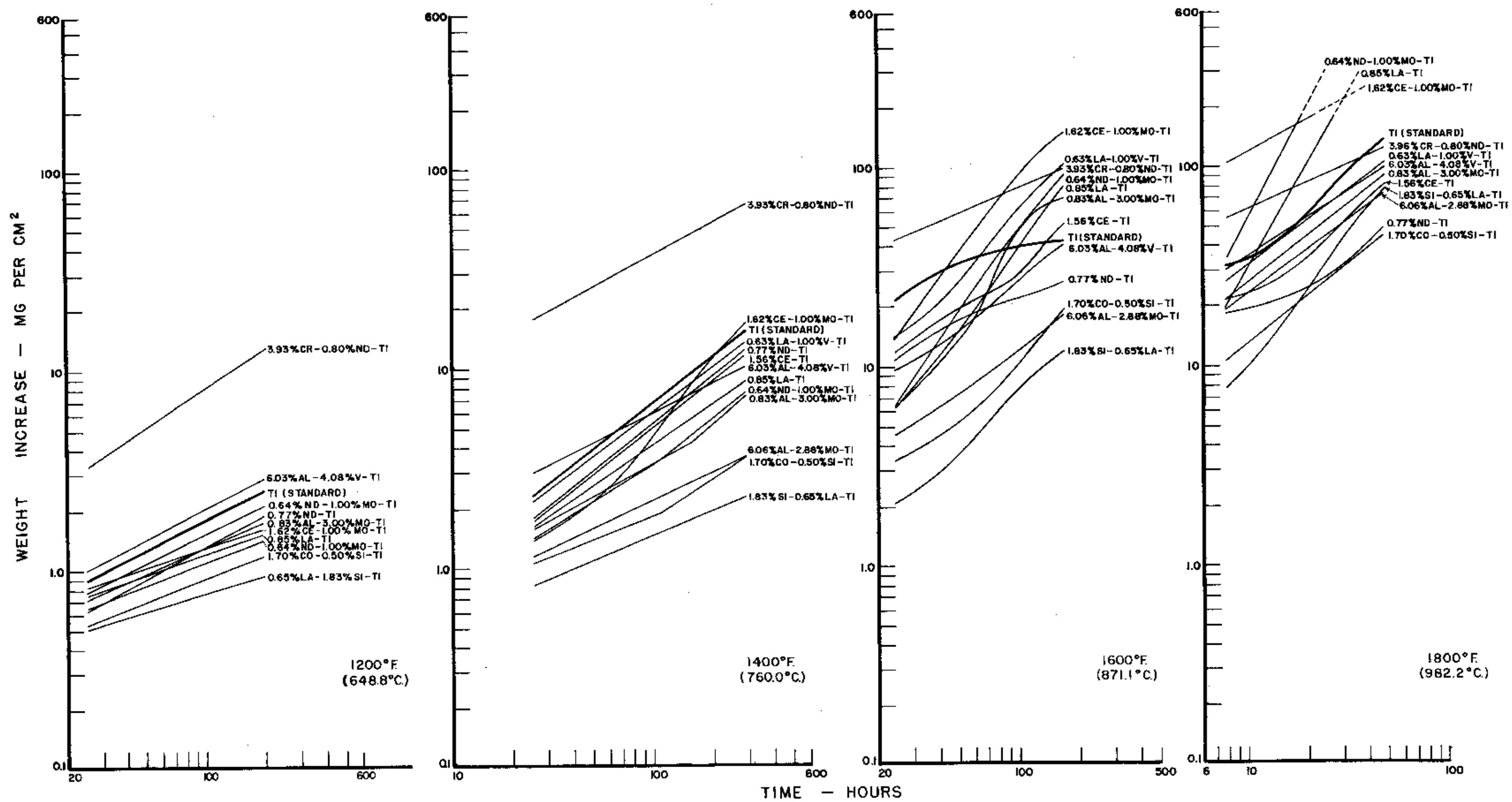

WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME FOR GROUP 2 ALLOYS AT 1200°, 1400°, 1600°, 1800°F.

FIG. 3

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TABLE 4

RELATIVE SCALING PROPENSITY OF GROUP II ALLOYS AT 1200° and 1400°F.

EXPOSURE TIME - 48 HOURS

1200°F.		1400°F.	
Composition of Specimens (Weight per cent)	Av. Total Wt. Increase Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%	Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%
6.06 Al-2.88 Mo	51.8	0.65 La-1.83 Si	27.8
0.65 La-1.83 Si	67.3	1.70 Co-0.50 Si	35.4
1.70 Co-0.50 Si	74.9	6.06 Al-2.88 Mo	40.4
0.64 Nd-1.00 Mo	90.8	1.62 Ce-1.00 Mo	54.5
1.56 Ce	94.4	0.64 Nd-1.00 Mo	54.5
Ti	100.0	0.83 Al-3.00 Mo	58.0
0.85 La	102.2	0.85 La	65.4
0.83 Al-3.00 Mo	103.3	1.56 Ce	73.5
0.77 Nd	103.3	0.77 Nd	77.2
1.62 Ce-1.00 Mo	112.1	0.63 La-1.00 V	91.1
0.63 La-1.00 V	117.6	Ti	100.0
6.03 Al-4.08 V	152.7	6.03 Al-4.08 V	108.4
3.93 Cr-0.80 Nd	550.5	3.93 Cr-0.80 Nd	656.2

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TABLE 5

RELATIVE SCALING PROPENSITY OF GROUP II ALLOYS AT 1600° and 1800°F.

EXPOSURE TIME - 48 HOURS

1600°F.		1800°F.	
Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%	Composition of Specimens (Weight per Cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%
0.65 La-1.83 Si	10.6	1.70 Co-0.50 Si	32.2
1.70 Co-0.50 Si	15.7	0.77 Nd	35.5
6.06 Al-2.88 Mo	20.7	6.06 Al-2.88 Mo	52.3
0.83 Al-3.00 Mo	39.0	0.65 La-1.83 Si	52.3
0.85 La	42.6	1.56 Ce	55.1
6.03 Al-4.08 V	44.8	0.83 Al-3.00 Mo	62.1
0.77 Nd	50.7	6.03 Al-4.08 V	70.9
0.64 Nd-1.00 Mo	55.0	0.63 La-1.00 V	76.1
1.56 Ce	56.8	3.93 Cr-0.80 Nd	90.3
0.63 La-1.00 V	77.9	Ti	100.0
Ti	100.0	1.62 Ce-1.00 Mo	208.2
3.93 Cr-0.80 Nd	175.9	0.85 La	370.9
1.62 Ce-1.00 Mo	185.0	0.64 Nd-1.00 Mo	783.6

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3. Experimental Alloys of Group III.

The composition of the titanium-base alloys in this group is given in Table I. Alloys in this group include binary compositions containing thorium and cerium; ternary compositions containing tungsten with lanthanum, and vanadium with thorium or aluminum; and quaternary compositions containing tantalum, silicon, and either lanthanum or thorium; chromium, manganese, and either lanthanum or thorium; and one alloy containing aluminum, molybdenum, and silicon. Included in this group were two commercial alloys, C-120AV (6Al - 4V-Ti) and A 110 AT (5 Al - 2.5 Sn - Ti).

Of the alloys in this group, those containing tantalum, silicon, and either lanthanum or thorium; aluminum, molybdenum, and silicon; aluminum and vanadium; and thorium were generally more resistant to scaling than unalloyed titanium. (See Fig. 4 and 38 to 41* and Tables 6, 7, and 21 to 24*.)

Discontinuities in the scaling rate of many of the alloys were observed at 1600°F. and also a few at 1800°F. (Fig. 4, 23* and 24*.)

The addition of either thorium or lanthanum to a ternary composition containing four per cent tantalum and one per cent silicon was slightly detrimental to the scaling resistance of the alloy. Additions of one per cent thorium or lanthanum to a ternary alloy containing four per cent chromium and one per cent manganese greatly increased the scaling resistance of this poor scaling resistant alloy, particularly at the higher exposure temperatures (1400° to 1800°F.). The addition of one per cent thorium or one-half per cent cerium to titanium increased the scaling resistance; however, at 1800°F. the one half per cent cerium alloy scaled at about twice the rate of unalloyed titanium. Addition of one per cent lanthanum to a binary alloy containing one per cent vanadium improved the scaling resistance of the alloy, particularly at the higher scaling temperatures (Fig. 7).

As was mentioned in connection with the previous groups of alloys, tungsten contamination in this group of alloys is also extremely high and the conclusions and data given above may be in error to some extent.

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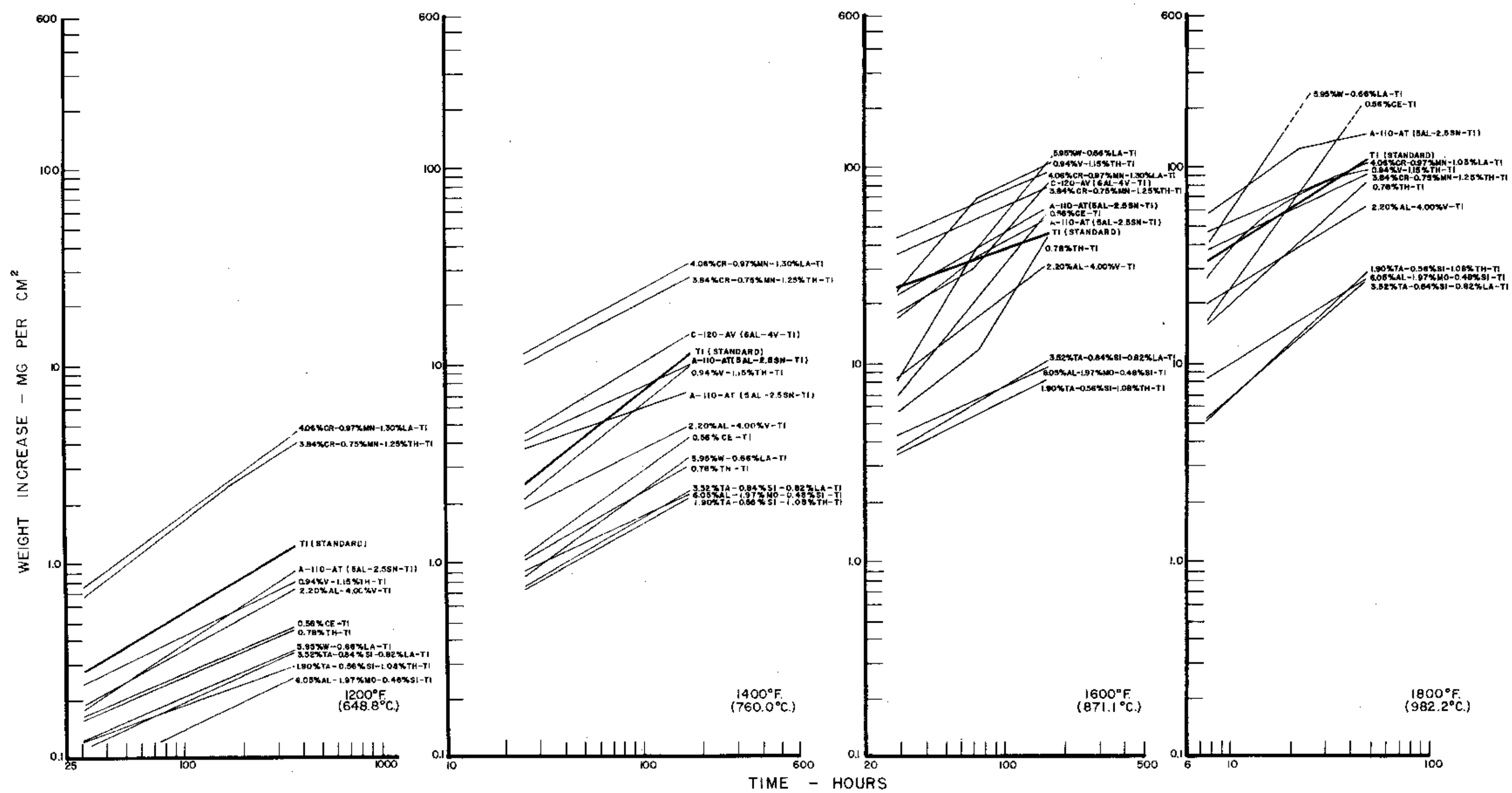

WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME FOR GROUP 3 ALLOYS AT 1200°, 1400°, 1600°, 1800°F.

FIG. 4

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TABLE 6

RELATIVE SCALING PROPENSITY OF GROUP III ALLOYS AT 1200° and 1400°F.

EXPOSURE TIME - 48 HOURS

1200°F.

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%
6.05 Al-1.97 Mo-0.48 Si	27.0
3.52 Ta-0.84 Si-0.82 La	37.3
1.90 Ta-0.56 Si-1.08 Th	39.1
5.95 W-0.66 La	40.9
0.78 Th	51.8
0.56 Ce	53.6
5Al-2.5 Sn*	64.6
2.20 Al-4.00 V	65.6
0.94 V-1.15 Th	80.0
Ti	100.0
3.84 Cr-0.75 Mn-1.25 Th	249.1
4.06 Cr-0.97 Mn-1.30 La	275.5

1400°F.

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area(cm^2) Relative to Ti = 100%
1.90 Ta-0.56 Si-1.08 Th	24.6
3.52 Ta-0.84 Si-0.82 La	26.0
6.05 Al-1.97 Mo-0.48 Si	28.7
5.95 W-0.66 La	31.7
0.78 Th	35.2
0.56 Ce	40.7
2.20 Al-4.00 V	60.9
0.94 V-1.15 Th	83.7
Ti	100.0
5 Al-2.5 Sn*	110.3
6 Al-4 V (C-120 AV)	156.3
3.84 Cr-0.75 Mn-1.25 Th	335.6
4.06 Cr-0.97 Mn-1.30 La	381.6

* (A-110AT)

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TABLE 7

RELATIVE SCALING PROPENSITY OF GROUP III ALLOYS AT 1600° and 1800°F.

EXPOSURE TIME - 48 HOURS

1600°F.		1800°F.	
Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%	Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%
1.90 Ta-0.56 Si-1.08 Th	15.2	3.52 Ta-0.84 Si-0.82 La	24.5
3.52 Ta-0.84 Si-0.82 La	16.8	6.05 Al-1.97 Mo-0.48 Si	24.9
6.05 Al-1.97 Mo-0.48 Si	18.5	1.90 Ta-0.56 Si-1.08 Th	27.0
0.78 Th	28.5	2.20 Al-4.00 V	59.5
2.20 Al-4.00 V	42.7	0.78 Th	77.8
0.56 Ce	42.9	3.84 Cr-0.75 Mn-1.25 Th	85.7
5.95 W-0.66 La	63.4	0.94 V-1.15 Th	91.4
6 Al-4 V (C-120AV)	82.6	4.06 Cr-0.97 Mn-1.30 La	97.2
Ti	100.0	Ti	100.0
5 Al-2.5 Sn*	101.1	5 Al-2.5 Sn*	137.0
0.94 V-1.15 Th	141.5	0.56 Ce	185.2
3.84 Cr-0.75 Mn-1.25 Th	152.6	5.95 W-0.66 La	592.6
4.06 Cr-0.97 Mn-1.30 La	184.7		

* (A-110AT)

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B. Weight Increase Versus Temperature

The relationship between weight increase and temperature in the temperature range from 1200° to 1800° F. (time constant at 48 hours) for the three groups of alloys under consideration is shown in Figs. 5, 6, and 7. These data are also presented in tabulated form in Tables 25*, 26*, and 27*.

The scaling resistance of those alloys more resistant to scaling than unalloyed titanium generally increases with increasing temperature.

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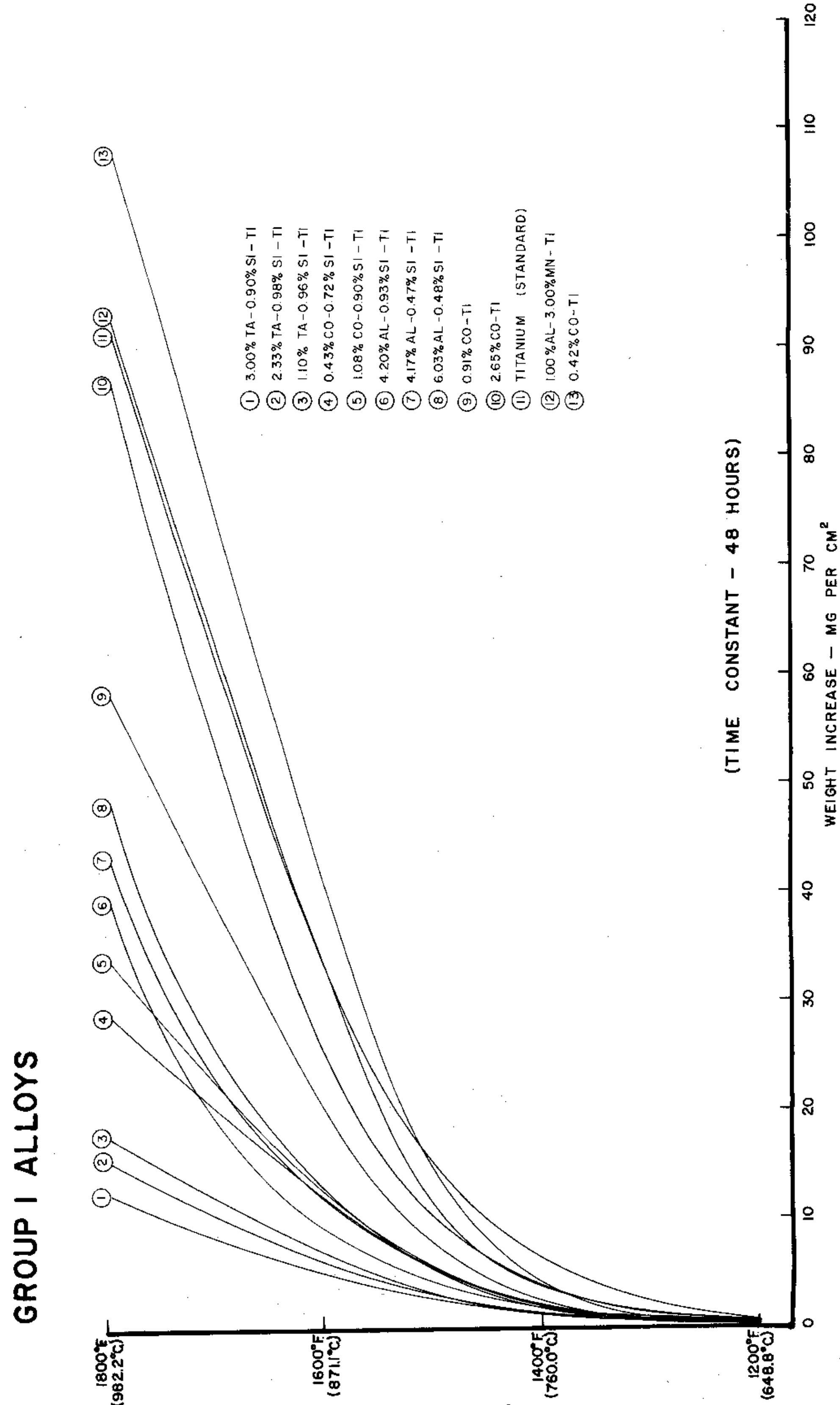

FIG. 5 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE

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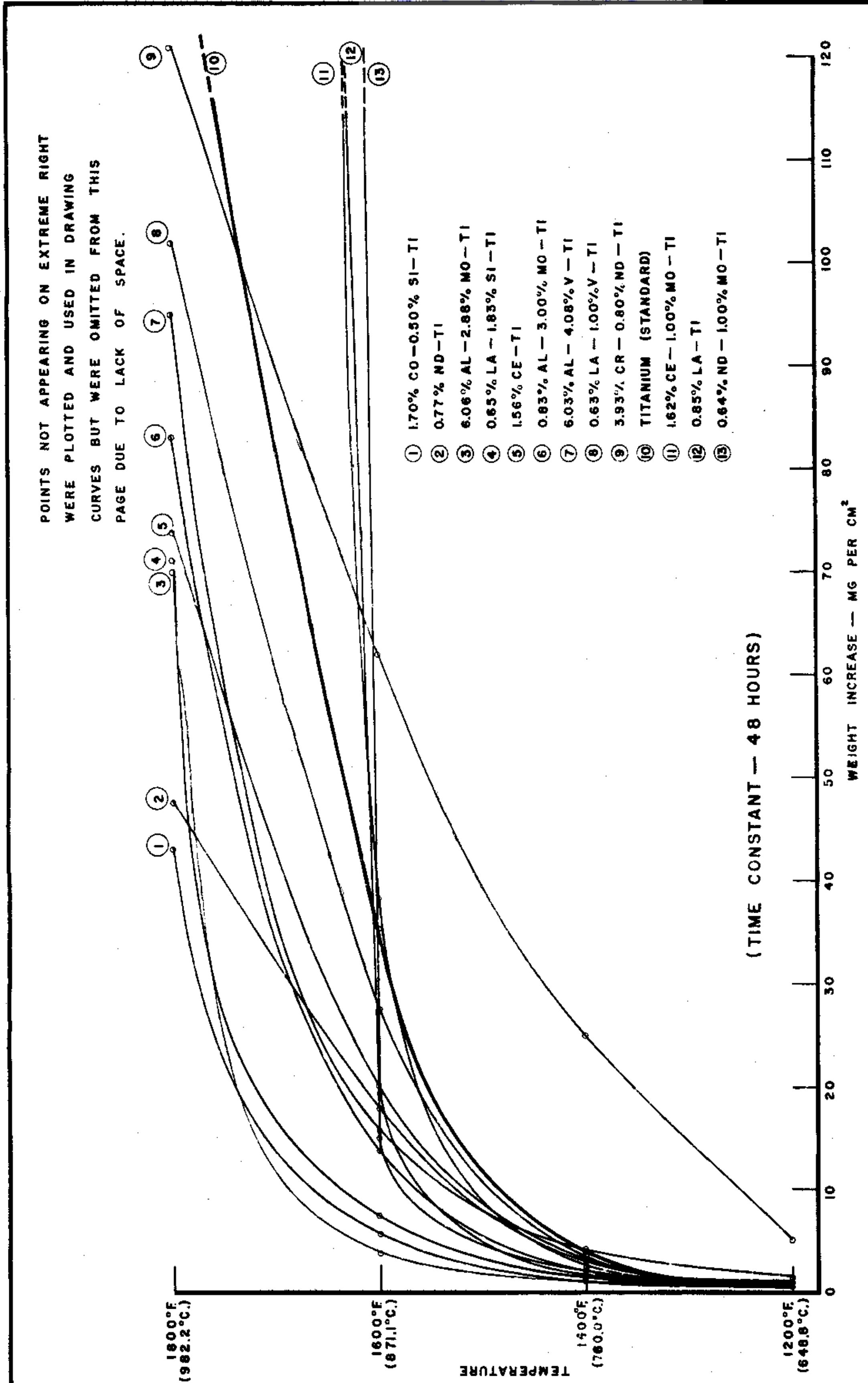

FIG. 6 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE — FOR GROUP 2 ALLOYS

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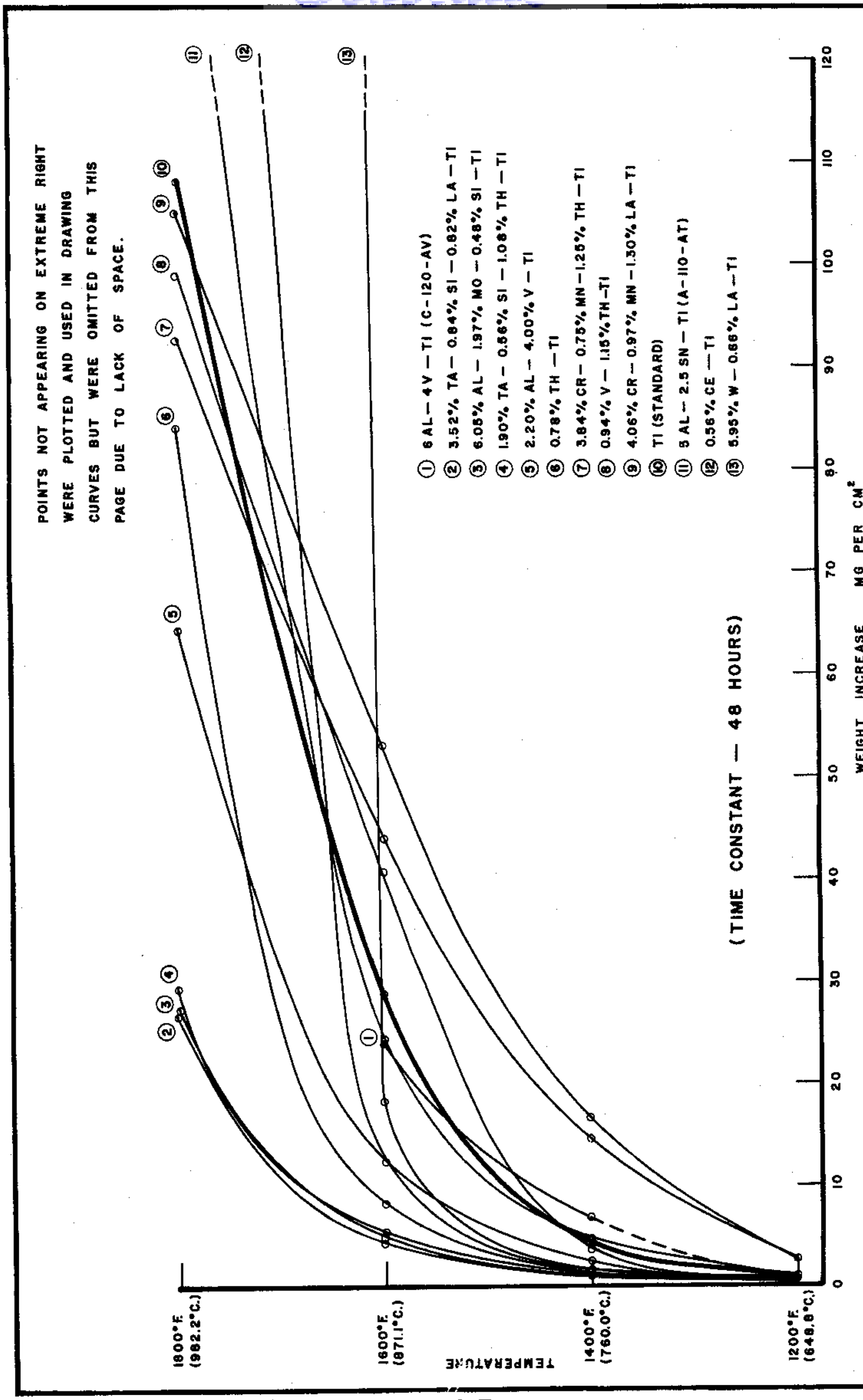

FIG. 7 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE — FOR GROUP 3 ALLOYS

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C. Investigation of Scales

The scales formed on certain alloys of titanium in air at various temperatures have been investigated by x-ray diffraction methods to determine if there is any correlation between the scaling rate, determined by the weight gain, and the crystallographic composition or orientation of the scale.

Except for a few back reflection patterns made in connection with the orientation work, all data were obtained with a geiger counter x-ray spectrometer**. This instrument scans the diffraction pattern of the specimen with a geiger counter in a plane perpendicular to the surface of the flat specimen and to the slit defining the incident x-ray beam. The diffracted intensity versus the Bragg angle is plotted by a strip chart recorder. Fig. 8 shows two typical traces, (a) of pure, randomly oriented rutile and (b) a typical rutile scale showing some preferred orientation, which is indicated by the changed relative intensities of the rutile lines, and some extra lines due to another unidentified corrosion product.

In the spectrometer, the position of the specimen in relation to the incident x-ray beam and the geiger counter is such that only crystallographic planes parallel to the surface of the specimen can diffract the beam in a direction such that it will be received by the counter and its intensity recorded. An increase in the relative intensity of a line over that obtained from a randomly oriented specimen indicates a preference, in the polycrystalline scale, for that set of planes to be parallel to the surface.

To check for preferred orientation in directions other than parallel to the surface several back reflection patterns on film were made. The incident beam in this case was perpendicular to the specimen surface and the film. Thus each diffraction ring arises from planes oriented at the Bragg angle, for their particular spacing, from the normal to the surface and in all possible rotation positions about the normal. In all cases each diffraction ring was of uniform intensity indicating a uniform distribution of the planes in reflecting position around the normal to the surface, i.e. in cases where preferred orientation existed it was of the fiber texture type with certain planes concentrating in or avoiding being parallel to the surface, but with complete randomness around the normal to that surface. Fiber textures of this sort are very commonly encountered in the cases of reaction products or deposits, such as evaporated films, on surfaces. Patterns on film were made of the air side of the 1600° F. scales of specimens from Heats 115, 121, 126# and 4% Cr and of Specimen 115 under the spalled off scale. The pattern of Heat 126 is shown in Fig. 9. The strong characteristic scatter due to the 1.54 Å copper K radiation used makes it almost impossible to obtain a pattern that will reproduce well.

** Manufactured by the North American Philips Company, Mt. Vernon, New York.

\# See Table I

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The results of the preferred orientation studies on 30 alloys and 34 specimens are summarized in Table 8. The specimens are identified by Heat Number, by the scaling run in which they were included, and by the port occupied in the scaling furnace. All were scaled at 1600°F. Run A being for a total time of 156 hours and B for 169 hours. The table is arranged in order of decreasing weight gain in 169 hours expressed as the per cent gain relative to pure Ti as 100% For purposes of comparison Run A weight gains were extrapolated linearly from 156 to 169 hours.

The scales apparently were adherent at the scaling temperatures but nearly all of them loosened on cooling. This made it possible to examine three different positions through the thickness of the scale. These are the outer surface (AS), the inner surface (MS) of the scale after separating from the underlying material and the layer of scale still adhering to the base metal (BM). The latter in all cases was thick enough so that no appreciable diffraction from the base metal was recorded.

All data were obtained with Copper K radiation and a scanning speed of 1° θ per minute.

The results are recorded in Table 8 as the percentage each line represents of the total intensity, as the height above background of the eleven lowest index lines. These lines, the indices of which are listed, represent nearly 80 % of the total intensity of the 35 lines available with copper radiation.

For comparison, the relative intensities calculated from the Bureau of Standards values[2] for randomly oriented rutile are given in the last column. Any relative line intensity higher than this standard indicates a preference for that set of planes to be parallel to the surface of the specimens.

It is readily seen from the table that there is no significant correlation between orientation and scaling rate. In most cases two specimens of the same alloy will have essentially the same orientation and little change occurs with depth within the scale.

The effect of temperature of scaling on preferred orientation was investigated in the cases of specimens 120 and 128 as shown in Table 9. This gives the relative intensities of the diffraction lines of scales formed at different temperatures. While there are definite orientation changes with temperature they are erratic and, in the light of the lack of correlation of orientation with scaling rate at any one temperature, are evidently of no significance for this problem.

A fair number of the scales were composed wholly of an oxide with the rutile structure while others showed lines in their diffraction patterns due to crystallographically different constituents. These are identified and the interplaner spacing represented by the extra lines are listed in Table 8.

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An attempt was made to identify the compounds giving rise to these extra lines by use of the ASTM card index[3] but in no case was it possible to make a reasonably certain identification. This is commonly the case in scales on complex alloys where the phase diagrams of the possible oxides are not even roughly known and there is no hint of the structures to be expected. Another factor that made identification of the other structures unduly difficult was that some of them were unstable at room temperature so in making powder specimens of the scale to get away from preferred orientation effects the compound of interest would decompose. An example of this is the 4% Cr scale listed in Table 8. in the as received condition, and after crushing. The mechanical work completely destroyed the original crystal structure and gave a mixture of rutile and another unidentified component.

Several recurring sets of lines however, could be picked out of the patterns of different scales. These are listed by interplaner spacings represented in Table 10 where each set is identified by a letter. These identification letters are used in Table 8 to summarize which of these sets are present in each scale.

The lack of correlation with scaling rate is notable. In several cases lines have been attributed to one of the standard patterns, though the interplaner spacings represented vary considerably from those of the typical pattern. These are included as being within the range of error due to lattice parameter changes resulting from solid solution effects and experimental error.

As changes of the lattice parameter of the rutile structure could have an effect on scaling rate the (110) and (112) spacings of rutile in various scales were compared for possible changes of this sort. The total spread as shown in Table 9 is less than 1% of the interplaner spacing, this is about the estimated experimental error.

Since the higher angle (smaller interplaner spacing) lines are more sensitive to changes in spacing, the total angular spread of the (112) lines would have been greater than that of the (110) if it was due to changes of the lattice parameter. This is seen not to be the case and any change of lattice parameter of the rutile with composition of the base metal is very small.

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TABLE 8

RELATIVE LINE INTENSITIES AND INTERPLANER SPACINGS REPRESENTED BY

EXTRA LINES IN 1600°F. SCALES

Heat No. / Run and Port	122 A 6	122 A 6	121 A 5	121 A 5	140 B 15	120 A 3	120 A 3	125 A 13	135 B 4	158 B 22	B 23	B 23
Amount of Rutile in scale	Trace	Trace	All	Trace	All	Most	Trace	Most	Most	All	All	Some
Wt. Gain in 169 hrs. relative to Ti	22%		27%		28%	32%		42%	42%	44%		
Position in scale	AS	BM	AS	BM	AS	AS	BM	AS	AS	AS	AS	BM
Miller Indices of Reflections Plane		Some rutile present		Some rutile present			Some rutile present					Considerable rutile, strongly interfering lines
110	30		35		34	32		23	13	42	34	
101	10		13		15	19		23	23	11	13	
200	3		6		4	4		3	1	3	2	
111	10		6		6	7		8	5	5	6	
210	0		4		3	2		2	1	3	2	
211	18		14		16	16		21	14	14	17	
220	3		5		5	4		4	2	6	6	
002	16		6		3	5		3	21	6	7	
310	3		3		3	2		2	1	3	3	
301	3		6		6	5		7	13	6	7	
112	3		4		3	3		4	7	3	4	
Interplaner spacing represented by extra lines	(4) 2.424	(1) 3.709		(3) 2.418		(45) 1.519	(>100) 1.514	(1) 3.440	(1) 3.466			(4) 3.709
	(2) 2.254	(1) 3.590		(3) 2.259		(3) 1.497	(10) 1.495	(2) 2.515	(2) 2.536			(3) 2.564
	(1) 2.131	(2) 2.431		(5) 2.108				(2) 2.362	(2) 2.378			(3) 2.437
	(5) 2.103	(3) 2.270		(1) 1.747				(3) 2.076	(2) 2.076			(3) 2.399
	(3) 1.672	(1) 2.141		(1) 1.558				(1) 1.735	(2) 1.735			(24) 2.265
	(>100) 1.512	(4) 2.113		(>100) 1.514				(2) 1.595	(1) 1.595			(4) 2.233
	(6) 1.493	(6) 1.678		(8) 1.495				(1) 1.401	(12) 1.372			(8) 2.113
		(2) 1.600						(3) 1.370				(10) 1.750
		(>100) 1.514						(1) 1.301				(1) 1.493
		(22) 1.497										(2) 1.289
												(1) 1.273
												(2) 1.259
Standard patterns of Table 10 represented in above	X V	X V		V		X Only	X Only	Y Only	Y Only			VZ

Heat No. / Run and Port	129 A 21	130 A 23	A 23	138 B 11	124 A 11	159 B 24	B 25	B 24	B 24	127 A 17	A 16	112 B 1
Amount of Rutile in scale	All	All	Some	All	Most	Most	Most	Most	Most	All	Most	All
Wt. Gain in 169 hrs. relative to Ti	50%	54%		61%	67%	92%				95%		100%
Position in scale	AS	AS	BM	AS	AS	AS	AS	BM	Powder Scale	AS	BM	AS
Miller Indices of Reflections Plane			Some rutile present									
110	32	36		33	37	20	21	33	25	33	43	58
101	16	13		18	15	25	24	16	15	15	12	25
200	4	6		5	2	2	1	2	3	2	2	12
111	7	6		6	4	9	9	7	7	7	5	7
210	3	3		3	2	2	1	2	3	3	3	4
211	17	14		14	17	15	15	18	21	19	14	20
220	5	5		4	5	3	4	6	7	5	8	9
002	4	5		5	3	10	9	3	3	5	2	5
310	2	3		3	2	2	2	2	3	2	3	5
301	6	6		5	11	6	5	6	8	6	5	8
112	4	4		5	3	7	7	3	5	4	3	5
Interplaner spacing represented by extra lines			(2) 3.478		(2) 3.576	(6) 3.466	(6) 3.492	(3) 2.380	(2) 2.081		(2) 3.590	
			(11) 2.557		(2) 3.453	(6) 2.550	(6) 2.550		(2) 1.372		(1) 2.265	
			(7) 2.424		(3) 2.543	(9) 2.374	(8) 2.380				(3) 2.233	
			(18) 2.374		(1) 2.378	(2) 2.300	(2) 2.300				(2) 1.756	
			(5) 2.103		(3) 2.081	(16) 2.081	(12) 2.085				(1) 1.652	
			(8) 1.747		(1) 1.741	(5) 1.738	(5) 1.738					
			(14) 1.512		(2) 1.595	(5) 1.600	(5) 1.600					
			(7) 1.489		(5) 1.372	(4) 1.403	(4) 1.407					
			(1) 1.281			(11) 1.373	(11) 1.373					
			(6) 1.258			(2) 1.241						
			(5) 1.238									
			(3) 1.191									
			(6) 1.130									
Standard patterns of Table 10 represented in above			X,Y,Z?		Y	Y Only	Y Only	Y Only	Y Only		V	

Heat No. / Run and Port	115 A 1	A 1	A 1	136 B 7	128 A	A	A	A	126 A 15	A 15	123 A	A	A
Amount of Rutile in scale	All	All	All	Most	All	All	All	Most	All	Most	All	All	Trace
Wt. Gain in 169 hrs. relative to Ti	100%			117%	119%				125%		156%		
Position in scale	AS	MS	BM	AS	AS	MS(a)	MS(b)	BM	AS	BM	AS	MS	BM
Miller Indices of Reflections Plane													Nearly pure Ti Pattern
110	30	41	41	30	31	38	38	37	33	40	20	35	
101	12	14	14	19	14	14	13	13	20	17	24	16	
200	22	1	2	2	2	2	2	2	2	2	2	2	
111	3	6	7	7	6	7	6	3	8	7	7	7	
210	3	3	3	2	5	3	3	17	2	3	3	3	
211	9	14	14	15	21	15	17	6	17	15	21	17	
220	6	7	7	4	5	7	7	4	5	5	1	6	
002	3	5	3	6	3	3	3	3	5	2	3	3	
310	5	3	6	2	3	3	2	6	2	2	1	2	
301	5	2	5	6	2	5	6	2	6	5	12	6	
112	1	4	3	5	3	4	3		5	2	4	4	
Interplaner spacing represented by extra lines				(9) 3.121				(1) 2.652		(5) 2.305			
				(1) 2.431				(2) 2.578					
				(1) 1.910				(1) 2.424					
								(3) 2.300					
								(1) 2.270					
								(3) 2.131					
								(2) 2.011					
Standard patterns of Table 10 represented in above				W Only				V		Y Only			

Heat No. / Run and Port	134 B 24	133 B 3	137 B 9	141 B 16	B 17	B 17	147 B 18	19	4% Cr	4% Cr Powder	139 B 13	NBS TiO_2
Amount of Rutile in scale	Most	Most	All	All	All	Most	All	All	None	Much	Most	
Wt. Gain in 169 hrs. relative to Ti	158%	160%	186%	215%			236%		High		--	
Position in scale	AS	AS	AS	AS	AS	BM	AS	AS	AS		AS	
110	21	26	32	27	30	45	28	26		20	26	35.0
101	23	22	19	20	18	15	19	20		18	20	14.3
200	2	2	2	4	3	0	3	4		4	5	2.4
111	6	6	6	6	7	5	6	6		7	6	7.7
210	1	2	2	3	2	10	2	2		3	2	3.1
211	17	13	15	15	15	5	14	14		18	15	17.5
220	5	4	4	4	4	0	4	4		10	5	5.6
002	12	13	7	8	8	15	8	9		2	6	2.8
310	3	1	2	3	2	7	3	6		5	3	3.5
301	5	6	5	6	7	5	7	6		5	7	5.6
112	6	6	5	5	5		5	5		5	5	2.4
Interplaner spacing represented by extra lines	(1) 3.834	(1) 3.453				(1) 3.414			(>100) 1.512	(2) 3.506	(22) 3.121	
	(9) 2.941	(1) 2.536				(2) 3.008			(high) 1.497	(3) 3.375	(6) 2.706	
	(15) 2.714	(1) 2.378				(1) 2.797				(1) 3.288	(11) 1.913	
	(4) 2.508	(2) 2.076				(1) 2.698				(1) 3.164	(3) 1.632	
	(3) 2.338	(1) 1.598				(14) 2.571				(3) 2.536		
	(1) 2.206	(1) 1.401				(1) 2.418				(2) 1.637		
	(1) 2.076	(2) 1.372				(30) 2.270				(2) 1.506		
	(4) 1.664					(13) 1.756				(1) 1.437		
	(2) 1.600					(1) 1.624				(2) 1.403		
	(1) 1.517					(5) 1.585						
	(2) 1.414					(61) 1.486						
						(6) 1.359						
Standard patterns of Table 10 represented in above		Y Only				V			X Only		W Only	

Note: Numbers in ( ) are line intensities in chart (arbitrary) units.

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TABLE 9

RELATIVE INTENSITIES OF RUTILE AND EXTRA LINES AT VARIOUS SCALING TEMPERATURES

	Heat 120 A				Heat 128 B			
Scaling Temp.	1200°F.	1400°F.	1600°F.	1800°F.	1200°F.	1400°F.	1600°F.	1800°F.
Miller Indices								
110	37	27	32	37	33	61	20	45
101	13	25	19	21	8	0	16	2
200	2	3	4	3	17	7	4	5
111	5	9	7	8	6	1	6	2
210	2	2	2	2	1	1	4	6
211	14	14	16	11	10	9	16	8
220	3	3	4	3	5	1	5	14
002	12	2	5	8	9	11	5	7
310	1	4	2	1	0	2	4	6
301	5	5	5	8	4	2	11	1
112	6	5	3	3	6	4	9	3
	2.557 (20) Ti 2.495 (16) 2.378 (8) Ti 2.254 (49) Ti 1.925 (3) 1.863 (6) 1.744 (15) Ti 1.637 (4) 1.493 (3) 1.419 (2) 1.391 (4) 1.258 (10) 1.238 (8)	1.866 (13) 1.514 (20)	1.519 (45) 1.497 (3)	1.863 (17) 1.634 (5) 1.502 (5)	2.553 (4) Ti 2.363 (3) Ti 1.738 (3) Ti 1.278 (2) 1.251 (4) Ti	2.538 (16) 2.349 (8) 2.152 (10) 2.098 (2) 1.977 (4) 1.469 (7) 1.274 (2) 1.233 (3)		

Note: -- Numbers in ( ) are line intensities in arbitrary (chart) units.

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TABLE 10

RECURRING GROUPS OF INTERPLANER SPACINGS
FOUND AMONG EXTRA LINES IN TABLE 8

V	W	X	Y
2.578	3.121	1.514	3.466
2.424	1.910	1.47	2.550
2.270			2.374
1.753			2.300
			2.081
			1.738
			1.600
			1.403
			1.373

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TABLE 11

2 θ ANGLES OF $K\alpha_1$ REFLECTION FROM 110 AND 112 PLANES OF RUTILE IN VARIOUS 1600°F. SCALES

Heat No.	2 θ ANGLE 110	2 θ ANGLE 112
122	27.7	69.4
121*	27.4	69.2
140	27.4	69.1
120*	27.4	69.0
125*	27.7	69.2
135*	27.6	69.2
158	27.5	69.1
129	27.7	69.4
130	27.6	69.3
138	27.6	69.2
124*	27.5	69.1
159*	27.4	69.1
127	27.5	69.2
112	27.3	69.0
115	27.6	69.3
136*	27.4	69.2
128	27.7	69.3
126	27.3	69.1
123	27.6	69.3
127	27.5	69.2
134*	27.5	69.1
133*	27.6	69.2
137	27.3	69.0
141	27.3	69.1

Note: --Unstarred heats had pure rutile scales.

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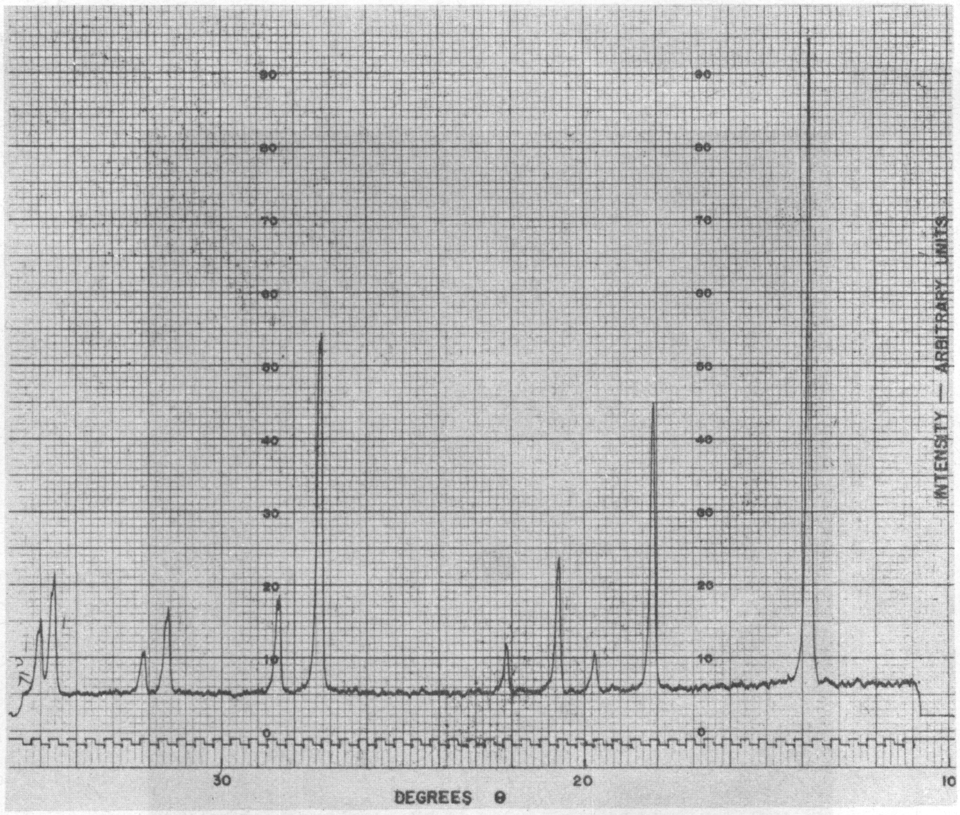
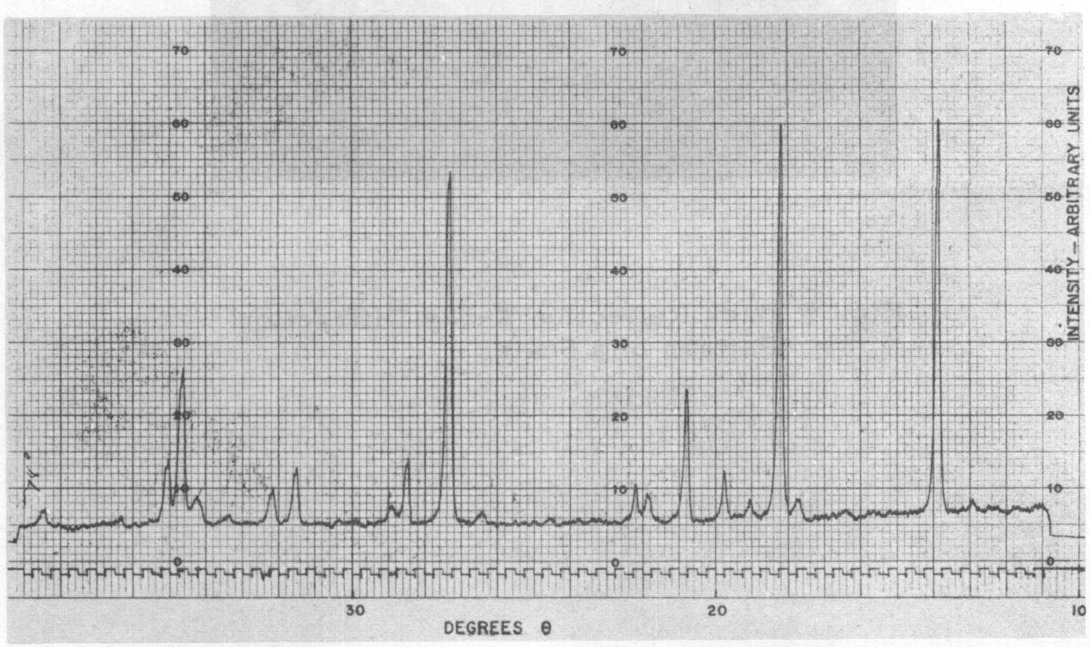


a - Pure, Randomly Oriented Rutile



b - Titanium Alloy Scale Showing Preferred Orientation of Rutile and Lines Due to an Unidentified Material

Fig. 8 Typical Diffraction Pattern Traces

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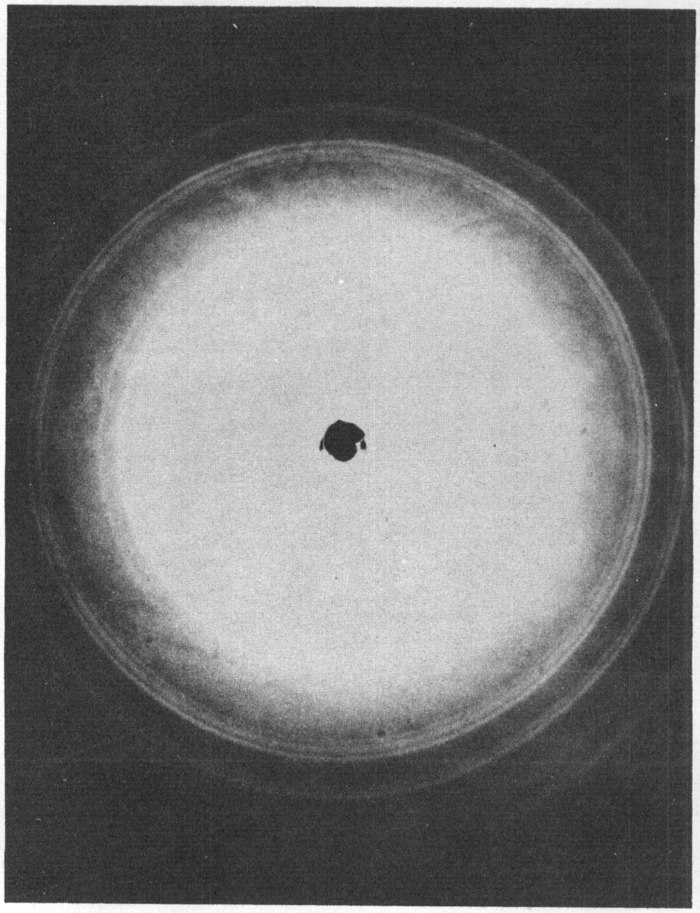

Fig. 9 Back Reflection X-ray Diffraction Pattern of a Scale

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D. Gaseous Penetration During High Temperature Exposure to Dry Atmosphere.

An investigation of gaseous penetration (oxygen and nitrogen interstitial diffusion) in the commercial materials RC-70, RC-130A, and RC-130B was made. The material used during this investigation was obtained from Rem-Cru Titanium, Incorporated, Midland, Pennsylvania. The chemical composition of the alloys RC-130A and RC-130B is as follows·

	Mn	Al	C	N
RC-130A (C-110M)	8.4%	-	0.15%	0.03%
RC-130B (C-130AM)	3.6%	3.5%	0.11%	0.02%

The analysis of the RC-70 (commercially pure titanium) material was not available.

The testing method utilized in this investigation was as follows: Specimens of RC-130A, RC-130B, And RC-70 1 in. x 2 in. x 0.065 to 0.080 in. (and later for RC-130B specimens 1 in. x 3 in. x 0.250 in.) were placed in the scaling furnace and scaled at either 1600° or 1800° F. The specimens in duplicate were exposed for a specific time, weighed in the furnace and immediately removed and air cooled to room temperature. The exposure times in the scaling furnace at 1600°F. were for periods of 1, 2, 4, 8, 16, and 24 hours; at 1800°F. exposure times of 1, 2, 4, 6, and 8 hours were used. Data on weight increase per unit area and inches penetration for each specimen were calculated and are presented in Figs.10 to 15 and Tables 28*-36*. There is generally good correlation between weight increase per unit area and inches penetration.

After cooling, all of the specimens for each alloy which were scaled at the same temperature were placed in a specimen holder. The specimens in the holder were then wet ground and an amount of metal equal to at least twice the thickness of the original specimen was removed from one end. The specimens were then metallographically polished and etched (2% HF, 12% HNO_3, and remainder H_2O). At this point the specimens were ready to be hardness tested for a determination of the extent of gaseous penetration.

Determination of the magnitude of gaseous penetration (diffusion of O_2 and N_2) into the base metal was made with a Vickers Hardness Tester to which the Microton from a Wilson Tukon Hardness Tester had been adapted. The Microton is a screw micrometer, calibrated in hundredths of millimeters (0.01 mm), through the use of which calibrated movement in two directions, 90° apart, in a horizontal plane may be obtained. The Microton was used in order to locate each hardness impression at a known point. A comparison of hardness results obtained with the Vickers Hardness Tester using a one Kilogram (lKg.) load applied for ten seconds and the Tukon Hardness Tester using a two-hundred gram (200 gr.) load did not indicate any significant differences. It was, therefore, decided that the Vickers Tester would be utilized for this investigation because of the greater speed with which the Vickers impressions could be read.

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In titanium and titanium-base alloys it is possible to utilize hardness as a measure of the gaseous penetration (interstitial diffusion of O_2 and N_2) since both oxygen and nitrogen in solid solution have such a marked effect on hardness. The addition of 5% oxygen, for instance, to titanium increases the hardness from 170 to 570 Vickers[4] (Fig. 16 from the work of Bump, Kessler, and Hansen[4] shows the relationship between Vickers hardness and oxygen concentration). Information as to the exact effect of nitrogen concentration on hardness is not available, these data not being included in the information given on the Titanium-Nitrogen system[5] or in the work of Wyatt and Grant[6] on the nitriding of titanium with ammonia. However, the effect of nitrogen is known to be similar to that of oxygen, small amounts in solid solution also causing a marked increase in hardness.

An initial investigation to determine a suitable technique for making the hardness traverses necessary in this study was made on the Vickers Testers. It was found that the first hardness impression of any traverse had to be made at a distance of at least 0.05 mm (0.002 in.) below the surface of the specimen in order to eliminate erroneous hardness data due to deformation of the surface. Subsequent hardness impressions were generally spaced 0.10 mm apart; however, in the case of the specimens which initially were 0.250 in. thick, this procedure was varied and impressions as far as 0.50 mm apart were sometimes used in order to reduce the number of impressions to a practical value. The number of impressions in each hardness traverse varied between 15 and 25 depending upon the thickness of the specimens after scaling.

Hardness traverses of the type described above were made for the materials RC-70, RC-130A, and RC-130B exposed at 1600° and 1800° F. for periods of from one to twenty-four hours to an atmosphere of dry air. Curves showing the change in hardness with depth below the specimen surface are shown in Figs. 17 to 22. The investigation was performed initially with specimens whose original thickness was between 0.065 and 0.080 in. It was found, however, that there was considerable hardening completely through some of these specimens after which they were not ideally suited for penetration studies. In the case of the RC-130B alloy, material having a thickness of 0.250 in. was readily available and penetration tests were also conducted on this thicker material.

Photomicrographs of all of these specimens at each time and temperature are shown in Figs. 23 to 28. The formation of a new phase (probably acicular alpha) at the surface of the specimens, surrounded by a matrix of alpha and beta titanium with oxygen and probably some nitrogen in solid solution was noted for the alloy RC-130A at both 1600° and 1800° F., for the alloy RC-130B at 1800° F., and for commercially pure Ti, RC-70, at 1800° F. This structure is the same as that noted by Moudry[7] after heating RC-130B in air to a temperature of 1875° F. and holding for one-half hour, and is identified by him as being oxygen penetration. It should be noted that in the RC-70 material this phase is present in amounts much less than in either RC-130A or RC-130B.

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As was noted previously, duplicate specimens were exposed at each time and temperature. Only one hardness traverse was made on each specimen, and the data from each traverse was used to plot the hardness curves; each hardness curve then represents an average of two traverses from different specimens which were exposed at the same time to the same temperature.

In some cases there was considerable variation between the hardness data obtained from the duplicate specimens. This variation, as may be seen from the photomicrographs (Figs. 23 to 28*), was due to the uneven gaseous penetration at various points along the surface of the specimens. The preferred diffusion of gases along grain boundaries and in certain preferred directions in individual grains was responsible for this. The growth of the acicular alpha mentioned previously appeared to have a definite preferredness for grain boundaries, and also a preferredness within individual grains. This effect is also shown by Fig. 29 in which isohardness lines are plotted for a small portion of one specimen.

The maximum extent of gaseous penetration as determined from the hardness curves was taken as the inflection point of the curves (Figs. 10 to 15). In some cases, gaseous penetration completely through the specimens was noted; where this occurred it was not possible to determine the maximum depth of penetration; however, curves showing change in hardness at a constant depth below the specimen surface (depth taken as the distance to the center of the thinnest specimen) reflect the trend of penetration in these cases.

It is stated by Finlay, Wentz, and Catlin[8] that for the alloy RC-130B (C-130AM) exposed to air at 1700°F. oxygen penetration into the metal follows the normal parabolic diffusion law and reaches a depth of about 0.015 in. in one hour, but four hours only produce a depth of 0.030 in. At longer times, loss of surface material by oxidation tends to keep pace with the growth of the subsurface layer, so that the latter does not increase in proportion to the time.

The present investigation, carried out at both 1600° and 1800°F. is in substantial agreement with the investigation mentioned above. The only difference noted in the present investigation in some cases was a change from a normal parabolic rate at longer exposure times (24 hours at 1600°F. and 8 hours at 1800°F.). For a more extensive study the reader is referred to the recent work of Reynolds, Ogden, and Jaffee[9,10] at Battelle.

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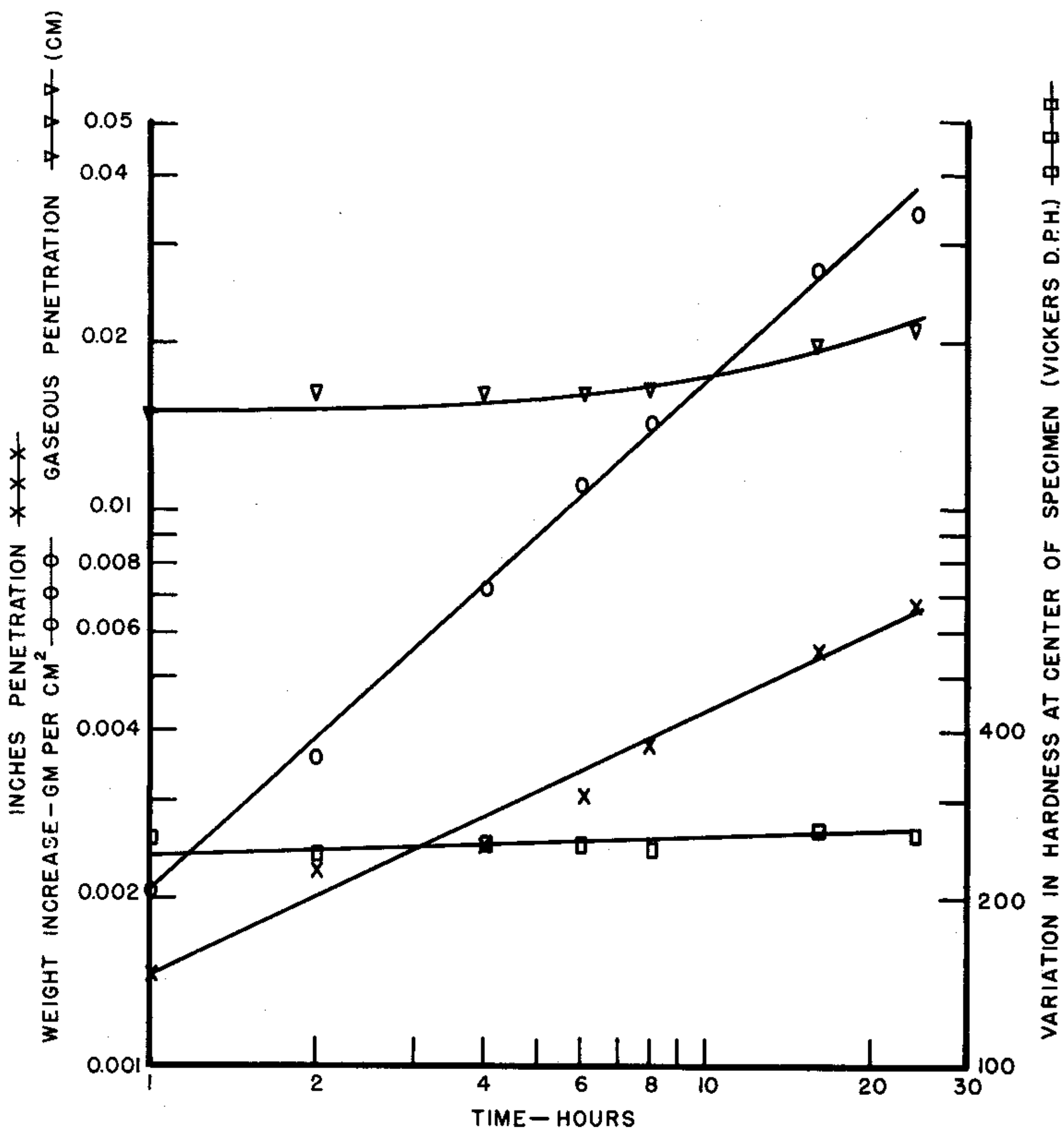

FIG. 10 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

FOR RC-70

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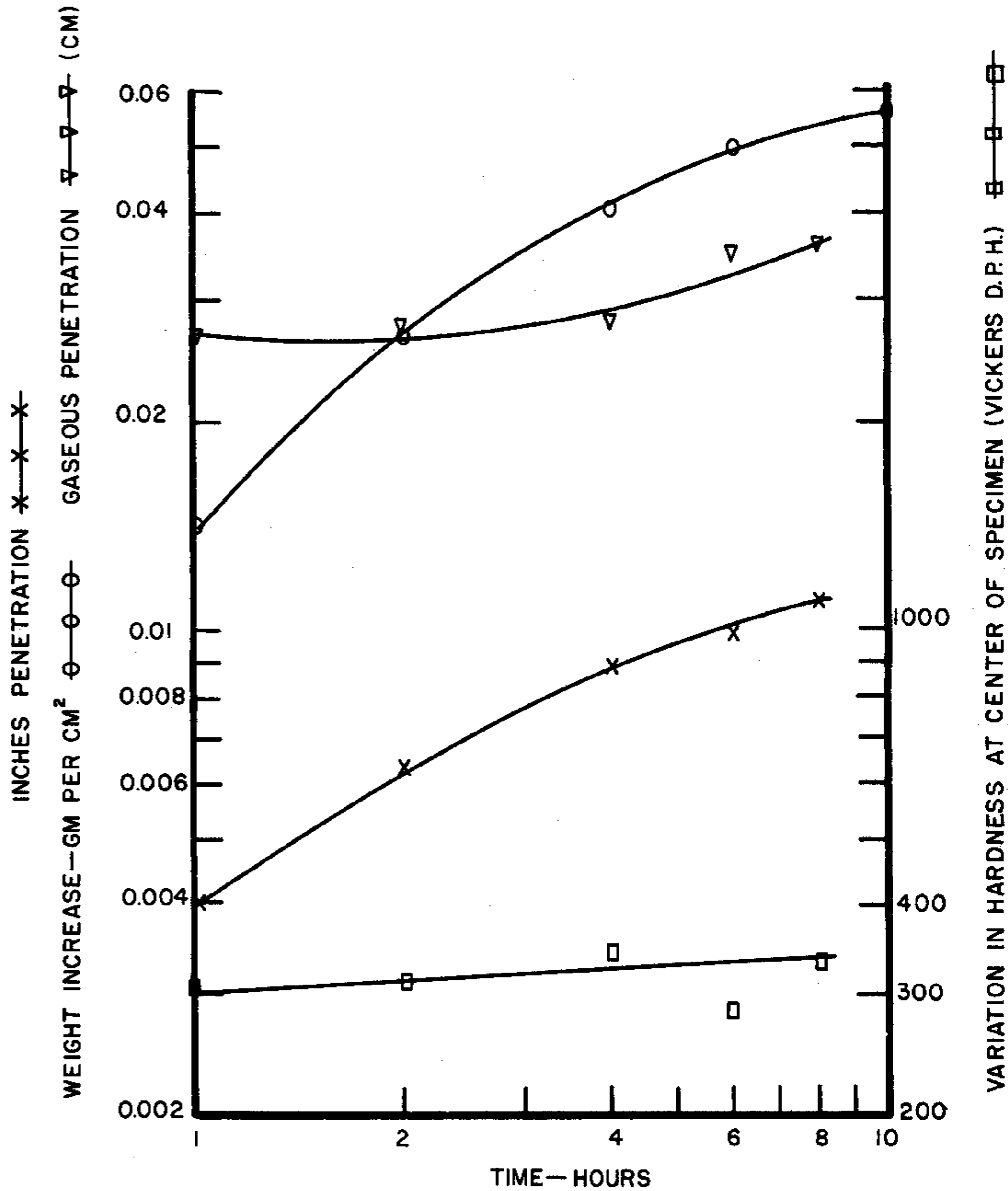

FIG. 11 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

FOR RC-70

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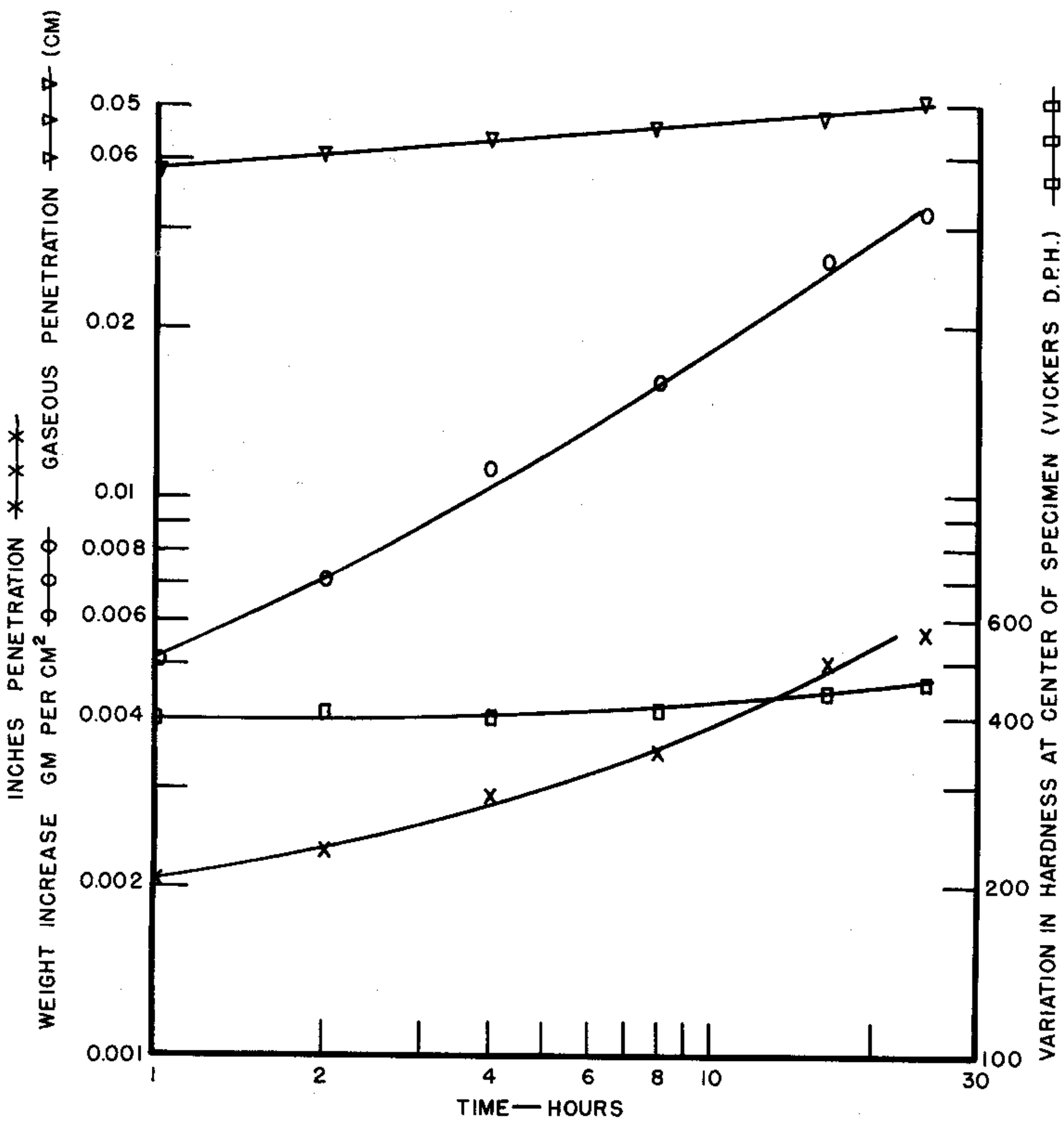

FIG. 12 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1600°F. (871.1°C.) FOR RC—130A

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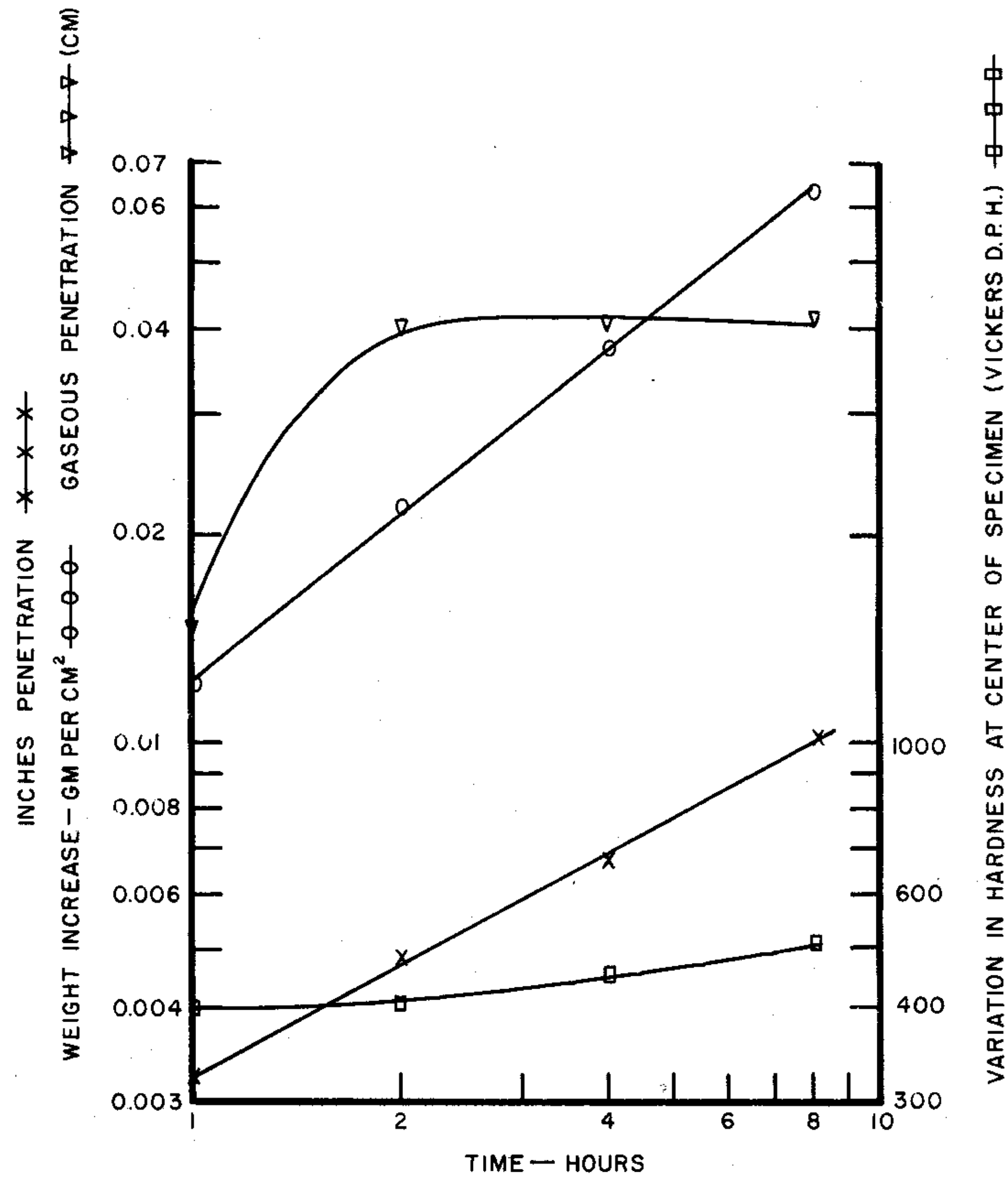

FIG. 13 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1800° F. (982.2°C.)

FOR RC-130A

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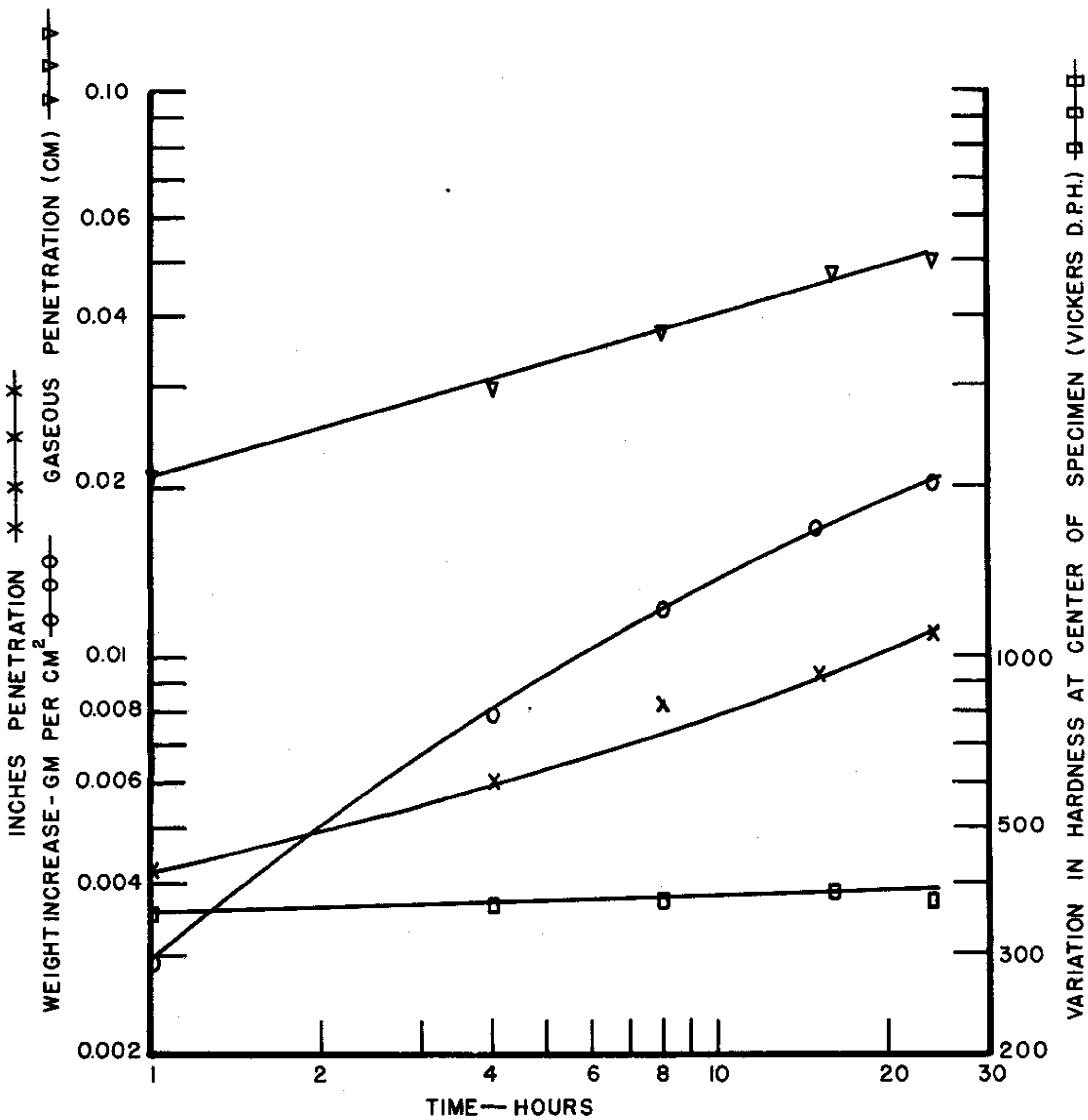

FIG. 14 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1600°F (871.1°C.) FOR RC-130B

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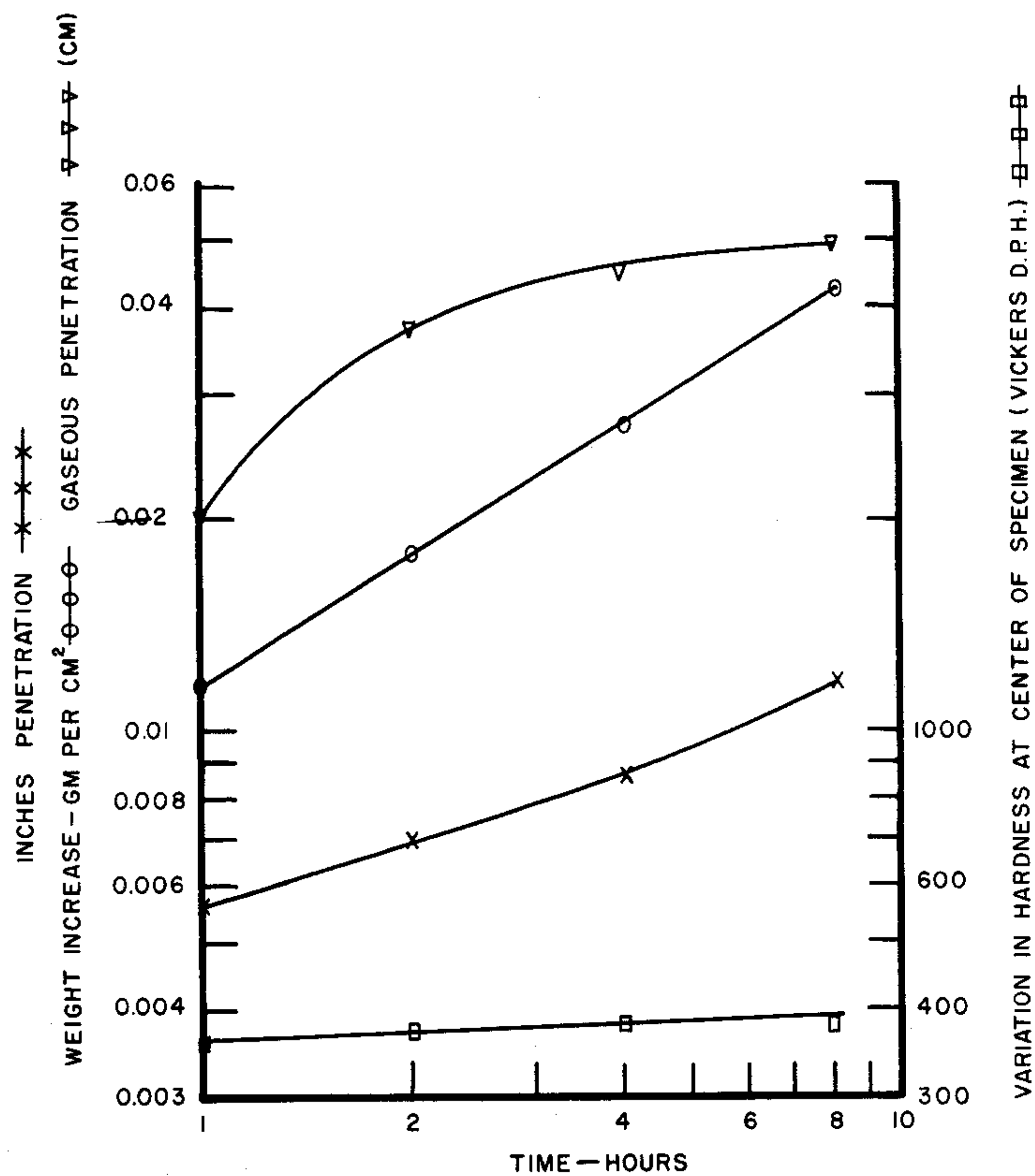

FIG. 15 AVERAGE WEIGHT INCREASE PER AVERAGE UNIT AREA, VARIATION IN HARDNESS (SPECIMEN CENTERS), AVERAGE INCHES PENETRATION, AND GASEOUS PENETRATION AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

FOR RC-130B

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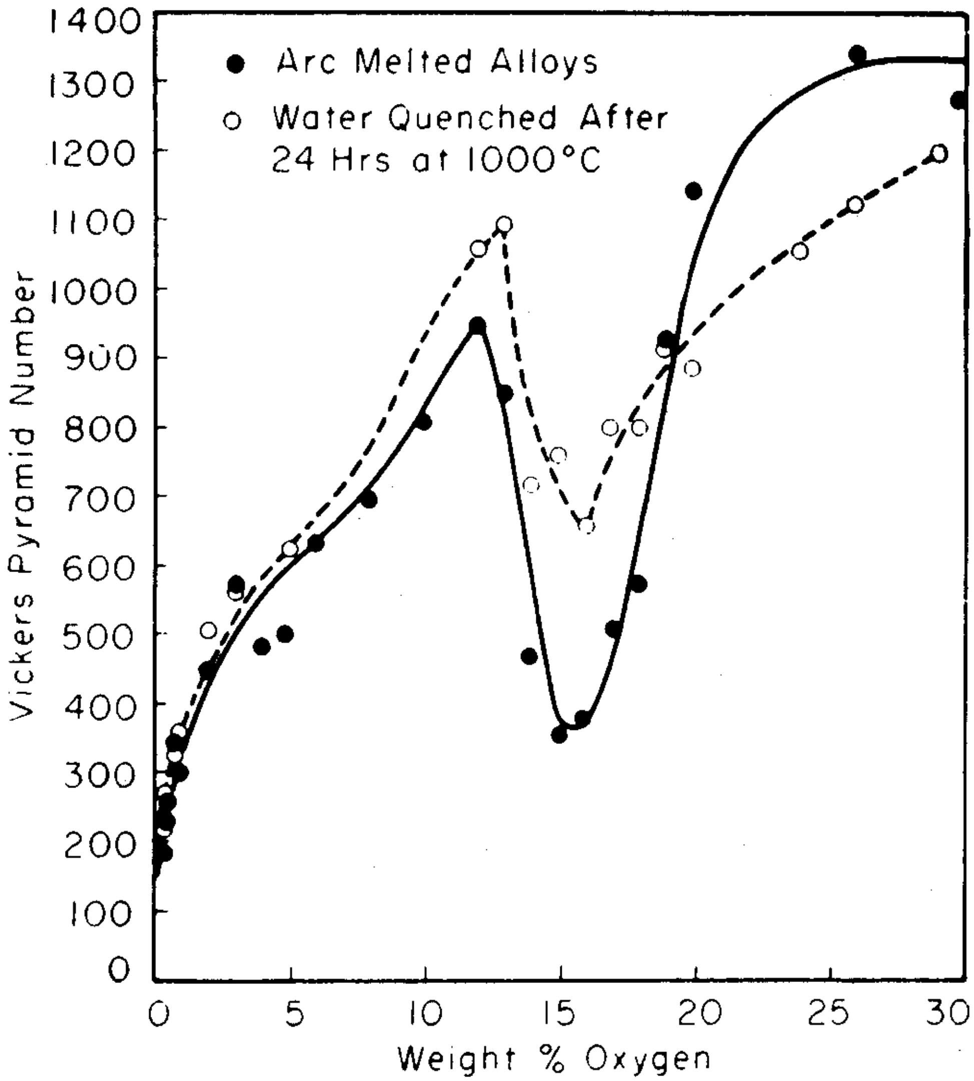

Fig. 16 Vickers Diamond Pyramid Hardness Versus Oxygen content for Titanium[4].

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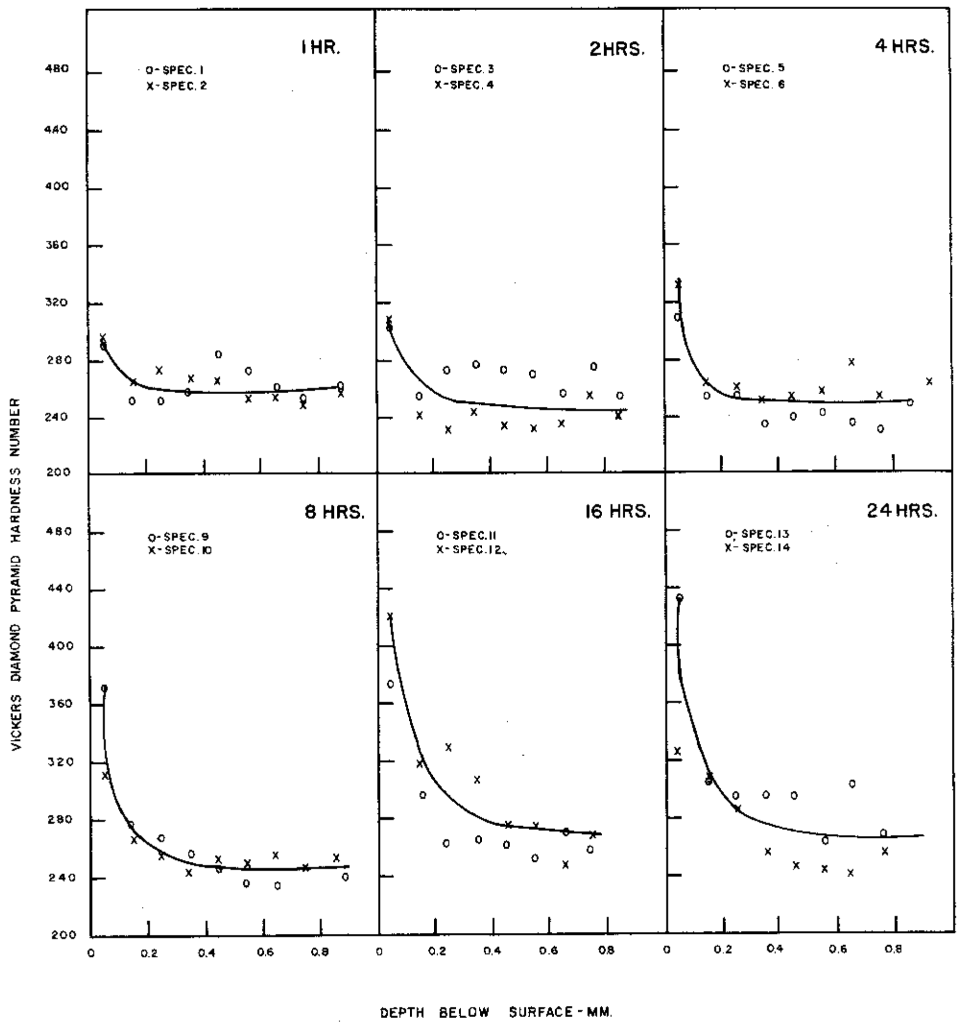

FIG. 17 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-70 SCALED IN DRY AIR AT 1600° F.

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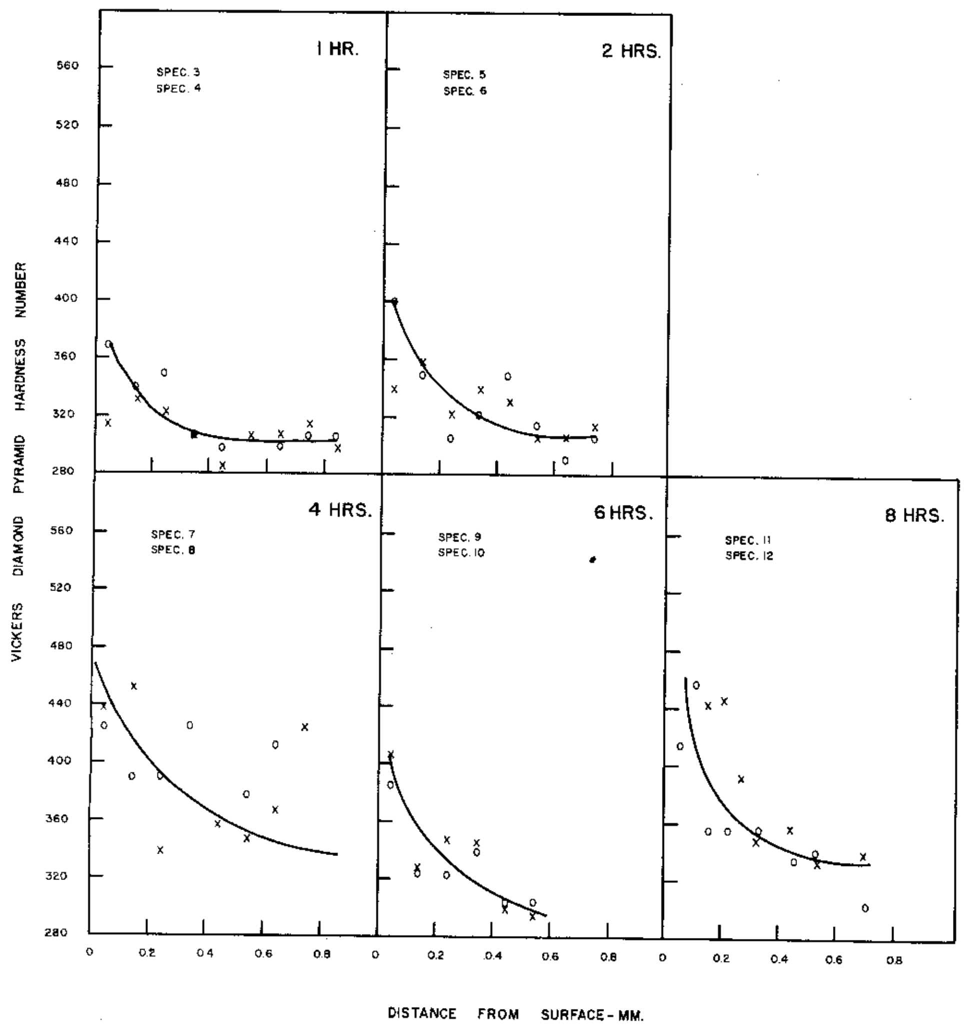

FIG. 18 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-70 SCALED IN DRY AIR AT 1800° F.

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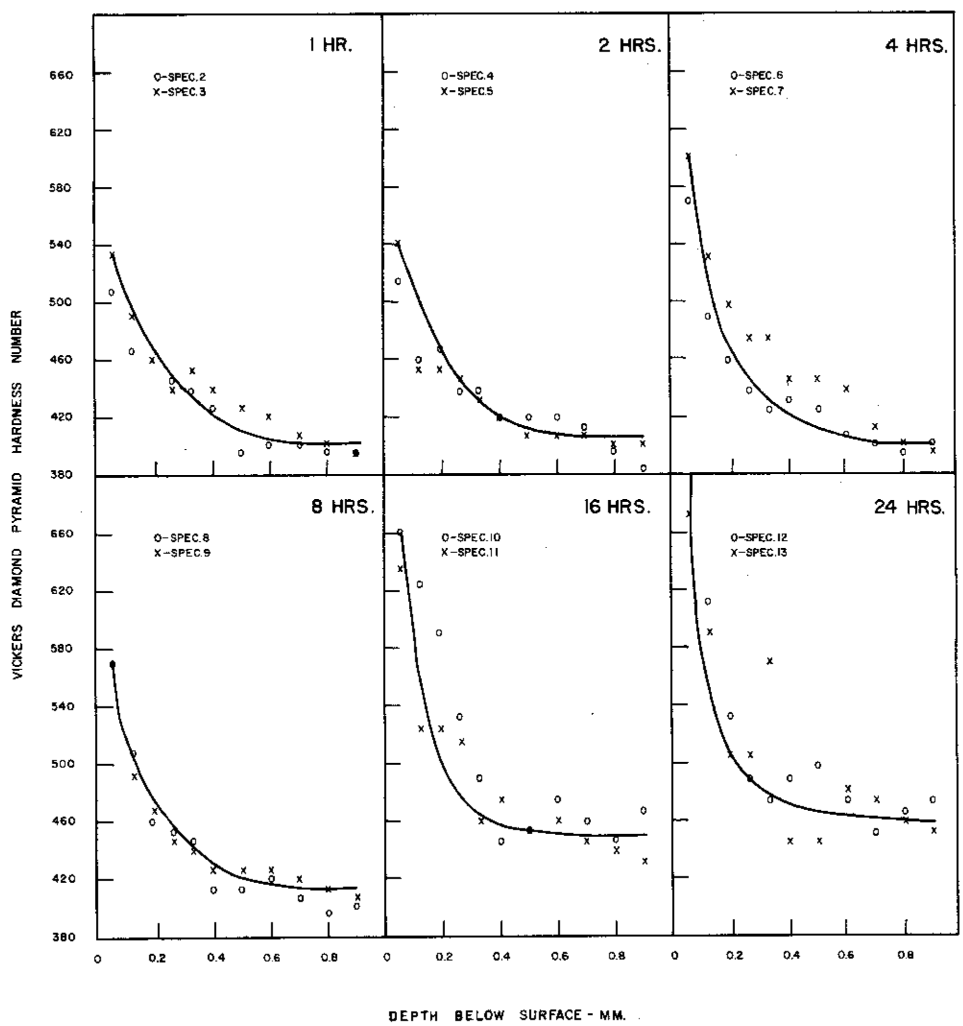

FIG. 19 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-130A SCALED IN DRY AIR AT 1600° F.

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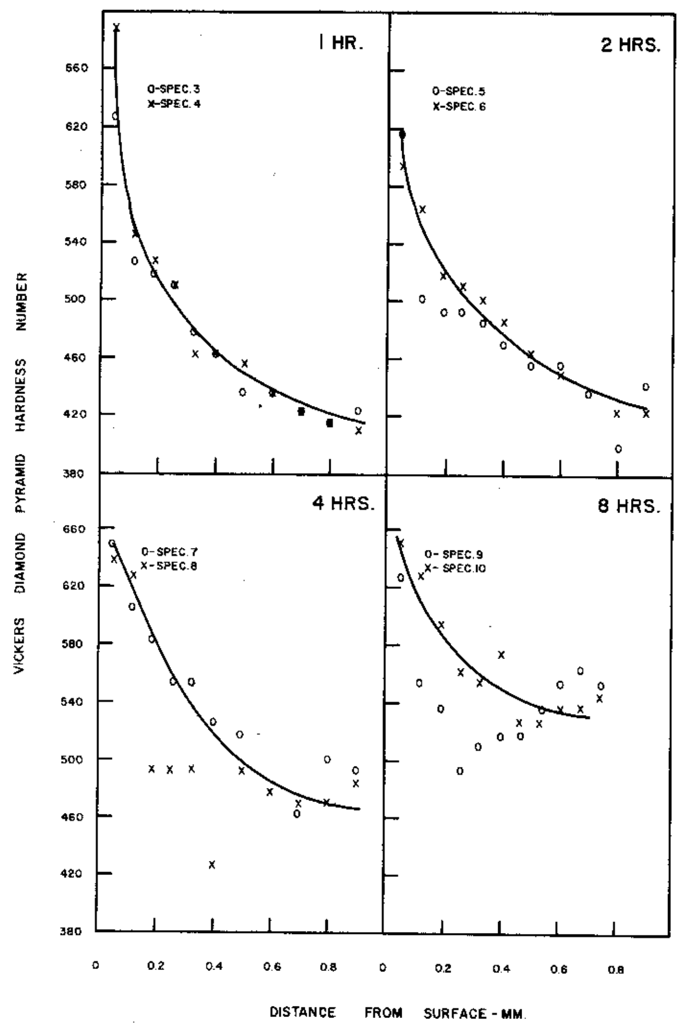

FIG. 20 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-130A SCALED IN DRY AIR AT 1800° F.

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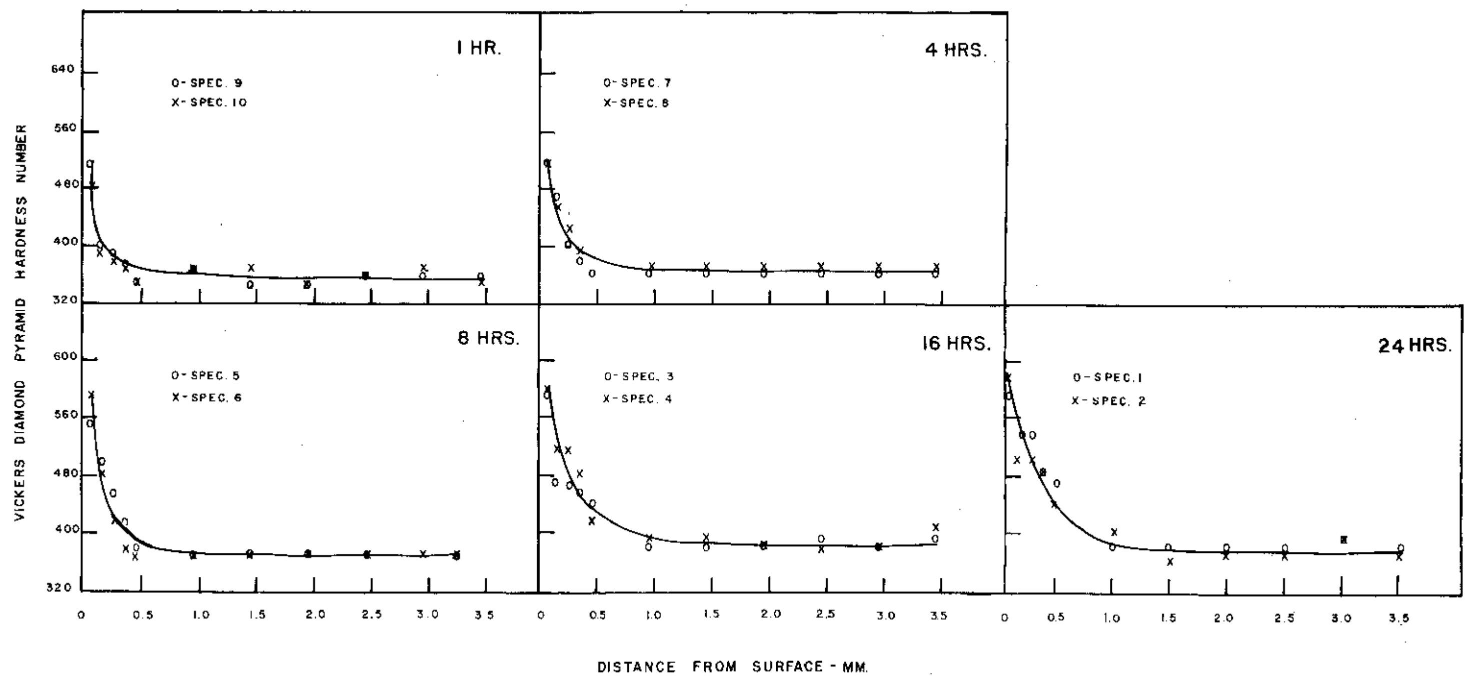

FIG. 21 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-130B SCALED IN DRY AIR AT 1600° F.

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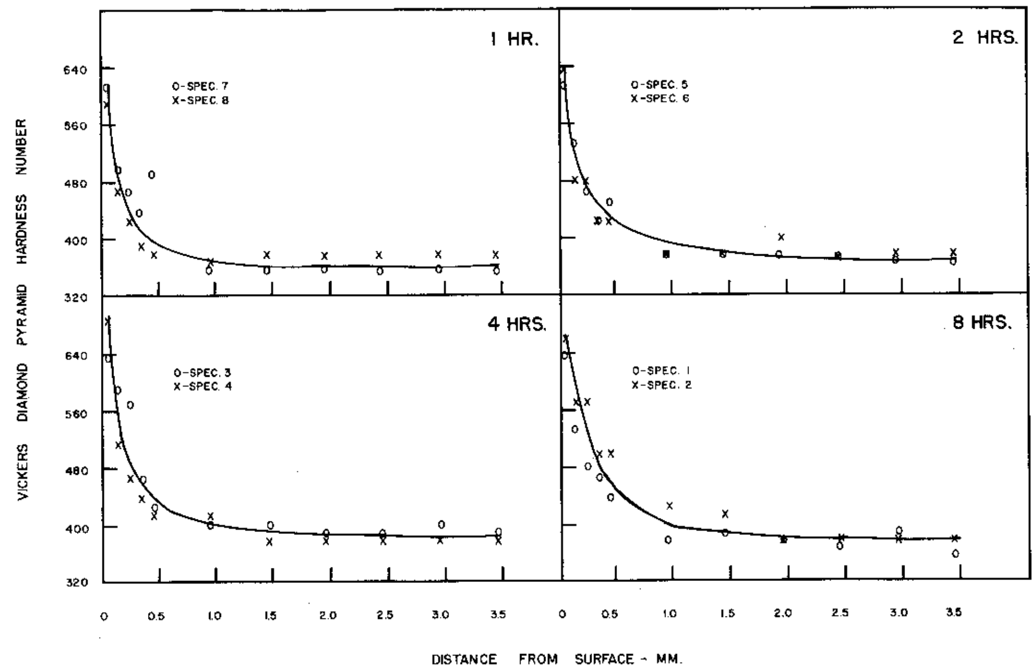

FIG. 22 VICKERS DIAMOND PYRAMID HARDNESS AS A FUNCTION OF DEPTH BELOW THE SCALED SURFACE FOR RC-130B SCALED IN DRY AIR AT 1800° F.

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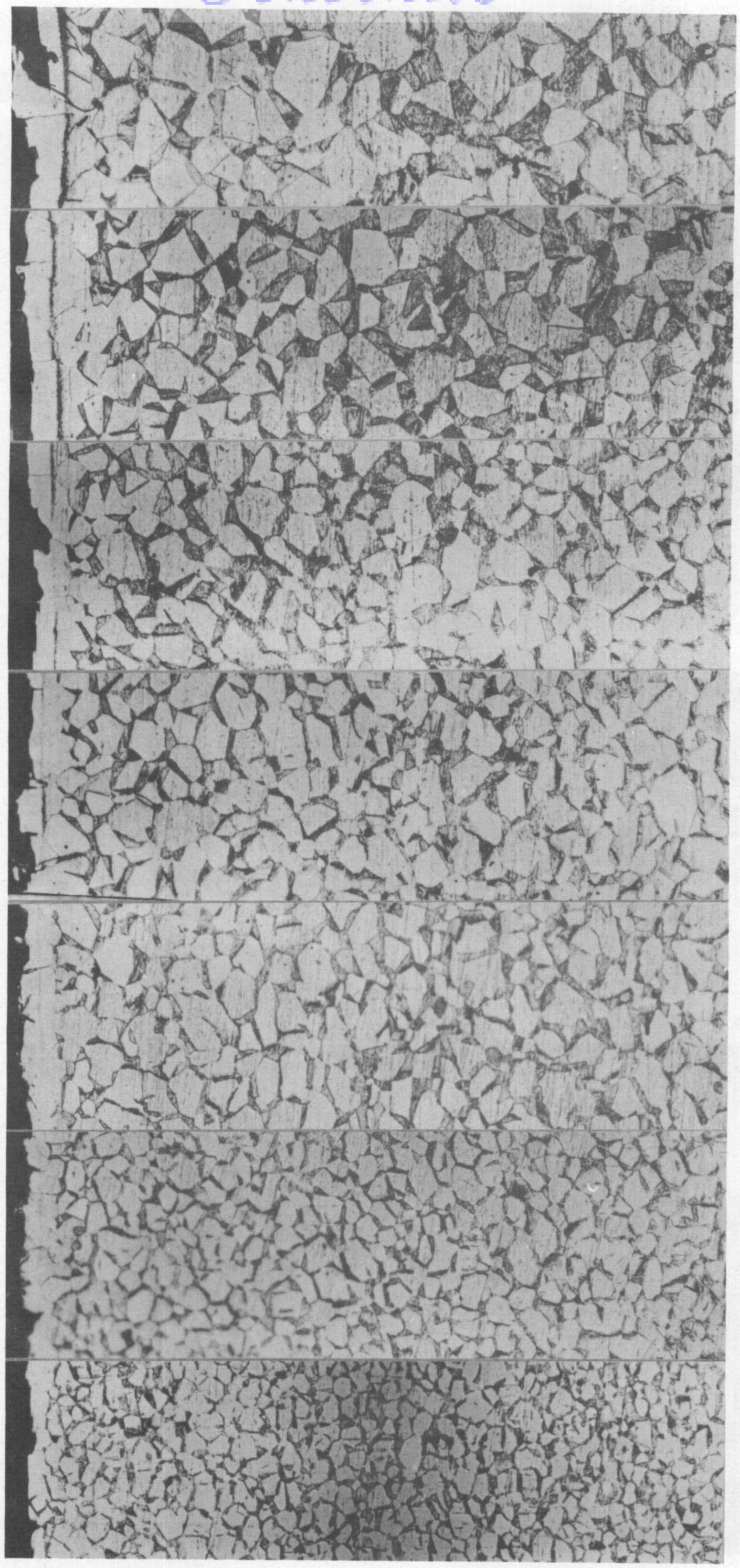

Fig. 23 Photomicrographs of Specimens of RC-70 Scaled in Dry Air for Periods of 1, 2, 4, 6, 8, 16, and 24 Hours at 1600°F.(871.1°C.)

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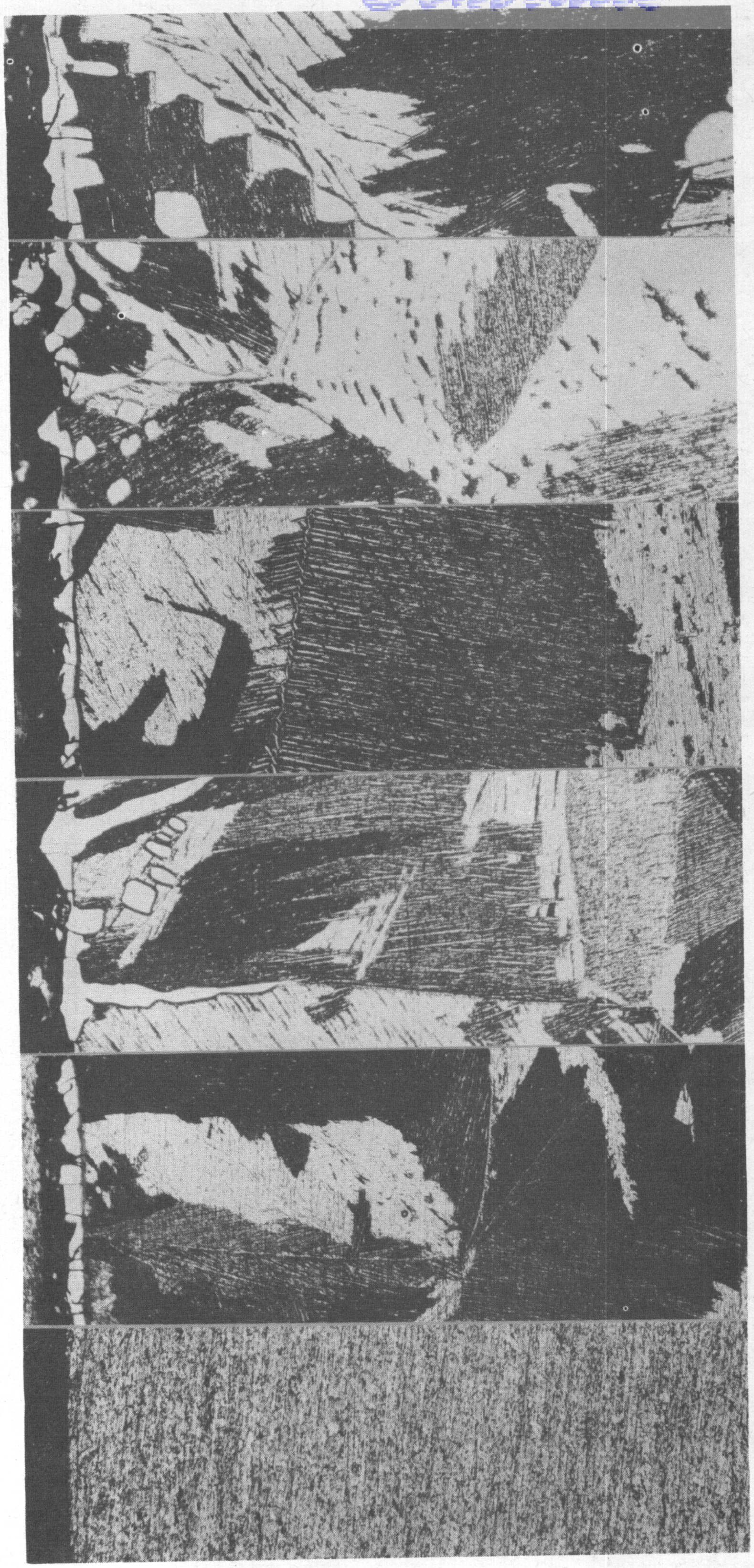

Fig. 24 Photomicrographs of Specimens of RC-70 Scaled in Dry Air for Periods of 0, 1, 2, 4, 6, and 8 Hours at 1800°F. (982.2°C.)

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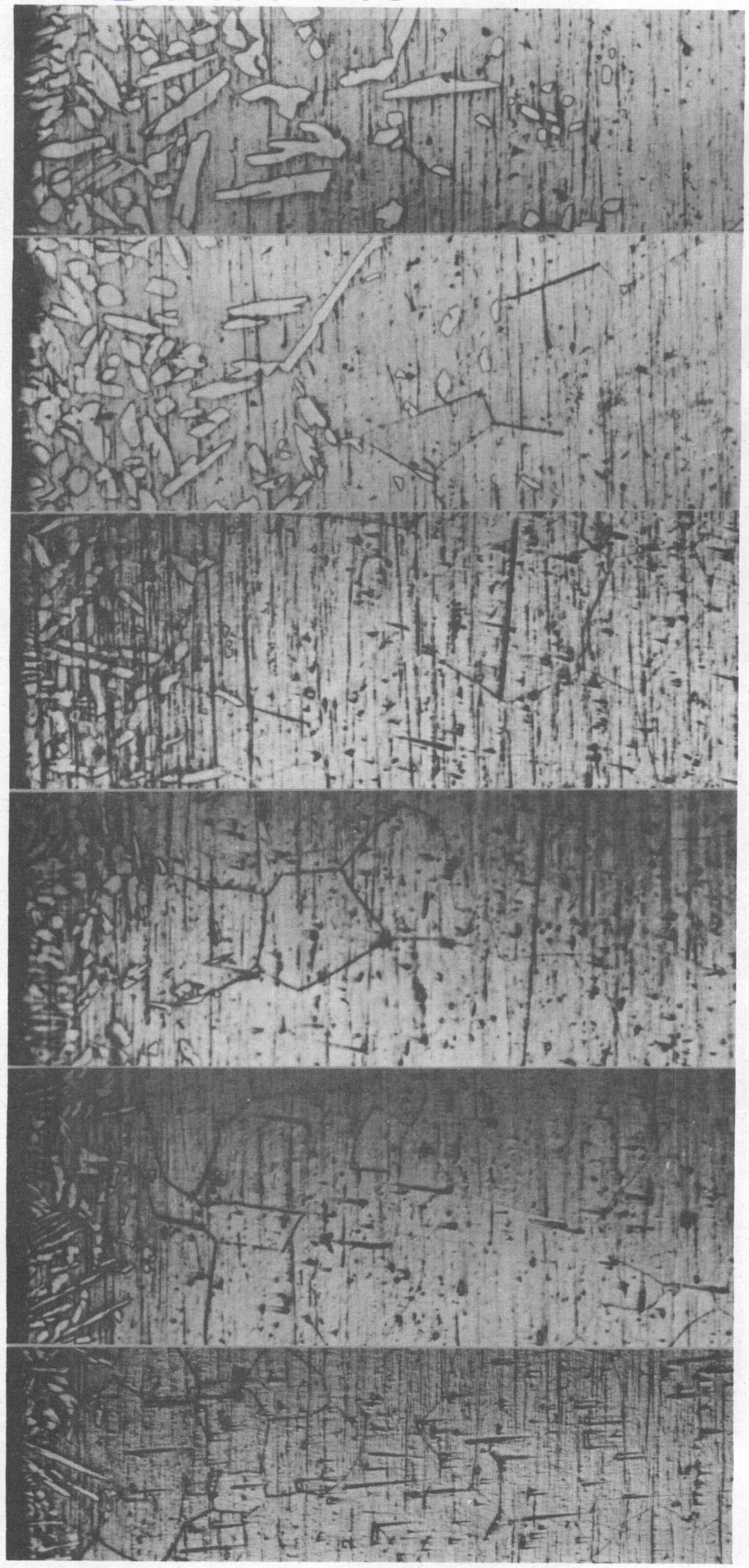

Fig. 25. Photomicrographs of Specimens of RC-130A Scaled in Dry Air for Periods of 1, 2, 4, 8, 16 and 24 Hours at 1600°F. (871.1°C.)

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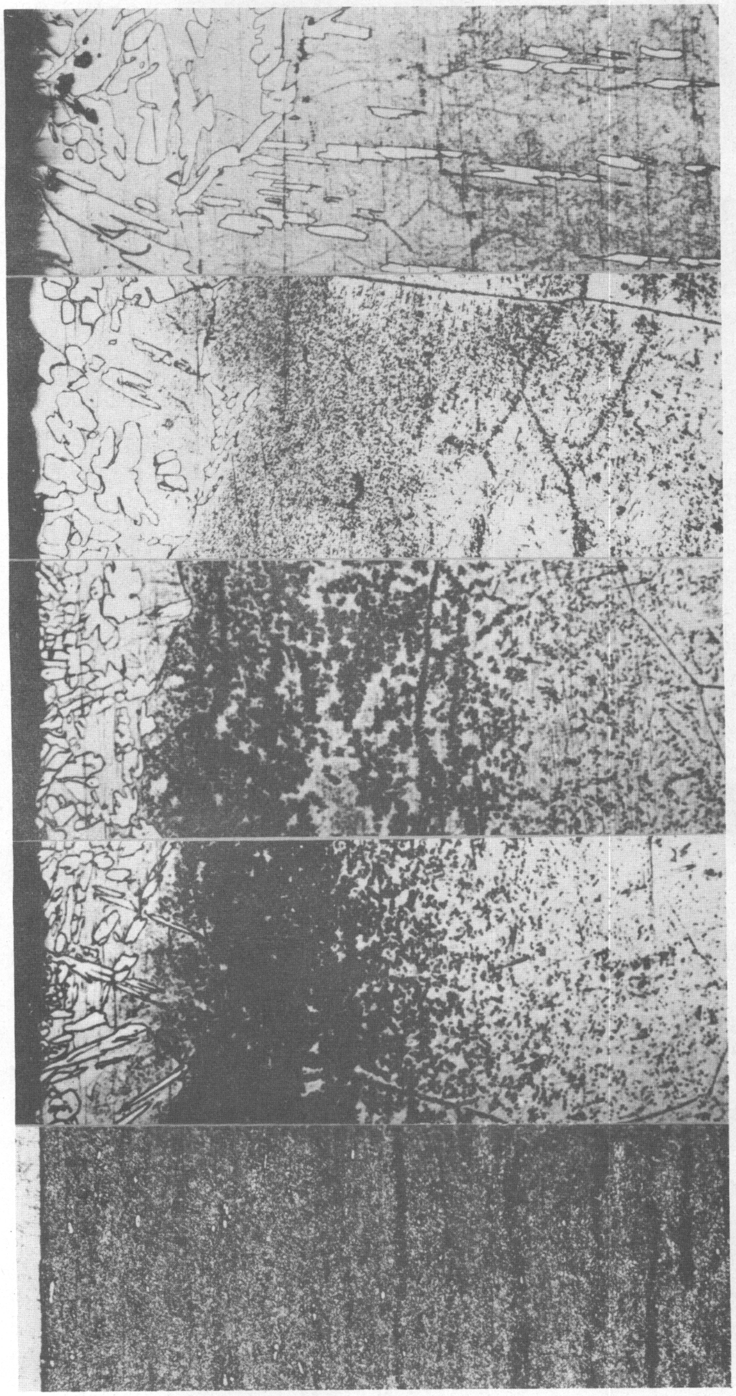

Fig. 26 Photomicrographs of Specimens of RC-130A Scaled in Dry Air for Periods of 0, 1, 2, 4, and 8 Hours at 1800°F. (982.2°C.)

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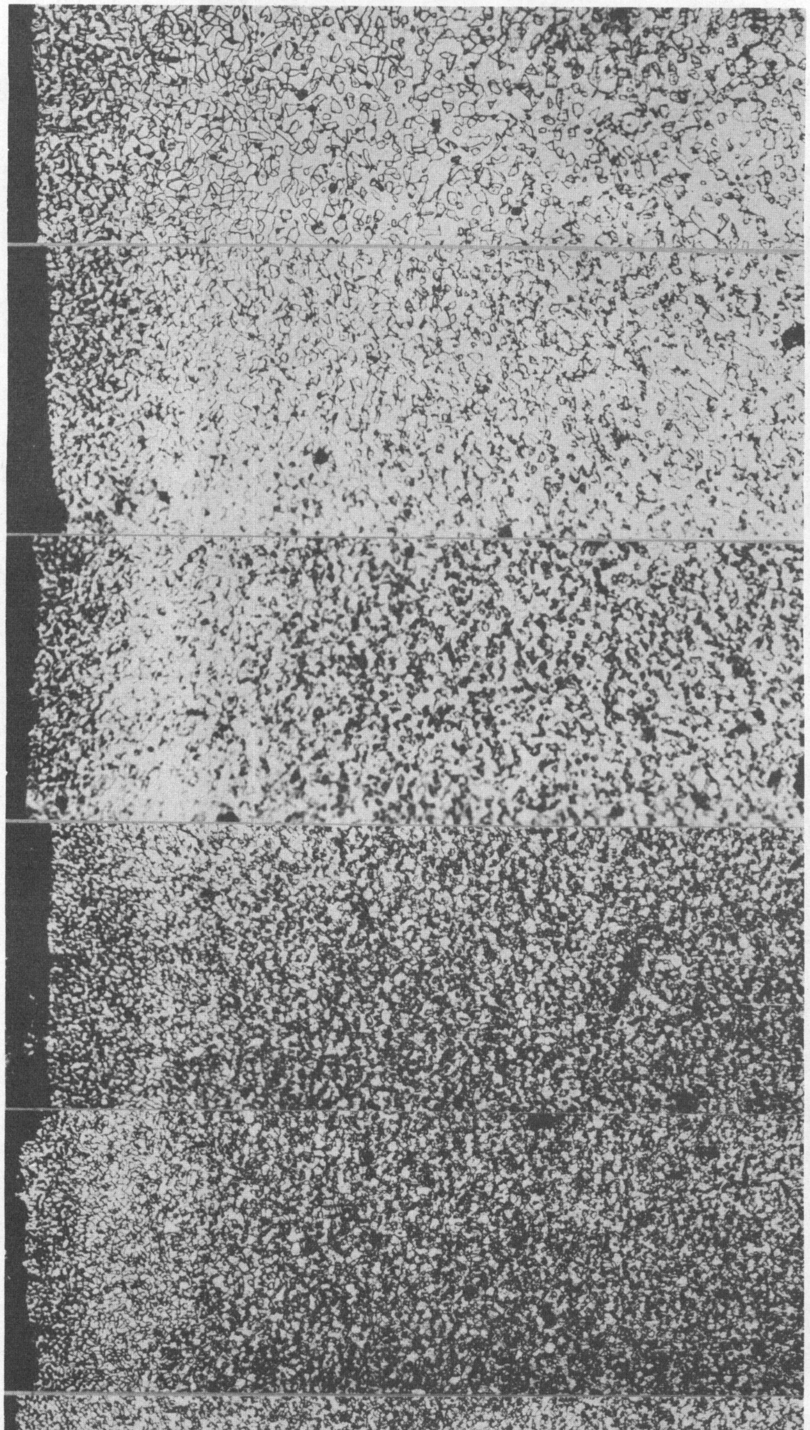

Fig. 27 Photomicrographs of Specimens of RC-130B Scaled in Dry Air for Periods of 2, 3, 4, 8, 16, and 24 Hours at 1600°F. (871.1°C.)

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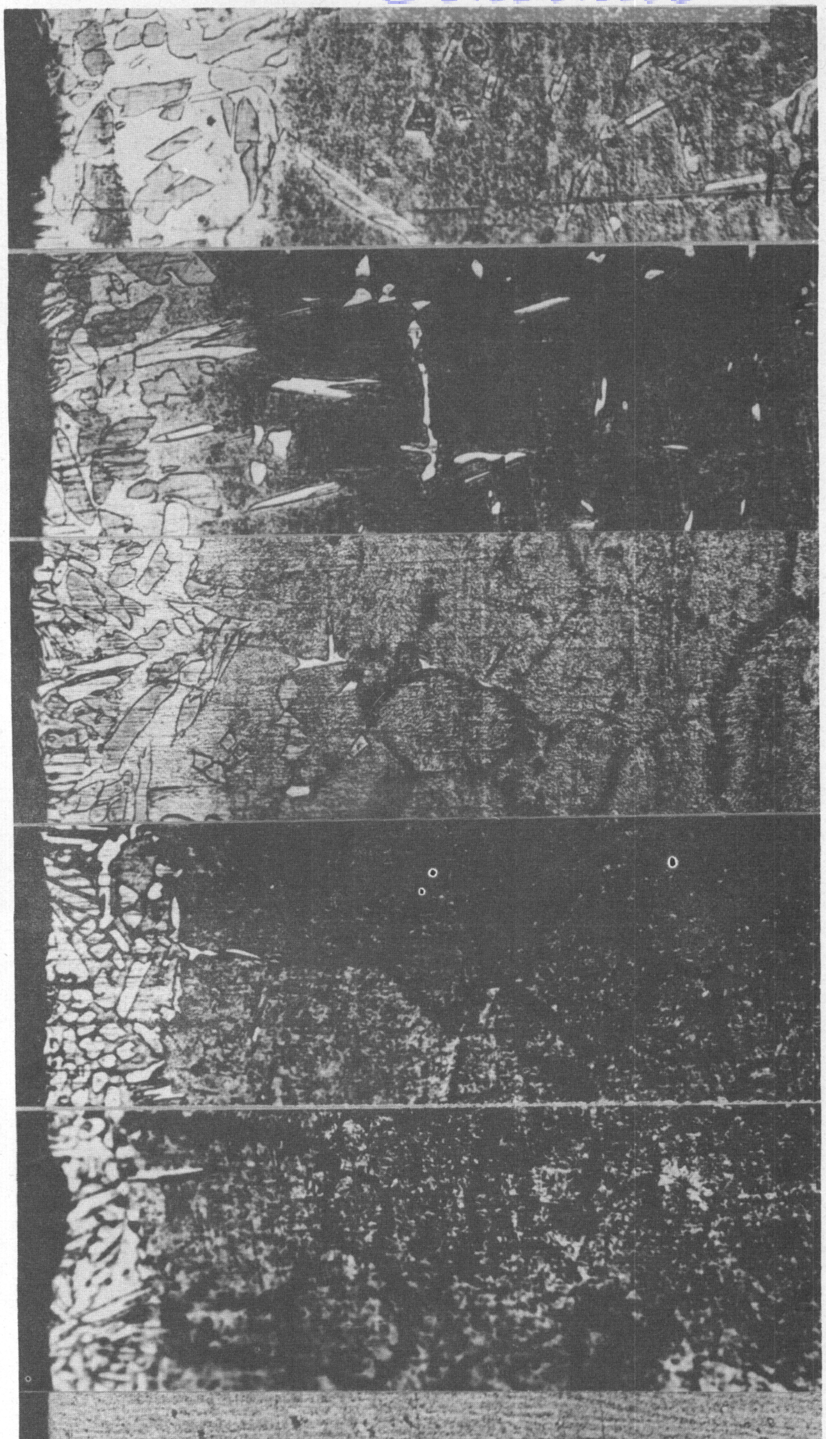

Fig. 28 Photomicrographs of Specimens of RC-130B Scaled in Dry Air for Periods of 0, 1, 2, 4, 6, and 8 Hours at 1800°F. (982.2°C.)

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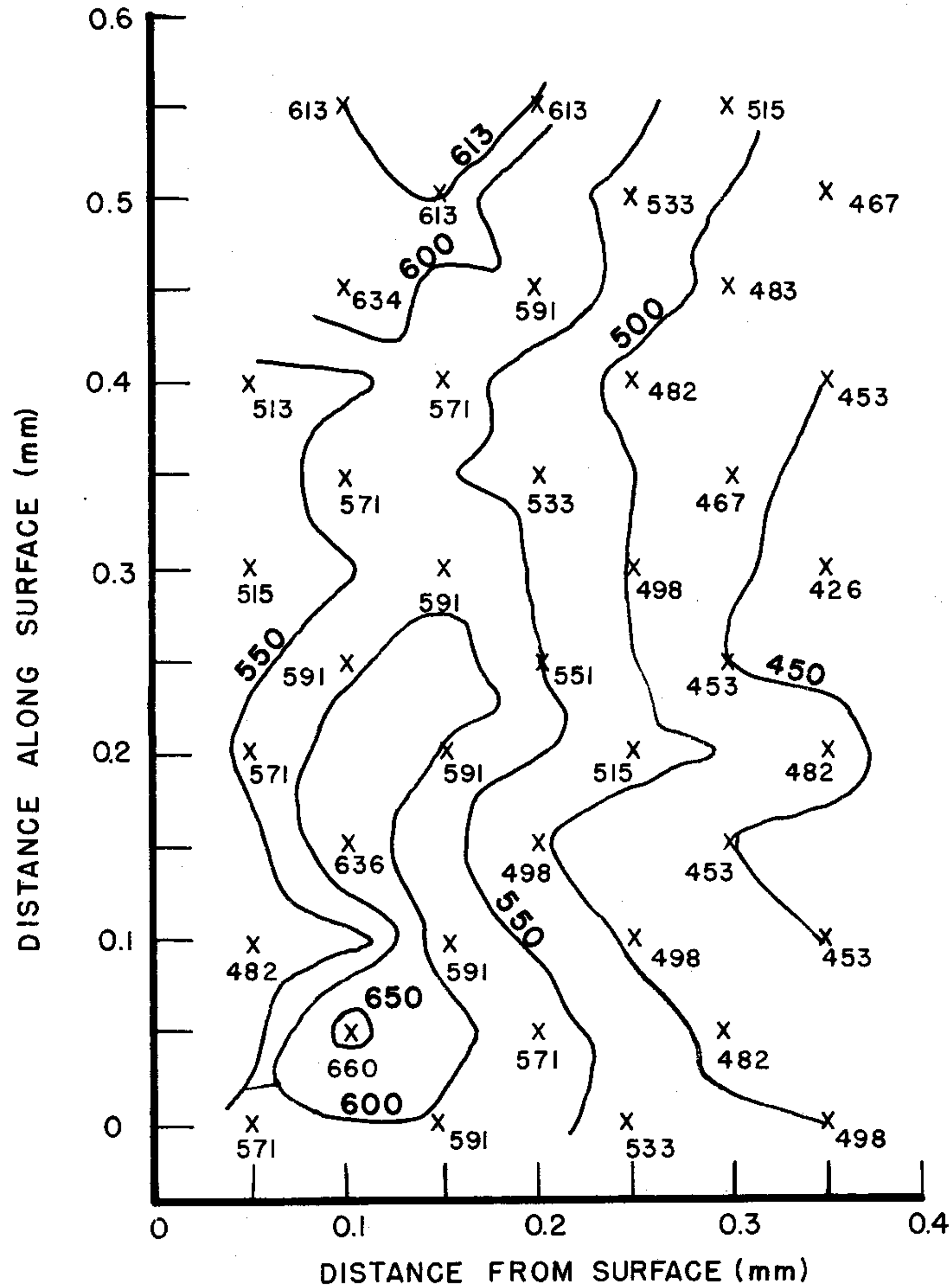

FIG. 29 HARDNESS CONTOUR OF SMALL PORTION OF SPECIMEN OF RC 130B SCALED FOR 4 HOURS AT 1800°F. (982.2°C.) SHOWING UNEVEN GASEOUS PENETRATION.

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V SUMMARY AND CONCLUSIONS

The evaluation of the relative scaling propensity of titanium-base alloys, experimentally and commercially produced, was based on the weight increase caused by the exposure of these materials to temperatures of 1200°, 1400°, 1600°, and 1800°F. in an atmosphere of dry air. Alloy additions of aluminum, cerium, cobalt, copper, chromium, lanthanum, manganese, molybdenum, neodymium, silicon, tantalum, thorium, tungsten, and vanadium to arc-melted process "A" titanium sponge (to form binary, ternary, and quaternary) were found to increase, decrease, or produce essentially no effect upon the scaling rate of titanium.

1. In certain instances it was noted that the effect of alloying additions in concentrations from approximately 0.5% to 10% produced radical changes in the scaling resistance of titanium.

2. It was noted that the alloy systems of titanium containing Co, Cu, Cr, Fe, Mn, Ni, and Si are rather similar in nature, all form intermetallic compounds, have limited solubility, and with the exception of Si these additions all are generally detrimental to the scaling resistance of titanium.

3. The alloy systems of titanium containing Al, Cb, Mo, Ta, and V generally show very good or complete solid solubility and they are, except for aluminum, also beta stabilizers. With the exception of V, additions of these metals to titanium greatly enhances the scaling resistance of the resulting alloys.

4. The addition of Ce, La, Nd, and Th to titanium and to binary and ternary titanium-base alloys generally produced the following effects.

a. In binary alloys these additions were generally beneficial in the alpha region and detrimental in the beta region to the scaling resistance of the alloys.
b. Addition of these elements to binary and ternary alloys which previously had shown poor scaling resistance resulted in a beneficial effect. It was noted, however, that this effect was most pronounced in the alpha region.
c. The addition of these elements to binary and ternary alloys which had previously shown good resistance to scaling was found to be negligible or slightly detrimental in the alpha region, but was generally extremely detrimental in the beta region.

5. Of the thirty-five alloys investigated those containing additions of Ta and Si, with or without other additions, were the most resistant to scaling. The only other alloy with the same order of scaling resistance contained 6.05% Al - 1.97% Mo - 0.48% Si.

6. The second most scale resistant group of alloys contained additions of Al and Si.

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7. The effect of Cr additions was to greatly accelerate the rate of scale formation in the temperature range of 1200° to 1800°F.

8. The adherence of the scale formed to the base metal appears to be a function of the scale thickness alone.

9. The addition of Ce, La, Nd, and Th to titanium produced alloys which were hard, brittle, and very difficult to fabricate.

10. An investigation of the scales formed on specimens exposed at 1600°F. was made using X-ray diffraction. From the investigation it was concluded that:

a. There is a definite preferred orientation in the scales and that it is primarily a fiber texture.
b. There is no correlation between the preferredness of the various scales and scaling rate.
c. Alloying titanium produces no significant differences in the lattice parameter of the rutile scale formed on most of the alloys.
d. There is no correlation between the scaling rate of the alloys studied and the appearance of various groups of unidentified X-ray diffraction lines.

11. A study of the gaseous penetration into the commercial materials RC-70, RC-130A, and RC-130B indicates that the rate of penetration of gas into the metal follows the normal parabolic diffusion law and at the times and temperatures investigated ranged from 0.015 cm to 0.051 cm.

12. Preferredness in gaseous penetration was noted along grain boundaries and also in certain directions within the grains.

13. On the basis of this investigation it appears that the mechanism which predominantly controls the scaling rate of titanium and its alloys is the diffusion of oxygen ions through the scale. This mechanism is also suggested by Davies and Birchenall[11] and Hauffe[12].

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APPENDIX

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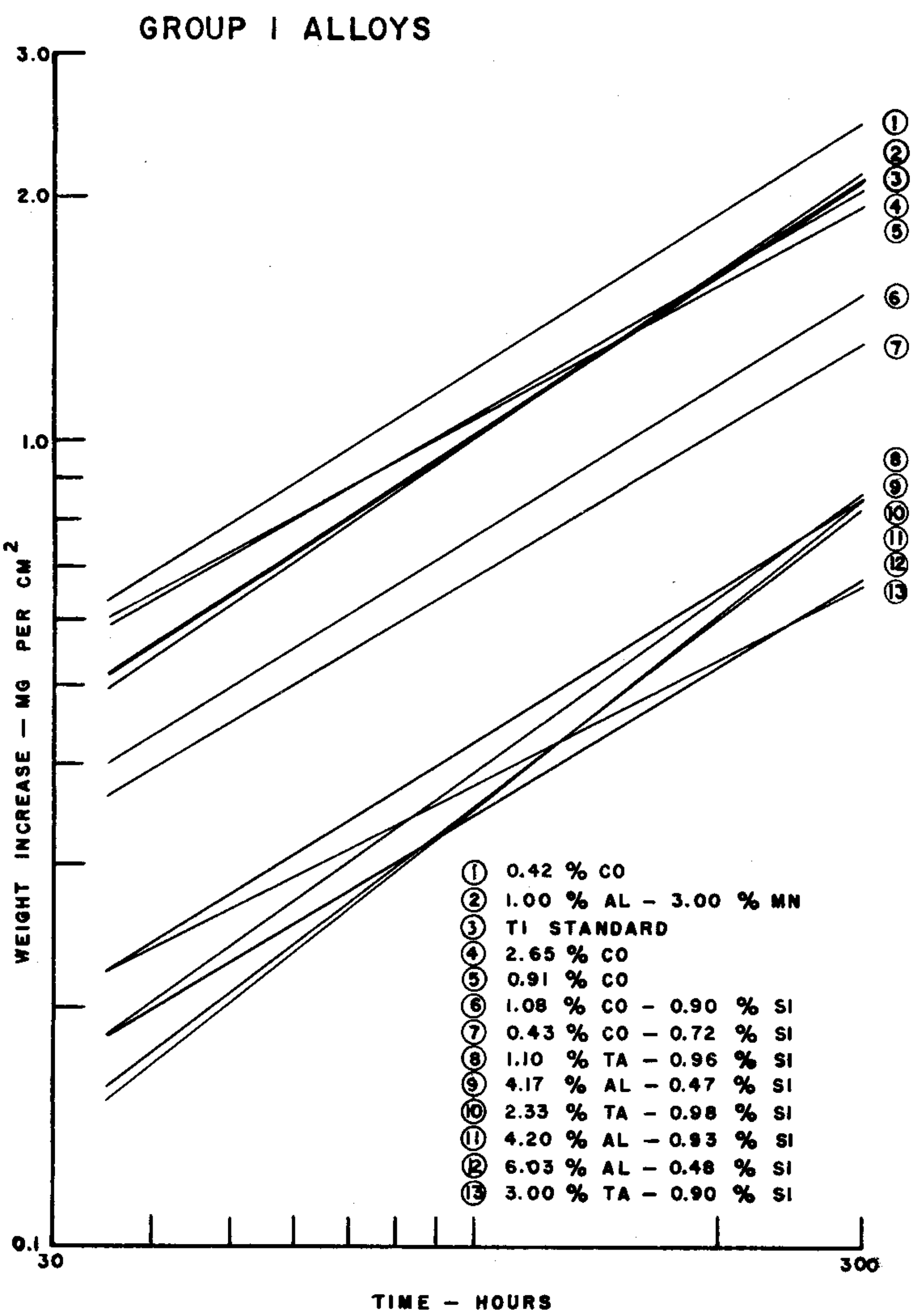

FIG. 30 WEIGHT INCREASE PER UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

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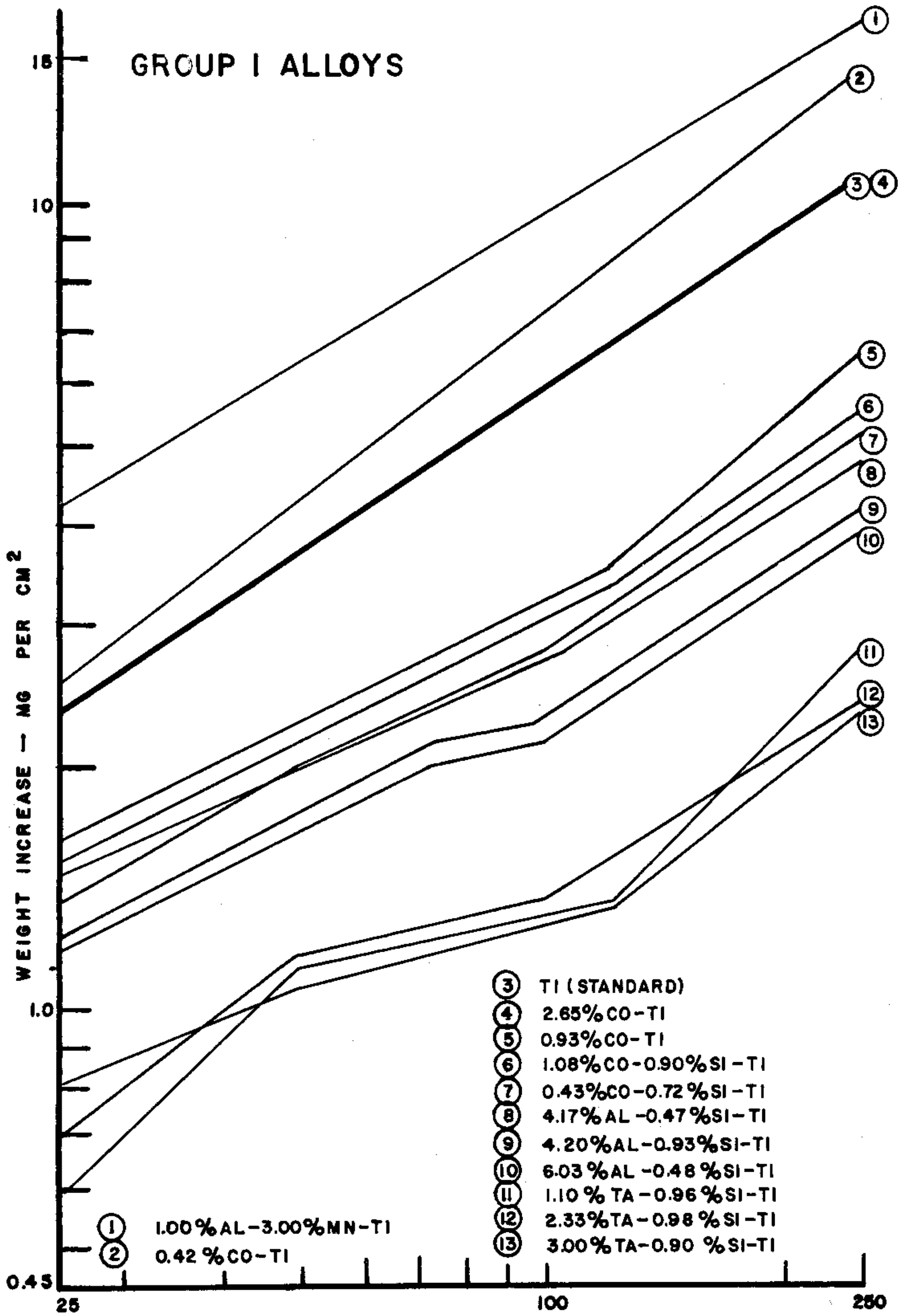

FIG. 31 WEIGHT INCREASE PER UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

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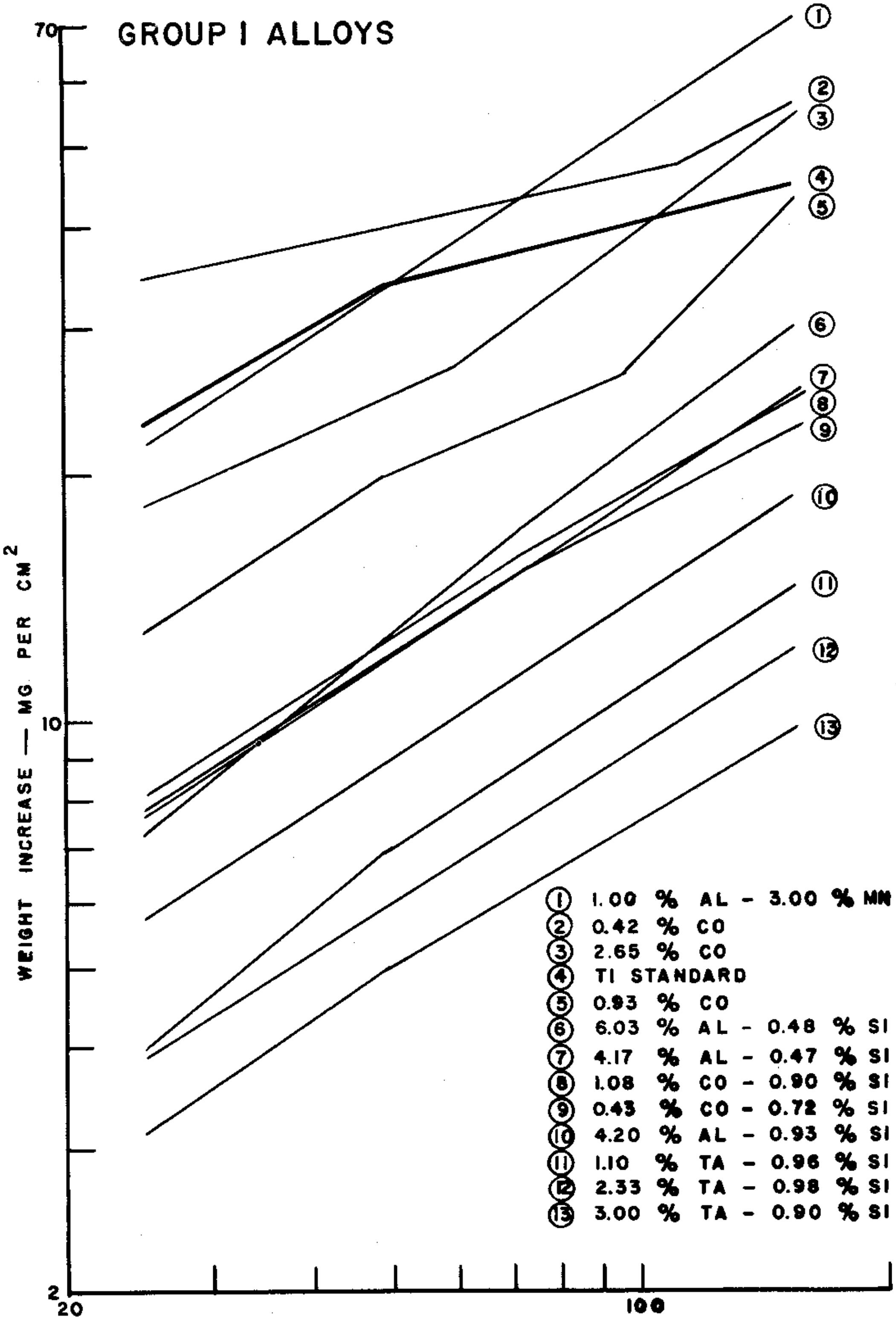

FIG. 32 WEIGHT INCREASE PER UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F (871.1°C.)

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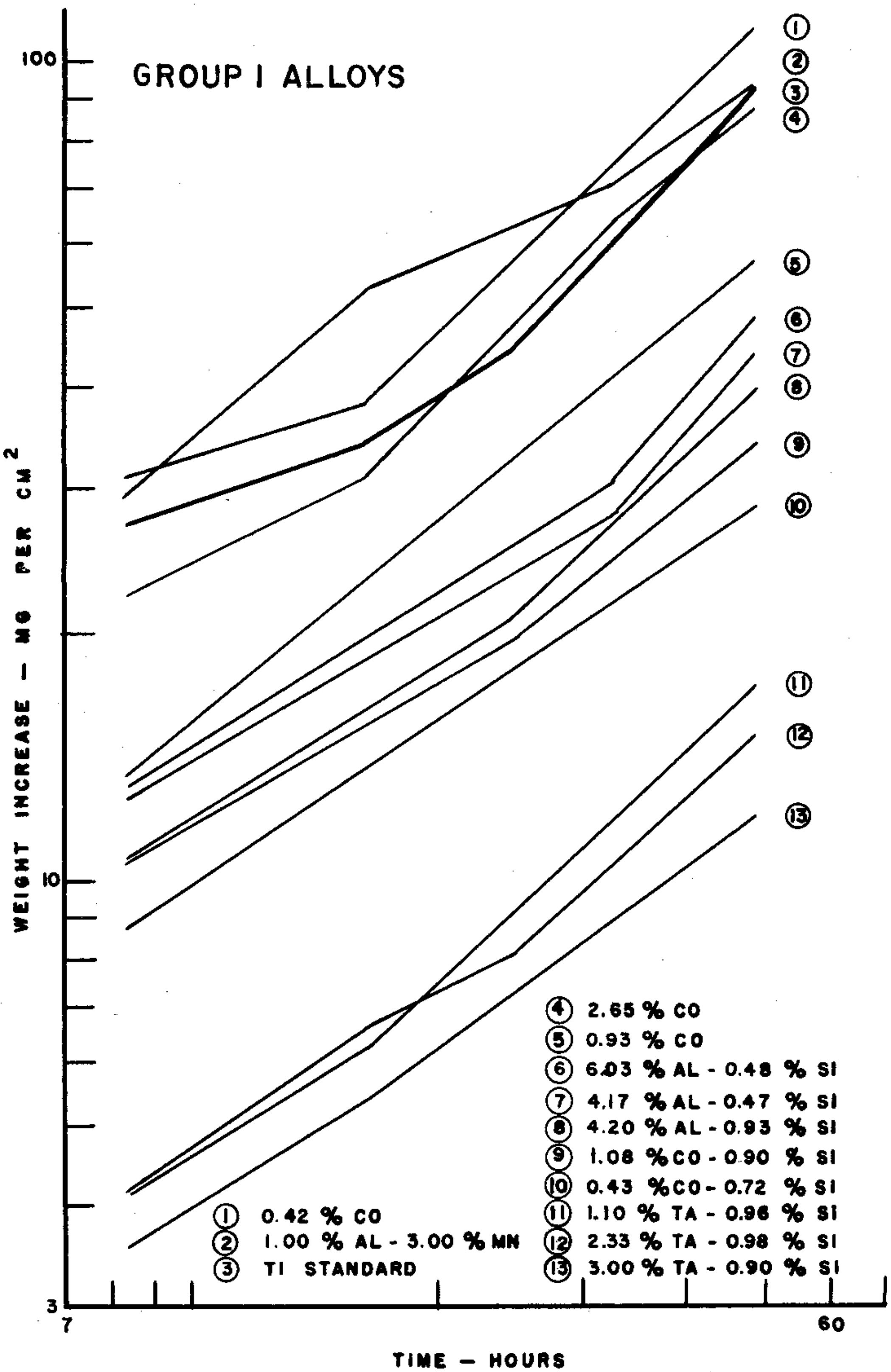

FIG. 33 WEIGHT INCREASE PER UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F (982.2°C)

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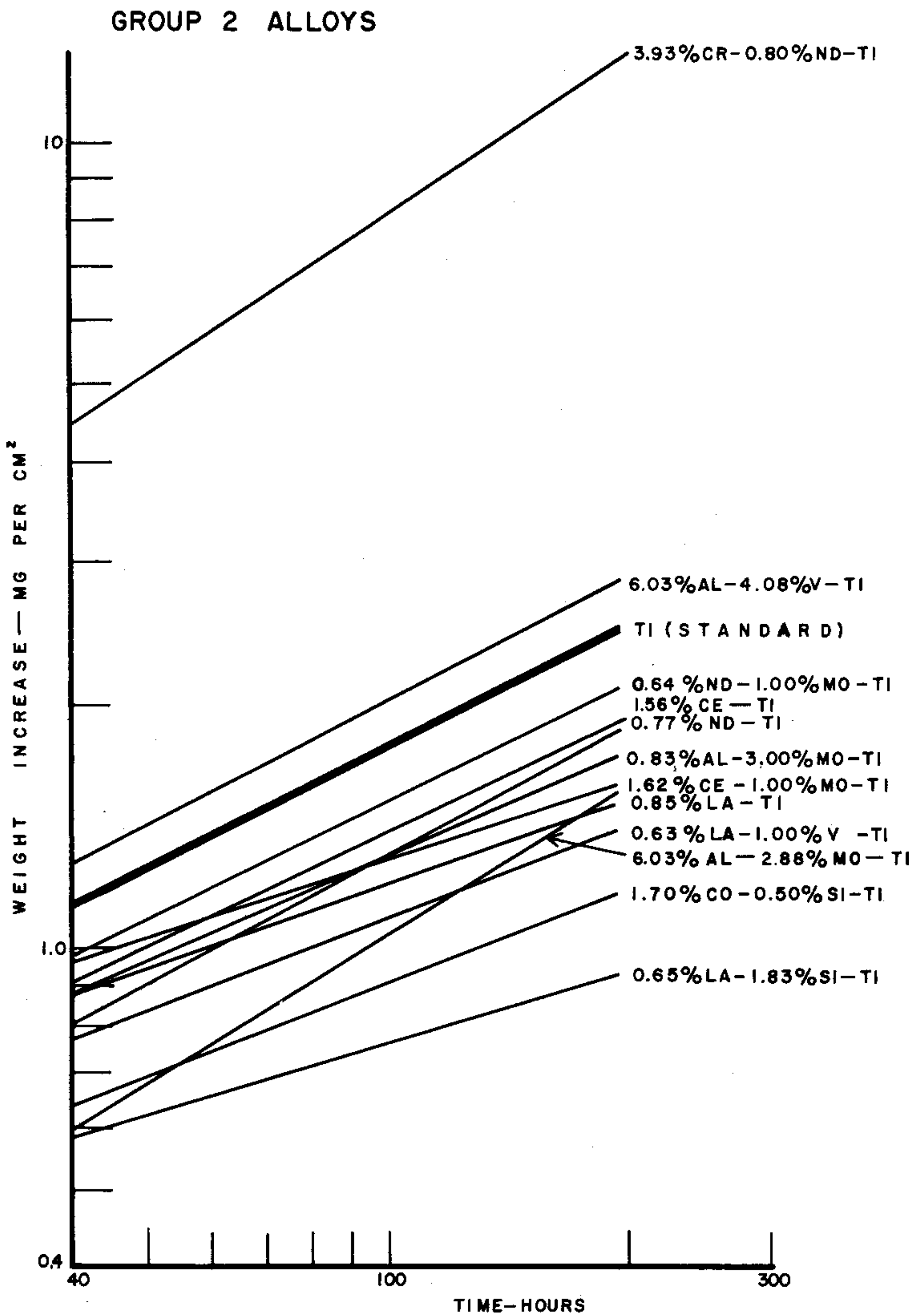

FIG. 34 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F.(648.8°C.)

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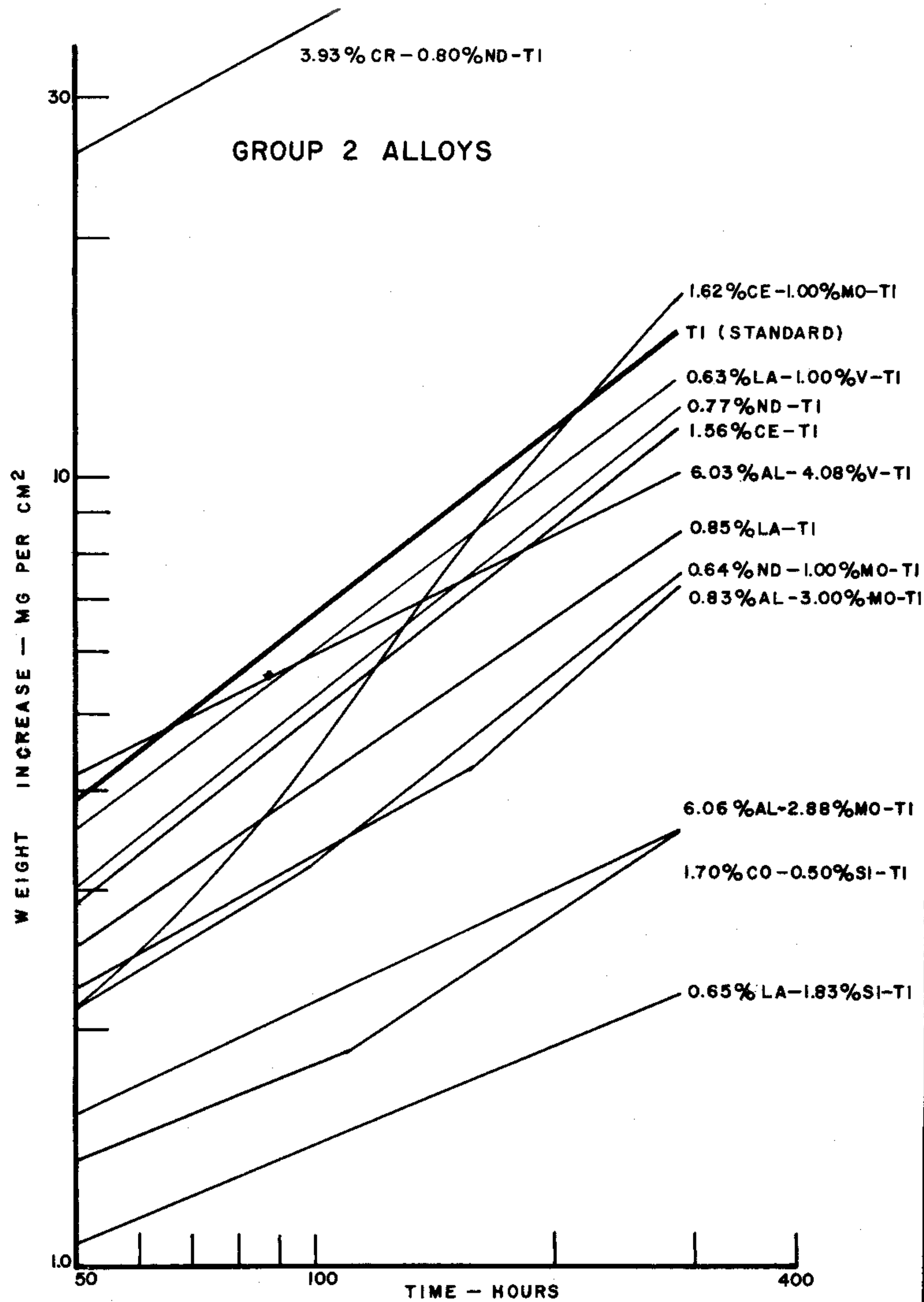

FIG. 35 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F (760.0°C.)

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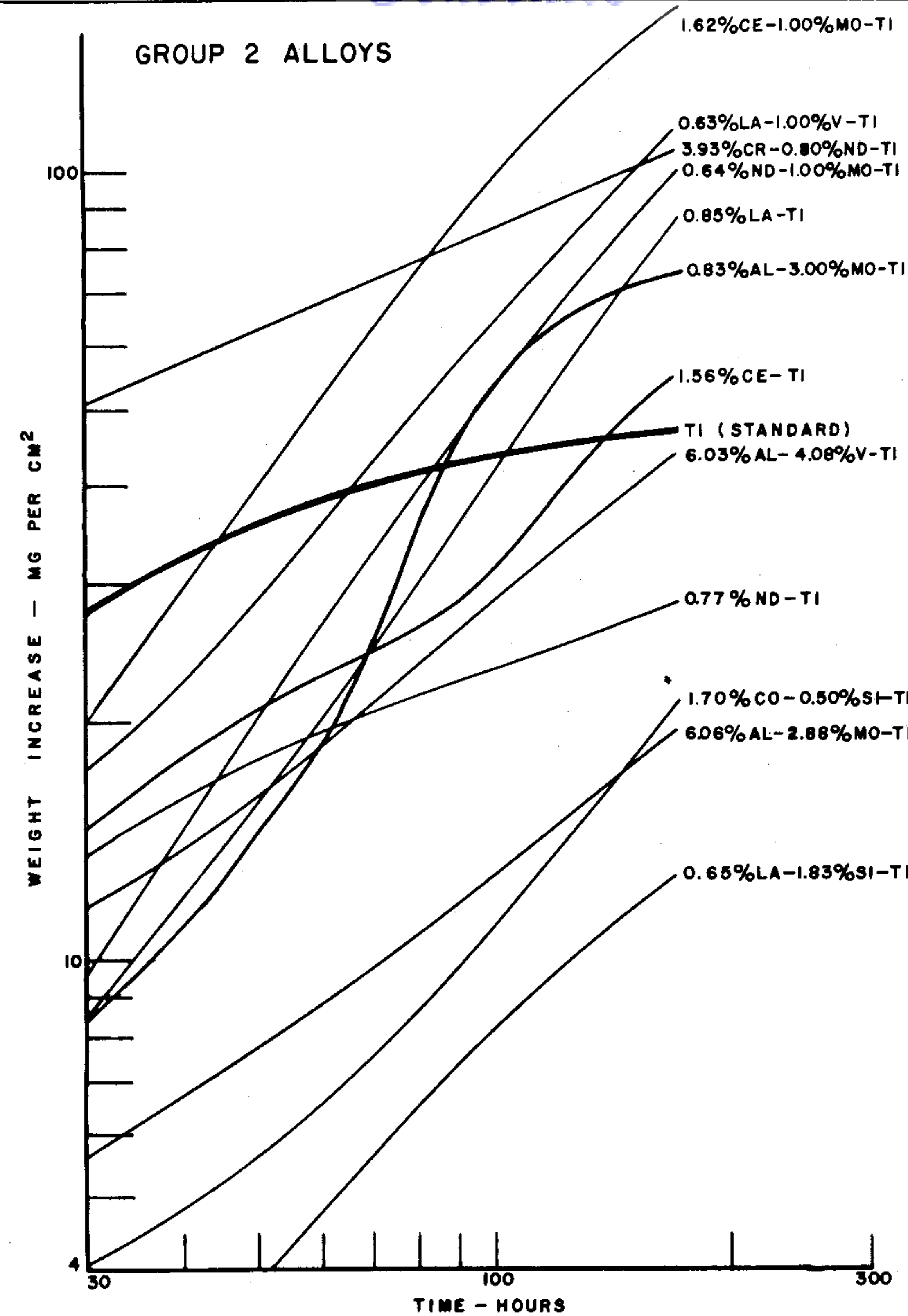

FIG. 36 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F (871.1°C.)

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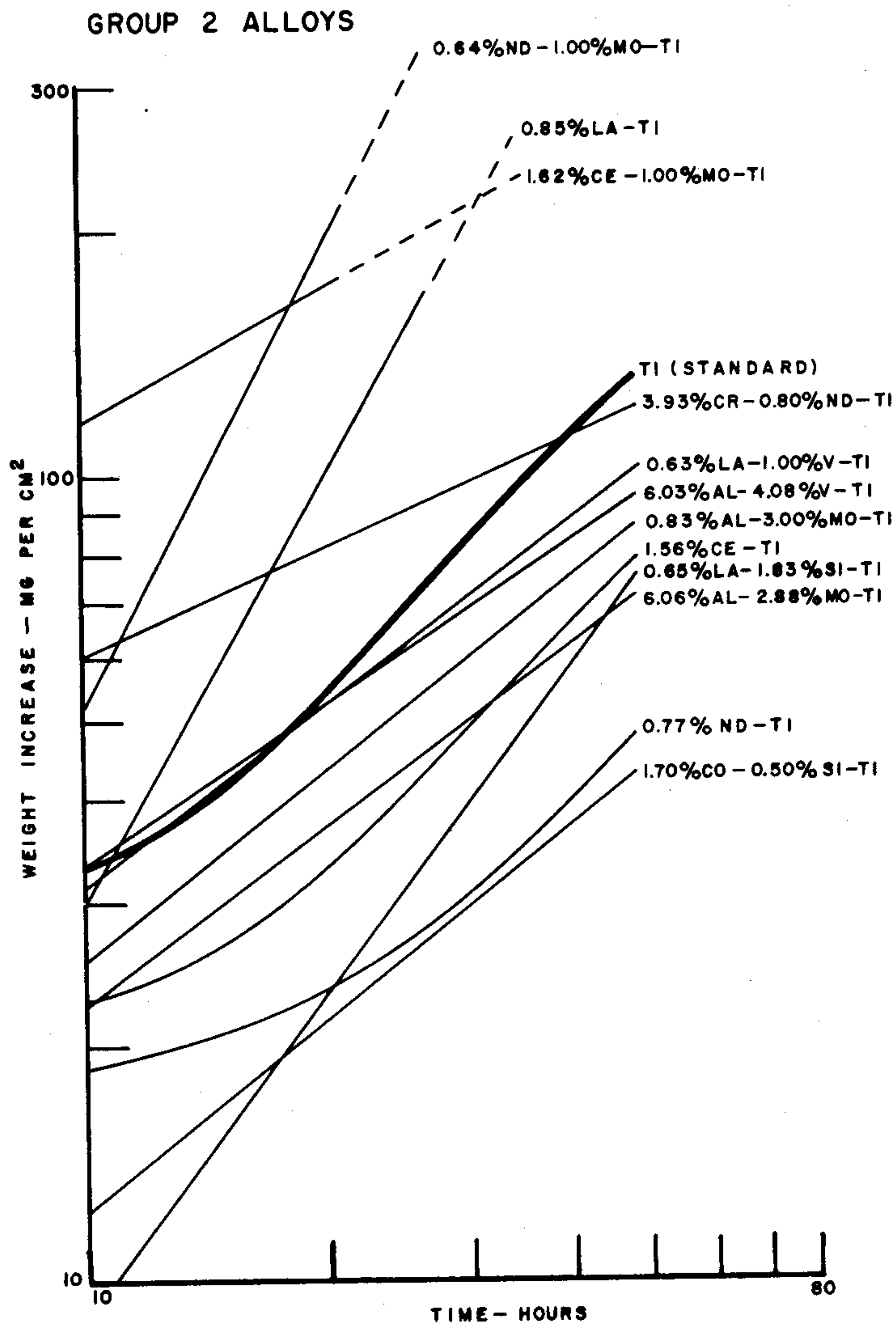

FIG.37 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

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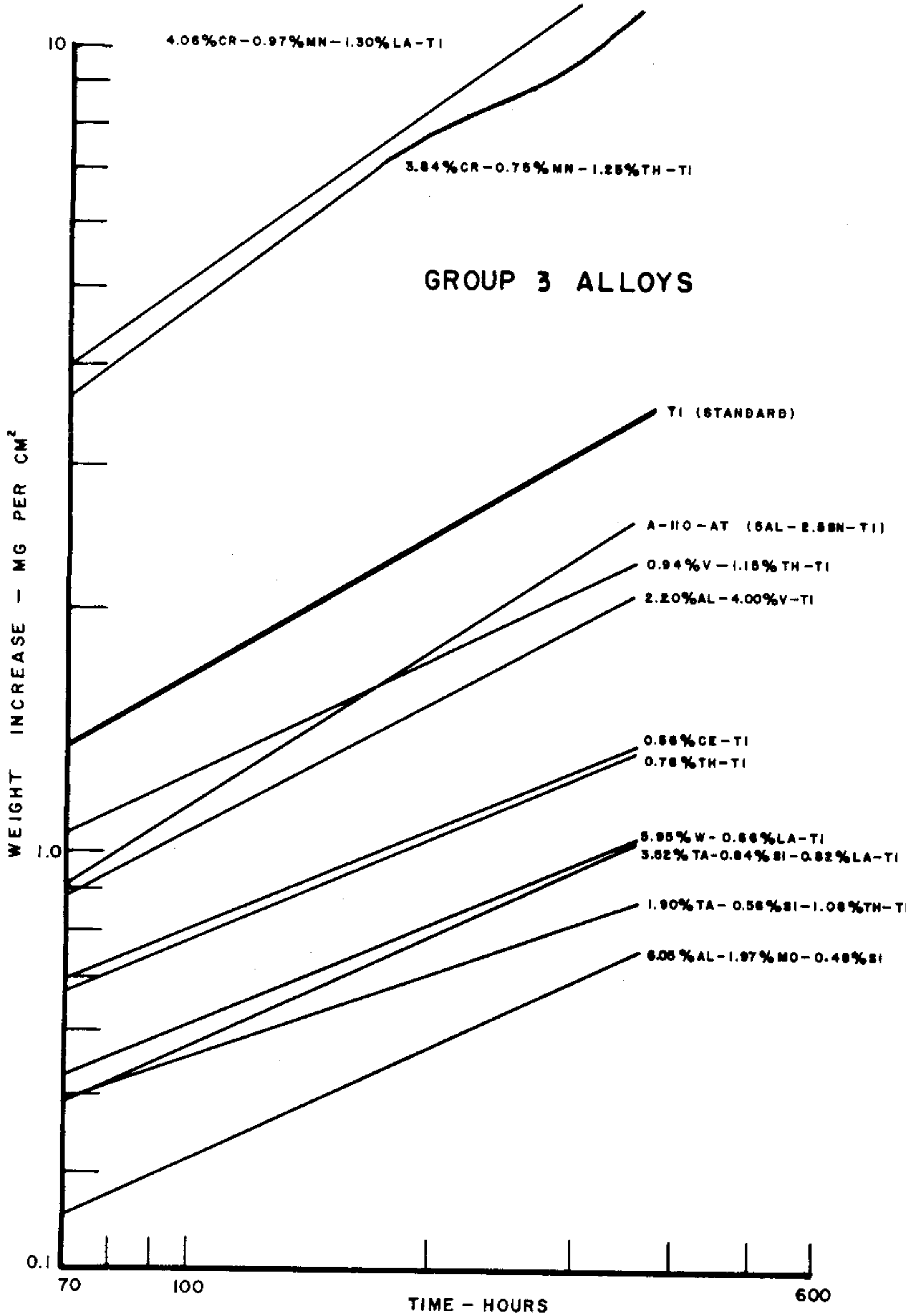

FIG. 38 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

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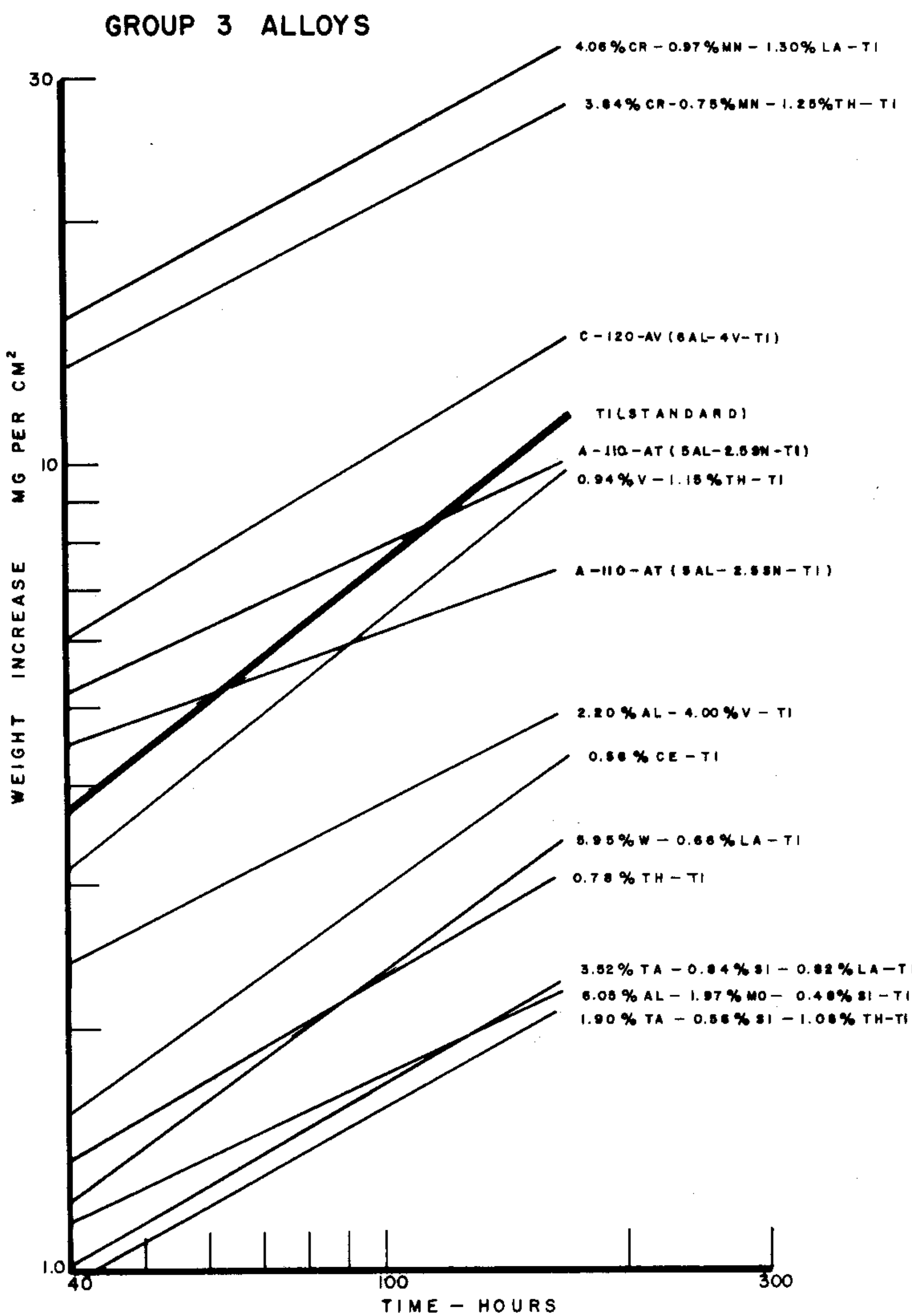

FIG. 39 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

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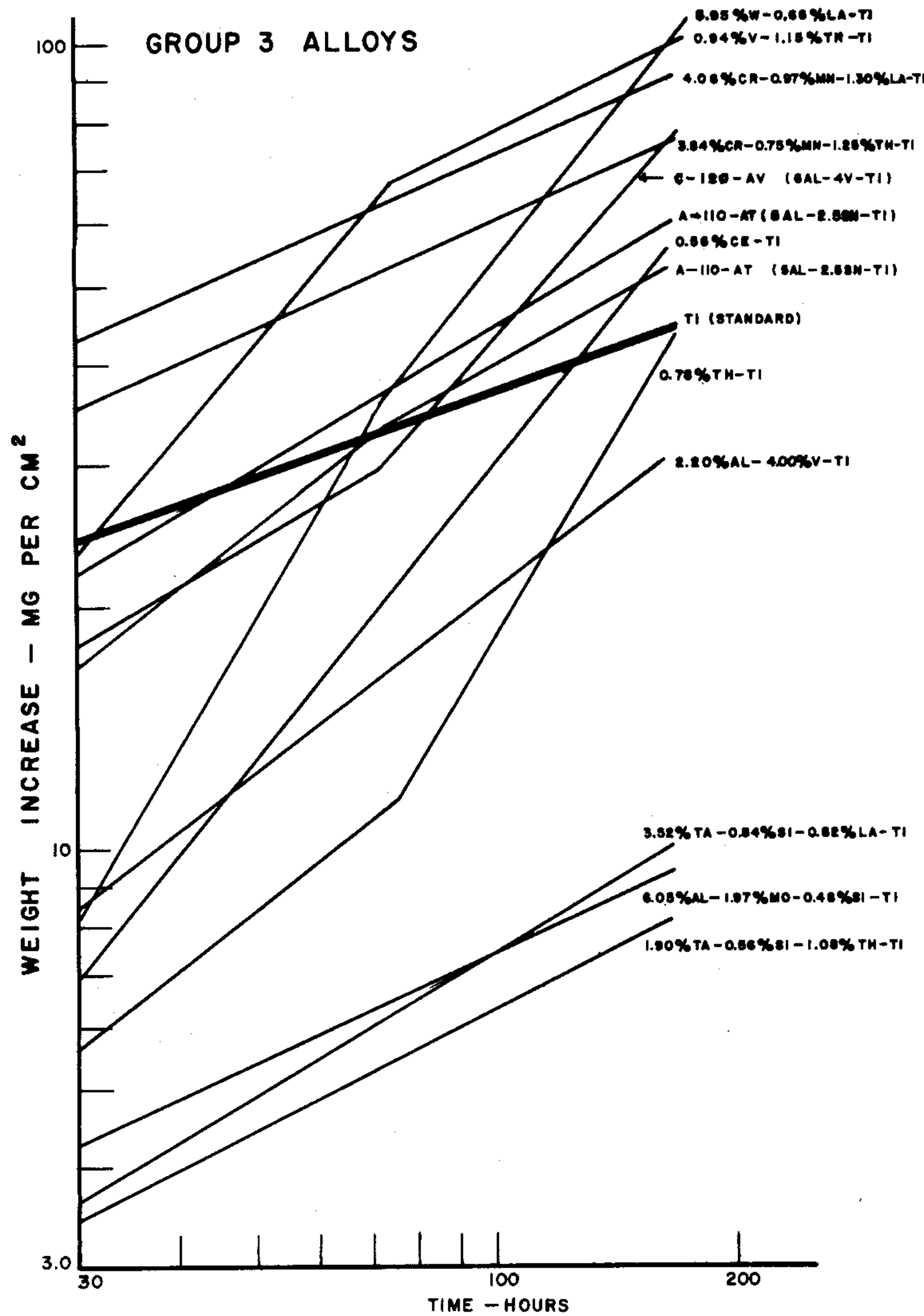

FIG. 40 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

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Contrails

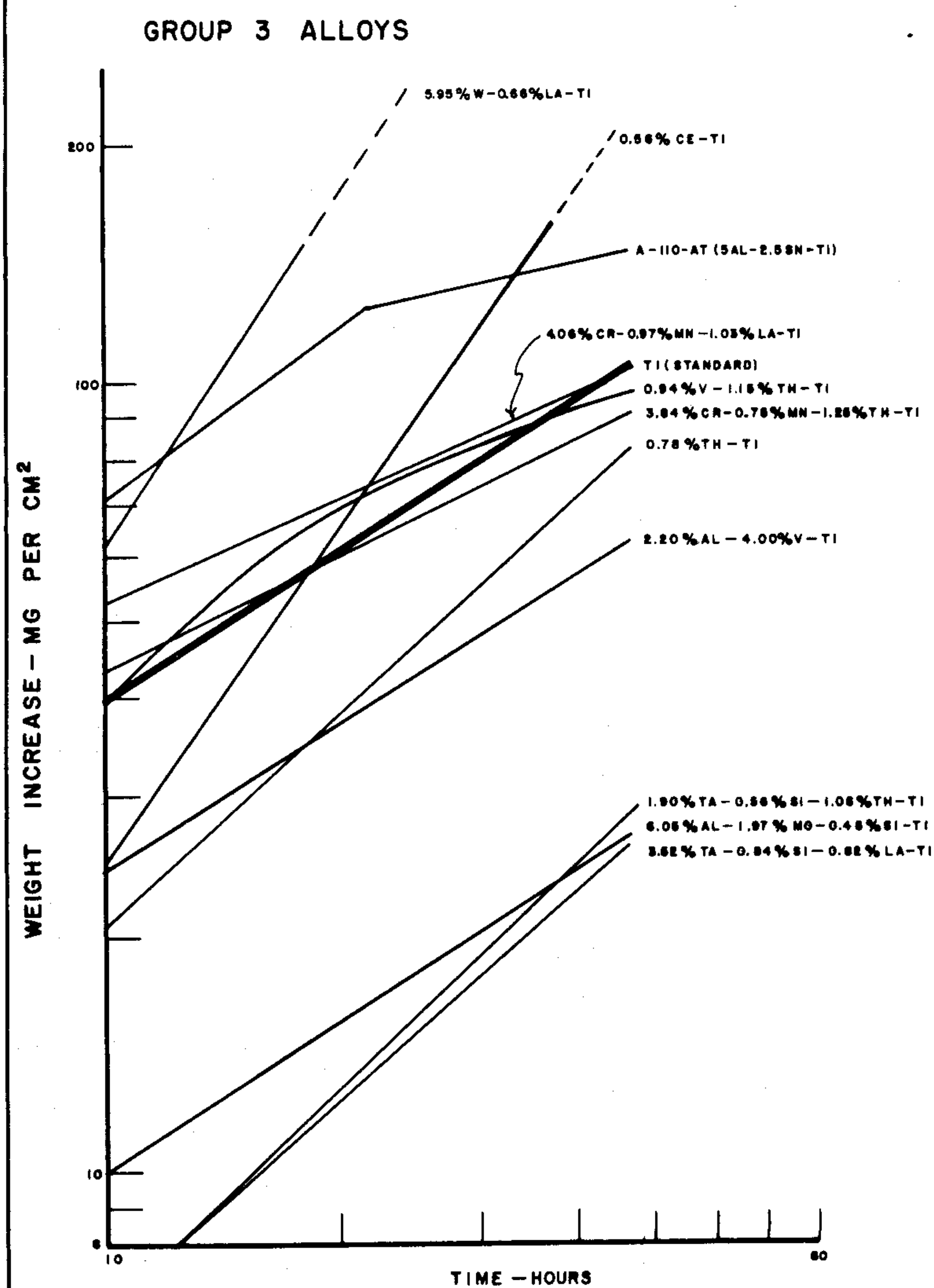

FIG. 41 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

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TABLE 12

GROUP I ALLOYS

SCALING DATA OBTAINED AT 1200°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si A	B	2.33% Ta 0.98% Si A	B	3.00% Ta 0.90% Si A	B	4.20% Al 0.93% Si A	B	6.03% Al 0.48% Si A	B	4.17% Al 0.47% Si A	B
2.7	3.1	0.3	0.9	0.5	0.5	2.0	1.3	1.7	0.3	0.8	1.4	0.7	0.6
24.8	11.0	0.9	5.9	5.0	4.7	4.3	6.0	5.7	5.9	3.8	3.4	4.6	3.8
48.6	17.2	2.5	8.0	5.1	5.1	5.4	6.8	6.6	6.1	3.4	3.0	4.0	5.2
72.9	26.3	8.7	13.7	13.2	17.5	11.8	11.5	11.9	12.0	8.2	11.8	13.2	7.7
98.5	28.9	6.7	15.0	12.8	19.8	12.6	14.0	15.6	14.5	9.6	12.8	14.6	8.9
120.9	28.3	3.2	12.0	10.4	13.9	9.7	12.1	11.5	11.8	9.1	11.7	13.9	9.6
145.4	35.7	8.1	16.2	13.6	18.9	13.1	13.3	15.2	14.8	9.9	13.5	16.3	12.7
168.9	40.4	5.8	15.3	12.8	18.2	12.5	12.2	14.1	12.8	8.3	8.1	14.6	11.4
193.0	42.7	5.3	18.2	14.8	20.6	13.1	15.5	17.0	17.3	11.6	11.2	17.8	14.1
216.7	45.0	6.7	16.9	14.6	18.8	13.6	15.0	16.3	16.4	10.7	15.1	18.8	13.4
240.2	48.2	8.7	20.3	17.7	21.4	15.2	17.6	20.4	20.4	13.7	18.6	22.1	17.8
268.9	53.9	10.3	24.2	21.8	28.5	20.8	20.2	24.4	25.6	17.4	22.7	25.2	21.0
293.1	55.7	11.1	23.5	19.9	23.4	17.6	18.0	19.9	22.2	13.8	19.9	23.5	17.7
317.2	57.2	7.4	21.2	17.8	23.0	17.1	18.6	21.8	20.2	13.6	17.0	19.0	15.7
341.2	60.3	10.1	23.2	21.6	26.6	19.1	20.0	21.7	22.8	15.3	19.1	21.6	18.1

Cumulative Time (Hours)	0.42% Co A	B	0.91% Co A	B	2.65% Co A	B	0.43% Co 0.72% Si A	B	1.08% Co 0.90% Si A	B	1% Al* 3% Mn A	B
2.7	1.3	2.9	4.0	4.0	1.1	2.7	1.2	3.2	1.5	3.1	2.6	1.7
24.8	13.8	14.3	12.7	15.8	14.2	13.0	9.8	10.1	10.0	10.8	13.3	12.9
48.6	21.3	17.3	17.2	20.9	19.2	17.7	9.9	11.7	13.0	12.8	17.2	19.4
72.9	31.1	25.6	21.9	27.1	26.2	25.2	14.7	16.9	16.9	17.5	22.8	25.9
98.5	37.2	37.8	28.8	31.6	32.7	30.8	20.4	21.7	21.2	24.2	28.4	33.8
120.9	39.8	37.5	30.2	33.3	34.2	32.8	19.6	22.0	23.7	26.4	38.3	38.6
145.4	46.0	47.7	36.6	40.5	39.3	38.2	24.2	25.1	27.6	28.3	40.8	41.2
168.9	44.8	45.4	33.8	38.9	38.5	36.5	21.7	23.0	25.4	26.5	40.3	40.7
193.0	49.4	53.8	39.9	43.3	43.6	41.4	27.1	28.3	28.9	31.5	44.8	45.7
216.7	49.8	51.9	37.2	43.4	44.2	41.8	27.6	28.3	29.6	31.1	46.9	48.2
240.2	54.3	58.3	43.9	47.7	49.9	46.5	31.3	33.4	35.3	36.5	54.6	52.0
268.9	64.8	63.9	48.0	52.3	55.1	49.9	34.3	36.8	39.3	39.7	58.5	55.5
293.1	65.9	64.2	50.6	52.8	56.4	49.8	31.4	35.6	38.8	39.1	57.3	54.5
317.2	65.0	64.1	48.1	50.4	54.9	49.8	32.4	36.6	38.8	39.4	60.8	59.1
341.2	67.1	67.3	50.2	52.2	56.1	50.1	32.9	35.9	39.8	39.8	62.7	65.1

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
2.7	3.1	0.6	0.5	1.7	1.0	1.1	0.7	2.1	4.0	1.9	2.2	2.3	2.2
24.8	11.0	3.4	4.9	5.2	5.8	3.6	4.2	14.1	14.3	13.6	10.0	10.4	13.1
48.6	17.2	5.3	5.1	6.1	6.4	3.2	4.6	19.3	19.1	18.5	10.8	12.9	18.3
72.9	26.3	10.2	15.4	11.7	12.0	10.0	10.5	28.4	24.5	25.7	15.8	17.2	24.4
98.5	28.9	10.9	16.3	13.3	15.1	11.2	11.8	37.5	30.2	31.8	21.1	22.7	31.1
120.9	28.3	7.6	12.2	10.9	11.7	10.4	11.8	38.7	31.8	33.5	20.8	25.1	38.5
145.4	35.7	12.2	16.3	13.2	15.0	11.7	14.5	46.9	38.6	38.8	24.7	28.0	41.0
168.9	40.4	10.6	15.5	12.4	13.5	8.2	13.0	45.1	36.4	37.5	22.4	26.0	40.5
193.0	42.7	11.8	17.7	14.3	17.2	11.4	16.0	51.6	41.6	42.5	27.7	30.2	45.3
216.7	45.0	11.8	16.7	14.3	16.4	12.9	16.1	50.9	40.3	43.0	28.0	30.4	47.6
240.2	48.2	14.5	19.6	16.4	20.4	16.2	20.0	56.3	45.8	48.2	32.4	35.9	53.3
268.9	53.9	17.3	25.2	20.5	25.0	20.1	23.1	64.4	50.2	52.5	35.6	39.5	57.0
293.1	55.7	17.3	21.7	17.8	21.1	16.9	20.6	65.1	51.7	53.1	33.5	39.0	55.9
317.2	57.2	14.3	20.4	17.9	21.0	15.3	17.4	64.6	49.3	52.4	34.5	39.1	60.0
341.2	60.3	16.7	24.1	19.6	22.3	17.2	19.9	67.2	51.2	53.1	34.4	39.8	63.9

Average Surface Area (cm^2) of Specimens

Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
27.57	21.92	29.59	28.74	27.27	27.24	27.72	27.99	27.37	27.43	27.72	27.81	29.11

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
2.7	0.11	0.03	0.02	0.06	0.04	0.04	0.03	0.08	0.15	0.07	0.08	0.08	0.08
24.8	0.40	0.16	0.16	0.18	0.21	0.13	0.15	0.50	0.52	0.50	0.36	0.37	0.45
48.6	0.62	0.24	0.17	0.21	0.23	0.12	0.17	0.69	0.70	0.67	0.39	0.46	0.63
72.9	0.95	0.47	0.52	0.41	0.44	0.31	0.38	1.01	0.90	0.94	0.57	0.62	0.84
98.5	1.05	0.48	0.55	0.46	0.55	0.41	0.43	1.34	1.10	1.16	0.76	0.82	1.07
120.9	1.03	0.35	0.41	0.38	0.43	0.38	0.43	1.38	1.16	1.22	0.75	0.90	1.32
145.4	1.29	0.56	0.55	0.46	0.55	0.43	0.52	1.68	1.41	1.41	0.89	1.01	1.41
168.9	1.47	0.48	0.52	0.43	0.50	0.30	0.47	1.61	1.33	1.37	0.81	0.93	1.39
193.0	1.54	0.54	0.60	0.50	0.63	0.42	0.58	1.84	1.52	1.55	1.00	1.09	1.56
216.7	1.63	0.54	0.56	0.50	0.60	0.47	0.58	1.82	1.47	1.57	1.01	1.09	1.64
240.2	1.75	0.66	0.66	0.57	0.75	0.59	0.72	2.01	1.67	1.76	1.17	1.29	1.83
268.9	1.96	0.79	0.85	0.71	0.92	0.74	0.83	2.30	1.83	1.91	1.28	1.42	1.96
293.1	2.02	0.79	0.73	0.62	0.77	0.62	0.74	2.33	1.89	1.94	1.21	1.40	1.92
317.2	2.07	0.65	0.69	0.62	0.77	0.56	0.63	2.31	1.80	1.91	1.24	1.41	2.06
341.2	2.19	0.76	0.81	0.68	0.82	0.63	0.72	2.40	1.87	1.94	1.24	1.43	2.20

*Intended Composition

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TABLE 13

GROUP I ALLOYS

SCALING DATA OBTAINED AT 1400°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si		2.33% Ta 0.98% Si		3.00% Ta 0.90% Si		4.20% Al 0.93% Si		6.03% Al 0.48% Si		4.17% Al 0.47% Si		0.42% Co		0.91% Co		2.65% Co		0.43% Co 0.72% Si		1.08% Co 0.90% Si		1% Al* 3% Mn	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
6.1	26.4	3.8	4.0	10.6	9.8	12.6	8.7	11.3	14.7	9.6	13.3	10.3	12.5	32.2	32.4	24.4	19.6	27.6	30.3	17.9	15.0	16.9	20.1	49.3	48.4
25.1	65.4	10.1	8.6	21.5	18.6	22.7	18.2	38.6	35.8	32.7	31.4	33.9	34.1	71.1	72.1	49.5	39.4	65.0	66.8	39.5	40.7	42.9	41.9	120.4	125.2
49.2	100.4	16.4	18.5	32.1	34.4	30.4	23.7	52.1	56.0	44.7	45.5	47.3	44.6	114.3	113.6	65.8	53.8	96.9	96.4	52.4	56.4	58.9	56.3	182.2	185.6
73.3	129.1	18.8	20.5	36.4	37.8	33.7	26.8	61.0	67.3	56.2	53.6	59.8	58.0	158.8	151.8	85.5	65.5	125.2	130.1	66.6	68.9	72.1	72.3	228.0	235.7
97.3	155.9	19.0	21.8	38.7	38.9	33.7	25.7	71.7	73.2	58.1	57.2	62.9	61.3	191.1	189.2	107.8	70.2	146.5	150.9	75.5	76.9	84.7	82.2	269.8	275.1
121.3	181.4	20.7	22.6	42.5	44.0	37.4	30.3	82.0	81.5	64.1	64.2	71.6	70.2	225.7	225.4	114.0	77.5	168.2	173.5	85.9	89.5	92.3	91.9	305.5	311.3
145.2	203.8	24.9	29.4	48.8	50.6	45.7	31.6	90.3	92.5	72.1	71.1	80.1	79.0	266.4	261.3	134.9	87.2	192.0	194.9	96.6	100.5	104.5	103.8	340.3	345.8
168.9	229.6	33.6	33.3	52.7	55.6	52.7	38.1	102.3	103.6	80.7	84.9	92.5	89.7	304.4	299.4	152.7	106.3	217.7	222.9	109.4	110.5	117.3	117.7	376.9	384.5
192.9	254.1	34.2	36.1	56.2	59.9	55.4	40.2	109.7	110.9	85.9	90.0	95.2	94.5	337.5	332.1	172.1	117.6	236.7	240.7	118.0	122.7	129.6	127.8	411.2	417.1
216.8	280.5	36.6	40.3	61.2	64.5	60.1	45.0	119.7	121.0	98.3	97.9	103.9	106.1	375.5	368.6	192.1	132.1	260.2	266.7	132.2	135.5	143.4	141.4	443.7	448.1
240.9	296.6	37.2	39.3	60.5	64.5	60.9	42.7	122.7	124.6	99.6	99.5	105.9	106.2	397.1	391.6	202.1	136.7	272.1	281.4	136.7	141.0	149.5	145.6	468.6	477.4

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
6.1	26.4	3.9	10.2	10.7	13.0	11.5	11.4	32.3	22.0	29.0	16.5	18.5	48.9
25.1	65.4	9.4	20.1	20.5	37.2	32.1	34.0	71.6	44.5	65.9	40.1	42.4	122.8
49.2	100.4	17.5	33.3	27.1	54.1	45.1	46.0	114.0	59.8	96.7	54.4	57.6	183.9
73.3	129.1	19.7	37.1	30.3	64.2	54.9	58.9	155.3	75.5	127.7	67.8	72.2	231.9
97.3	155.9	20.4	38.8	29.7	72.5	57.7	62.1	190.2	89.0	148.7	76.2	83.5	272.5
121.3	181.4	21.7	43.3	33.9	81.8	64.2	70.9	225.6	95.8	170.9	87.7	92.1	308.4
145.2	203.8	27.2	49.7	38.7	91.4	71.6	79.6	263.9	111.1	193.5	98.6	104.2	343.1
168.9	229.6	33.5	54.2	45.4	103.0	82.8	91.1	301.9	129.5	220.3	110.0	117.5	380.7
192.6	254.1	35.2	58.1	47.8	110.3	88.0	94.9	334.8	144.9	238.7	120.4	128.7	414.2
216.8	280.5	38.5	62.9	52.6	120.4	98.1	105.0	372.1	162.1	263.5	133.9	142.4	445.9
240.9	296.6	38.3	62.5	51.8	123.7	99.6	106.1	394.4	169.4	276.8	138.9	147.6	473.0

Average Surface Area (cm^2) of Specimens

Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
27.46	15.96	28.66	25.27	27.21	27.15	27.68	27.82	27.41	27.19	27.72	27.67	29.09

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
6.1	0.96	0.24	0.36	0.42	0.48	0.42	0.41	1.16	0.80	1.07	0.60	0.67	1.68
25.1	2.38	0.59	0.70	0.81	1.37	1.18	1.23	2.57	1.62	2.42	1.45	1.53	4.22
49.2	3.65	1.10	1.16	1.07	1.99	1.66	1.66	4.10	2.18	3.56	1.96	2.08	6.32
73.3	4.69	1.23	1.29	1.20	2.36	2.02	2.13	5.58	2.75	4.70	2.45	2.61	7.97
97.3	5.67	1.28	1.35	1.18	2.66	2.13	2.24	6.84	3.25	5.47	2.75	3.02	9.37
121.3	6.59	1.36	1.51	1.34	3.01	2.36	2.56	8.11	3.49	6.29	3.16	3.33	10.60
145.2	7.41	1.70	1.73	1.53	3.36	2.64	2.88	9.49	4.05	7.12	3.56	3.77	11.79
168.9	8.35	2.18	1.89	1.80	3.79	3.05	3.29	10.85	4.72	8.10	3.97	4.25	13.09
192.9	9.24	2.21	2.03	1.89	4.05	3.24	3.43	12.03	5.29	8.78	4.34	4.65	14.24
216.8	10.20	2.41	2.19	2.08	4.42	3.61	3.79	13.38	5.91	9.69	4.83	5.15	15.33
240.9	10.78	2.40	2.18	2.05	4.55	3.67	3.83	14.18	6.18	10.18	5.01	5.33	16.26

*Intended Composition

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TABLE 14

GROUP I ALLOYS

SCALING DATA OBTAINED AT 1600°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si A	B	2.33% Ta 0.98% Si A	B	3.00% Ta 0.90% Si A	B	4.20% Al 0.93% Si A	B	6.03% Al 0.48% Si A	B	4.17% Al 0.47% Si A	B
24.9	641.5	118.2	55.6	104.2	113.8	91.9	83.0	208.2	208.4	196.7	201.2	161.3	157.1
48.9	932.4	199.4	97.9	167.2	181.9	146.0	131.7	324.0	319.9	319.5	324.7	251.4	245.0
72.5	1040.4	258.0	132.3	209.3	237.0	183.9	165.2	414.9	408.7	457.1	475.9	320.0	312.9
97.0	1102.9	308.2	161.1	247.6	284.2	221.7	201.5	504.2	495.1	567.6	590.7	388.4	381.0
120.4	1151.2	351.1	185.4	280.9	319.6	247.2	219.7	577.1	566.0	654.2	681.4	444.3	434.5
144.9	1205.5	389.2	207.5	318.2	357.1	278.2	241.4	657.0	643.2	751.6	776.4	495.0	485.0
156.0	1241.5	405.4	217.8	333.8	377.3	289.2	252.1	688.7	674.0	796.9	828.4	519.5	507.5

Cumulative Time (Hours)	0.42% Co A	B	0.91% Co A	B	2.65% Co A	B	0.43% Co 0.72% Si A	B	1.08% Co 0.90% Si A	B	1% Al* 3% Mn A	B
24.9	870.3	908.1	348.3	365.7	524.0	489.6	214.8	214.6	222.4	229.8	623.8	648.4
48.9	1085.5	1121.7	520.9	568.7	701.5	656.3	334.6	331.0	343.2	352.5	939.8	966.9
72.5	1167.1	1205.2	600.9	652.8	876.7	825.0	422.9	412.8	434.0	445.5	1224.3	1267.9
97.0	1243.8	1284.9	709.3	742.0	1097.8	1063.5	498.4	482.2	516.2	530.6	1570.7	1608.6
120.4	1324.6	1370.2	942.4	922.3	1225.6	1249.0	555.2	533.0	580.8	597.5	1753.8	1787.9
144.9	1432.7	1512.2	1081.5	1146.7	1330.4	1449.0	609.1	584.8	641.2	657.9	1964.8	2002.2
156.0	1494.4	1597.2	1122.9	1198.3	1381.7	1532.5	627.2	601.3	659.9	677.6	2051.5	2090.2

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
24.9	641.5	86.9	109.0	87.5	208.3	199.0	159.2	889.2	353.0	506.8	214.7	226.1	636.1
48.9	932.4	148.7	174.6	138.9	322.0	322.1	248.2	1103.6	544.8	678.9	322.8	347.9	953.4
72.5	1040.4	195.2	223.2	174.6	411.8	466.5	316.5	1186.2	626.9	850.9	417.9	439.8	1246.1
97.0	1102.9	234.7	265.9	211.6	499.7	579.2	384.7	1264.4	725.7	1080.7	490.3	523.4	1589.7
120.4	1151.2	268.3	300.3	233.5	571.6	667.8	439.4	1347.4	932.4	1237.3	544.1	589.2	1770.9
144.9	1205.5	298.4	337.7	259.8	650.5	764.0	490.0	1472.5	1114.1	1393.7	597.0	649.6	1983.5
156.0	1241.5	311.6	355.6	270.7	681.4	808.7	513.5	1545.8	1160.6	1457.1	614.3	668.8	2070.9

Average Surface Area (cm^2) of Specimens

Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
27.95	21.84	29.31	28.00	27.25	27.13	27.75	27.89	27.55	27.70	27.71	27.87	29.48

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
24.9	22.95	3.98	3.72	3.13	7.64	7.34	5.74	31.88	12.81	18.30	7.75	8.11	21.63
48.9	33.36	6.81	5.96	4.96	11.82	11.87	8.94	39.57	19.77	24.51	12.81	12.48	32.42
72.5	37.22	8.94	7.62	6.24	15.12	17.19	11.41	42.53	22.75	30.72	15.08	15.78	42.34
97.0	39.46	10.75	9.07	7.56	18.34	21.35	13.86	45.34	26.34	39.01	17.69	18.78	54.05
120.4	41.19	12.29	10.25	8.34	20.98	24.61	15.83	48.31	33.84	44.67	19.64	21.14	60.21
144.9	43.13	13.66	11.52	9.28	23.87	28.16	17.66	52.80	40.44	50.31	21.54	23.31	67.44
156.0	44.42	14.27	12.13	9.67	25.01	29.81	18.50	56.42	42.13	52.60	22.17	24.00	70.41

*Intended Composition

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TABLE 15

GROUP I ALLOYS

SCALING DATA OBTAINED AT 1800°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si A	1.10% Ta 0.96% Si B	2.33% Ta 0.98% Si A	2.33% Ta 0.98% Si B	3.00% Ta 0.90% Si A	3.00% Ta 0.90% Si B	4.20% Al 0.93% Si A	4.20% Al 0.93% Si B	6.03% Al 0.48% Si A	6.03% Al 0.48% Si B	4.17% Al 0.47% Si A	4.17% Al 0.47% Si B
8.3	754.7	115.0	61.8	121.8	123.1	99.5	98.8	340.4	342.1	348.7	359.0	293.6	294.5
16.3	953.3	173.4	93.8	194.9	195.4	156.9	152.8	507.9	512.9	545.4	536.9	449.1	442.5
24.4	1226.2	239.0	129.8	238.3	241.8	288.7	193.9	632.1	641.6	665.9	679.0	582.5	570.5
32.6	1718.1	336.8	184.0	320.5	305.5	258.3	241.3	753.6	777.8	816.9	873.0	748.2	729.7
48.4	2538.5	479.3	264.1	460.0	431.1	353.6	325.3	1189.4	1217.1	1304.2	1352.8	1136.4	1081.2

Cumulative Time (Hours)	0.42% Co A	0.42% Co B	0.91% Co A	0.91% Co B	2.65% Co A	2.65% Co B	0.43% Co 0.72% Si A	0.43% Co 0.72% Si B	1.08% Co 0.90% Si A	1.08% Co 0.90% Si B	1% Al* 3% Mn A	1% Al* 3% Mn B
8.3	854.1	869.7	365.4	371.1	638.0	634.2	244.3	241.6	293.9	292.4	751.5	971.4
16.3	1046.5	1060.9	533.5	538.5	869.2	849.8	376.1	365.9	418.2	416.7	1436.0	1636.4
24.4	1499.7	1562.4	904.5	888.2	1343.8	1318.2	500.2	498.5	548.2	557.7	1695.2	1981.7
32.6	2090.8	2165.4	1154.6	1141.0	1759.8	1753.0	606.0	609.5	686.5	699.7	1858.3	2252.5
48.4	2981.5	3048.7	1576.1	1569.5	2452.5	2410.3	783.2	809.5	956.0	948.1	2261.9	3186.9

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
8.3	754.7	88.4	122.5	99.2	341.3	353.9	294.1	861.9	368.3	636.1	243.0	293.2	861.5
16.3	953.3	133.6	195.2	154.9	510.4	541.2	445.8	1053.7	536.0	859.5	371.0	417.5	1536.2
24.4	1226.2	184.4	240.1	201.3	636.9	672.5	576.5	1531.1	896.4	1331.0	499.4	553.0	1838.5
32.6	1718.1	260.4	313.0	249.8	765.7	845.0	739.0	2128.1	1147.8	1756.4	607.8	693.1	2055.4
48.4	2538.5	371.7	445.6	339.5	1203.3	1328.5	1108.8	3015.1	1572.8	2431.4	796.4	952.1	2724.4

Average Surface Area (cm^2) of Specimens

Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
27.73	21.29	29.53	28.02	27.22	27.18	27.60	27.73	27.37	27.69	27.73	27.89	29.15

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Cumulative Time (Hours)	Ti(115)	1.10% Ta 0.96% Si	2.33% Ta 0.98% Si	3.00% Ta 0.90% Si	4.20% Al 0.93% Si	6.03% Al 0.48% Si	4.17% Al 0.47% Si	0.42% Co	0.91% Co	2.65% Co	0.43% Co 0.72% Si	1.08% Co 0.90% Si	1% Al* 3% Mn
8.3	27.22	4.15	4.15	3.54	12.54	13.02	10.66	31.08	[illegible]	22.97	8.76	10.51	29.55
16.3	34.38	6.28	6.61	5.53	18.75	19.91	16.15	38.00	[illegible]	31.04	13.38	14.97	52.70
24.4	44.22	8.66	8.13	7.18	23.40	24.74	20.89	55.21	32.75	48.07	18.01	19.83	63.07
32.6	61.96	12.23	10.60	8.92	28.13	31.09	26.78	76.74	41.94	63.43	21.92	24.85	70.51
48.4	91.54	17.46	15.09	12.12	44.21	48.88	40.17	108.73	57.46	87.81	28.72	34.14	93.46

*Intended Composition

Contrails
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Contrails

TABLE 16

GROUP I ALLOYS

DATA ON ADHERENCE OF SCALE WHEN AIR COOLED TO ROOM TEMPERATURE

Composition	Scaling Temperature 1200°F.	1400°F.	1600°F.	1800°F.
Ti Standard	X	#	#	X
1.10% Ta - 0.96% Si	X	X	#	#
2.33% Ta - 0.98% Si	X	X	#	#
3.00% Ta - 0.90% Si	X	X	#	#
4.20% Al - 0.93% Si	X	X	#	#
6.03% Al - 0.48% Si	X	#	#	X
4.17% Al - 0.47% Si	X	X	#	#
0.42% Co	X	#	#	X
0.91% Co	X	#	#	X
2.65% Co	X	#	#	#
0.43% Co - 0.72% Si	X	#	#	#
1.08% Co - 0.90% Si	X	#	#	#
0.93% Al - 2.92% Mn	X	#	#	#

X Adherent scale.
\# Scale spalled.

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Contrails

TABLE 17

GROUP II ALLOYS

SCALING DATA OBTAINED AT 1200°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Composition / Cumulative Time(Hours)	Ti	0.83%Al 3.00%Mo	6.06%Al* 2.88%Mo	1.56%Ce*	0.85%La	0.77%Nd	1.62%Ce 1.00%Mo	1.83%Si 0.65%La	0.64%Nd 1.00%Mo	0.63%La 1.00%V	3.93%Cr 0.80%Nd	1.70%Co 0.50%Si	6.03%Al 4.08%V
23.7	26.9	19.9	7.9	12.6	17.9	17.9	15.6	14.1	17.1	22.6	79.8	14.4	15.8
47.6	34.5	23.5	11.8	17.3	23.5	23.3	19.1	15.6	21.3	25.3	123.9	16.2	23.5
71.4	41.7	26.9			26.1	26.7	20.3	16.6	19.6	31.7	163.4	20.0	27.5
95.5	48.7	32.6			29.3	28.9	24.3	20.8	24.5	38.3	203.2	22.6	32.5
143.6	55.7	37.2			33.5	35.2	26.6	21.1	25.6	45.1	264.8	21.9	39.7
191.4	71.1	43.5			43.7	47.4	33.3	27.3	33.2	52.5	336.0	30.1	51.3

Surface Area (cm^2) of Specimens

	Ti	0.83%Al 3.00%Mo	6.06%Al* 2.88%Mo	1.56%Ce*	0.85%La	0.77%Nd	1.62%Ce 1.00%Mo	1.83%Si 0.65%La	0.64%Nd 1.00%Mo	0.63%La 1.00%V	3.93%Cr 0.80%Nd	1.70%Co 0.50%Si	6.03%Al 4.08%V
	27.90	25.12	24.67	20.01	24.93	24.52	19.08	26.99	22.19	24.63	25.50	25.34	16.53

Cumulative Weight Increase (mg) Per Original Unit Area (cm^2)

Cumulative Time(Hours)	Ti	0.83%Al 3.00%Mo	6.06%Al* 2.88%Mo	1.56%Ce*	0.85%La	0.77%Nd	1.62%Ce 1.00%Mo	1.83%Si 0.65%La	0.64%Nd 1.00%Mo	0.63%La 1.00%V	3.93%Cr 0.80%Nd	1.70%Co 0.50%Si	6.03%Al 4.08%V
23.7	0.96	0.79	0.426	0.70	0.72	0.73	0.82	0.52	0.77	0.92	3.13	0.57	0.96
47.6	1.24	0.94	0.66	0.97	0.94	0.95	1.00	0.58	0.96	1.03	4.86	0.64	1.42
71.4	1.49	1.07	0.850	1.18	1.05	1.09	1.06	0.62	0.88	1.29	6.41	0.79	1.66
95.5	1.75	1.30	1.010	1.35	1.18	1.18	1.27	0.77	1.10	1.56	7.97	0.89	1.97
143.6	2.00	1.48	1.29	1.64	1.34	1.44	1.39	0.78	1.15	1.83	10.38	0.86	2.40
191.4	2.55	1.73	1.54	1.88	1.75	1.93	1.75	1.01	1.50	2.13	13.18	1.19	3.10

* Indicates that weight increase data for these specimens was extrapolated from previous experiment.

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TABLE 18

GROUP II ALLOYS

SCALING DATA OBTAINED AT 1400°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	133		135		136		137		138		139		140		141		147		148		158		159	
Composition	Ti	0.83% Al 3.00% Mo		6.06% Al 2.88% Mo		1.56% Ce		0.85% La		0.77% Nd		1.62% Ce 1.00% Mo		1.83% Si 0.65% La		0.64% Nd 1.00% Mo		0.63% La 1.00% V		3.93% Cr 0.80% Nd		1.70% Co 0.50% Si		6.03% Al 4.08% V	
Cumulative Time (Hours)		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
25.5	68.8	35.7	42.2	28.3	28.4	38.0	37.6	39.9	38.4	41.9	43.6	26.1	25.5	19.1	19.9	32.9	36.2	52.5	50.9	460.8	455.6	26.9	26.5	70.8	72.7
48.9	107.9	50.0	60.5	39.6	39.8	55.4	54.3	63.2	60.8	72.4	77.2	41.4	39.2	26.6	26.4	48.9	55.0	83.4	81.7	658.3	652.6	34.9	33.4	103.4	106.4
96.4	184.1	74.0	89.0	50.7	50.9	92.5	89.1	97.3	95.2	119.6	127.1	83.4	78.2	33.3	34.7	76.4	83.7	142.2	138.2	935.4	921.1	46.3	44.8	144.2	149.2
144.7	258.6	87.6	108.0	62.9	65.2	134.7	130.9	131.6	129.0	163.6	173.7	151.6	142.2	41.1	40.9	104.4	115.2	201.2	194.6	1183.2	1166.7	57.5	57.7	175.4	180.2
192.8	315.4	117.6	141.6	72.1	74.2	169.9	166.5	159.1	156.3	204.0	214.5	210.9	199.9	44.9	46.9	128.0	142.7	247.1	238.2	1367.6	1347.7	68.5	68.2	201.4	207.7
239.9	371.9	137.0	171.0	78.7	82.2	201.9	198.1	186.3	183.5	239.0	252.1	267.2	253.4	49.5	50.7	151.9	172.5	285.3	274.6	1533.8	1505.1	79.1	77.3	224.4	231.1
288.6	421.8	153.6	204.0	86.4	91.2	230.4	227.3	217.9	212.9	273.0	287.1	325.9	308.2	54.9	56.1	180.0	208.1	323.0	311.1	1679.8	1647.7	85.9	86.7	248.4	253.4

Average Cumulative Weight Increase (mg) of Specimens

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
25.5	68.8	39.0	28.4	37.8	39.2	42.8	25.8	19.5	34.6	51.7	458.2	26.7	71.8
48.9	107.9	55.3	39.7	54.9	62.0	74.8	40.3	26.5	52.0	82.6	655.5	34.2	104.9
96.4	184.1	81.5	50.8	90.8	96.3	123.4	80.8	34.0	80.1	140.2	928.3	45.6	146.7
144.7	258.6	97.8	64.1	132.8	130.3	168.7	146.9	41.0	109.9	197.9	1175.0	57.6	177.8
192.8	315.4	129.6	73.2	168.2	157.7	209.3	205.4	45.9	135.4	242.7	1357.7	68.4	204.6
239.9	371.9	154.0	80.5	200.0	184.9	245.6	260.3	50.1	162.2	280.0	1519.5	78.2	227.8
288.6	421.8	178.8	88.8	228.9	215.4	280.1	317.1	55.5	194.1	317.1	1663.8	86.3	250.9

Average Surface Area (cm^2) of Specimens

	112	133	135	136	137	138	139	140	141	147	148	158	159
	27.85	25.01	24.98	19.98	24.52	24.16	19.02	24.27	24.97	24.25	25.49	25.32	24.97

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
25.5	2.47	1.56	1.14	1.89	1.60	1.77	1.36	0.80	1.39	2.13	17.98	1.05	2.88
48.9	3.87	2.21	1.59	2.75	2.53	3.10	2.12	1.09	2.08	3.41	25.72	1.35	4.20
96.4	6.61	3.26	2.03	4.54	3.93	5.11	4.25	1.40	3.21	5.78	36.42	1.80	5.88
144.7	9.29	3.91	2.57	6.65	5.31	6.98	7.72	1.69	4.40	8.16	46.10	2.27	7.12
192.8	11.32	5.18	3.02	8.42	6.43	8.66	10.80	1.89	5.42	10.01	53.26	2.70	8.19
239.9	13.35	6.16	3.22	10.01	7.54	10.54	13.69	2.06	6.50	11.55	59.61	3.09	9.12
288.6	15.15	7.15	3.55	11.46	8.78	11.59	16.67	2.29	7.77	13.08	65.27	3.41	10.05

Contrails

Approved for Public Release

TABLE 19

GROUP II ALLOYS

SCALING DATA OBTAINED AT 1600°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	133		135		136		137		138		139		140		141		147		148		158		159	
Composition	Ti	0.83% Al 3.00% Mo		6.06% Al 2.88% Mo		1.56% Ce		0.85% La		0.77% Nd		1.62% Ce 1.00% Mo		1.83% Si 0.65% La		0.64% Nd 1.00% Mo		0.63% La 1.00% V		3.93% Cr 0.80% Nd		1.70% Co 0.50% Si		6.03% Al 4.08% V	
Cumulative Time (Hours)		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
24.1	644.9	161.8	181.5	121.0	120.9	250.8	256.3	168.2	167.6	279.8	280.2	266.9	289.4	56.0	50.7	173.4	170.9	376.4	377.0	1144.2	1189.7	92.8	88.6	256.6	259.3
48.2	990.7	348.6	370.3	185.0	191.7	421.1	416.4	395.2	381.3	437.6	428.4	729.6	747.7	97.5	86.3	486.1	488.8	677.4	701.2	1596.9	1517.0	143.8	137.1	395.6	398.6
72.3	1123.2	707.3	527.6	243.5	257.1	523.1	518.2	709.6	652.6	522.1	507.2	1243.1	1244.4	148.0	130.6	877.5	896.7	1112.0	1137.2	1932.1	1848.6	197.9	195.7	541.8	535.4
96.5	1181.5	1277.1	1080.9	309.7	321.5	612.7	632.5	1068.5	971.4	574.6	560.9	1782.8	1763.2	200.9	180.5	1286.9	1329.7	1544.6	1568.1	2186.0	2097.4	272.9	276.7	708.0	700.2
120.6	1223.9	1649.1	1547.3	361.2	366.8	772.1	767.0	1466.2	1329.1	618.4	607.0	2333.1	2286.7	245.9	224.7	1685.4	1766.2	1962.9	1986.7	2378.3	2300.2	362.3	362.7	845.1	848.8
144.4	1261.3	1832.7	1739.8	416.5	417.7	972.1	924.4	1877.2	1696.7	657.2	645.9	2854.6	2827.2	283.2	262.4	2084.3	2183.4	2354.2	2378.4	2541.5	2466.1	445.7	442.0	960.8	977.9
169.3	1303.8	1922.6	1829.5	473.4	499.1	1109.5	1076.1	2278.0	2064.5	702.2	680.5	3061.7	3015.0	324.3	302.9	2487.7	2599.8	2720.7	2737.9	2710.4	2630.9	533.2	515.7	1072.5	1097.8

Average Cumulative Weight Increase (mg) of Specimens

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
24.1	644.9	171.7	121.0	253.6	167.9	280.0	278.2	53.4	172.2	376.7	1167.0	90.7	258.0
48.2	990.7	359.5	188.4	418.8	388.3	433.0	738.7	91.9	487.5	689.3	1557.0	140.5	397.1
72.3	1123.2	617.5	250.3	520.7	681.1	514.7	1243.8	139.3	887.1	1124.6	1890.4	196.8	538.6
96.5	1181.5	1179.0	315.6	618.1	1020.0	567.8	1773.0	190.7	1308.3	1556.4	2141.7	274.8	704.1
120.6	1223.9	1598.2	364.0	769.6	1397.7	612.7	2309.9	235.3	1725.8	1974.8	2339.3	362.5	846.6
144.4	1261.3	1786.3	417.1	948.3	1787.0	651.2	2840.9	272.8	2133.9	2366.3	2503.8	443.9	969.4
169.3	1303.8	1876.1	486.3	1092.8	2171.3	691.4	3038.4	313.6	2543.8	2729.3	2670.7	524.5	1085.2

Average Surface Area (cm^2) of Specimens

	112	133	135	136	137	138	139	140	141	147	148	158	159
	27.90	25.17	24.72	20.04	24.95	24.25	19.09	24.30	25.27	24.60	25.35	25.39	25.07

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
24.1	23.11	6.82	4.89	12.65	6.73	11.55	14.57	2.20	6.81	15.31	46.04	3.57	10.29
48.2	35.51	14.28	7.62	20.90	15.56	17.86	38.70	3.78	19.29	28.02	61.42	5.53	15.84
72.3	40.26	24.53	10.13	25.98	27.30	21.22	65.15	5.73	35.10	45.72	74.57	7.75	21.48
96.5	42.35	46.84	12.77	30.84	40.88	23.41	92.88	7.85	51.77	63.27	84.49	10.82	28.09
120.6	43.87	63.50	14.72	38.40	56.02	25.27	121.00	10.68	68.29	80.28	92.28	14.28	33.77
144.4	45.21	70.97	16.87	47.32	71.62	26.85	148.82	11.23	84.44	96.19	98.77	17.48	38.67
169.3	46.73	74.54	19.67	54.53	87.03	28.51	159.16	12.91	100.66	110.95	106.86	20.66	43.29

Contrails

Approved for Public Release

TABLE 20

GROUP II ALLOYS

SCALING DATA OBTAINED AT 1800°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	133		135		136		137		138		139		140		141		147		148		158		159	
Composition	Ti	0.83% Al 3.00% Mo		6.06% Al 2.88% Mo		1.56% Ce		0.85% La		0.77% Nd		1.62% Ce 1.00% Mo		1.83% Si 0.65% La		0.64% Nd 1.00% Mo		0.63% La 1.00% V		3.93% Cr 0.80% Nd		1.70% Co 0.50% Si		6.03% Al 4.08% V	
Cumulative Time (Hours)		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7.8	868.0	515.8	475.2	454.8	440.2	394.6	385.9	471.7	468.7	429.8	420.8	2069.3	1808.5	158.2	208.2	846.0	864.1	630.3	654.3	1383.1	1380.6	250.8	267.2	743.2	775.9
17.1	1286.0	1013.4	935.4	833.0	815.6	591.7	601.5	1816.3	1884.7	560.7	532.5	3182.6	2671.2	461.7	440.8	3668.3	3840.6	1108.7	1180.2	1953.9	1952.1	483.7	515.5	1192.5	1201.6
24.4	1956.6	1351.1	1259.5	1097.9	1060.5	773.6	774.2	3700.4	3778.5	673.1	619.5	3162.0*	2648.0*	819.2	659.3	4054.7	4055.8	1441.9	1529.1	2301.0	2293.1	639.0	675.0	1463.1	1507.7
32.2	2539.1	1669.8	1527.7	1306.3	1283.2	1177.8	920.2	4042.1	3834.6	822.4	755.9	-	-	1217.4	1027.5	3946.9*	3991.6*	1794.6	1874.0	2608.9	2591.8	784.1	836.9	1827.8	1862.9
40.5	3097.3	1981.4	1858.4	1546.3	1527.9	1700.0	1058.7	-	-	1004.7	961.1	-	-	1631.1	1369.9	-	-	2179.7	2238.5	2894.0	2869.5	922.8	1004.1	2180.5	2166.4
48.6	3514.5	2251.2	2113.2	1789.3	1745.3	1916.1	1187.3	-	-	1163.2	1133.8	-	-	1959.3	1568.3	-	-	2507.6	2549.7	3132.0	3102.8	1051.6	1162.4	2414.5	2388.9

Average Cumulative Weight Increase (mg) of Specimens

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
7.8	868.0	495.5	447.5	390.3	470.2	425.3	1938.9	183.2	855.1	642.3	1381.9	259.0	759.6
17.1	1286.0	1124.4	824.3	596.6	1850.5	546.6	2926.9	451.3	3754.5	1144.5	1953.0	499.6	1197.1
24.4	1956.6	1305.3	1079.2	773.9	3739.5	646.3	-	739.3	4055.3	1485.5	2297.1	657.0	1485.4
32.2	2539.1	1598.8	1294.8	1049.0	3938.4	789.2	-	1122.5	-	1834.3	2600.4	810.5	1845.4
40.5	3097.3	1919.9	1537.1	1379.4	-	982.9	-	1500.5	-	2209.1	2881.8	963.5	2173.5
48.6	3514.5	2182.2	1767.3	1551.7	-	1148.5	-	1763.8	-	2528.7	3117.4	1107.0	2401.7

Average Surface Area (cm^2) of Specimens

	112	133	135	136	137	138	139	140	141	147	148	158	159
	27.90	25.15	24.68	20.04	24.89	24.13	18.79	24.35	24.89	24.61	25.52	25.39	25.05

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Time (Hours)	112	133	135	136	137	138	139	140	141	147	148	158	159
7.8	31.11	19.70	18.13	20.48	18.89	17.63	103.19	7.52	34.36	26.10	54.15	10.20	30.32
17.1	46.09	44.71	33.40	29.77	74.35	22.65	155.77	18.53	150.84	46.51	76.53	19.68	47.79
24.4	70.13	51.90	43.73	38.62	150.24	26.78	-	30.36	162.93	60.36	90.02	25.88	59.30
32.2	91.01	63.57	52.46	52.35	158.23	32.71	-	46.10	-	74.53	101.90	31.92	73.67
40.5	111.01	76.34	62.28	68.83	-	40.73	-	61.62	-	89.76	112.92	37.95	86.77
48.6	125.97	86.67	71.61	77.43	-	47.60	-	72.44	-	102.75	122.16	43.60	95.88

*Completely scaled.

Approved for Public Release

TABLE 21

GROUP III ALLOYS

SCALING DATA OBTAINED AT 1200°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	A 110		143 A		150		152		153		154		156		157		160		161		162	
Composition	Ti	5% Al 2.5% Sn		3.52% Ta 0.84% Si 0.82% La		1.30% La 4.06% Cr 0.97% Mn		0.78% Th		1.90% Ta 0.56% Si 1.08% Th		1.25% Th 3.84% Cr 0.75% Mn		1.15% Th 0.94% V		0.56% Ce		2.20% Al 4.00% V		6.05% Al 1.97% Mo 0.48% Si		5.95% W 0.66% La	
Cumulative Time(Hours)		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
24.2	19.8	13.2	12.9	7.0	7.3	45.1	50.8	13.1	11.0	8.0	7.0	44.3	45.5	15.8	15.9	12.5	12.8	13.9	15.9	6.2	5.6	6.2	6.0
49.3	30.6	19.7	18.7	9.5	9.9	75.5	83.8	15.1	13.2	9.0	10.5	75.3	76.8	22.8	21.7	16.0	15.2	16.9	19.4	6.8	6.6	7.2	8.4
73.1	39.2	24.7	24.5	12.2	11.6	102.5	112.3	17.6	15.9	10.5	11.0	101.0	102.8	26.0	26.4	19.3	17.7	21.4	23.9	7.9	10.6	9.7	11.0
97.3	43.6	26.2	24.0	9.3	11.4	124.5	135.8	21.1	19.5	12.7	13.4	127.3	128.8	30.8	30.9	22.3	21.7	26.2	28.3	10.8	10.0	10.5	11.6
121.9	53.4	36.0	34.3	18.5	17.4	148.8	160.7	22.6	21.5	14.7	13.5	148.0	150.3	35.3	34.2	23.5	21.7	28.4	30.9	10.3	10.6	11.2	11.8
169.6	62.6	44.1	42.4	16.5	16.9	181.0	196.0	24.5	23.5	14.5	13.5	185.7	185.8	39.0	38.2	26.0	24.2	33.9	36.3	13.3	12.1	13.0	13.6
217.9	72.3	51.7	50.5	19.5	20.1	214.5	230.5	28.0	26.5	17.6	17.0	218.9	220.0	44.7	45.7	30.0	29.7	41.1	42.9	17.3	16.1	15.9	16.4
291.3	84.7	62.7	60.7	20.0	20.6	254.0	274.3	30.6	28.7	18.0	17.4	262.8	261.2	50.2	50.4	33.5	31.2	44.9	46.9	16.9	16.8	16.2	17.2
362.1	91.6	69.2	68.2	21.2	21.8	290.0	311.8	33.1	32.2	18.5	20.0	299.3	295.8	54.5	54.7	36.5	34.5	49.1	51.5	21.3	19.9	18.1	19.5

Average Cumulative Weight Increase (mg)

Cumulative Time (Hours)	112	A 110	143 A	150	152	153	154	156	157	160	161	162
24.2	19.8	13.1	7.2	48.0	12.1	7.5	44.9	15.9	12.7	14.9	5.9	6.1
49.3	30.6	19.2	9.7	79.7	14.2	9.8	76.1	22.3	15.6	18.2	6.7	7.8
73.1	39.2	24.6	11.9	107.4	16.8	10.8	101.9	26.2	18.5	22.7	9.3	10.4
97.3	43.6	25.1	10.4	130.2	20.3	13.1	128.1	30.9	22.0	27.3	10.4	11.1
121.9	53.4	35.2	18.0	154.8	22.1	14.1	149.2	34.8	22.6	29.7	10.5	11.5
169.6	62.6	43.3	16.7	188.5	24.0	14.0	185.8	38.6	25.1	35.1	12.7	13.3
217.9	72.3	51.1	19.8	222.5	27.3	17.3	219.5	45.2	29.9	42.0	16.7	16.2
291.3	84.7	61.7	20.3	264.2	29.7	17.7	262.0	50.3	32.4	45.9	16.9	16.7
362.1	91.6	68.7	21.5	300.9	32.7	19.3	297.6	54.6	35.5	50.3	20.6	18.8

Average Surface Area (cm^2) of Specimens

112	A 110	143 A	150	152	153	154	156	157	160	161	162
27.77	27.16	23.75	25.92	25.09	22.38	27.29	24.99	26.35	25.43	24.80	18.15

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Cumulative Time (Hours)	112	A 110	143 A	150	152	153	154	156	157	160	161	162
24.2	0.71	0.48	0.30	1.85	0.48	0.34	1.65	0.64	0.48	0.59	0.24	0.34
49.3	1.10	0.71	0.41	3.07	0.57	0.44	2.79	0.89	0.59	0.72	0.27	0.43
73.1	1.41	0.91	0.50	4.14	0.67	0.48	3.73	1.05	0.70	0.89	0.38	0.57
97.3	1.57	0.92	0.44	5.02	0.81	0.59	4.69	1.24	0.83	1.07	0.42	0.61
121.9	1.92	1.30	0.76	5.97	0.88	0.63	5.47	1.39	0.86	1.17	0.42	0.63
169.6	2.31	1.59	0.70	7.27	0.96	0.63	6.81	1.54	0.95	1.38	0.51	0.73
217.9	2.60	1.88	0.83	8.58	1.09	0.77	8.04	1.81	1.13	1.65	0.67	0.89
291.3	3.05	2.27	0.85	10.19	1.18	0.79	9.60	2.01	1.23	1.80	0.68	0.92
362.1	3.30	2.53	0.91	11.61	1.30	0.86	10.91	2.18	1.35	1.98	0.83	1.04

Contrails
Approved for Public Release

TABLE 22

GROUP III ALLOYS

SCALING DATA OBTAINED AT 1400°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	A110	143A		150		152		153		154		156		157		160		161		162		AS		BV
Composition	Ti	5% Al 2.5% Sn	3.52% Ta 0.84% Si 0.82% La		1.30% La 4.06% Cr 0.97% Mn		0.78% Th		1.90% Ta 0.56% Si 1.08% Th		1.25% Th 3.84% Cr 0.75% Mn		1.15% Th 0.94% V		0.56% Ce		2.20% Al 4.00% V		6.05% Al 1.97% Mo 0.48% Si		5.95% W 0.66% La		5% Al 2.5% Sn		6% Al 4% V
Cumulative Time (Hours)	A	A	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
24.7	73.5	79.7	13.4	19.8	299.0	295.0	28.2	29.7	16.6	16.5	277.0	282.9	52.4	53.0	29.7	31.5	50.2	44.5	24.7	21.7	17.0	17.4	89.9	90.8	123.1
47.1	115.5	129.7	18.2	29.1	430.3	430.0	36.7	37.3	22.3	22.1	399.0	401.9	86.4	87.0	44.7	44.0	69.7	61.5	30.4	27.9	22.4	23.7	144.4	150.5	184.1
72.1	166.5	151.2	22.9	36.5	544.0	548.0	46.2	48.8	28.9	31.9	506.5	503.9	126.4	128.8	59.6	59.0	87.7	79.9	40.2	38.7	35.5	35.0	186.9	194.5	231.6
*95.5	208.9	165.2	28.1	41.8	631.0	639.9	54.2	60.8	35.9	37.5	591.0	580.5	163.9	166.5	76.7	73.5	102.7	93.9	45.7	43.7	43.5	43.5	216.0	222.5	269.4
120.1	244.8	177.9	30.9	47.6	709.8	724.7	60.0	63.5	36.7	39.3	652.7	639.0	185.7	187.9	85.8	82.5	110.9	101.2	47.7	45.6	51.0	49.3	234.8	241.0	308.4
168.4	320.9	204.2	37.4	56.9	846.0	869.0	78.7	83.3	45.3	49.5	780.0	752.9	242.4	246.0	113.2	108.5	128.7	119.3	52.2	51.7	62.5	60.5	257.4	264.5	393.6

Specimen No.	112	A110	143A	150	152	153	154	156	157	160	161	162	AS	BV
Average Cumulative Weight Increase (mg) of Specimens														
24.7	73.5	79.7	16.6	297.0	29.0	16.6	280.0	52.7	30.6	47.4	23.2	17.2	90.4	123.1
47.1	115.5	129.7	23.7	430.2	37.0	22.2	400.5	86.7	44.4	65.6	29.2	23.1	147.5	184.1
72.1	166.5	151.2	29.7	546.0	47.5	30.4	505.2	127.6	59.3	83.8	39.5	35.3	190.7	231.6
95.5	208.9	165.2	35.0	635.5	57.5	36.7	585.8	165.2	75.1	98.3	44.7	43.5	219.3	269.4
120.1	244.9	177.9	39.3	726.1	61.8	38.0	645.9	186.8	84.2	106.1	46.7	50.2	237.9	308.4
168.4	320.9	204.2	42.2	857.5	81.0	47.4	766.5	244.2	110.9	124.0	52.0	61.5	261.0	393.6
Average Surface Area (cm^2) of Specimens														
	27.91	27.12	21.22	25.86	25.04	22.39	27.29	25.04	25.66	25.47	24.81	18.20	26.77	27.64
Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)														
24.7	2.63	2.94	0.78	11.48	1.16	0.74	10.26	2.10	1.19	1.86	0.94	0.95	3.38	4.45
47.1	4.14	4.78	1.12	16.64	1.48	0.99	14.68	3.46	1.73	2.58	1.18	1.27	5.51	6.66
72.1	5.97	5.58	1.40	21.11	1.90	1.36	18.51	5.10	2.31	3.29	1.59	1.94	7.12	8.38
95.5	7.48	6.09	1.65	24.57	2.30	1.64	21.47	6.60	2.93	3.86	1.80	2.39	8.19	9.75
120.1	8.77	6.56	1.85	28.08	2.47	1.70	23.67	7.46	3.28	4.17	1.88	2.76	8.89	11.16
168.4	11.50	7.53	1.99	33.16	3.23	2.12	28.09	9.75	4.32	4.87	2.10	3.38	9.75	14.24

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Contrails

TABLE 23

GROUP III ALLOYS

SCALING DATA OBTAINED AT 1600°F.
(Weight Increase of Ribbons Included)

Specimen No.	112	A110	143A		150		152		153		154		156		157		160		161		162		AS	BV	
Composition	Ti	5% Al 2.5% Sn	3.52% Ta 0.84% Si 0.82% La		1.30% La 4.06% Cr 0.97% Mn		0.78% Th		1.90% Ta 0.56% Si 1.08% Th		1.25% Th 3.84% Cr 0.75% Mn		1.15% Th 0.94% V		0.56% Ce		2.20% Al 4.00% V		0 6.05% Al 1.97% Mo 0.48% Si		5.95% W 0.66% La		5% Al 2.5% Sn	6% Al 4% V	
Cumulative Time (Hours)	A	A	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	A	B
Cumulative Weight Increase (mg) of Specimens																									
29.4	677.6	486.5	89.7	90.7	1085.0	1139.9	142.2	144.0	75.1	67.5	1009.8	966.2	529.8	605.0	180.6	187.0	205.7	213.2	103.9	105.3	138.2	143.7	572.0	498.0	494.5
48.4	816.4	658.5	114.7	116.7	1333.0	1417.4	198.2	200.0	95.1	86.5	1234.3	1167.7	967.8	1051.5	295.1	291.0	293.7	302.7	130.4	131.3	321.2	335.2	809.0	625.0	639.0
72.4	899.4	916.0	146.7	150.7	1631.0	1724.9	288.2	288.5	121.1	106.5	1506.8	1416.7	1563.8	1650.0	537.6	502.0	418.7	427.2	161.4	163.8	633.2	662.2	994.0	819.0	834.5
96.4	985.4	1076.5	167.7	175.7	1814.0	1914.9	487.7	472.5	137.1	123.0	1670.3	1577.7	2006.4	2065.5	768.1	708.0	526.2	530.2	179.4	180.3	883.2	933.7	1125.5	1108.0	1150.0
143.8	1152.9	1323.0	213.2	221.7	2152.0	2261.9	855.2	898.5	168.1	152.5	1998.8	1880.7	2435.3	2366.5	1236.1	1161.5	700.2	700.7	218.9	216.8	1470.2	1563.7	1429.0	1789.5	1820.5
168.4	1251.9	1437.5	236.2	247.2	2340.0	2411.4	1025.2	1090.0	181.1	165.5	2168.8	2024.7	2551.3	2419.5	1491.1	1415.0	775.7	778.7	234.9	232.8	1801.2	1906.7	1617.0	2076.0	2116.5
Average Cumulative Weight Increase (mg) of Specimens																									
29.4	677.6	486.5	90.2		1112.5		143.1		71.3		988.0		567.4		183.8		209.5		104.6		141.0		572.0	496.3	
48.4	816.4	658.5	115.7		1375.2		199.1		90.8		1201.0		1009.7		293.1		298.2		130.9		328.2		809.0	632.0	
72.4	899.4	916.0	148.7		1678.0		288.4		113.8		1461.8		1606.9		519.8		423.0		162.6		647.7		994.0	826.8	
96.4	985.4	1076.5	171.7		1864.5		480.1		130.1		1624.0		2036.0		738.1		528.2		179.9		908.5		1125.5	1129.0	
143.8	1152.9	1323.0	217.5		2207.0		876.9		160.3		1939.8		2400.9		1198.8		700.5		217.9		1517.0		1429.0	1805.0	
168.4	1251.9	1437.5	241.7		2375.7		1057.6		173.3		2096.8		2485.4		1453.1		777.2		233.9		1854.0		1617.0	2096.3	
Average Surface Area (cm^2) of Specimens																									
	27.91	27.11	23.69		25.87		25.04		20.87		27.24		25.03		25.69		25.45		24.86		17.90		26.75	27.58	
Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)																									
29.4	24.28	17.95	3.81		43.00		5.71		3.42		36.27		22.67		7.15		8.23		4.23		7.88		21.38	17.99	
48.4	29.25	24.29	4.88		53.16		7.95		4.35		44.09		40.34		11.41		11.72		5.27		18.34		30.24	22.92	
72.4	32.23	33.79	6.28		64.86		11.52		5.45		53.66		64.20		20.23		16.62		6.54		36.18		37.16	29.98	
96.4	35.31	39.71	7.25		72.07		16.78		6.23		59.62		81.34		28.73		20.75		7.24		50.75		42.07	40.94	
143.8	41.31	48.80	9.18		85.31		35.02		7.68		71.21		81.54		46.66		27.52		8.77		84.75		53.42	65.45	
168.4	44.85	53.02	10.20		91.83		42.24		8.30		76.98		99.30		56.56		30.54		9.41		103.56		60.45	76.01	

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TABLE 24

GROUP III ALLOYS

SCALING DATA OBTAINED AT 1800°F.
(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Specimen No.	112	A 110		143A		150		152		153		154		156		157		160		161		162	
Composition	Ti	5% Al 2.5% Sn		3.52% Ta 0.84% Si 0.82% La		1.30% La 4.06% Cr 0.97% Mn		0.78% Th		1.90% Ta 0.56% Si 1.08% Th		1.25% Th 3.84% Cr 0.75% Mn		1.15% Th 0.94% V		0.56% Ce		2.20% Al 4.00% V		6.05% Al 1.97% Mo 0.48% Si		5.95% W 0.66% La	
Cumulative Time (Hours)		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7.5	760.6	1567.4	1630.5	132.5	95.4	1153.3	1214.9	387.3	372.7	110.5	120.4	1106.6	1044.2	776.8	712.8	428.1	434.1	518.3	515.4	190.2	236.4	700.8	769.6
13.0	1307.4	2420.3	2451.6	209.9	152.8	1546.0	1641.7	731.6	682.9	183.9	201.4	1468.2	1379.2	1339.0	1246.3	944.0	980.1	770.1	761.4	291.7	312.7	1580.3	1692.8
24.3	1936.8	3588.8	3544.2	330.1	243.6	1999.7	2119.4	1225.0	1056.0	314.4	341.6	1897.7	1772.5	1908.7	1920.2	2123.7	2178.8	1069.0	1053.3	421.5	420.4	-	-
32.2	2346.8	3813.6	3758.2	431.2	320.1	2285.0	2422.7	1605.7	1363.6	430.8	463.2	2193.1	2029.2	2201.0	2074.9	3397.7	3508.3	1294.8	1274.1	525.9	504.9	-	-
38.0	2622.0	3947.1	3890.6	501.0	369.8	2453.8	2615.1	1872.3	1578.4	510.7	546.9	2372.4	2180.3	2359.9	2214.3	4138.1	4009.4	1420.3	1396.0	591.1	560.7	-	-
47.3	2973.5	4161.1	4107.3	619.4	455.9	2710.8	2880.8	2258.1	1913.5	638.1	677.6	2638.6	2428.1	2567.4	2384.8	-	-	1593.5	1566.0	695.1	646.0	-	-

Average Cumulative Weight Increase (mg) of Specimens

Time (Hours)	112	A 110	143A	150	152	153	154	156	157	160	161	162
7.5	760.6	1598.9	114.0	1184.1	380.0	115.5	1075.4	744.8	431.1	516.9	213.3	735.2
13.0	1307.4	2436.0	181.4	1593.9	707.3	192.7	1423.7	1292.7	962.1	765.8	302.2	1636.6
24.3	1936.8	3566.5	286.9	2059.6	1140.5	328.0	1835.1	1914.5	2151.3	1061.2	421.0	-
32.2	2346.8	3785.9	375.7	2353.9	1484.7	447.0	2111.2	2138.0	3453.0	1284.5	515.4	-
38.0	2622.0	3918.9	435.4	2534.5	1725.4	528.8	2276.4	2287.1	4073.8	1408.2	575.9	-
47.3	2973.5	4134.2	537.7	2795.8	2085.8	657.9	2533.4	2476.1	-	1579.8	670.6	-

Average Surface Area (cm^2) of Specimens

112	A 110	143A	150	152	153	154	156	157	160	161	162
27.75	27.87	20.50	26.59	25.08	22.46	27.94	25.07	25.70	25.42	24.83	18.21

Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)

Time (Hours)	112	A 110	143A	150	152	153	154	156	157	160	161	162
7.5	27.41	57.37	5.56	44.53	15.15	5.14	38.49	29.71	16.77	20.33	8.59	40.37
13.0	47.11	87.41	8.85	59.94	28.20	8.58	50.96	51.56	37.44	30.13	12.17	89.87
24.3	69.79	127.97	14.00	77.46	45.47	14.60	65.68	76.37	83.71	41.75	16.96	-
32.2	84.57	135.84	18.33	88.53	59.20	19.90	75.56	85.28	134.36	50.53	20.76	-
38.0	94.49	140.61	21.24	95.32	68.80	23.54	81.47	91.23	158.51	55.40	23.19	-
47.3	107.15	148.34	26.23	105.14	83.17	29.29	90.67	98.77	-	62.15	27.01	-

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TABLE 25

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2) FOR GROUP I ALLOYS

Data Obtained over Period of Forty-eight Hours at 1200°, 1400°, 1600°, and 1800°F.

Composition of Alloy	1200°F.	1400°F.	1600°F.	1800°F.
Ti Standard	0.63	3.60	33.2	90.8
1.10% Ta - 0.96% Si	0.23	1.08	6.79	17.2
2.33% Ta - 0.98% Si	0.20	1.14	5.84	15.0
3.00% Ta - 0.90% Si	0.26	1.06	4.89	11.9
4.20% Al - 0.93% Si	0.27	1.97	11.7	43.2
6.03% Al - 0.48% Si	0.22	1.64	12.4	47.9
4.17% Al - 0.47% Si	0.20	1.72	8.79	39.3
0.42% Co	0.77	4.14	39.4	107.5
0.91% Co	0.71	2.22	19.5	57.8
2.65% Co	0.70	3.60	24.3	86.5
0.43% Co - 0.72% Si	0.44	1.97	11.8	28.3
1.08% Co - 0.90% Si	0.48	2.08	12.3	33.5
0.93%Al - 2.92% Mn	0.61	6.21	33.0	92.3

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TABLE 26

GROUP II ALLOYS

AVERAGE CUMULATIVE WEIGHT INCREASE (mg)
PER AVERAGE ORIGINAL UNIT AREA (cm^2)

Data Obtained Over Period of Forty-eight Hours at 1200°, 1400°, 1600°, and 1800°F.

Nominal Composition of Alloy	1200°F.	1400°F.	1600°F.	1800°F.
Ti (unalloyed)	0.91	3.81	35.3	134.0
Ti - 1 Al - 3 Mo	0.94	2.21	13.8	83.2
Ti - 6 Al - 3 Mo	0.47	1.54	7.3	70.1
Ti - 2 Ce	0.86	2.80	20.1	73.8
Ti - 1 La	0.93	2.49	15.0	497.0
Ti - 1 Nd	0.94	2.94	17.9	47.6
Ti - 2 Ce - 1 Mo	1.02	2.08	38.3	279.0
Ti - 4 Si - 1 La	0.61	1.06	3.8	70.1
Ti - 1 Mo - 1 Nd	0.83	2.08	19.4	1050.0
Ti - 1 V - 1 La	1.07	3.47	27.5	102.0
Ti - 4 Cr - 1 Nd	5.01	25.00	62.1	121.0
Ti - 2 Co - 1/2 Si	0.68	1.35	5.5	43.1
Ti - 6 Al - 4 V	1.39	4.13	15.8	95.0

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TABLE 27

GROUP III ALLOYS

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)

Data Obtained over Period of Forty-eight Hours at 1200°, 1400°, 1600°, and 1800°F.

Nominal Composition of Alloy	1200°F.	1400°F.	1600°F.	1800°F.
Ti (unalloyed)	1.10	4.35	28.7	108.0
Ti - 5 Al - 2.5 Sn	0.71	4.80	24.2	148.0
Ti - 4 Ta - 1 Si - 1 La	0.41	1.13	4.8	26.5
Ti - 4 Cr - 1 Mn - 1 La	3.03	16.60	53.0	105.0
Ti - 1 Th	0.57	1.53	8.2	84.0
Ti - 4 Ta - 1 Si - 1 Th	0.43	1.07	4.4	29.2
Ti - 4 Cr - 1 Mn - 1 Th	2.74	14.60	43.8	92.5
Ti - 1 V - 1 Th	0.88	3.64	40.6	98.7
Ti - 0.5 Ce	0.59	1.77	12.3	200.0
Ti - 2 Al - 4 V	0.72	2.65	12.1	64.3
Ti - 6 Al - 2 Mo - 0.5 Si	0.30	1.25	5.3	26.9
Ti - 4 W - 1 La	0.45	1.38	18.2	640.0
Ti - 5 Al - 2.5 Sn	--	5.75	29.0	--
Ti - 6 Al - 4 V	--	6.80	23.7	--

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TABLE 28

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 70 AT 1600°F.

Weight Increase (mg) of Specimens

Spec. No. / Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	52.8	57.3												
2			97.2	97.6										
4					197.7	212.9								
6							309.1	311.2						
8									393.5	397.4				
16											709.2	762.2		
24													920.0	918.7

Average Weight Increase (mg) of Specimens

Time (Hours)	1–2	3–4	5–6	7–8	9–10	11–12	13–14
1	55.05						
2		97.4					
4			205.3				
6				310.2			
8					395.5		
16						735.7	
24							919.4

Surface Area (cm^2) of Specimens

1	2	3	4	5	6	7	8	9	10	11	12	13	14
27.34	27.35	27.34	27.34	27.43	27.34	27.30	27.32	27.42	27.35	27.33	27.21	27.46	27.35

Average Surface Area (cm^2) of Specimens

1–2	3–4	5–6	7–8	9–10	11–12	13–14
27.34	27.34	27.39	27.31	27.39	27.27	27.41

Weight Increase (mg) per Original Unit Area (cm^2)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.93	2.10	3.56	3.57	7.21	7.19	11.3	11.4	14.4	14.5	25.9	28.0	33.5	33.6

Average Weight Increase (mg) per Original Unit Area (cm^2)

1–2	3–4	5–6	7–8	9–10	11–12	13–14
2.02	3.57	7.20	11.35	14.45	27.00	33.55

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TABLE 29

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 70 AT 1800°F.

Weight Increase (mg) of Specimens

Time (Hours) / Spec. No.	3	4	5	6	7	8	9	10	11	12
1	384.7	400.1								
2			715.3	725.6						
4					1092.6	1112.1				
6							1345.0	1352.0		
8									1511.2	1520.8

Average Weight Increase (mg) of Specimens

Time (Hours)	Spec. 3, 4	Spec. 5, 6	Spec. 7, 8	Spec. 9, 10	Spec. 11, 12
1	392.4				
2		720.5			
4			1102.4		
6				1348.5	
8					1516.0

Surface Area (cm^2) of Specimens

3	4	5	6	7	8	9	10	11	12
27.47	27.47	27.51	27.50	27.44	27.46	27.42	27.44	27.47	27.44

Average Surface Area (cm^2) of Specimens

Spec. 3, 4	Spec. 5, 6	Spec. 7, 8	Spec. 9, 10	Spec. 11, 12
27.47	27.50	27.45	27.43	27.46

Weight Increase (mg) per Original Unit Area (cm^2)

3	4	5	6	7	8	9	10	11	12
14.0	14.6	26.0	26.4	39.8	40.5	49.1	49.3	55.0	55.4

Average Weight Increase (mg) per Original Unit Area (cm^2)

Spec. 3, 4	Spec. 5, 6	Spec. 7, 8	Spec. 9, 10	Spec. 11, 12
14.3	26.2	40.2	49.2	55.2

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TABLE 30

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 130A AT 1600°F.

Weight Increase (mg) of Specimens

Spec. No. / Time (Hours)	2	3	4	5	6	7	8	9	10	11	12	13
1	136.4	143.4										
2			218.9	220.1								
4					310.0	322.2						
8							470.6	473.7				
16									734.4	748.7		
24											900.3	895.0

Average Weight Increase (mg) of Specimens

Time (Hours)	2	3	4	5	6	7	8	9	10	11	12	13
1	139.9											
2			219.5									
4					316.1							
8							472.2					
16									741.6			
24											897.7	

	2	3	4	5	6	7	8	9	10	11	12	13
Surface Area (cm^2) of Specimens	27.84	27.76	27.96	27.74	27.73	28.04	27.77	27.85	28.02	28.03	27.95	27.87
Average Surface Area (cm^2) of Specimens	27.80		27.85		27.89		27.81		28.02		27.91	
Weight Increase (mg) per Original Unit Area (cm^2)	4.90	5.17	7.83	7.93	11.2	11.5	16.9	17.0	26.2	26.7	32.2	32.1
Average Weight Increase (mg) per Average Original Unit Area (cm^2)	5.0		7.88		11.35		16.95		26.45		32.15	

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TABLE 31

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 130A AT 1800°F.

Weight Increase (mg) of Specimens

Spec. No. / Time (Hours)	3	4	5	6	7	8	9	10
1	341.8	382.8						
2			618.4	640.2				
4					1082.1	1069.1		
8							1811.7	1696.7

Average Weight Increase (mg) of Specimens

Time (Hours)	3–4	5–6	7–8	9–10
1	362.3			
2		629.3		
4			1075.6	
8				1754.2

Surface Area (cm^2) of Specimens

	3	4	5	6	7	8	9	10
	27.92	27.84	27.80	27.82	27.84	27.82	27.78	28.05

Average Surface Area (cm^2) of Specimens

3–4	5–6	7–8	9–10
27.88	27.81	27.83	27.92

Weight Increase (mg) per Original Unit Area (cm^2)

3	4	5	6	7	8	9	10
12.24	13.75	22.24	23.01	38.87	38.40	65.22	60.48

Average Weight Increase (mg) per Average Original Unit Area (cm^2)

3–4	5–6	7–8	9–10
12.99	22.63	38.64	62.85

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TABLE 32

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 130B AT 1600°F.

Weight Increase (mg) of Specimens										
Spec. No.	10	9	8	7	6	5	4	3	2	1
Time (Hours)										
1	138.4	159.9								
4			397.9	402.6						
8					622.5	620.0				
16							893.3	910.1		
24									1104.3	1097.0
Average Weight Increase (mg) of Specimens										
1	149.2									
4			400.3							
8					621.3					
16							901.7			
24									1100.7	
Surface Area (cm^2) of Specimens										
	51.21	51.15	51.15	51.13	51.13	51.20	51.04	51.12	50.93	51.22
Average Surface Area (cm^2) of Specimens										
	51.18		51.14		51.17		51.08		51.08	
Weight Increase (mg) per Original Unit Area (cm^2)										
	2.70	3.13	7.78	7.87	12.2	12.1	17.5	17.8	22.4	21.4
Average Weight Increase (mg) per Original Unit Area (cm^2)										
	2.92		7.83		12.15		17.7		21.9	

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TABLE 33

WEIGHT INCREASE DATA OBTAINED FROM SCALING TESTS OF RC - 130 B AT 1800°F.

Weight Increase (mg) of Specimens

Spec. No.	8	7	6	5	4	3	2	1
Time (Hours)								
1	581.2	612.7						
2			896.6	922.6				
4					1378.5	1361.8		
8							2160.4	2216.9

Average Weight Increase (mg) of Specimens

Time (Hours)	8, 7	6, 5	4, 3	2, 1
1	597.0			
2		909.6		
4			1370.2	
8				2188.7

Surface Area (cm^2) of Specimens

8	7	6	5	4	3	2	1
51.03	51.17	51.08	51.04	51.17	51.03	51.04	51.18

Average Surface Area (cm^2) of Specimens

8, 7	6, 5	4, 3	2, 1
51.10	51.06	51.10	51.11

Weight Increase (mg) per Original Unit Area (cm^2)

8	7	6	5	4	3	2	1
11.4	12.0	17.6	18.1	26.9	26.7	42.3	43.3

Average Weight Increase (mg) per Original Unit Area (cm^2)

8, 7	6, 5	4, 3	2, 1
11.7	17.9	26.8	42.8

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TABLE 34

INCHES PENETRATION DATA OBTAINED AT 1600° AND 1800°F. FOR RC - 70

1600°F.							1800°F.						
Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration	Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration
1	1	0.068	0.065	0.003	0.0015	0.0015							
2	1	0.067	0.064	0.003	0.0015								
3	2	0.068	0.063	0.005	0.0025	0.00225	3	1	0.068	0.060	0.008	0.0040	0.0040
4	2	0.067	0.063	0.004	0.0020		4	1	0.068	0.060	0.008	0.0040	
5	4	0.068	0.063	0.005	0.0025	0.0025	5	2	0.068	0.056	0.012	0.0060	0.00625
6	4	0.067	0.062	0.005	0.0025		6	2	0.068	0.055	0.013	0.0065	
7	6	0.067	0.061	0.006	0.0030	0.0030	7	4	0.068	0.048	0.020	0.010	0.009
8	6	0.067	0.061	0.006	0.0030		8	4	0.068	0.052	0.016	0.008	
9	8	0.068	0.061	0.007	0.0035	0.00375	9	6	0.068	0.048	0.020	0.010	0.00975
10	8	0.067	0.059	0.008	0.0040		10	6	0.068	0.049	0.019	0.0095	
11	16	0.068	0.057	0.011	0.0055	0.0055	11	8	0.068	0.045	0.023	0.0115	0.01075
12	16	0.067	0.056	0.011	0.0055		12	8	0.068	0.048	0.020	0.010	
13	24	0.068	0.056	0.012	0.006	0.00675							
14	24	0.067	0.052	0.015	0.0075								

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TABLE 35

INCHES PENETRATION DATA OBTAINED AT 1600° and 1800°F. FOR RC - 130A

1600°F

Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration
2	1	.0784	.0744	.0040	.002	.002025
3	1	.0781	.0740	.0041	.00205	
4	2	.0785	.0740	.0045	.00225	.00235
5	2	.0789	.0740	.0049	.00245	
6	4	.0788	.0732	.0056	.0028	.0029
7	4	.0800	.0740	.0060	.0030	
8	8	.0779	.0705	.0074	.0037	.0035
9	8	.0786	.0720	.0066	.0033	
10	16	.0796	.0697	.0099	.00495	.005025
11	16	.0787	.0685	.0102	.0051	
12	24	.0784	.0669	.0115	.00575	.005725
13	24	.0780	.0666	.0114	.0057	

1800°F.

Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration
3	1	.0803	.0744	.0059	.00295	.00325
4	1	.0791	.0720	.0071	.00355	
5	2	.0792	.0697	.0095	.00475	.004825
6	2	.0795	.0697	.0098	.0049	
7	4	.0788	.0654	.0134	.0067	.00685
8	4	.0794	.0654	.0140	.0070	
9	8	.0792	.0594	.0198	.0099	.0101
10	8	.0800	.0594	.0206	.0103	

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TABLE 36

INCHES PENETRATION DATA OBTAINED AT 1600° AND 1800°F. FOR THICK RC - 130B

1600°F.							1800°F.						
Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration	Spec. No.	Time (Hours)	Thickness before scaling (in)	Thickness after scaling (in)	Loss (in)	Inches Penetration	Average Inches Penetration
10	1	0.259	0.250	0.009	0.0045	0.00425	8	1	0.258	0.247	0.011	0.0055	0.00575
9	1	0.258	0.250	0.008	0.004		7	1	0.259	0.247	0.012	0.006	
8	4	0.258	0.246	0.012	0.006	0.006	6	2	0.259	0.245	0.014	0.007	0.007
7	4	0.258	0.246	0.012	0.006		5	2	0.258	0.244	0.014	0.007	
6	8	0.258	0.241	0.017	0.0085	0.00825	4	4	0.259	0.242	0.017	0.0085	0.0085
5	8	0.259	0.243	0.016	0.0080		3	4	0.258	0.241	0.017	0.0085	
4	16	0.258	0.238	0.020	0.010	0.00925	2	8	0.258	0.235	0.023	0.0115	0.01175
3	16	0.258	0.241	0.017	0.0085		1	8	0.259	0.235	0.024	0.012	
2	24	0.258	0.236	0.022	0.011	0.011							
1	24	0.259	0.237	0.022	0.011								

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TABLE 37

GASEOUS PENETRATION IN RC-70 EXPOSED AT 1600° AND 1800°F.

1600°F.		1800°F.	
Time (Hours)	Penetration (Cm)	Time (Hours)	Penetration (Cm)
1	0.0150	1	0.0265
2	0.0165	2	0.0275
4	0.0165	4	0.0280
6	0.0165	6	0.0350
8	0.0165	8	0.0360
16	0.0200		
24	0.0210		

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TABLE 38

GASEOUS PENETRATION IN RC-130A EXPOSED AT 1600° AND 1800°F.

1600°F.		1800°F.	
Time (Hours)	Penetration (Cm)	Time (Hours)	Penetration (Cm)
1	0.0390	1	0.0150
2	0.0420	2	0.0400
4	0.0440	4	0.0415
8	0.0460	8	0.0420
16	0.0480		
24	0.0510		

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TABLE 39

GASEOUS PENETRATION IN RC-130B EXPOSED AT 1600° AND 1800°F.

1600°F.		1800°F.	
Time (Hours)	Penetration (Cm)	Time (Hours)	Penetration (Cm)
1	0.0205	1	0.0200
4	0.0292	2	0.0375
8	0.0376	4	0.0450
16	0.0480	8	0.0500
24	0.0500		

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