WADC TECHNICAL REPORT 54-109

SCALING OF TITANIUM AND TITANIUM ALLOYS

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MARCH 1955

MATERIALS LABORATORY
CONTRACT No. AF 18(600)-60
PROJECT No. 7351

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield,O.
600 - 21 June 1955

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 7351, "Metallic Materials", Task No. 73510, "Titanium Metal and Alloys", RDO No. 615-11, "Titanium Metal and Alloys", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. H. J. Middendorp acting a project engineer.

Acknowledgement is given to the Department of Mining and Metallurgical Engineering of the University of Kentucky for laboratory facilities, to Howard J. Siegel for aid in the reorganization of this report, to Charles S. Crouse for his interest and direction, to Joseph P. Hammond for suggestions, to Cullie J. Sparks, James E. Fox, Carl C. Duncan, Douglas W. Cox, Thomas A. Kendall, and Fritz Mangelsen for their work on this contract, and to Roy E. Swift for the immediate supervision of the activities in connection with Contract AF 18 (600)-60. The research covered in this report is for the period November 15, 1951 to January 1, 1954. Additional work which is being carried on will be presented in subsequent reports.

ABSTRACT

A preliminary study of the scaling characteristics in air of experimentally produced titanium and titanium-base alloys, and commercially-produced titanium and titanium-base alloys was conducted at temperatures of 1200°, 1400°, 1600°, and 1800° F. (650°, 760°, 870°, and 980° C.) in the time range of approximately four to three hundred hours. A total of forty-three titanium-base alloys, one commercial grade of titanium (RS-70), and Type 302 stainless steel were scaled at each of these temperatures; two additional alloys were employed at temperatures of 1200° and 1600° F. Scales formed on a 4.02% Al-Ti alloy were studied in detail and a scaling mechanism was suggested; scales formed on a 4.03% Cr-Ti alloy and a 2.95% W-Ti alloy were studied in less detail. Scaling propensity of titanium-base alloys, relative to titanium and stainless steel, was evaluated on the basis of weight gain with time. Attempts to evaluate scaling propensity on the basis of weight loss with time, through the application of various descaling processes, were unsuccessful; however, results of essentially the same nature were obtained in terms of inches penetration of oxide scale. Isothermal transitions in the parabolic scaling rate were observed for experimentally-produced titanium at 1200°F.; transitions were observed, but not studied in detail, for 3.96% Mo-Ti at 1400°F., 1.19% Mo-Ti at 1600°F., and 0.91% Ni-Ti at 1600°F.; transitions were indicated, but not studied in detail, for experimentally-produced titanium at 1800°F.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
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I. INTRODUCTION

The recent development of titanium as a commercial engineering material has stimulated a considerable amount of research. Titanium alloys possess many desirable characteristics, two of which are outstanding. At temperatures up to 800°F., titanium alloys have a greater strength-weight ratio than any other common metal or alloy. Titanium is practically non-corrosive in all ordinary situations, and in many extraordinary ones. The development of titanium technology has been markedly accelerated because of the possibility of utilizing it in component parts of aviation gas turbines and other aircraft applications. The development of alloys with good resistance to scaling at moderately high temperatures is one prerequisite to the large scale use of titanium in jet engines.

II. OBJECT AND SCOPE OF INVESTIGATION

The objectives of this research were to investigate and study the scaling phenomena of titanium and titanium alloys and to develop titanium-base alloys of high scale resistance. The alloying elements which were investigated include: copper, aluminum, silicon, vanadium, columbium, tantalum, chromium, molybdenum, tungsten, manganese, iron, nickel, and carbon. The investigation was first conducted on binary compositions and later on ternary and commercial alloys.

The investigation also included attempts to develop a technique for descaling and determining weight loss of the specimens after descaling, and the study of the progress of scaling on one outstanding alloy.

III. PREPARATION OF TEST SPECIMENS

A <u>Arc Melting</u>

The arc-melting furnace consists of the following components: a jacket, head, electrode (tungsten), and a copper crucible, all of which are water cooled. (See Figures 1 and 2). 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.

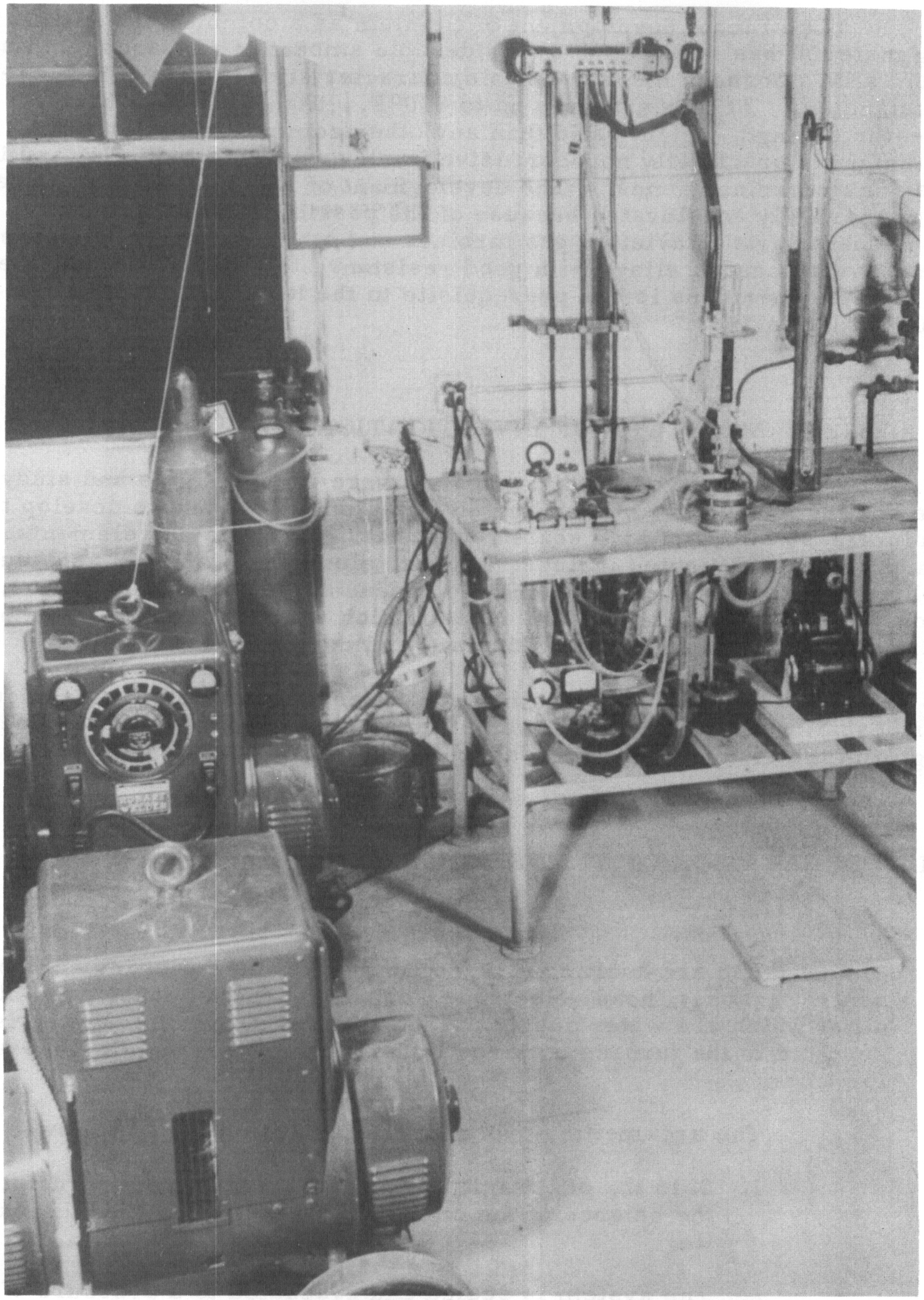
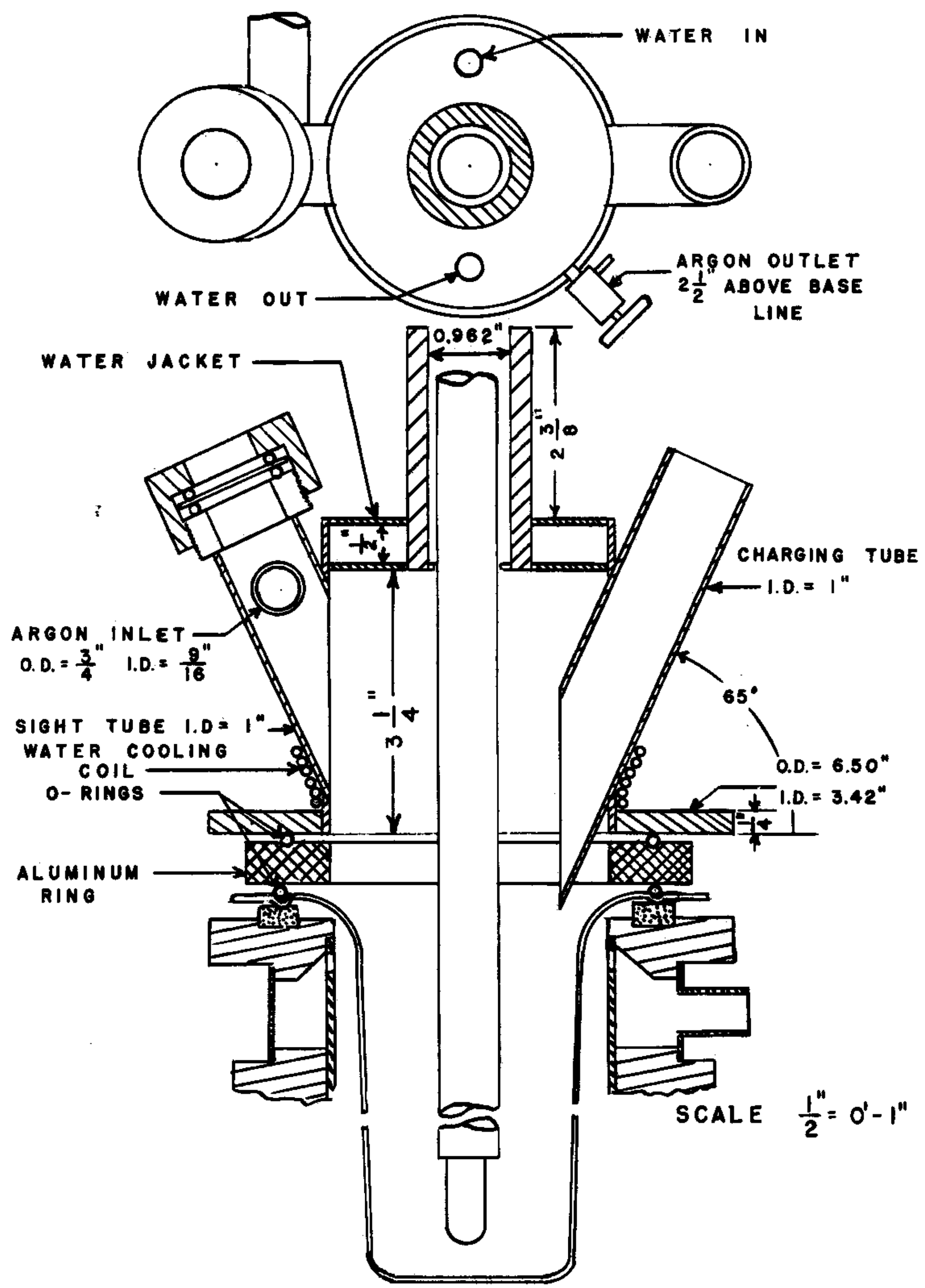


Fig. 1 Arc-melting furnace and auxiliary equipment, inclusive of power source.



VACUUM ARC FURNACE
(MODIFIED)
FIG. 2

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.

7. The charge is added over a period of from 15 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°F. 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 homogeneous, 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" x 3" x 1/8") into strips of approximate dimensions 1-1/16" x 3" x 1/8" with a radial cut-off wheel (using a soluble oil type coolant).

12. Roll strips (at 1450°F.) to approximate dimensions 8" x 1-1/16" x 0.060".

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

14. Stress relieve in a partial vacuum (-100 microns Hg) at 1000°F. for one hour. (Specimens are inserted in a ceramic sleeve of circular cross section which permits only the edges of the specimens to attain intimate contact with the sleeve wall; the sleeve, in turn, is inserted in a stainless steel tube which is subsequently evacuated).

Figure 3 shows the raw materials and the intermediate and final products in the production of specimens for scaling tests. The various steps are: A, sponge titanium; B, chips of forging for remelting; C, arc-melted ingot; D, forging; E, strips cut from final forging; F, hot-rolled strips; and G, finished specimens.

C. Analytical Results

The concentration of alloying elements in the binary, ternary, and commercial alloys employed in scaling tests is shown in Tables 1, 4 and 7 respectively.

Considerable difficulty has been encountered in attempts to determine the concentration of tungsten present as a contaminant in arc-melted titanium and titanium-base alloys. An analytical procedure described in a report of the Battelle Memorial Institute[1] was employed initially in the determination of this impurity. However, the results generally were of such a large order of magnitude that it appeared doubtful that they were representative. Accordingly, a number of samples from alloys previously employed were submitted to a commercial laboratory where they were analyzed spectrographically for tungsten. In almost every instance these results indicated a considerably lesser degree of contamination than was obtained with the previous procedure. Results obtained by the Battelle procedure were greater than those obtained spectrographically by factors up to 10.

Subsequently, the Battelle procedure was modified by employing standards in the form of solutions of known tungsten

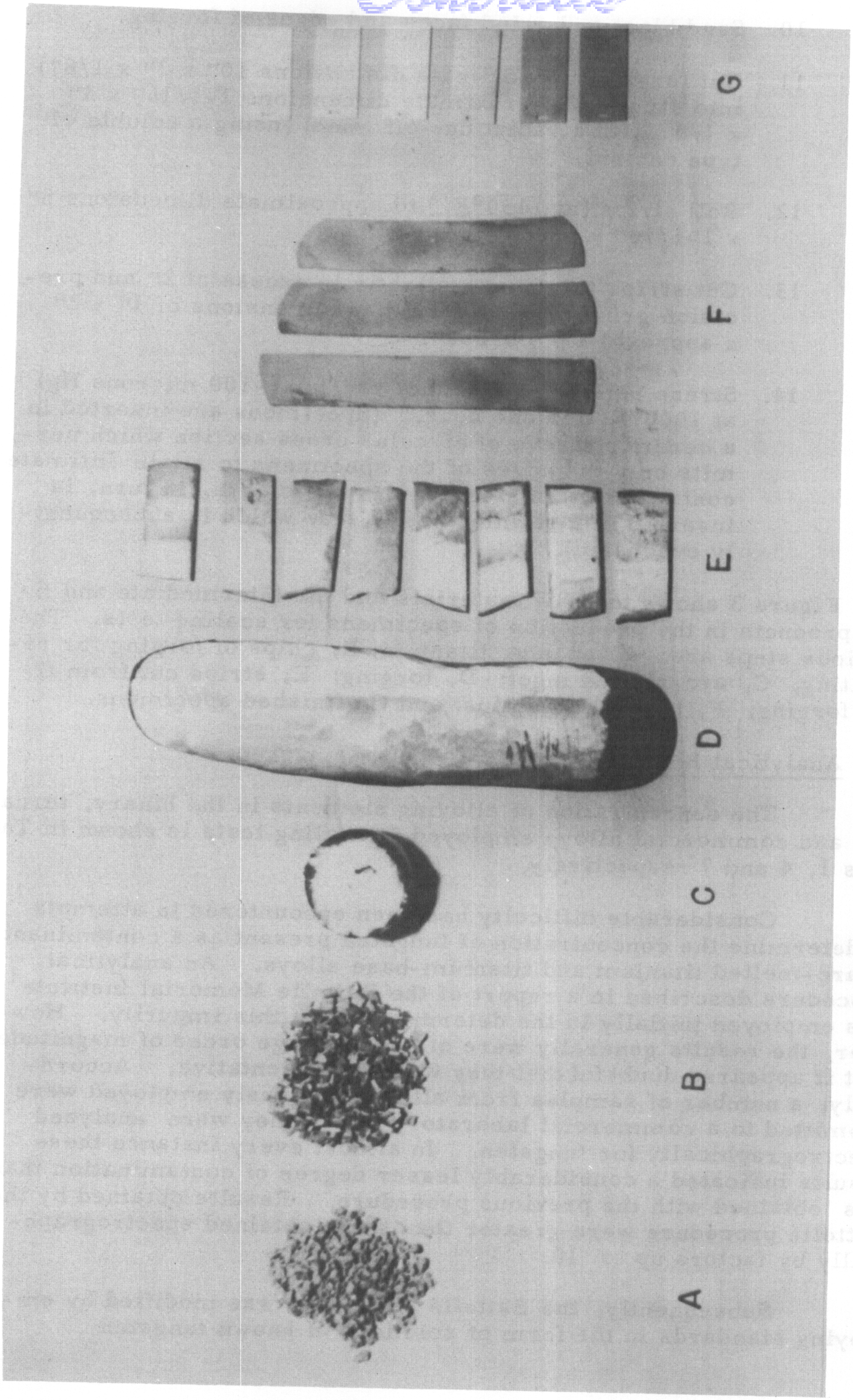


Fig. 3 Raw Materials and Steps in the Production of Specimens for Scaling Tests.

concentration along with solutions of alloy samples containing unknown quantities of tungsten. Ultimately, a carefully prepared correction curve was obtained and is currently being used in conjunction with the Battelle procedure. If this procedure proves to be unsatisfactory, all samples will be analyzed spectrographically.

IV. TEST EQUIPMENT

Scaling Furnace

The description of the scaling furnace, based on a furnace used used by Day and Smith[2], 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 plates of heat resistant steel 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 geared, motor driven mechanism. This arrangement insures that the specimens will be maintained at reasonably constant temperatures, up to a maximum of 2000°F., for sustained periods of operation (See Figs. 4 and 6).

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 (See Fig. 5).

The temperature of the furnace is regulated by 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.

The furnace top is made of a heat resistant steel, perforated to decrease its weight, to which are attached two concentrically positioned strips of the same material located so that they project perpendicularly to the plane of the larger section. Each of these projections is located near the bottom and in the center of troughs of "U" shaped cross section which are in turn attached to the horizontal retaining wall

Fig. 4 View of assembled scaling furnace showing rotating top and balance.

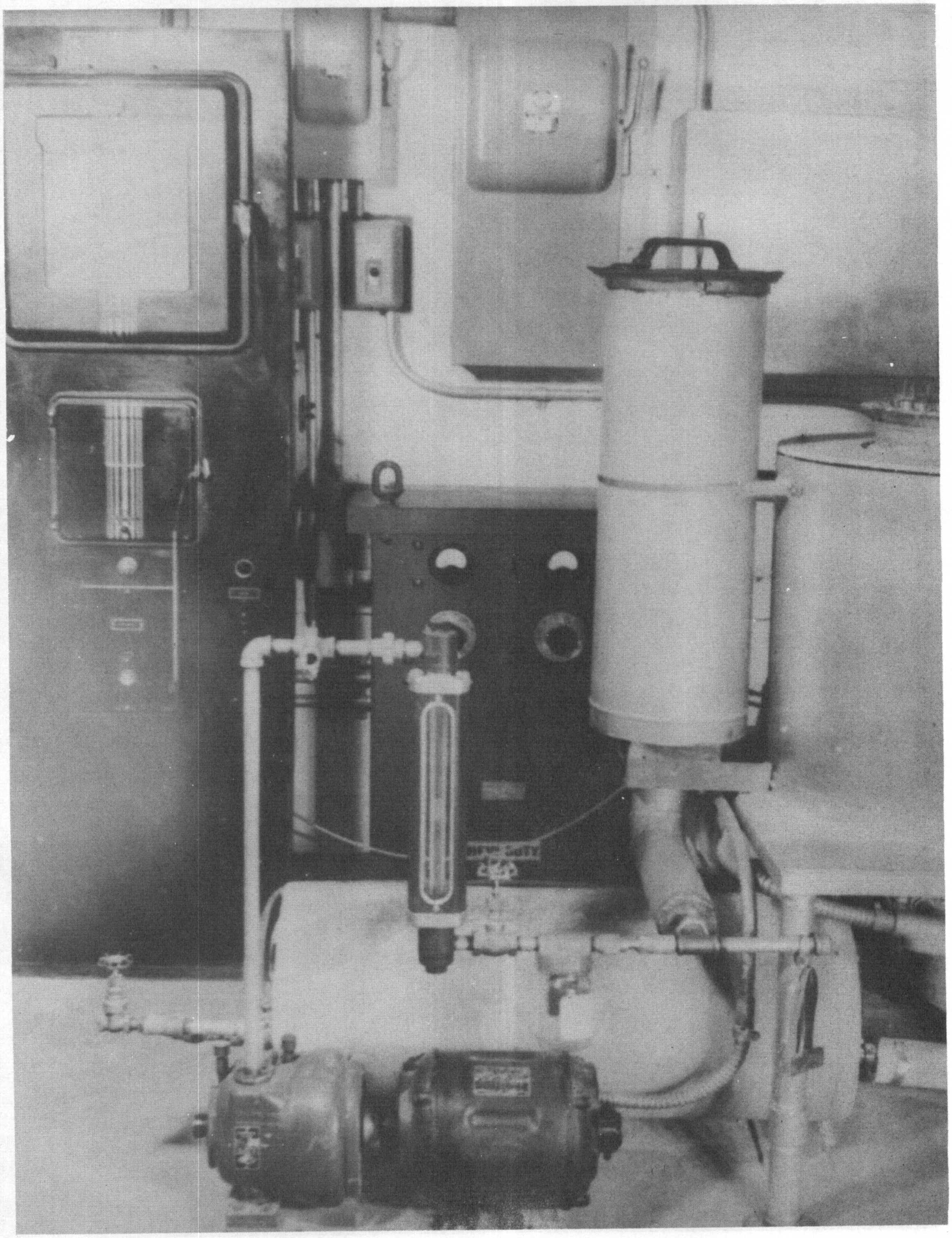


Fig. 5 View showing Details of Preheat Furnace and Its Auxiliary Equipment

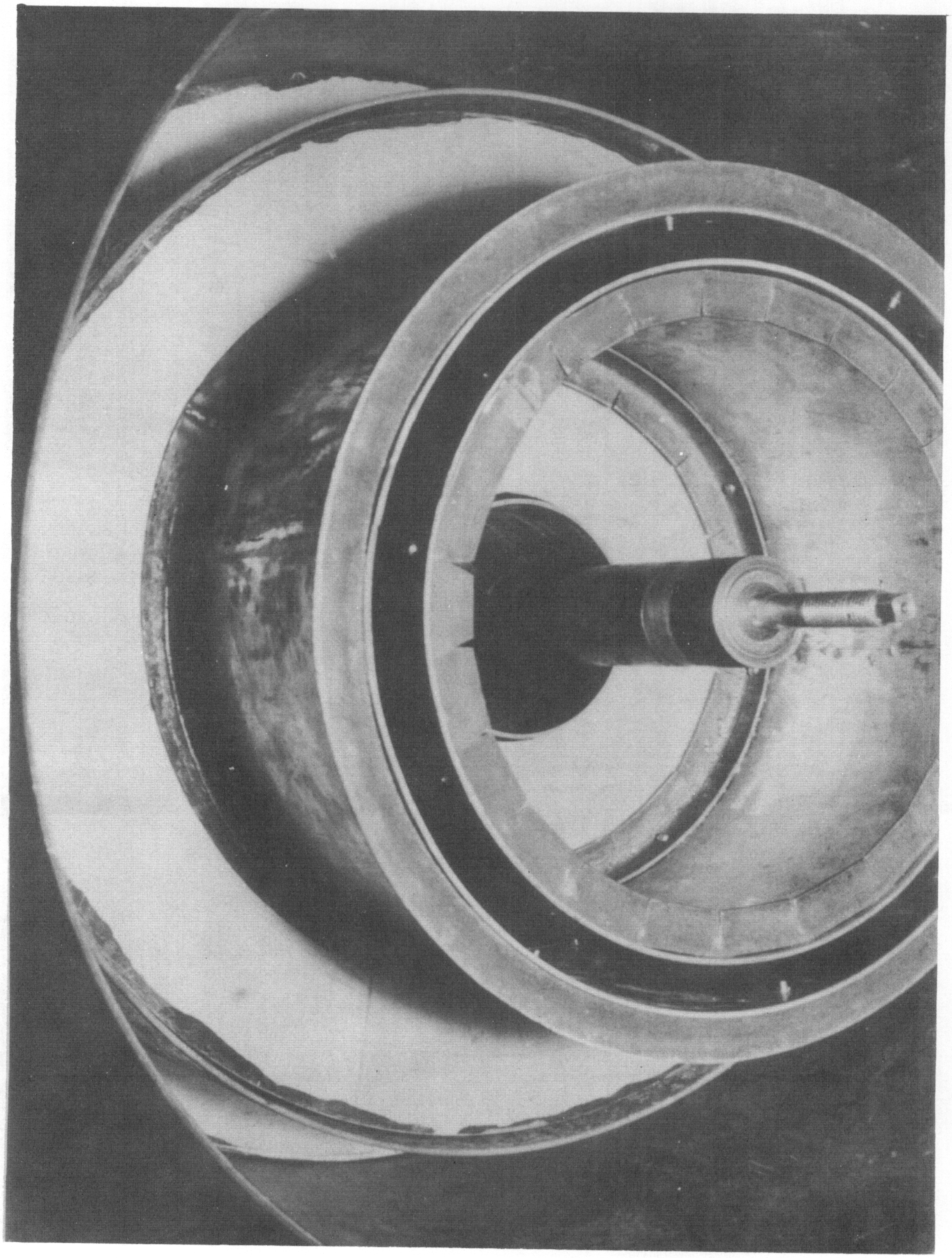


Fig. 6 View looking down on scaling furnace showing level of annulus directly above that of the heating chamber.

of the furnace proper. Originally, it was intended that the troughs be filled with sand in order to provide a thermal seal; however, the baffling effect of the projection-trough arrangement made it unnecessary to further restrict heat losses. The furnace top accommodates conically shaped plugs, split and grooved along their vertical axes. The grooves of the plugs are just large enough to admit lengths of Nichrome-V ribbon by which the specimens are suspended. The split plugs are removed just before the specimens are introduced into the furnace and, subsequently, just before weighing the specimens. Afterwards they are replaced in order to hold the ribbons in place and to reduce heat losses. In order to insure an excess of air of constant low moisture content in the furnace, an air cooled pump rated at 3.3 cubic feet per minute is employed in conjunction with a desiccating agent such as silica gel containing a cobalt indicator. A Fisher and Porter flow meter permits measurement of the quantity of air introduced.

The refractory bricks required for the scaling furnace are not of standard size and could be obtained only by cutting standard sized bricks or by molding bricks to the desired dimensions. The latter method was adopted and four collapsible molds were constructed for use with Harbison Walker's HW-85 Lightweight Castable. This material is hydraulic setting, can be removed from the mold in 12 hours, and requires a period of 24 additional hours for setting.

The power source for the resistance heating of 35 feet of Nichrome-V tubing consists of a transformer of 6.4 KVA, 230-32/4 volts, possessing a secondary capacity of 200 amperes at all voltage taps. Thirty-six steps of input are provided between 32 and 4 volts.

The power source employed to heat the Nichrome-V wire elements of the furnace consists of a transformer of 36.62 KVA, 230-18.3/10.57 volts, and a secondary capacity of 200 amperes at all voltage taps. Seventy-two steps of input are provided between 183.1 and 10.57 volts.

The temperature calibration of the scaling furnace is carried out in the following manner: prior to introducing the specimens to the furnace couple No. 1, utilized for controlling the temperature within the hot zone, is positioned approximately 1/2 inch below the level to be occupied by the lower edge of the rotating specimens during the scaling test. Thermocouple No. 2 is raised to a level corresponding to that of the center of the specimens. After the furnace has been allowed to heat for a period of time necessary to insure the attainment of thermal equilibrium the temperatures indicated by the two thermocouples are observed. The temperature indicated by thermocouple No. 2 is then adjusted to correspond to the desired temperature. The latter process is accomplished by placing the respective thermocouples in the controlling circuit in such rapid succession that the two readings are obtained almost simultaneously. Four toggle switches facilitate the rapid introduction of any of the four thermocouples to the thermocouple circuit. After several temperature readings for each thermocouple are observed and the relationship between dissimilarly positioned thermocouples established thermocouple No. 2 is lowered below the level to be occupied by the lower edge of the specimens in order to avoid contact between the two during subsequent rotation of the latter. Thermocouple No. 1 is then made to control at the temperature corresponding to the desired temperature previously indicated ty thermocouple No. 2.

The temperature calibration of the pre-heat furnace is of considerably less critical nature than that of the scaling furnace, since the small quantity of air produced by the air pump produces a negligible effect on the temperature of the hot zone of the scaling furnace. This procedure is not repeated before each scaling test as is the case for the temperature calibration of the scaling furnace. Data representative of the performance of the pre-heat furnace are as follows:

Heating Coil Amperage	Heating Coil Voltage	Approximate Power (Watts) Delivered to Heating Coil	Temp. of Coil (°F.)	Temp. of Air (°F.)	Flow Rate of Air (C. F. M.)[1]
150	17	2550	1083	110	1.1
150	17	2550	1734	465	2.2
150	17	2550	1707	520	3.3
130	14	1820	----	300	1.7

Original calculations pertaining to the performance of the pre-heat furnace were based on an empirical equation[3], $hD/k = 1.86\ (Re)^{1/3} \times (Pr)^{1/3} \times (D/L)^{1/3} \times (M_m/M_s)^{0.14}$.

h = heat transfer coefficient (B. T. U. /hr. /ft.^{2}/°F.)
D diameter (ft.)
k thermal conductivity (B. T. U. /hr. /ft. /°F.)
Re Reynolds number
Pr Prandtl number
L length (ft.)
M_m dynamic viscosity of the liquid at temperature t_m (pound - hr. /ft.^{2})
M_s same at mean surface temperature t_s

Since this equation is intended for use in conjunction with streamline flow in pipes with viscous liquids (specifically, petroleum oils) its application to the problem of streamline flow in pipes with gas (air

1. When air was passed through silica gel the effect of this obstruction caused the maximum flow rate to be reduced from 3.3 to 1.7 cu ft/ min.

supplied from the pre-heat furnace to the scaling furnace), is not completely satisfactory. For example: heat transfer calculation which indicated that the pre-heat furnace would raise the temperature of air, at flow rates up to 3.3 cu ft/min, to approximately 1000°F. resulted in the attainment of temperatures only one-half as high despite the fact that the initial calculated wattage requirements were doubled in order to insure that the desired performance would be realized. The indicated temperatures were achieved only after the installation of a spring-type turbulator throughout the entire length of the coil of the pre-heat furnace.

The pre-heat furnace is consistently regulated for each scaling test as follows: the current input to the furnace is adjusted to 130 amperes, the air pump to full capacity (1.7 cu ft/min) and the furnace allowed to heat for approximately 4 hours. Just prior to the time the specimens are inserted in the furnace, a cartridge containing approximately 50 pounds of silica gel is inserted in the air line. The silica gel is used for approximately 150 hours after which the cartridge containing the spent material is removed from the line and placed in a regenerator maintained at 300°F. A fresh cartridge is placed in the line immediately with the result that the air is continually dried to the same extent (approximately 0.7 grain per cubic foot, or less than 5% moisture).

V. DISCUSSION OF EXPERIMENTAL RESULTS

A. Scaling Data and Results

The relationship between weight increase per unit area and time for the various alloys investigated is shown graphically in Figures 7-12, 27-30*, 31-34*, 35-38*, 39-42*, and 43-46*. An aggregate of curves consisting respectively of:

(1) experimentally-produced binary titanium-base alloys;

(2) experimentally-produced ternary titanium-base alloys;

(3) commercial grades of titanium-base alloys;

(4) experimentally-produced and commercial grades of titanium, is shown for each of the temperatures 1200°, 1400°, 1600° and 1800° F. Comparisons essentially were drawn between aggregates of curves as units, rather than between individual curves of any particular group. Also included is an aggregate of curves consisting of the more scaling resistant titanium and titanium-base alloys referred to above, plus stainless steel (Figs. 12 and 43-46*).

1. Experimental Binary Titanium-base Alloys

The experimental binary titanium alloys referred to above include alloys containing aluminum, chromium, columbium, copper, iron, manganese, molybdenum, nickel, silicon, tantalum, tungsten, and vanadium. Specific compositions of these alloys are given in Table 1.

Of the binary alloys investigated, alloys containing Cb, Ta, W, Si, Mo, and Al were generally more resistant to scaling than unalloyed titanium; alloys containing Cr, Mn, Fe, Cu, Ni, and V were generally less resistant to scaling than unalloyed titanium (See Figs. 7-8 and 27-30*).

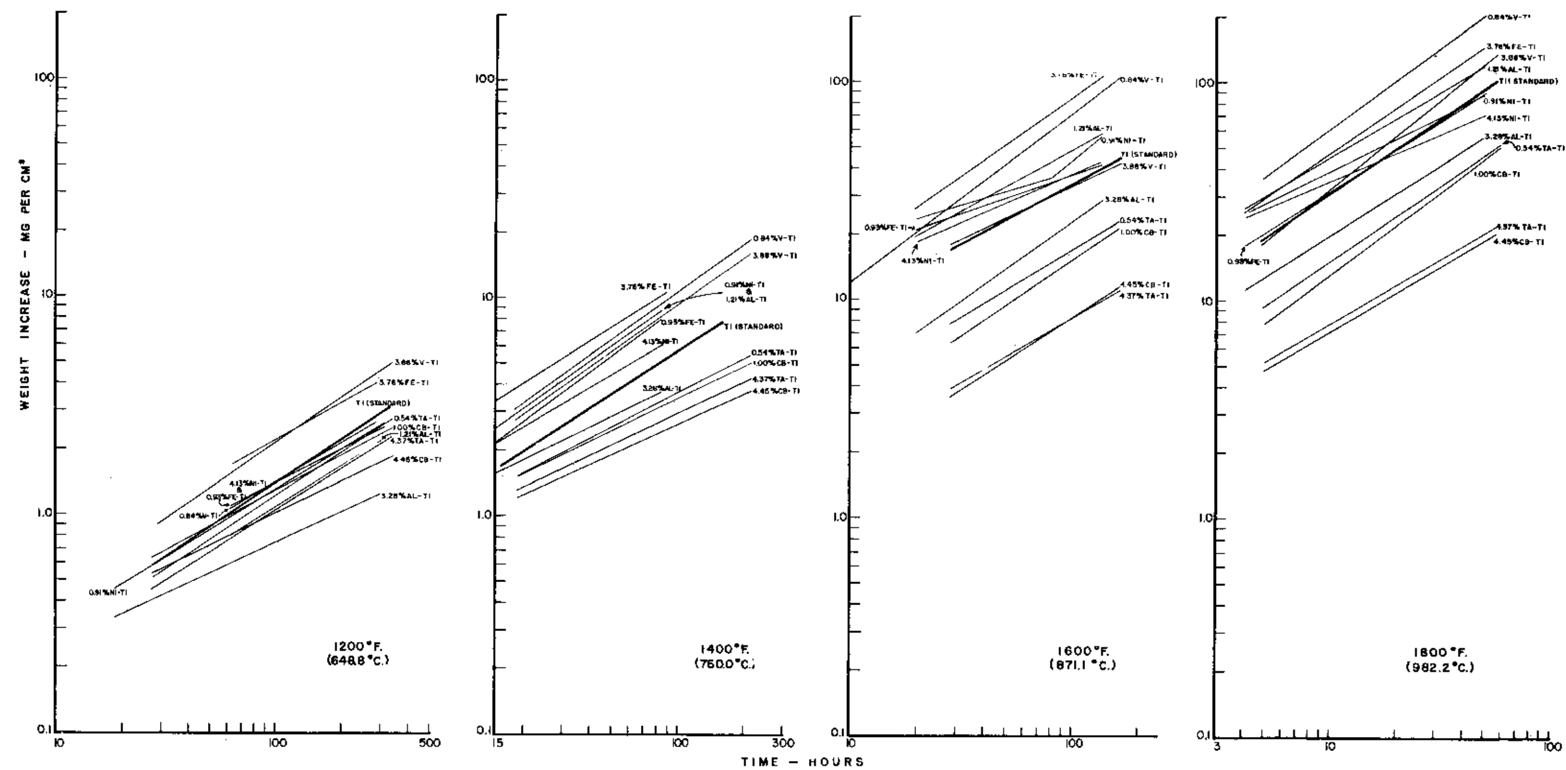
As the testing temperature was increased the difference in the slope of the curves became more pronounced and the scaling rate of all the alloys increased; however, the rate of increase of the alloys was less than that for unalloyed titanium.

The relationship between weight increase and time for these binary alloys was of an exponential nature. The indication of a transition in the scaling rate was observed in only three instances; one at 1400°F. (Figs. 7 and 23) and two at 1600°F. (Figs. 8 and 29). In each case after the transition the rate of scale formation

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

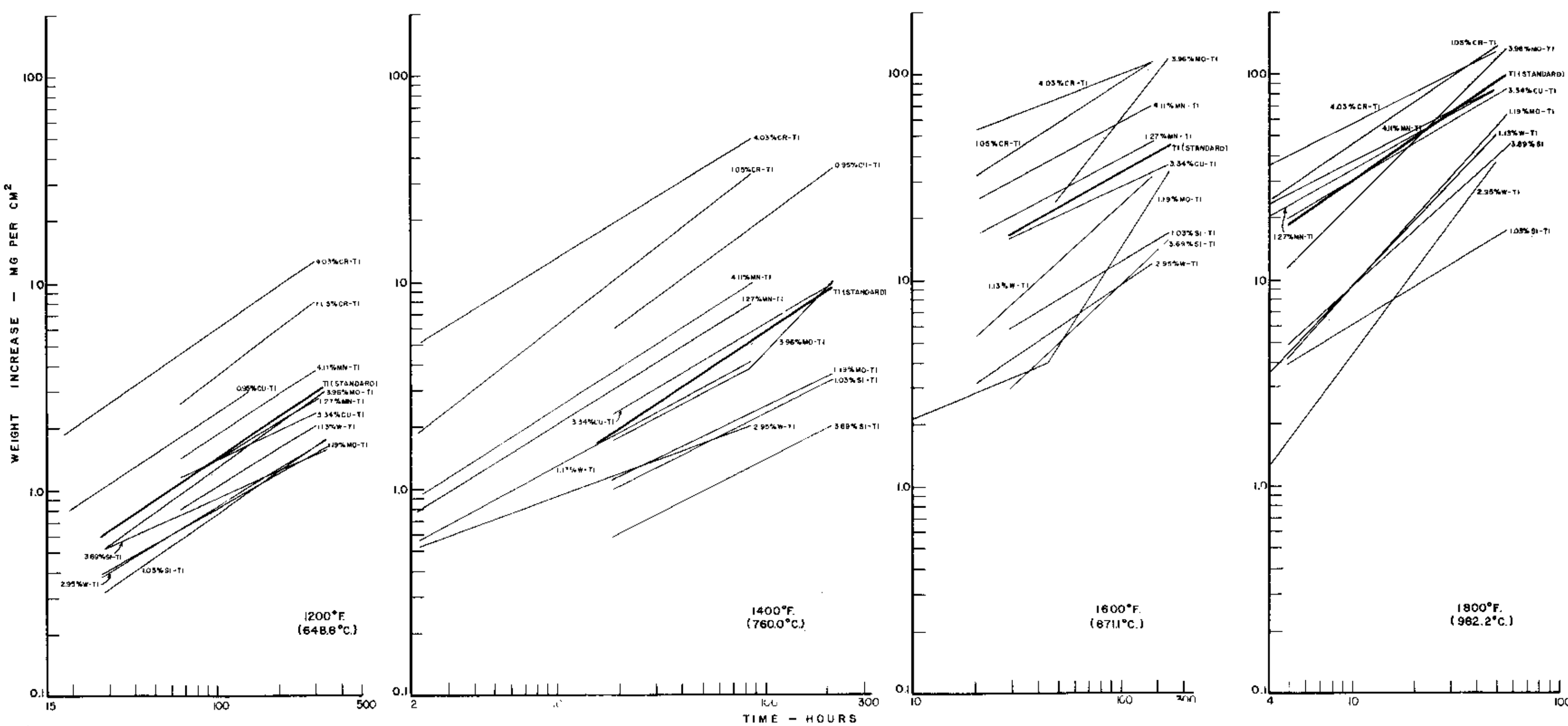
was increased.

The alloys which showed the greatest resistance to scaling at the four testing temperatures were: 1200°F., 3.28% Al-Ti; 1400°F., 3.69% Si-Ti; 1600°F., 4.38% Ta-Ti and 4.45% Cb-Ti; and 1800°F., 1.03% Si-Ti. See Tables 2 and 3 for the relative scaling resistance of the alloys in this group at each of the testing temperatures.



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

FIG. 7



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

FIG. 8

TABLE 1

CHEMICAL COMPOSITION OF BINARY TITANIUM-BASE ALLOYS

Heat No.	Intended Composition Percent	Analysis* Percent	Alloying Element
110-R	4	4.48	Aluminum
25	4	3.28	Aluminum
37	1	1.21	Aluminum
42-R1**	4	2.95	Tungsten
40	1	1.13	Tungsten
49	4	4.13	Nickel
44	1	0.91	Nickel
43	4	4.03	Chromium
47	1	1.05	Chromium
45	4	4.11	Manganese
46	1	1.27	Manganese
51	4	3.76	Iron
48	1	0.93	Iron
54	4	3.34	Copper
100-R	1	0.95	Copper
71	4	3.88	Vanadium
53	1	0.84	Vanadium
58-R3	4	4.37	Tantalum
63-R2	1	0.54	Tantalum
59-R2	4	3.96	Molybdenum
61-R2	1	1.19	Molybdenum
101-R3	1	1.23	Molybdenum
79	4	3.69	Silicon
67	1	1.03	Silicon
77-R3	4	4.45	Columbium
81-R3	1	1.00	Columbium

* Average analysis of two representative samples obtained from the final forging.

** The designation "R" denotes three melting and forging operations; "R1", four, etc.

TABLE 2

RELATIVE SCALING PROPENSITY OF BINARY ALLOYS AT 1200° AND 1400°F.

EXPOSURE TIME - 48 HOURS

1200°F. Composition of Specimens (Weight per cent)	1200°F. Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area ($cm.^2$) Relative to Ti = 100%	1400°F. Composition of Specimens (Weight per cent)	1400°F. Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area ($cm.^2$) Relative to Ti = 100%
3.28% Al	52.2	3.69% Si	26.1
1.19% Mo	53.6	2.95% W	41.3
1.03% Si	53.6	1.19% Mo	43.5
2.95% W	57.1	1.03% Si	43.5
3.69% Si	57.1	4.45% Cb	47.8
4% Cb	60.7	4.37% Ta	54.3
4.37% Ta	64.3	1.00% Cb	63.0
1.13% W	67.8	0.54% Ta	67.4
1.21% Al	75.0	3.28% Al	73.9
1% Cb	82.1	3.96% Mo	76.1
3.34% Cu	82.1	1.13% W	82.6
0.54% Ta	85.7	Ti	100.0
0.93% Fe	89.2	3.34% Cu	100.9
4.13% Ni	89.2	4.13% Ni	117.4
1.27% Mn	92.8	1.27% Mn	150.0
0.84% V	92.8	0.93% Fe	152.2
Ti	100.0	3.88% V	160.9
0.91% Ni	104.3	0.91% Ni	163.0
4.11% Mn	132.1	1.21% Al	178.3
3.76% Fe	142.8	0.84% V	187.0
4% V	160.7	4.11% Mn	189.1
1% Cu	257.1	3.76% Fe	197.8
1.05% Cr	285.7	1% Cu	241.3
4.03% Cr	508.7	1.05% Cr	619.6
		4.03% Cr	956.5

TABLE 3

RELATIVE SCALING PROPENSITY OF BINARY ALLOYS AT 1600° AND 1800°F.

EXPOSURE TIME - 48 HOURS

1600°F. Composition of Specimens (Weight per cent)	1600°F. Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area ($cm.^2$) Relative to Ti = 100%	1800°F. Composition of Specimens (Weight per cent)	1800°F. Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area ($cm.^2$) Relative to Ti = 100%
4.37% Ta	24.4	1.03% Si	17.8
4.45% Cb	25.3	4.45% Cb	21.1
2.95% W	30.4	4.37% Ta	22.8
3.69% Si	35.1	2.95% W	42.3
1.03% Si	37.8	3.69% Si	43.6
1.00% Cb	47.8	0.54% Ta	49.4
0.54% Ta	51.1	1.00% Cb	49.9
3.28% Al	71.6	1.13% W	56.4
1.19% Mo	72.2	1.19% Mo	61.0
3.34% Cu	80.4	3.28% Al	63.2
1.13% W	83.8	4.13% Ni	79.1
3.88% V	97.8	3.34% Cu	87.1
0.93% Fe	99.6	1.27% Mn	91.9
Ti	100.0	4.11% Mn	93.9
4.13% Ni	104.4	0.91% Ni	98.6
1.27% Mn	115.6	0.93% Fe	98.6
1.21% Al	142.2	Ti	100.0
0.91% Ni	143.1	3.96% Mo	124.3
4.11% Mn	173.8	3.88% V	131.0
0.84% V	223.3	1.21% Al	131.6
3.96% Mo	226.7	4.03% Cr	142.8
3.76% Fe	271.1	1.05% Cr	148.6
4.03% Cr	277.8	3.76% Fe	162.6
1.05% Cr	286.7	0.84% V	227.5

2. Experimental Ternary Titanium-base Alloys

The experimental ternary titanium-base alloys contain the following combinations of two alloying elements: Al with W or Si; Cr with Fe or Mn; Ni with Cu; Ta with Cb, Si, or W; and W with C, Mo, or Si. (See Table 4 for specific alloy composition.)

The scaling rate of titanium increased more rapidly than the scaling rate of the titanium alloys with increasing temperature and the differential in slopes of aggregates of curves did not increase consistently with increasing temperatures, but was most pronounced at 1800°F. and least pronounced at 1400°F.

The alloys containing chromium consistently displayed poor resistance to scaling at all temperatures. All of the other alloys in this group showed better resistance to scaling than unalloyed titanium. The most scale-resistant alloy at each temperature is: 1200°F., 6% Al-1% Si; 1400°F., 4% W-1% Si; 1600°F., 4% W-1% Si and 4% Ta-1% Si; and 1800°F., 4% Ta-1% Si. Comparative scaling data relevant to the alloys in this group are shown in Tables 5 and 6 and in Figures 9 and 31-34*.

There was no indication of a transition in the scaling rate of any of the alloys in this group.

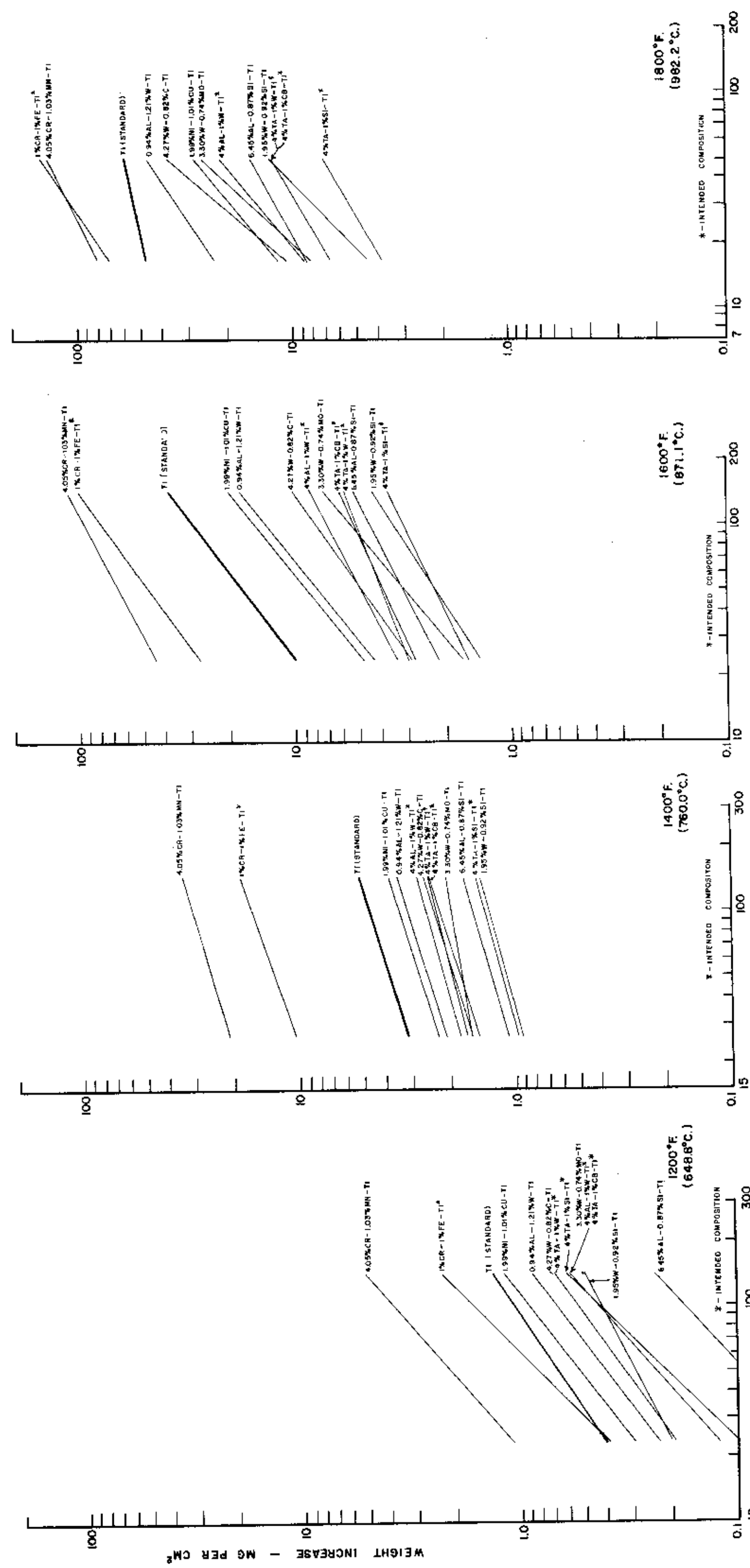
TABLE 4

CHEMICAL COMPOSITION OF TERNARY TITANIUM-BASE ALLOYS

Heat Number	Intended Composition Percent	Analysis* Percent
86-R3**	2 Ni - 1 Cu	1.99 Ni - 1.01 Cu
87-R	6 Al - 1 Si	6.45 Al - 0.87 Si
102-R3	1 Al - 1 W	0.94 Al - 1.21 W
103-R5	4 Ta - 1 Si	.... Ta - 1.20 Si
104	4 Cr - 1 Mn	4.05 Cr - 1.03 Mn
105-R5	4 Ta - 1 Cb	.... Ta -.... Cb
106-R2	6W - 1 C	4.27 W - 0.82 C
107-R1	1 Cr - 1 Fe	....Cr - 0.98Fe
108-R3	4 W - 1 Si	1.95 W - 0.92 Si
114-R7	4 Al - 1W	3.99 Al-.... W
118-R6	4 Ta - 1 W	.... Ta - 0.98 W
119-R6	4 W - 1 Mo	3.30 W - 0.74 Mo

* Average analysis of two representative samples obtained from the final forging.

** The designation "R" denotes three melting and forging operations; "R1", four, etc.



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

FIG. 9

TABLE 5

RELATIVE SCALING PROPENSITY OF TERNARY 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 Al - 1 Si	13.6
4 Ta - 1 Si	30.3
4 Ta - 1 Cb	34.8
4 Al - 1 W	34.8
4 W - 1 Mo	34.8
4 W - 1 Si	43.9
4 Ta - 1 W	48.5
6 W - 1 C	48.5
1 Al - 1 W	59.1
2 Ni - 1 Cu	78.8
Ti	100.0
1 Cr - 1 Fe	121.1
4 Cr - 1 Mn	303.0

1400°F.

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area ($cm.^2$) Relative to Ti=100%
4 W 1 Si	28.2
4 Ta - 1 Si	29.5
6 Al - 1 Si	33.3
4 Ta - 1 Cb	46.2
4 W - 1 Mo	46.2
6 W - 1 C	49.8
4 Ta - 1 W	51.3
4 Al - 1 W	55.1
1 Al - 1 W	66.7
2 Ni - 1 Cu	71.8
Ti	100.00
1 Cr - 1 Fe	333.0
4 Cr - 1 Mn	654.0

TABLE 6

RELATIVE SCALING PROPENSITY OF TERNARY ALLOYS AT 1600° AND 1800°F.

EXPOSURE TIME - 48 HOURS

1600°F.

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm.^{2}) Relative to Ti=100%
4 Ta - 1 Si	12.9
4 W - 1 Si	12.9
4 W - 1 Mo	17.6
6 Al - 1 Si	18.2
4 Ta - 1 Cb	22.9
4 Ta - 1 W	22.9
4 W - 1 C	28.2
4 Al - 1 W	28.8
1 Al - 1 W	44.7
2 Ni - 1 Cu	55.1
Ti	100.0
1 Cr - 1 Fe	270.7
4 Cr - 1 Mn	376.0

1800°F.

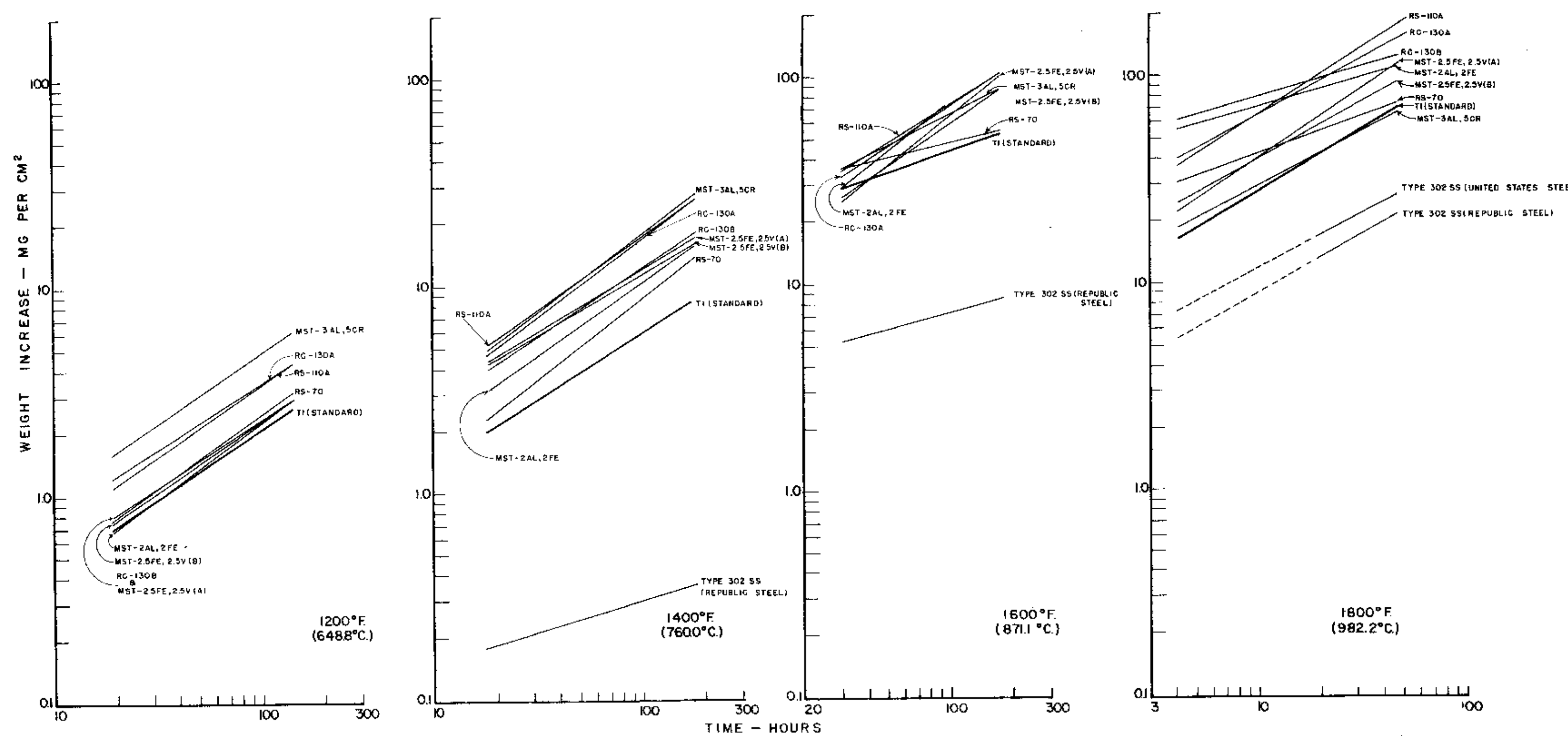
Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm.^{2}) Relative to Ti=100%
4 Ta - 1 Si	11.9
4 Ta - 1 W	20.4
4 Ta - 1 Cb	20.4
4 W - 1 Si	21.0
6 Al - 1 Si	25.8
4 Al - 1 W	35.5
4 W - 1 Mo	43.5
2 Ni - 1 Cu	46.8
6 W - 1 C	62.9
1 Al - 1 W	77.4
Ti	100.0
4 Cr - 1 Mn	217.8
1 Cr - 1 Fe	233.8

3. Commercial Titanium-base Alloys

The following commercial titanium-base alloys were investigated relative to scaling resistance: RC 130A, RC 130B, RS 70, RS 110A, MST - 3%Al - 5%Cr, MST 2.5% Fe - 2.5%V, and MST - 2% Fe.

The scaling rate of all the commercial alloys increased more rapidly than the scaling rate of unalloyed titanium with increasing temperature and the differential in the slopes of aggregates of curves became more pronounced as the temperature increased (See Figs. 10 and 35-38*). The scaling rate of the commercial alloys was greater than that of unalloyed titanium at all temperatures. The scaling rate of stainless steel (Type 302) increased more rapidly than the scaling rate of the commercial alloys and unalloyed titanium with increasing temperature. Generally the relationship between weight increase and time was exponential and no indication of a transition in scaling rate was observed.

The difference in the scaling rate of the commercial alloys generally was not marked. The alloys most resistant to scaling at each temperature were: 1200°F., MST - 2Al - 2Fe; 1400°F., MST - 2Al - 2Fe; 1600°F., MST - 2.5Fe - 2.5V; and 1800°F., MST - 3Al - 5Cr. Additional comparative data relative to the scaling resistance of alloys in this group are shown in Tables 8 and 9. The chemical composition of this group of alloys is shown in Table 7.



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

FIG. 10

TABLE 7

CHEMICAL COMPOSITION OF COMMERCIAL GRADES OF UNALLOYED TITANIUM AND TITANIUM-BASE ALLOYS

Manufacturer	Manufacturer's Designation	Composition
Rem-Cru Titanium	RC 130 A	8% Mn, Bal. Ti
Rem-Cru Titanium	RC 130 B	4% Mn, 4% Al, Bal. Ti
Republic Steel	RS 70	Ti
Republic Steel	RS 110 A	4% Cr, 4% Fe, Bal. Ti
Mallory-Sharon	MST-3% Al, 5% Cr	1.93% Al, 5.38% Cr, Bal. Ti
Mallory-Sharon	A MST-2.5% Fe, 2.5% V	2.67% Fe, 2.68% V, Bal. Ti
Mallory-Sharon	B MST-2.5% Fe, 2.5% V	2.28% Fe, 2.55% V, Bal. Ti
Mallory-Sharon	MST-2% Al, 2% Fe	2.19% Al, 3.45% Fe, Bal. Ti

TABLE 8

RELATIVE SCALING PROPENSITY OF COMMERCIAL ALLOYS AT 1200° AND 1400°F.

EXPOSURE TIME - 48 HOURS

1200°

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm^2) Relative to Ti = 100%
302 S.S. (Republic)	11.5
302 S.S. (U.S.S.)	----
Titanium	100.0
MST 2% Fe -2% Al	100.0
MST 2.5% Fe - 2.5% V(A)	107.7
MST 2.5% Fe - 2.5% V(B)	107.7
RC - 130 B	107.7
RS - 70	115.3
RS 110A	161.6
RC 130A	169.1
MST 3% Al - 5% Cr	223.1

1400°

Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm.^{2}) Relative to Ti = 100%
302 S.S. (Republic)	6.3
302 S.S. (U.S.S.)	---
Titanium	100.0
RS - 70	131.7
MST 2% Fe - 2%	168.5
MST 2.5% Fe - 2.5% V(A)	200.0
RC - 130B	200.0
MST 2.5% Fe - 2.5% V(B)	210.3
RC - 130A	263.0
RS - 110A	276.1
MST 3% Al - 5% Cr	276.1

TABLE 9

RELATIVE SCALING PROPENSITY OF COMMERCIAL ALLOYS AT 1600° AND 1800°F.

EXPOSURE TIME - 48 HOURS

1600°F. Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm.^{2}) Relative to Ti = 100%	1800°F. Composition of Specimens (Weight per cent)	Av. Total Wt. Increase (mg.) Per Av. Orig. Unit Area (cm.^{2}) Relative to Ti = 100%
302 S.S. (Republic)	17.1	302 S.S. (Republic)	30.6
302 S.S. (U.S.S.)	----	302 S.S. (U.S.S.)	37.6
Titanium	100.0	MST 3% Al-5% Cr	95.9
MST 2.5% Fe-2.5% V(A)	100.0	Titanium	100.0
MST 2.5% Fe-2.5% V(B)	105.8	RS - 70	108.3
MST 2% Fe-2% Al	117.1	MST 2.5% Fe-2.5% V (B)	133.5
RS - 70	117.1	MST 2% Fe - 2% Al	152.9
RC - 130B	131.4	MST 2.5% Fe-2.5% V (A)	166.8
RC - 130A	131.4	RC - 130 B	180.8
MST 3% Al - 5% Cr	131.4	RC - 130A	215.3
RS - 110A	134.1	RS - 110A	255.8

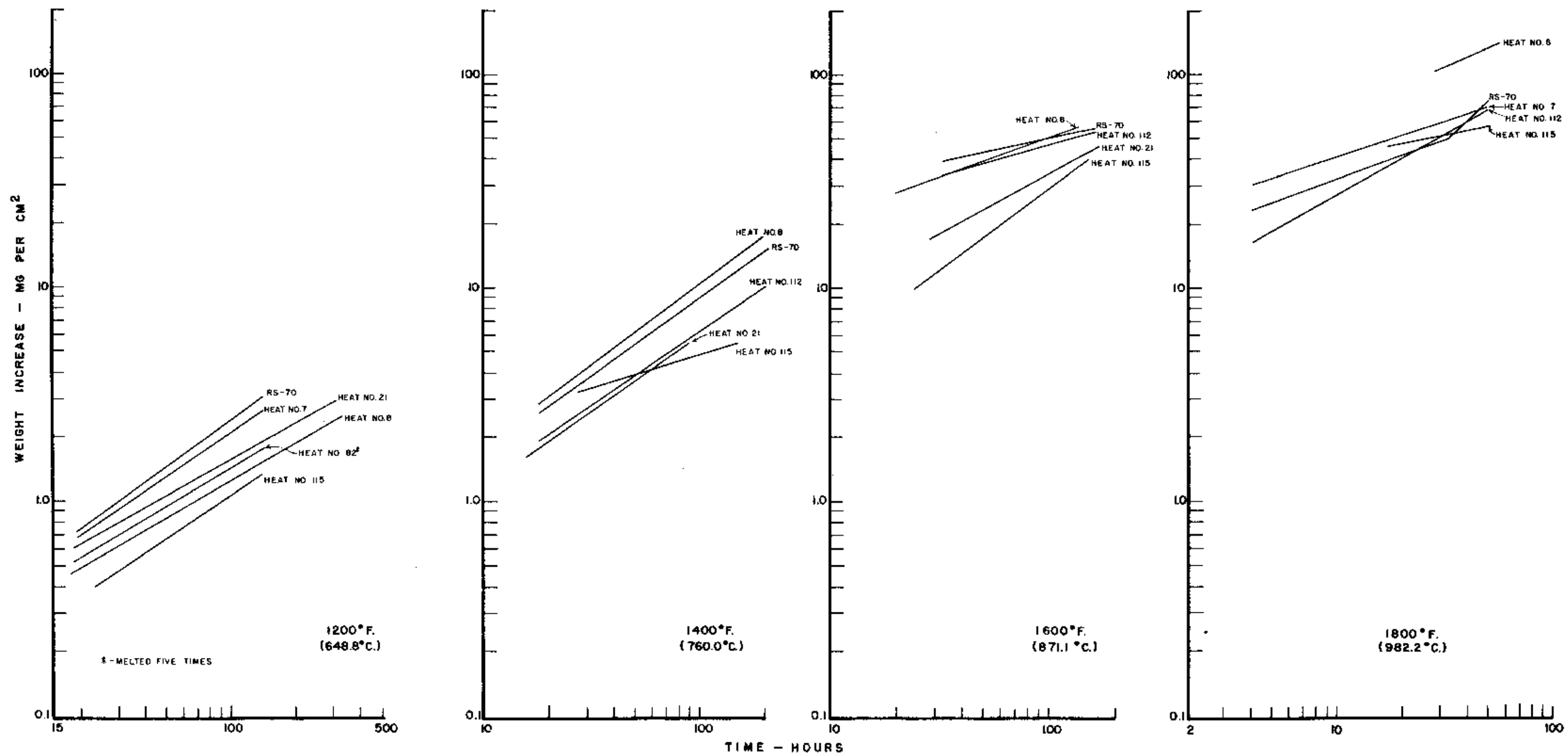
4. Experimental and Commercial Heats of Unalloyed Titanium

The investigation of several experimental heats and one commercial heat of pure titanium resulted in the following observations:

There was a more pronounced variation in the slopes of aggregates of curves for the temperatures of 1600° and 1800°F. Variation in slope occurred not only for the same heat at different temperatures, but with different heats at the same temperature (Fig. 11). The numerical values of slopes corresponding to commercial titanium and different heats of experimental titanium at 1200°, 1400°, 1600° and 1800°F. are shown in Table 56.

At 1200°F. a transition in slope was observed between 1 and 1.5 hours. A second transition was observed between 4 and 23.4 hours. The change in slope corresponding to the first transition was from 1.08 to 0.5: the change corresponding to the second transition was from 0.5 to 0.65. The change in the value of the rate constant K for the first transition was from 14.70 $(mg)^{0.93}$ per $(dm)^{1.36}$ per hour to 311.0 $(mg)^2$ per $(dm)^4$ per hour; the change for the second transition was from 311.0 $(mg)^2$ per $(dm)^4$ per hour to 15.37 $(mg)^{1.54}$ per $(dm)^{3.08}$ per hour. (These results are shown in Figures 11, 18*, 19*, and 20* and Tables 51*, 52*, 53*, 54*.) On the other hand, Morton and Baldwin[4], utilizing commercial titanium (U. S. Bureau of Mines) exposed to temperatures between 1290° and 1560°F. made the following observations: between these temperatures the slope was 0.5, except for recurrent discontinuities, and could therefore be described by a parabolic relationship.

At 1800°F. an indicated transition in slope was observed for the time period of 7.3 to 28.2 hours (Figures 22* -23* and Table 55*). However, since the data for the time period of 0 to 7.3 hours were limited and data for the time period of 7.3 to 28.2 hours were not obtained, the corresponding change in the rate constant was not determined. Morton and Baldwin[4] utilizing commercial titanium (U. S. Bureau of Mines) exposed to temperatures between 1560° and 1830°F. made the following observations: between these temperatures the curves were sigmoidal, following a straight line with slope 0.5 from approximately 0.1 to 1 hour. At 1 hour the curves increased abruptly, but gradually diminished until approximately 10 hours had elapsed. At this time the curves resumed their original slope of 0.5. (No results were shown for time periods beyond 10 hours.)



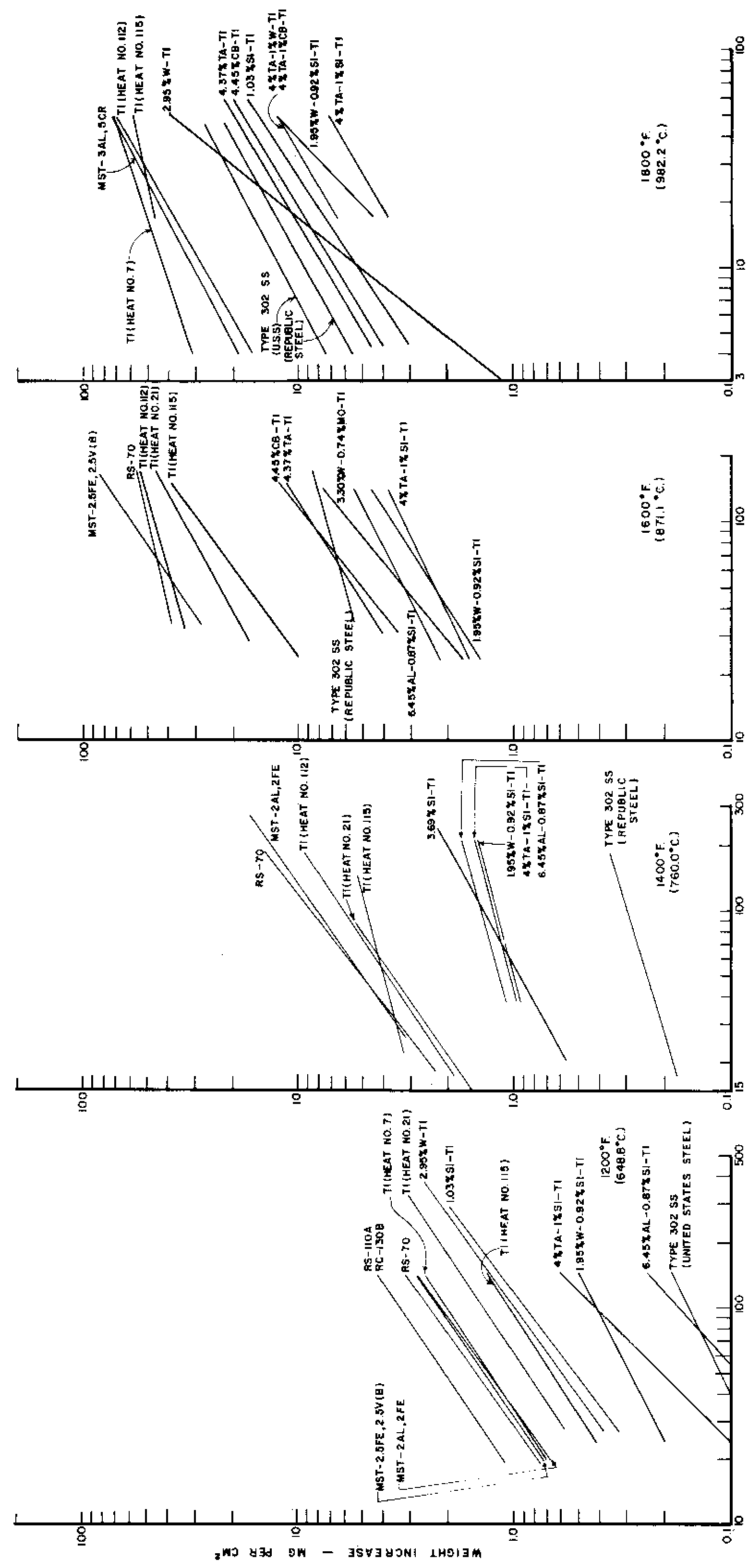
WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME FOR UNALLOYED TITANIUM AT 1200, 1400, 1600, 1800°F.

FIG. 11

5. Experimental and Commercial Heats of Unalloyed Titanium and Titanium-base Alloys

Comparison of commercial titanium, experimental titanium, commercial alloys, experimental binary alloys, experimental ternary alloys, and stainless steel is shown in Figures 12 and 43-46*. The alloys which were superior in scaling resistance to experimental and commercial titanium are shown in Table 10.

COMPARISON OF COMMERICAL AND EXPERIMENTAL GRADES OF ALLOYED AND UNALLOYED TITANIUM, AND STAINLESS STEEL.



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

FIG. 12

TABLE 10

COMPARATIVE SCALING PROPENSITY OF ALL ALLOYS INVESTIGATED

ALLOYS LISTED IN APPROXIMATE ORDER OF DECREASING RESISTANCE TO SCALING

1200°F.

Alloy
302 S. S. (U. S. S.)
6% Al - 1% Si - Ti
4% Ta - 1% Si - Ti
4% W - 1% Si - Ti
1.03% Si - Ti
2.95% W - Ti

1400°F.

Alloy
302 S.S. (Republic)
3.69% Si - Ti
4% W - 1% Si - Ti
4% Ta - 1% Si - Ti
6% Al - 1% Si - Ti

1600°F.

Alloy
4% Ta - 1% Si - Ti
4% W - 1% Si - Ti
6% Al - 1% Si - Ti
4% W - 1% Mo - Ti
302 S. S. (Republic)
4.45% Cb - Ti
4.37% Ta - Ti

1800°F.

Alloy
4% Ta - 1% Si - Ti
4% W - 1% Si - Ti
4% Ta - 1% Cb - Ti
4% Ta - 1% W - Ti
1.03% Si - Ti
2.95% W - Ti
4.45% Cb - Ti
4.37% Ta - Ti
302 S. S. (Republic)
302 S. S. (U. S. S.)

B. Weight Increase Versus Temperature

The relationship between weight increase and temperature for the temperature range 1200° to 1800°F. (time constant at 48 hours) is shown in Figures 13, 14, 15, 16, and 17 for: experimental binary titanium-base alloys, experimental ternary titanium-base alloys, commercial grades of titanium-base alloys and commercial and experimental grades oftitanium.

The relationship between weight increase and temperature was approximately linear in the case of the 4.03% Cr-Ti alloy (Fig. 14) and also in the case of the 4% Cr-1% Mn - Ti alloy (Fig. 15).

The relatively greater scaling rate observed for Heat No. 8 (Fig. 17) in the temperature range 1500° to 1800°F. was not considered typical of the behavior of titanium.

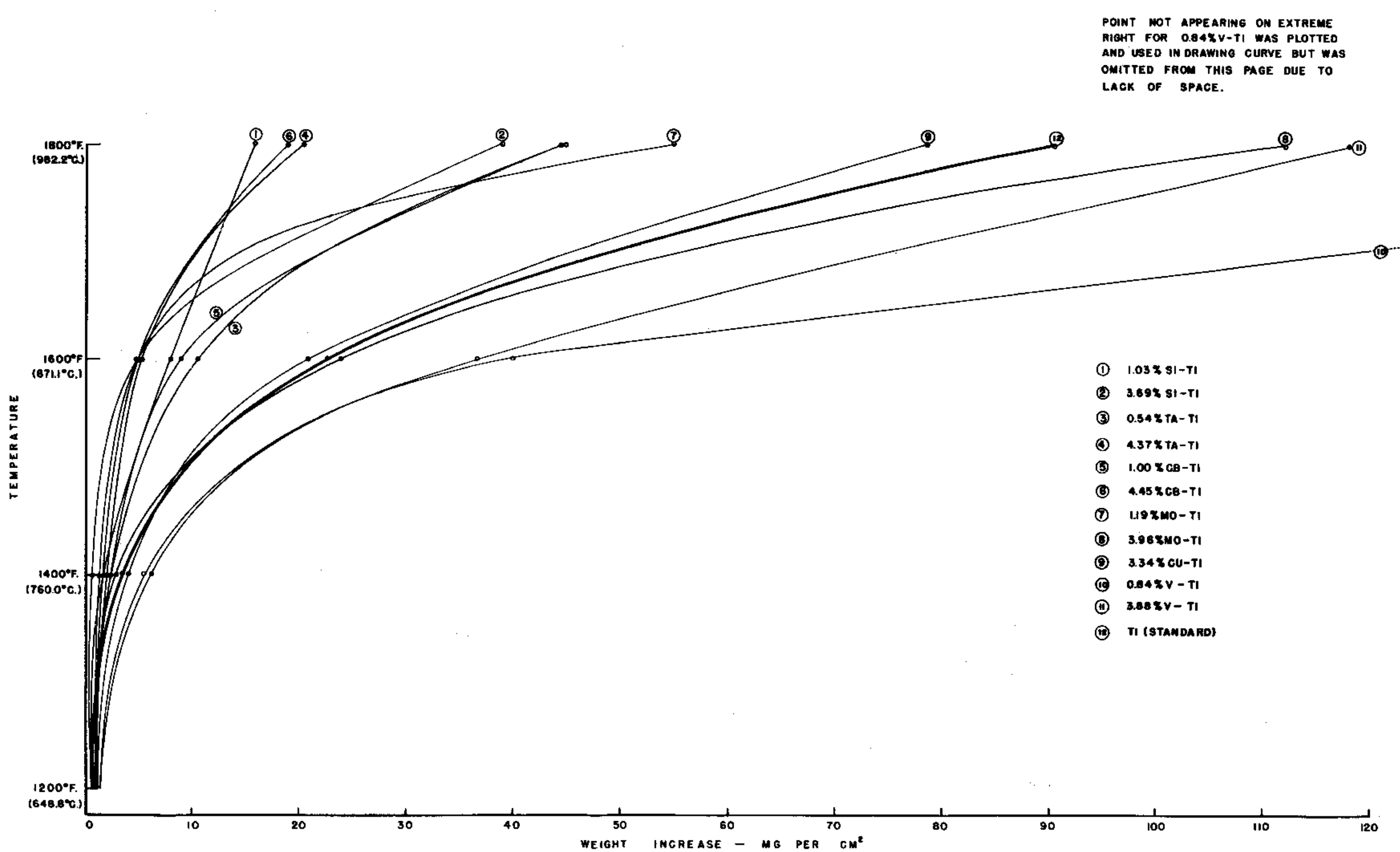


FIG. 13 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE (TIME CONSTANT – 48 HOURS)

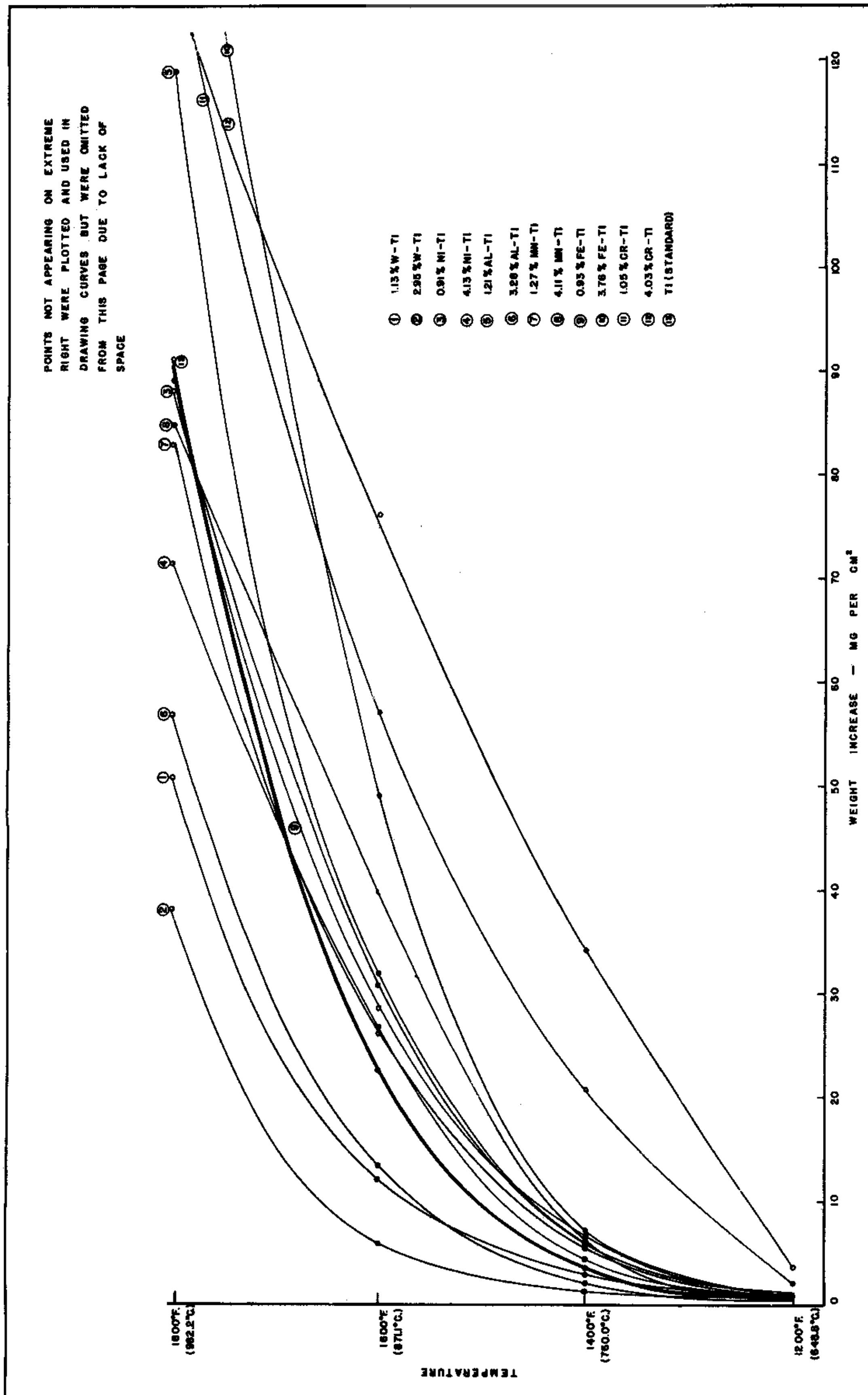


FIG. 14 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE (TIME CONSTANT — 48 HOURS)

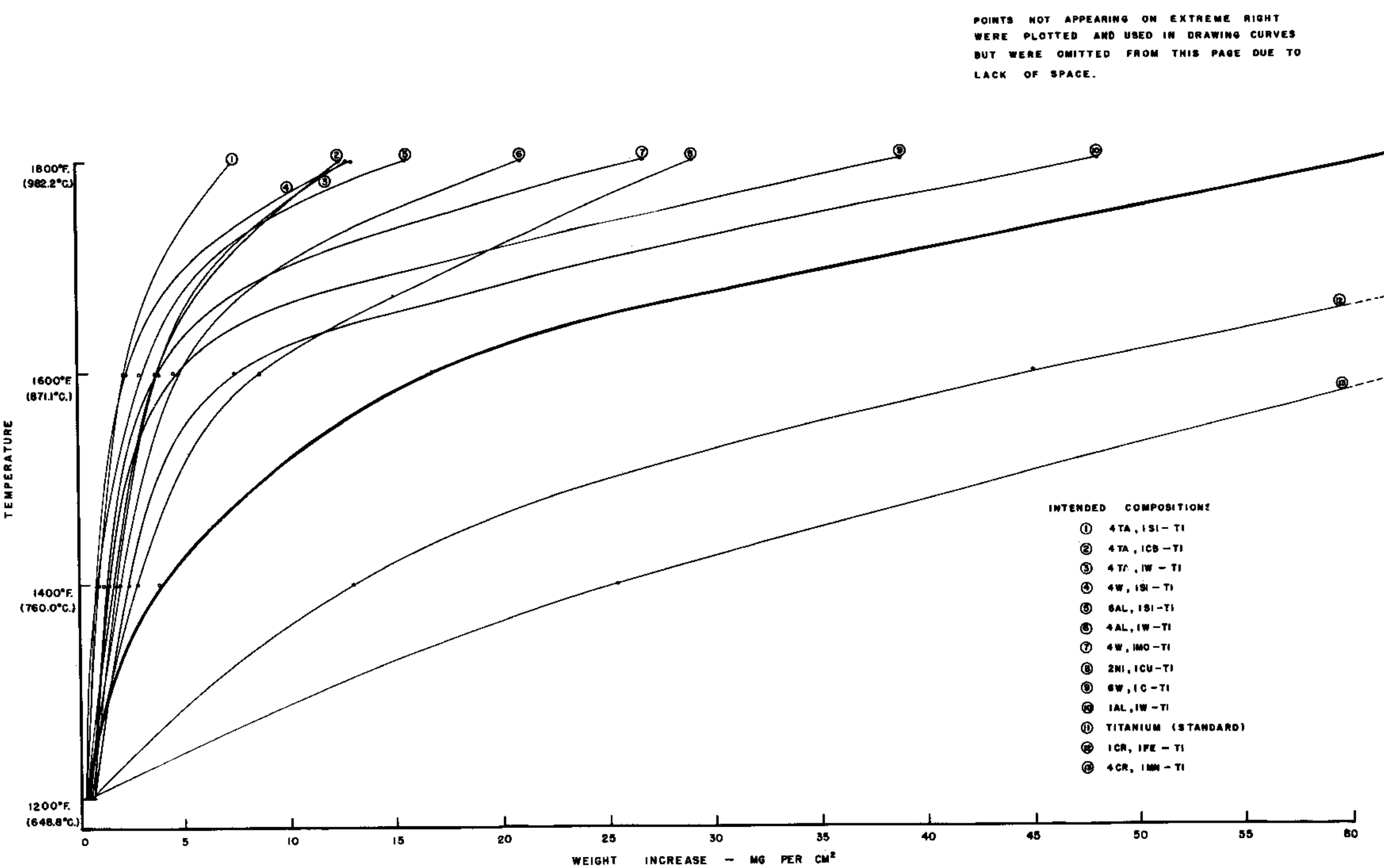


FIG. 15 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE (TIME CONSTANT – 48 HOURS)

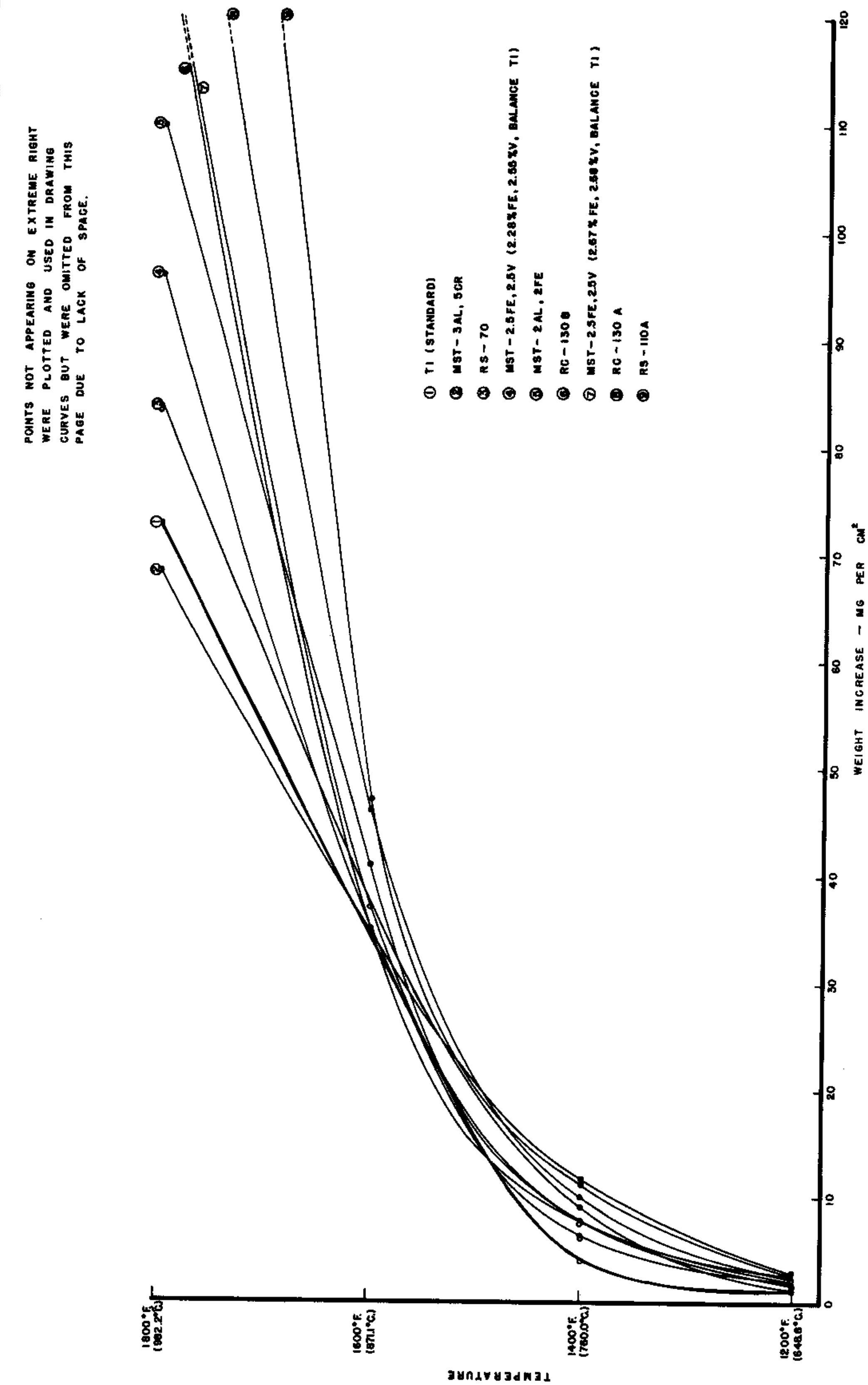


FIG. 16 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE (TIME CONSTANT — 48 HOURS)

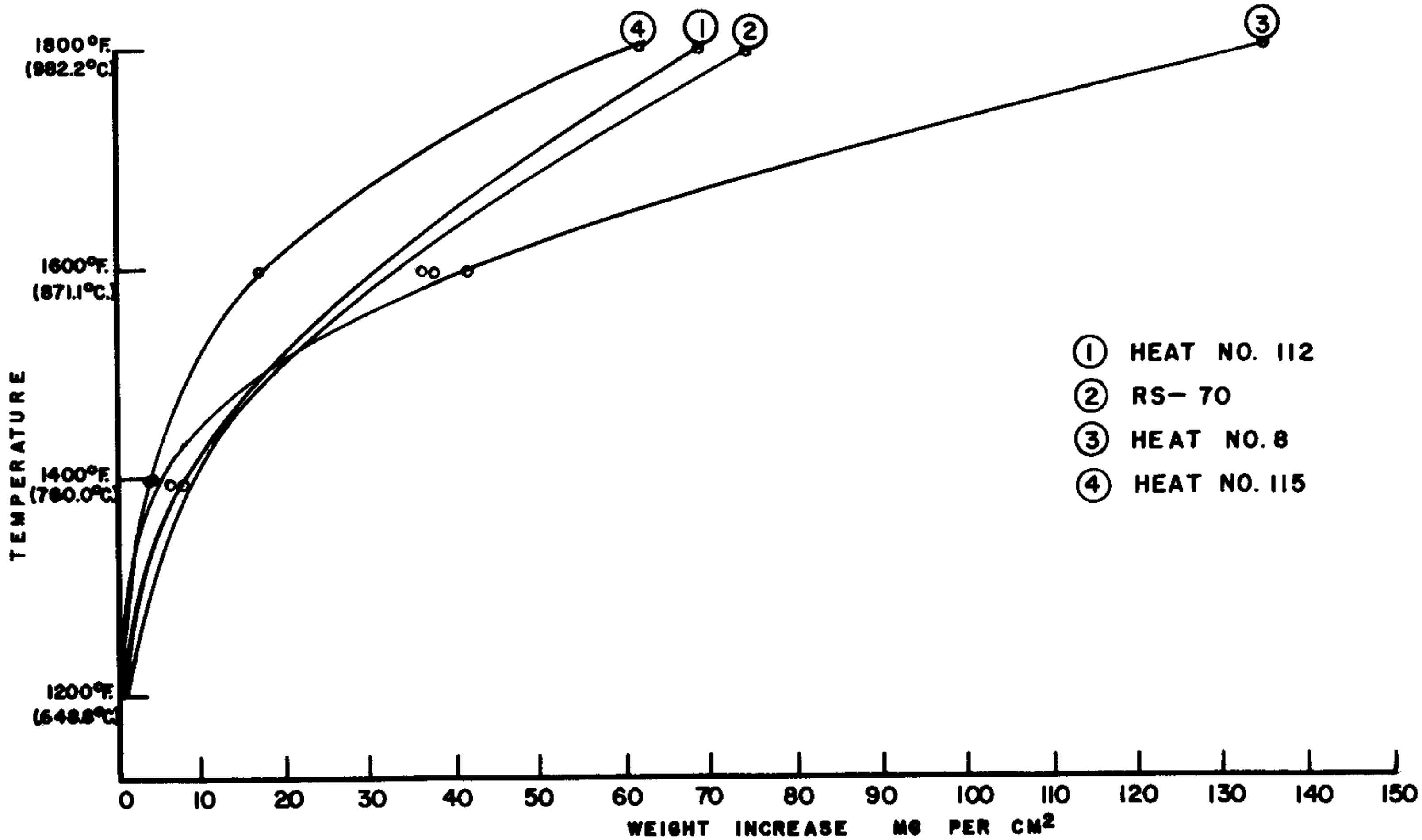


FIG.17 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TEMPERATURE (TIME CONSTANT — 48 HOURS)

C. Inches Penetration of Scale

Originally, it had been planned to determine weight-loss of metal due to scaling; however, the inability to develop a suitable descaling method prevented accomplishment of this work. In lieu of obtaining weight-decrease data, a different criterion of scaling propensity has been employed, namely, inches penetration of the base metal by the oxide scale. This method gives approximately the same relative information as the weight-loss determinations.

Procedure: After the specimens were scaled and weight-increase determinations observed, the specimens were mounted, twelve at a time, between two parallel plates. One-sixteenth of an inch of metal was removed from the bottom of the specimens by a belt grinder. This was followed by abrading with No. 1, 1/0, 2/0, and 3/0, polishing papers. This procedure produced sharp edges with no edge disintegration and was very satisfactory for specimens scaled at 1200°F. and 1400°F. After exposure to 1600°F. the specimens were very brittle and the base metal was nearly depleted. Accordingly, it became difficult to polish to a sharp edge as the specimens broke at the ends and edges very readily. For this reason the specimens were broken on a line one-third the distance from the bottom edge. This procedure produced sharp, well-delineated edges.

The original and final thicknesses were determined through the use of polarized light, a magnification of 150X, and a metallograph with a microscope stage having a micrometer screw accurate to 0.00004". The average of three readings was taken as the thickness of individual specimens.

As the time of scaling varied between the different scaling tests, it was decided to divide the total inches penetration (calculated by subtracting final specimen thickness from original specimen thickness) by the total time (in hours) of exposure to the scaling temperature. Accordingly, the data presented are in terms of inches penetration per hour.

Attempts to correlate inches penetration data with total weight-increase data indicated the existence of certain discrepancies, particularly in the case of the binary alloys. Better results were obtained with the commercial alloys, and still better results were obtained with the ternary alloys. In the case of the binary alloys, the errors of measurement were of the same order as the metal loss at the lower temperatures, and it is believed that the more sensitive determinations made on the latter groups of alloys alleviated this effect to an appreciable extent.

At the higher temperatures several specimens were completely converted to scale, resulting in erroneous indications of total weight gain and no significant values for inches penetrations. By disregarding these specimens the correlation was improved.

Inches penetration data for the binary, ternary, and commercial alloys are given in Tables 11-16.

Table 11.

Inches Penetration per Hour at 1200o F. for Binary Alloys.

Specimen	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at 1200° F.	Average Inches Penetration per Hour X 10^{-6}
1.19% Mo	0.0500 0.0493	0.0490 0.0492	0.0010 0.0001	0.0006	337	1
2.95% W	0.0513 0.0520	0.0506 0.0507	0.0007 0.0013	0.0010	337	2
1.03% Si	0.0530 0.0530	0.0524 0.0516	0.0006 0.0014	0.0010	337	2
3.69% Si	0.0530 0.0533	0.0514 0.0522	0.0016 0.0011	0.0014	337	4
3.28% Al	0.0480 0.0483	0.0465 0.0465	0.0015 0.0018	0.0017	332	5
0.91% Ni	0.0440 0.0430	0.0421 0.0411	0.0019 0.0019	0.0019	332	5
3.88% V	0.0500 0.0513	0.0485 0.0488	0.0015 0.0025	0.0020	337	5
4.13% Ni	0.0503 0.0503	0.0494 0.0472	0.0009 0.0031	0.0020	290	6
0.54% Ta	0.0490 0.0490	0.0454 0.0479	0.0036 0.0011	0.0024	337	7
1.13% W	0.0536 0.0536	0.0517 0.0511	0.0019 0.0025	0.0022	290	7
Ti	0.0470 0.0470	0.0447 0.0440	0.0023 0.0030	0.0027	337	8
3.34% Cu	0.0500 0.0500	0.0472 0.0474	0.0028 0.0026	0.0027	290	9
4.37% Ta	0.0500 0.0500	0.0460 0.0468	0.0040 0.0032	0.0036	337	10
4.45% Cb	0.0460 0.0460	0.0427 0.0421	0.0033 0.0039	0.0036	337	10
1.21% Al	0.0506 0.0506	0.0466 0.0478	0.0040 0.0028	0.0034	290	11
0.84% V	0.0483 0.0483	0.0445 0.0449	0.0038 0.0034	0.0036	290	12
1.00% Cb*	0.0467	0.0424	0.0043		337	12
4.11% Mn	0.0483 0.0483	0.0445 0.0441	0.0038 0.0042	0.0040	290	13
4.03% Cr	0.0437 0.0433	0.0382 0.0390	0.0043 0.0055	0.0049	332	14
1.27% Mn	0.0410 0.0410	0.0368 0.0367	0.0042 0.0043	0.0043	290	14
0.93% Fe**	0.0450	0.0403	0.0047		290	16
3.76% Fe	0.0480 0.0480	0.0432 0.0395	0.0048 0.0085	0.0067	290	23

* One specimen lost in furnace.
** Specimen not suitable for use.

Table 12.

Inches Penetration per Hour at 1600° F. for Binary Alloys

Specimens	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at 1600° F.	Average Inches Penetration per Hour X 10^{-6}.
4.37% Ta	0.0540 0.0542	0.0518 0.0520	0.0022 0.0022	0.0022	169	13
4.45% Cb*	0.0437	0.0390	0.0047		169	27
0.54% Ta	0.0498 0.0489	0.0450 0.0435	0.0048 0.0054	0.0051	169	30
Ti*	0.0423	0.0362	0.0061		169	36
3.34% Cu	0.0471 0.0504	0.0398 0.0434	0.0073 0.0070	0.0072	169	42
1.00% Cb*	0.0470	0.0394	0.0076		169	45
1.03% Si	0.0539 0.0541	0.0460 0.0469	0.0079 0.0072	0.0076	169	45
2.95% W	0.0530 0.0540	0.0467 0.0484	0.0073 0.0056	0.0065	140	46
3.88% V	0.0494 0.0494	0.0373 0.0403	0.0121 0.0091	0.0106	169	62
1.27% Mn	0.0398 0.0399	0.0292 0.0308	0.0106 0.0091	0.0098	140	70
1.19% Mo	0.0490 0.0491	0.0349 0.0372	0.0141 0.0119	0.0130	169	76
3.28% Al	0.0500 0.0502	0.0368 0.0376	0.0132 0.0126	0.0129	140	92
1.13% W	0.0433 0.0549	0.0304 0.0409	0.0129 0.0140	0.0135	140	96
3.69% Si	0.0550 0.0533	0.0378 0.0377	0.0172 0.0156	0.0164	169	97
0.93% Fe	0.0460 0.0462	0.0342 0.0309	0.0118 0.0153	0.0136	140	97
4.13% Ni	0.0442 0.0385	0.0294 0.0253	0.0148 0.0132	0.0140	140	100
1.21% Al	0.0503 0.0396	0.0334 0.0239	0.0169 0.0157	0.0163	140	116
4.13% Ni	0.0497 0.0503	0.0335 0.0318	0.0162 0.0185	0.0174	140	124
4.11% Mn	0.0393 0.0398	0.0211 0.0216	0.0182 0.0182	0.0182	140	130
0.84% V	0.0478 0.0456	0.0184 0.0182	0.0294 0.0274	0.0284	169	168
1.05% Cr	0.0425 0.0428	0.0163 0.0179	0.0262 0.0249	0.0256	140	183
3.96% Mo	0.0524 0.0524	0.0219 0.0174	0.0305 0.0350	0.0328	169	194
3.76% Fe	0.0481 0.0470	0.0186 0.0163	0.0295 0.0307	0.0301	140	215
4.03% Cr	0.0462 0.0386	0.0140 0.0065	0.0322 0.0321	0.0322	140	230

* Duplicate specimen lost in furnace.

Table 13.

INCHES PENETRATION PER HOUR AT 1400° F. (760.0° C.)
TERNARY ALLOYS

Alloy Specimen	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at 1400°	Average Inches Penetration Per Hour
4 Ta - 1 Si	0.0501	0.0499	0.0001			
	0.0459	0.0456	0.0002	0.0001	146	0.1×10^{-6}
4 W - 1 Si	0.0535	0.0532	0.0001			
	0.0539	0.0534	0.0002	0.0002	146	0.1×10^{-6}
6 W - 1 C	0.0509	0.0503	0.0003			
	0.0504	0.0498	0.0003	0.0003	146	0.2×10^{-6}
6 Al - 1 Si	0.0541	0.0532	0.0004			
	0.0548	0.0539	0.0004	0.0004	146	0.3×10^{-6}
4 W - 1 Mo	0.0537	0.0520	0.0009			
	0.0525	0.0523	0.0001	0.0005	146	0.3×10^{-6}
4 Ta - 1 W	0.0486	0.047[illegible]	0.0004			
	0.0550	0.0531	0.0009	0.0007	146	0.5×10^{-6}
2 Ni - 1 Cu	0.0508	0.0501	0.0003			
	0.0503	0.0466	0.0019	0.0008	146	0.5×10^{-6}
4 Ta - 1 Cb	0.0419	0.0400	0.0009			
	0.0415	0.0397	0.0009	0.0009	146	0.6×10^{-6}
1 Al - 1 W	0.0479	0.0462	0.0009			
	0.0518	0.0500	0.0009	0.0009	146	0.6×10^{-6}
4 Al - 1 W	0.0314	0.0295	0.0009			
	0.0295	0.0269	0.0013	0.0011	146	0.8×10^{-6}
Ti	0.0500	0.0478	0.0011	0.0011	146	0.8×10^{-6}
1 Cr - 1 Fe	0.0546	0.0499	0.0023			
	0.0561	0.0520	0.0020	0.0021	146	1.4×10^{-6}
4 Cr - 1 Mn	0.0482	0.0384	0.0049			
	0.0474	0.0374	0.0048	0.0048	146	3.3×10^{-6}

Note: Compositions are intended; see Table 32 for actual compositions.

Table 14

INCHES PENETRATION PER HOUR AT 1600° F.* (871.1° C.)
TERNARY ALLOYS

Alloy Specimen	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at 1600° F.	Average Inches Penetration Per Hour
4 W - 1 Si	0.0535 0.0531	0.0525 0.0516	0.0005 0.0007	0.0006	145	0.4×10^{-6}
4 Ta - 1 Cb	0.0411 0.0404	0.0376 0.0360	0.0017 0.0022	0.0019	145	1.3×10^{-6}
4 Ta - 1 W	0.0552 0.0550	0.0527 0.0523	0.0012 0.0013	0.0012	145	0.8×10^{-6}
6 Al - 1 Si	0.0545 0.0518	0.0512 0.0497	0.0016 0.0010	0.0013	145	0.9×10^{-6}
4 W - 1 Mo	0.0518 0.0522	0.0479 0.0481	0.0019 0.0020	0.0019	145	1.3×10^{-6}
4 Ta - 1 Si	0.0504 0.0512	0.0456 0.0463	0.0024 0.0024	0.0024	145	1.7×10^{-6}
6 W - 1 C	0.0491 0.0487	0.0414 0.0386	0.0038 0.0050	0.0044	145	3.0×10^{-6}
4 Al - 1 W	0.0317 0.0338	0.0196 0.0221	0.0060 0.0058	0.0059	145	4.1×10^{-6}
2 Ni - 1 Cu	0.0506 0.0493	0.0387 0.0353	0.0059 0.0070	0.0064	145	4.4×10^{-6}
1 Al - 1 W	0.0477 0.0518	0.0336 0.0395	0.0070 0.0061	0.0065	145	4.5×10^{-6}
Ti	0.0455	0.0316	0.0069	0.0069	145	4.8×10^{-6}
1 Cr - 1 Fe	0.0561 0.0563	0.0310 0.0290	0.0125 0.0136	0.0130	145	9.0×10^{-6}
4 Cr - 1 Mn				Completely Oxidized		

* Intended compositions; see Table 32 for actual compositions.

Table 15

INCHES PENETRATION PER HOUR AT 1400° F. (760.0° C.)
COMMERCIAL ALLOYS

Alloy Specimen	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at at 1400	Average Inches Penetration Per Hour
Ti	0.0387 0.0407	0.0379 0 0393	0.0004 0.0007	0.00065	185	0.4×10^{-6}
RC-130A	0.0389 0.0383	0.0368 0.0360	0.0011 0.0013	0.0012	185	0.6×10^{-6}
MST-2.5% Fe, 2.5% V[a]	0.0255 0.0243	0.0193 0.0199	0.0031 0.0022	0.0027	185	1.5×10^{-6}
MST-2.5% Fe, 2.5% V[b]	0.0420 0.0440	0.0365 0.0376	0.0028 0.0032	0.0030	185	1.6×10^{-6}
MST-2% Al, 2% Fe	0.0211 0.0211	0.0144 0.0154	0.0033 0.0029	0.0031	185	1.7×10^{-6}
RS-70	0.0336 0.0324	0.0264 0.0268	0.0036 0.0028	0.0032	185	1.7×10^{-6}
RS-110A	0.0461 0.0492	0.0390 0.0425	0.0035 0.0033	0.0034	185	1.8×10^{-6}
MST-3% Al, 5% Cr	0.0567 0.0568	0.0483 0.0497	0.0041 0.0035	0.0038	185	2.1×10^{-6}
RC-130B	0.0402 0.0432	0.0335 0.0330	0.9033 0.0051	0.0042	185	2.3×10^{-6}

a. 2.28% Fe, 2.55% V, balance Ti
b. 2.67% Fe, 2.68% V, balance Ti

Table 16

INCHES PENETRATION PER HOUR AT 1600° F. (871.1° C.)
COMMERCIAL ALLOYS

Alloy Specimen	Original Thickness	Final Thickness	Inches Penetration	Average Inches Penetration	Hours at 1600°	Average Inches Penetration Per Hour
MST-3% Al, 5% Cr	0.0564	0.0331	0.0116			
		. . . .	. . . .	0.0116	162	6.7×10^{-6}
RC-130A	0.0387	0.0162	0.0112			
	0.0398	0.0123	0.0137	0.0124	162	7.2×10^{-6}
Ti	0.0559	0.0285	0.0137			
	0.0571	0.0308	0.0131	0.0135	162	7.8×10^{-6}
RC-130B		. . . .	. . . .			
	0.0432	0.0149	0.0141	0.0141	162	8.2×10^{-6}
RS-110A	0.0474	0.0169	0.0152			
	0.0480	0.0182	0.0149	0.0151	162	8.8×10^{-6}
RS-70				Completely oxidized		
MST-2% Al, 2% Fe				Completely oxidized		
MST-2.5% Fe, 2.5% V[a]				Completely oxidized		
MST-2.5% Fe, 2.5% V[b]				Completely oxidized		

a. 2.28% Fe, 2.55% V, balance Ti
b. 2.67% Fe, 2.68% V, balance Ti

D. Investigation of Scale Characteristics

Investigations of scale characteristics were first confined essentially to the identification of scales formed on the 4% Al-Ti alloy, chosen on the basis of its relatively good resistance to scaling.

This study was primarily concerned with x-ray diffraction techniques, and microscopic and chemical investigations. The 4% Al-Ti alloy was scaled at temperatures of 1200°, 1400°, 1600°, 1800°, and 2000°F. for very short (30 minutes to 2 hours) and relatively long (up to 300 hours) periods of time. The scales thus produced were observed, microscopically, under a low power (30X) stereomicroscope, and microscopically at magnifications up to 1000X. Representative samples were separated mechanically and prepared for x-ray powder diffraction study. Patterns thus obtained were then compared with standard patterns of the various oxides and the alpha solid solution of oxygen in titanium. These comparisons provided positive identification of the phases and structures of the scale.

Since neither aluminum nor its oxide appeared as a separate phase, it was necessary to effect a qualitative chemical analysis of the various strata in order to define the position of each stratum and its effect upon the scale. A semimicro process was developed and the analysis carried out with multiple samples, employing positive and negative controls.

These investigations revealed that the scales appearing on this alloy were composed of several strata which varied in number and nature with temperature and time of exposure. Comparison of the scale on the alloy with that on a specimen of pure titanium disclosed no radical differences, other than those of a dimensional nature.

From the data accumulated (Table 17), it is apparent that aluminum additions to titanium do not decrease scaling rates through the formation of a pure aluminum oxide stratum in the scale. Rather, the aluminum appears as a double oxide or solution of aluminum oxide in titanium dioxide, and is essentially confined to the metallic and gray powder strata. This phenomenon is explainable, perhaps, on the basis of relative oxidation tendencies of the two metals.

Aluminum, as well as certain other metals, forms a refractory oxide through which diffusion is difficult, whether it appears as a distinct stratum, or as a double oxide in solution. It would appear that this may explain the mechanism whereby aluminum increases scale resistance when added to certain other metals as an alloying element. This explanation is somewhat borne out by these experiments and further proven by those conducted on other alloys, notably iron-aluminum[5].

The investigation of scale characteristics has been extended to include studies of the scales formed on the 4.03% Cr and 2.95% W alloys. Unfortunately, specimens scaled at all temperatures in the range 1200° to 1800°F. were not available in either case, many having been rendered useless in previous attempts to effect descaling. Furthermore, specimens were not available for short-time scaling tests, which are almost essential to the determination of scaling mechanisms.

Considering first the scale formed on the 4.03% Cr alloy at 1600°F. (Table 18), the sequence of strata did not coincide with that of pure titanium. The gray inner strata usually found were conspicuously absent, and the appearance of a vitreous stratum adjacent to the metal was inconsistent with other scales observed.

The scale was adherent yet soft and brittle with no apparent macro- or micro-porosity. Spalling was not evident. X-ray diffraction studies revealed no crystal structure other than that of rutile in individual strata or composite specimens. Chemical analysis of the individual strata indicated the presence of Cr in all except the outermost. The yellow coloration of the inner strata, as opposed to gray in other alloy scales, may well be explained by the effect of Cr pigments upon TiO_2, familiar to the paint industry.[6]

Scales formed on 2.95% W alloys at 1200°F. and at 1800°F. were studied (Table 19). These scales were stronger and definitely harder than any of the other studied to date. There were no powdery layers in these scales such as appeared in other cases; all strata encountered were quite adherent.

X-ray diffraction studies indicated again that only the rutile crystal structure was obtained. No macro- or micro-porosity was observed. Sensitive qualitative analysis for tungsten in the scales gave very weak positive results in every case. It was postulated that tungsten would produce a beneficial effect on the scaling resistance of titanium as a result of the reduction of the partial pressure of oxygen by tungsten oxide.[7]

Due to the necessity of obtaining scaling data relevant to the commercial and ternary alloys, a more detailed investigation, such as that carried out for the 4.02% Al-Ti alloy, was not permitted.

Table 17.

TA Scale Investigation 4% Al-Ti, Tabulated Data.

Temp. (Deg. F.)	Time (Hours)	No. of Strata	Sequence* and Color	Form, Thickness	Diffraction Pattern	Aluminum Analysis	Remarks
1200	2	1	Lt. bronze	Metallic, about 0.0001 cm	Alpha	Not done	
1200	300	2	Lt. blue Gray	0.0008 cm 0.0003 cm	Rutile**	Positive**	Very hard, adherent.
1400	2	2	Green Gray	0.0006 cm 0.0004 cm	Rutile**	Positive**	Very hard scale, adherent.
1400	72	2	Gray-green	Small crystals 0.0010 cm	Rutile	Positive*	Adherent scale
			Gray	Two-phase 0.0028 cm	Rutile & Alpha		
1600	2	3	Yellow Lt. gray Dk. Gray		Rutile** Rutile**	Not done	Micro exam. not done; scale too friable; spalls readily.
1600	120	5	Brown	Granular 0.0043 cm	Rutile**	Negative	Scale adherent but cracks and spalls under external pressure.
			White	Friable 0.0007 cm		Negative	
			Gray	Two-phase 0.0049 cm		Positive	
			Silver-gray	Two-phase 0.0049 cm	Rutile**	Positive	
			Lt. gray	One-phase 0.0011 cm		Positive	
1800	1-1/2	5	Brown	Fine grain 0.0690 cm	Rutile	Negative	Scale spalled upon air cooling.
			White	Powder 0.0663 cm	Rutile	Negative	
			Silver-gray	Two-phase 0.0047 cm	Rutile	Positive	
			Gray	Powder, two-phase 0.0111 cm	Rutile	Positive	
			White	Powder, fine 0.0005 cm	Rutile	Negative	

* Sequence of strata is from outside toward metal.
** Composite scale specimens.

Note: Scales appearing on specimens exposed at 2000° F were the same as those at 1800° F. except for dimensional variations.

Table 18

TABULATED DATA OF Ti - 4.03% Cr SCALE INVESTIGATIONS

Temp. Deg. F.	Time (Hours)	No. of Strata	Sequence* and Color	Form —	Thickness	Diffraction Pattern	Chromium Analysis	Remarks
1600	139.9	5	Amber	Granular	0.0605 cm	Rutile	Negative	Very thick scale comparatively soft, brittle, adherent. No spalling or cracking.
			Amber	Powder	0.0090 cm	Rutile	Positive**	
			Amber	Glassy	0.0143 cm	Rutile		
			Yellow-Green	Powder	0.0138 cm	Rutile	Positive	
			Dk. Amber	Glassy	0.0147 cm	Rutile	Positive	

* Sequence of Strata is from outside toward metal.

** Composite Scale Specimens

Table 19

TABULATED DATA OF Ti - 2.95% W SCALE INVESTIGATIONS

Temp. Deg. F.	Time (Hours)	No. of Strata	Sequence* and Color	Form — Thickness	Diffraction Pattern	Tungsten Analysis	Remarks
1800	48.2	3	Red-Brown	Large fused grains; 0.0518 cm	Rutile	Weak Positive	Very hard, strong, adherent scale. No spalling or cracking.
			Dark Gray	0.0498 cm	Rutile	Weak Positive**	
			Light Gray	0.0208 cm	Rutile		
1200	336.9	2	Tan	Fine grain 0.0011 cm	Rutile**	Weak Positive	Thin, adherent scale.
			Gray	Granular 0.0007 cm			

* Sequence of Strata is from outside toward metal.
** Composite Scale Specimens

VI. SUMMARY AND CONCLUSIONS

Evaluations of relative scaling tendencies of titanium and titanium-base alloys (produced commercially and experimentally) were made on the basis of weight increase caused by exposure of these materials to the temperatures of 1200°, 1400°, 1600°, and 1800°F. It was observed that the effect of additions of the alloying elements Cu, Al, Si, V, Cb, Ta, Cr, Mo, W, Mn, Fe, and Ni, in various combinations, to commercially pure arc-melted titanium sponge was to increase, decrease, or essentially produce no effect upon the scaling resistance of this material (titanium).

1. In certain instances, the effect of specific alloying elements, in concentrations of not less than approximately 0.5% to not more than 8% was to produce radical changes in the scaling resistance of titanium.

2. Binary and ternary titanium alloys, produced experimentally, generally became increasingly superior to titanium on being exposed to progressively higher temperatures within the range 1200° to 1800°F.

3. Titanium alloys, produced commercially, became increasingly inferior to titanium on being exposed to progressively higher temperatures within the range 1200°F. to 1800°F.

4. The scaling resistance of different heats of titanium, produced experimentally, generally was erratic.

5. Alloys of approximate composition (see Table 31 for actual composition of ternary alloys) 4% Ta, 1% Si-Ti; 4% W, 1% Si - Ti; and 6% Al, 1% Si - Ti possessed maximum resistance to scaling, relative to titanium, when exposed to temperatures within the range 1200° to 1800°F.

6. Alloys of approximate composition 4% Ta, 1% Si - Ti; 4% W, 1% Si - Ti; 6% Al, 1% Si - Ti; and 4% W, 1% Mo - Ti were more resistant to scaling than Type 302 stainless steel at the temperature of 1600°F.

7. Alloys of approximate composition 4% Ta, 1% Si - Ti; 4% W, 1% Si - Ti; 4% Ta, 1% Cb - Ti; 4% Ta, 1% W - Ti, and alloys of composition 1.03% Si - Ti; 2.95% W - Ti; 4.45% Cb - Ti, and 4.37% Ta - Ti were more resistant to scaling than Type 302 stainless steel at the temperature of 1800°F.

8. Alloys of approximate composition 4% Cr, 1% Mn - Ti; 1% Cr, 1% Fe - Ti and alloys of composition 1.05% Cr - Ti; and 4.03% Cr -Ti possessed minimum resistance to scaling relative to titanium, when exposed to temperatures within the range of 1200° to 1800°F. The effect of chromium in concentrations of approximately 1 and 4%, alone and in combination with other elements, was to markedly accelerate scaling.

9. The effect of increasing the aluminum concentration of binary alloys from 1% to 4% resulted in a rather substantial increase in scaling resistance. Increasing the aluminum concentration from 4% to 8% (intended composition) produced only a slight change in scaling resistance. On this basis it would appear that the excellent scaling resistance, relatively, of the alloy of approximate composition 6% Al, 1% Si - Ti, might be attributed predominantly to the effect of silicon alone, or to combination of aluminum and silicon in these proportions.

10. A transition in the scaling rate of titanium was observed between 1 hour and 1.5 hours, and between 4 and 23.4 hours at the temperature of 1200°F. An indicated transition in the scaling rate of titanium was observed between 7.3 and 28.2 hours at the temperature of 1800°F. (In the latter instance, data were not obtained for the time period prior to 7.3 hours or the time period ot 7.3 to 28.2 hours.)

11. The inability to effect a removal of scale from underlying metal, without at the same time removing excessive amounts of metal, prohibited the determination of weight decrease of metal caused by exposure of titanium and titanium alloys to temperatures within the range 1200° to 1800°F.

12. Inches penetration (loss of metal) resulting from exposure to the above temperatures was determined for titanium and titanium alloys, produced commercially and experimentally. This method permitted a determination of metal loss without necessitating the application of descaling procedures. Even though penetration data were expressed in terms of inches of metal lost, it would appear that the expression of these data in terms of weight decrease (calculated from the density and optically observed dimensions of the unscaled portion of the metal) would be justified. Whereas weight decrease determined by calculations would reflect the inability to measure accurately the distance of the irregular scale-metal interface from the surface of the scaled specimen, weight decrease determined by observing the descaled weight would reflect the weight of gases in solution in the metal.

13. The correlation (not included) of inches penetration data and weight-decrease data generally was unsatisfactory, that is, the order of resistance to scaling usually was not the same for the two methods. The ternary alloys, as a group, proved relatively more amenable to correlation.

14. The inability to obtain generally satisfactory correlations of inches penetration data and weight-increase data was attributed to the fact the former did not reflect the weight of gases in combined form (such as O_2 in TiO_2) plus those in uncombined form (such as O_2 in solution in and/or absorbed by the scale). Even though it is rather doubtful that these gases were reflected in inches penetration data, or if so, to the same extent as in weight-increase data.

15. On the basis of limited data, it would appear that the mechanism of scaling of the 4.02% Al - Ti alloy involves:

(a) The depletion of aluminum in the region of the scale-metal interface.

(b) Predominant diffusion of metal ions to the oxide-air interface, rather than non-metal ions, toward the oxide-metal interface.

(c) The existence of oxide or oxides of rutile structure, only, in the temperature range 1200° to 2000°F.

16. The structure of the scale formed on the 4.03% Cr - Ti Alloy in the temperature range of 1200° to 1800°F. was that of rutile. The presence of chromium was not observed in the outermost layer of the scale. After exposure to temperatures of 1600° and 1800°F., the external scale formed on the chromium bearing alloys employed, appeared to have undergone incipient melting. The increase in dimensions of scaled specimens was marked.

17. The structure of the scale formed on the 2.95% W - Ti alloy in the temperature range of 1200° to 1800°F. was that of rutile. Scales formed on this and other alloys containing approximately 4% W were characterized by their adherence and hardness.

18. An indication of the strength and/or the coefficient of linear thermal expansion of oxide scales was obtained by quenching scaled specimens from elevated temperatures in ice water. The only alloy (not heavily scaled) from which scale did not spall on being quenched from 1600°F. in ice water was of approximate composition 4% Ta, 1% Si - Ti. The scales from certain other alloys (not heavily scaled) did not spall when air cooled from temperatures as high as 1800°F. In general, the scale of alloys having relatively high resistance to scaling tended to resist spalling when air cooled from temperatures within the range 1200° to 1800°F.

19. Alloys containing aluminum and/or silicon were particularly unamenable to hot forging. Temperatures of 2200° to 2300°F. were required from this operation.

20. Although the strength of alloys was not determined either before or after scaling tests were conducted, it was apparent that this property was generally severely reduced due to the formation of subscales.

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APPENDIX

TABLE 20

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1200°F. (648.8°C.)

NON-CUMULATIVE WEIGHT[1] INCREASE (Mg.) OF SPECIMENS[2]

Non-Cumulative Time (Hours)	Ti A	Ti B	1.27% Mn A	1.27% Mn B	1.21% Al A	1.21% Al B	% W[3] A	% W[3] B	1.05% Cr A	1.05% Cr B	4.11% Mn A	4.11% Mn B	% Fe[4] A	% Fe[4] B	% Fe[5] A	% Fe[5] B	4.13% Ni A	4.13% Ni B	0.84% V A	0.84% V B	3.34% Cu A	3.34% Cu B
64.6	31	31	30.8	29.6	23.2	23.9	25.6	25.4	81.4	61.3	40.7	38.9	31.1	28.9	47.5	46.3	36.5	32.7	30.2	29.0	30.2	29.4
52.6	13.4	15.8	12.6	10.9	9.6	8.0	7.8	9.5	40.7	33.7	19.3	15.6	10.5	11.9	20.4	19.5	10.1	11.0	12.3	10.2	10.9	10.4
24.4	6.8	4.2	4.3	4.9	3.3	4.5	4.4	2.3	19.0	16.3	7.9	7.7	5.1	3.7	6.7	7.1	4.9	2.9	4.6	4.8	4.6	3.6
47.7	10.7	9.8	9.9	9.4	8.9	7.8	6.4	7.0	35.8	28.6	13.9	11.3	8.6	7.7	13.3	13.3	7.8	5.5	10.2	9.0	7.4	7.6
29.1	5.6	6.2	4.0	2.4	3.8	4.0	1.7	2.0	17.6	15.6	6.4	7.6	4.6	2.5	5.9	7.2	3.8	3.8	5.4	3.9	3.7	4.0
24.1	2.3	3.2	2.7	5.0	0.6	0.0	3.6	1.6	14.0	13.7	6.7	4.9	2.9	4.7	5.2	5.4	3.7	3.0	4.2	4.0	2.2	1.8
47.3	9.3	6.0	8.0	7.4	7.6	9.1	4.8	5.7	31.8	26.7	12.6	10.9	9.3	7.4	12.4	10.4	6.2	6.8	7.7	6.9	6.0	6.1
Total Time (Hours) — TOTAL NON-CUMULATIVE WEIGHT[1] INCREASE (Mg.) OF SPECIMENS[2]																						
289.8	79.1	76.2	72.3	69.6	57.0	57.3	54.3	53.5	240.3	195.9	107.5	96.9	72.1	66.8	111.4	109.2	73.0	65.7	74.6	67.8	65.0	62.9

PERCENT DIFFERENCE OF NON-CUMULATIVE WEIGHT[1] INCREASE OF SPECIMENS[2]

	Ti	1.27% Mn	1.21% Al	% W[3]	1.05% Cr	4.11% Mn	% Fe[4]	% Fe[5]	4.13% Ni	0.84% V	3.34% Cu
	3.66%	3.73%	0.52%	1.47%	18.4%	9.86%	7.35%	1.97%	10.0%	9.11%	3.23%
Non-Cumulative Time (Hours) — AVERAGE NON-CUMULATIVE WEIGHT[1] INCREASE (Mg.) OF SPECIMENS[2]											
64.6	31.0	30.2	23.6	25.5	71.4	39.8	30.0	46.9	34.6	29.6	29.8
52.6	14.6	11.8	8.5	8.7	37.2	17.5	11.2	20.0	10.6	11.3	10.7
24.4	5.5	4.6	3.9	3.4	17.7	7.8	4.4	6.9	3.9	4.7	4.1
47.7	10.3	9.7	8.4	6.7	32.2	12.6	8.2	13.3	6.7	9.6	7.5
29.1	5.9	3.2	3.9	1.9	16.6	7.0	3.6	6.6	3.8	4.7	3.9
24.1	2.8	3.9	0.3	2.6	13.9	5.8	3.8	5.3	3.4	4.1	2.0
47.3	7.7	7.7	8.4	5.3	29.3	11.8	8.4	11.4	6.5	7.3	6.1
Cumulative Time (Hours) — AVERAGE CUMULATIVE WEIGHT[1] INCREASE (Mg.) OF SPECIMENS[2]											
64.6	31.0	30.2	23.6	25.5	71.4	39.8	30.0	46.9	34.6	29.6	29.8
117.2	45.6	42.0	32.1	34.2	108.6	57.3	41.2	66.9	45.2	40.9	40.5
141.6	51.1	46.6	36.0	37.6	126.3	65.1	45.6	73.8	49.1	45.6	44.6
189.3	61.4	56.3	44.4	44.3	158.5	77.7	53.8	87.1	55.8	55.2	52.1
218.4	67.3	59.5	48.3	46.2	175.1	84.7	57.4	93.7	59.6	59.9	56.0
242.5	70.1	63.4	48.6	48.8	189.0	90.5	61.2	99.0	63.0	64.0	58.0
289.8	77.8	71.1	57.0	54.1	218.3	102.3	69.6	110.4	69.5	71.3	64.1
Tot. Time (Hours) — TOTAL WEIGHT[1] INCREASE (Mg.) OF SPECIMENS[2]											
289.8	77.8	71.1	57.0	54.1	218.3	102.3	69.6	110.4	69.5	71.3	64.1
AVERAGE SURFACE AREA (Cm^2) OF SPECIMENS[2]											
	27.59	27.45	27.77	27.86	27.35	27.57	27.57	27.66	27.74	27.61	27.74
Cumulative Time (Hours) — AVERAGE CUMULATIVE WEIGHT[1] INCREASE (Mg.) PER AVERAGE ORIGINAL UNIT AREA ($Cm.^2$)											
64.6	1.1	1.1	0.8	0.9	2.6	1.4	1.1	1.7	1.2	1.1	1.1
117.2	1.7	1.5	1.2	1.2	4.0	2.1	1.5	2.4	1.6	1.5	1.5
141.6	1.9	1.7	1.3	1.3	4.6	2.4	1.7	2.7	1.8	1.7	1.6
189.3	2.2	2.1	1.6	1.6	5.8	2.8	2.0	3.1	2.0	2.0	1.9
218.4	2.4	2.2	1.7	1.7	6.4	3.1	2.1	3.4	2.1	2.2	2.0
242.5	2.5	2.3	1.8	1.8	6.9	3.3	2.2	3.6	2.3	2.3	2.1
289.8	2.8	2.6	2.1	1.9	8.0	3.7	2.5	4.0	2.5	2.6	2.3
Total Time (Hours) — AVERAGE TOTAL WEIGHT[1] INCREASE (Mg.) PER AVERAGE ORIGINAL UNIT AREA ($Cm.^2$)											
289.8	2.8	2.6	2.1	1.9	8.0	3.7	2.5	4.0	2.5	2.6	2.3
AVERAGE TOTAL WEIGHT[1] INCREASE (Mg.) PER AVERAGE ORIGINAL UNIT AREA (Cm^2) RELATIVE TO Ti = 100%											
	100	92.8	75.0	67.8	285.7	132.1	89.2	142.8	89.2	92.8	82.1

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B
3 - Analysis not available at present; intended composition 1.00%
4 - Analysis not available at present; intended composition 1.00%
5 - Analysis not available at present; intended composition 4.00%

TABLE 21

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1200°F. (648.8°C.)

Cumulative Time (Hours)	Ti A	Ti B	% Cu[3] A	% Cu[3] B	4.37% Ta A	4.37% Ta B	1.24% Mo A	1.24% Mo B	0.54% Sn A	0.54% Sn B
4.0	8.6	10.8	23.5	21.4	6.2	10.1	4.9	5.3	8.3	8.8
27.6	10.4	17.3	49.1	48.6	16.0	15.9	8.7	12.1	14.7	14.3
42.8	23.7	24.7	67.8	65.7	18.6	19.7	13.3	15.4	21.2	21.4
48.4	25.4	26.0	73.3	69.8	19.0	22.2	13.9	16.6	24.6	27.7
71.8	36.4	36.3	95.9	90.5	24.0	27.9	19.9	20.1	31.7	28.1
96.2	40.7	40.1	109.2	104.5	29.3	33.5	23.3	24.2	39.2	35.9
120.3	50.4	47.4	123.5	117.1	33.9	38.6	27.0	29.7	46.4	41.5
144.7	52.3	49.4	131.6	125.0	34.5	37.7	27.1	29.7	47.2	45.6
168.5	56.0	55.4	147.5	142.4	36.2	39.3	30.9	32.6	52.2	52.8
192.4	62.6	59.8	162.8	157.3	38.8	43.3	32.4	33.9	55.5	50.5
216.2	68.0	66.6	176.9	167.8	46.4	45.9	34.6	38.0	61.7	57.8
240.0	70.9	67.5	183.8	175.2	40.8	45.5	34.7	38.2	61.3	57.3
286.9	81.9	76.4	205.1	194.5	48.5	54.5	42.9	44.7	70.1	66.3
313.7	83.7	81.5	209.8	198.6	48.9	52.3	41.2	45.1	70.5	66.7
336.9	88.6	84.6	214.7	207.0	51.7	58.2	43.9	47.4	76.1	68.7

Cumulative Time (Hours)	% Y[4] A	% Y[4] B	2.95% V A	2.95% V B	% Nb[3] A[5]	% Nb[3] B	% Cr[4] A	% Cr[4] B[5]	% Mn[4] A[6]	% Mn[4] B[6]	1.03% Al A	1.03% Al B	3.69% Al A	3.69% Al B
4.0	10.2	11.4	7.0	4.8	-	6.5	6.0	7.6	8.5	16.7	7.0	4.8	11.2	6.8
27.6	21.9	26.6	11.6	14.1	-	20.5	14.9	13.0	15.2	35.5	10.5	10.8	19.4	14.4
42.8	28.4	33.5	19.5	14.9	-	21.2	17.4	19.9	18.3	41.2	13.9	16.2	26.4	15.7
48.4	32.4	37.6	16.1	17.1	-	25.7	18.7	29.4	20.7	44.6	17.4	13.4	24.0	15.5
71.8	47.3	47.9	22.3	20.6	-	31.6	22.4	28.4	27.6	53.3	20.2	18.7	28.3	19.7
96.2	57.4	59.3	26.2	24.2	-	35.7	28.0	-	35.1	60.9	24.1	22.8	28.9	20.8
120.3	70.6	71.9	30.0	27.7	-	43.0	31.9	-	41.7	69.8	28.6	27.2	33.4	22.2
144.7	74.9	77.7	30.1	27.7	-	43.2	34.3	-	45.4	73.5	28.7	27.2	34.0	22.7
168.5	90.7	88.7	35.6	31.2	-	48.0	37.3	-	47.4	82.3	30.8	28.9	39.3	26.8
192.4	95.5	96.4	35.8	34.3	-	52.0	37.7	-	50.3	85.7	32.4	31.0	38.0	28.4
216.2	103.3	106.3	39.4	39.5	-	56.9	40.8	-	58.2	94.0	38.6	37.3	43.6	30.5
240.0	107.4	112.4	37.0	39.7	-	58.7	42.9	-	59.6	96.2	35.4	35.3	39.9	-
286.9	120.8	129.0	46.0	46.4	-	65.1	49.2	-	70.9	111.1	41.9	41.4	46.0	-
313.7	131.3	135.8	44.3	47.3	-	65.2	49.9	-	71.5	116.5	42.7	41.4	44.9	-
336.9	138.1	141.1	47.6	48.7	-	71.1	52.0	-	77.5	123.7	43.8	43.1	46.4	45.5

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	Ti	% Cu	4.37% Ta	1.24% Mo	0.54% Sn	% Y	2.95% V	% Nb	% Cr	% Mn	1.03% Al	3.69% Al
4.0	9.7	22.4	8.1	5.1	8.6	10.8	5.9	6.5	6.8	-	5.9	9.0
27.6	17.8	48.8	15.9	10.4	14.5	24.2	12.8	20.5	13.9	-	10.6	16.9
42.8	24.2	66.7	19.1	14.3	21.3	30.9	14.2	21.2	18.6	-	15.0	21.0
48.4	25.7	71.5	20.6	15.2	26.1	35.0	16.6	25.7	24.1	-	15.4	19.7
71.8	36.3	93.2	25.9	20.0	29.9	47.6	21.4	31.6	25.4	-	19.4	24.0
96.2	40.4	106.8	31.4	23.7	37.5	58.3	25.2	35.7	28.0	-	23.4	24.0
120.3	48.8	120.3	35.4	28.3	43.9	71.2	28.8	43.0	31.9	-	27.9	27.9
144.7	50.3	128.3	36.1	28.4	46.4	76.3	28.9	43.2	34.3	-	27.9	28.3
168.5	55.7	144.9	37.7	31.7	52.5	89.7	33.4	48.0	37.3	-	29.8	33.0
192.4	61.2	160.0	41.0	33.1	53.0	95.9	35.0	52.0	37.7	-	31.7	33.2
216.2	67.3	172.3	46.1	36.3	59.7	104.8	39.4	56.9	40.8	-	37.9	37.0
240.0	69.2	179.5	43.1	36.4	59.3	109.9	38.3	58.7	42.9	-	35.3	39.9
286.9	79.1	199.8	51.5	43.8	68.1	124.9	46.2	65.1	49.2	-	41.6	46.0
313.7	82.6	204.2	50.6	43.1	68.6	133.5	45.8	65.2	49.9	-	42.0	44.9
336.9	86.6	210.8	54.9	45.6	72.4	139.6	48.1	71.1	52.0	-	43.4	45.9

AVERAGE SURFACE AREA (cm²) OF SPECIMENS[2]

	Ti	% Cu	4.37% Ta	1.24% Mo	0.54% Sn	% Y	2.95% V	% Nb	% Cr	% Mn	1.03% Al	3.69% Al
	27.55	27.51	27.66	27.67	27.45	27.65	27.75	27.53	27.49	27.49	27.84	27.72

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm²)

Cumulative Time (Hours)	Ti	% Cu	4.37% Ta	1.24% Mo	0.54% Sn	% Y	2.95% V	% Nb	% Cr	% Mn	1.03% Al	3.69% Al
4.0	0.3	0.8	0.2	0.1	0.3	0.3	0.2	0.2	0.2	-	0.2	0.3
27.6	0.6	1.7	0.5	0.3	0.5	0.8	0.4	0.7	0.5	-	0.3	0.6
42.8	0.8	2.4	0.6	0.5	0.7	1.1	0.5	0.7	0.6	-	0.5	0.7
48.4	0.9	2.5	0.7	0.5	0.9	1.2	0.5	0.9	0.8	-	0.5	0.7
71.8	1.3	3.3	0.9	0.7	1.0	1.7	0.7	1.1	0.9	-	0.6	0.8
96.2	1.4	3.8	1.1	0.8	1.3	2.1	0.9	1.2	1.0	-	0.8	0.8
120.3	1.7	4.3	1.2	1.0	1.5	2.5	1.0	1.5	1.1	-	1.0	1.0
144.7	1.8	4.6	1.3	1.0	1.6	2.7	1.0	1.5	1.2	-	1.0	1.0
168.5	2.0	5.2	1.3	1.2	1.9	3.2	1.2	1.7	1.3	-	1.0	1.1
192.4	2.2	5.8	1.4	1.3	1.9	3.4	1.2	1.8	1.3	-	1.1	1.2
216.2	2.4	6.2	1.6	1.3	2.1	3.7	1.3	2.0	1.4	-	1.3	1.3
240.0	2.5	6.5	1.5	1.3	2.1	3.9	1.4	2.1	1.5	-	1.2	1.4
286.9	2.8	7.2	1.8	1.5	2.4	4.5	1.6	2.3	1.7	-	1.5	1.6
313.7	2.9	7.2	1.8	1.5	2.5	4.8	1.6	2.3	1.8	-	1.5	1.6
336.9	3.1	7.6	1.9	1.6	2.6	5.0	1.7	2.5	1.9	-	1.5	1.6

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B
3 - Analysis not available at present; intended composition 1.00%
4 - Analysis not available at present; intended composition 4.00%
5 - Specimen became detached from ribbon
6 - Specimens apparently of different composition; identity of specimens to be determined by analysis

TABLE 22

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1400° F. (760 C.)

CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	3.88% V A	3.88% V B	0.84% V A	0.84% V B	1% Cu[3] A	1% Cu[3] B	3.34% Cu A	3.34% Cu B	1.03% Si A	1.03% Si B	3.69% Si A	3.69% Si B	0.54% Ta A	0.54% Ta B	4.37% Ta A	4.37% Ta B	4.45% Cb A	4.45% Cb B	1.00% Cb A	1.00% Cb B	3.96% Mo A	3.96% Mo B	1.19% Mo A	1.19% Mo B
2.9	23.2	22.5	22.1	24.7	39.5	38.5	22.1	20.5	9.9	13.3	7.4	8.8	15.6	19.1	18.6	17.3	13.7	14.3	19.9	17.5	20.6	20.5	15.6	13.8
18.5	80.4	78.3	78.0	85.4	164.0	164.9	61.9	65.9	26.3	27.9	17.8	16.5	42.0	38.2	37.7	36.4	33.6	32.0	44.3	40.7	48.5	46.6	28.6	31.1
24.2	97.7	95.5	108.0	105.2	200.5	200.4	77.0	77.9	31.5	31.6	18.5	17.6	51.0	42.8	41.3	40.1	35.4	36.7	50.4	48.2	56.4	53.9	32.9	38.2
71.2	187.8	191.2	220.9	226.8	440.4	440.1	137.6	143.0	56.0	54.1	34.1	34.0	84.0	84.3	68.2	68.4	57.2	62.2	78.4	81.9	97.3	97.8	53.5	57.1
96.1	228.4	239.2	276.3	282.4	558.5	557.6	167.6	171.1	64.2	61.4	37.1	35.3	97.7	98.3	79.3	78.1	67.0	72.7	94.8	93.0	121.2	121.9	56.6	63.6
168.8	358.2	397.3	427.4	434.9	962.8	962.6	235.1	244.5	86.1	78.4	49.2	49.0	133.1	131.5	104.7	97.7	95.8	97.9	123.2	123.9	213.9	221.3	77.2	80.4
191.8	403.1	449.2	474.7	475.8	1096.9	1098.0	258.5	270.4	92.0	80.5	50.2	50.6	141.6	141.2	111.1	110.0	102.1	102.9	130.5	133.0	248.9	258.2	78.2	83.4
214.3	488.8	543.0	556.2	555.3	1344.5	1349.6	301.1	310.8	104.0	98.6	58.3	57.4	160.1	165.4	123.0	125.3	115.4	114.7	148.2	148.7	328.2	336.3	89.1	95.0

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	3.88% V	0.84% V	1% Cu[3]	3.34% Cu	1.03% Si	3.69% Si	0.54% Ta	4.37% Ta	4.45% Cb	1.00% Cb	3.96% Mo	1.19% Mo
2.9	22.8	23.4	39.0	21.3	11.6	8.1	17.3	17.9	14.0	18.7	20.6	14.7
18.5	79.3	81.7	164.4	63.9	27.1	17.1	40.1	37.0	32.8	42.5	47.5	29.8
24.2	96.6	106.6	200.5	77.5	31.6	18.0	46.9	40.7	36.0	49.3	55.1	35.5
71.2	189.5	223.8	440.3	140.3	55.0	34.1	84.2	68.3	59.7	80.1	97.6	55.3
96.1	233.8	279.3	558.0	169.3	62.8	98.0	98.0	78.7	69.8	93.9	121.6	60.1
168.8	377.8	431.2	962.7	239.8	82.3	49.1	132.3	101.2	96.9	123.6	217.6	78.8
191.8	426.2	475.3	1097.5	264.5	86.3	50.4	141.4	110.6	102.5	131.8	253.6	80.8
214.3	515.9	555.8	1347.1	305.9	101.3	57.9	162.7	124.2	115.1	148.5	332.3	92.1

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

3.88% V	0.84% V	1% Cu[3]	3.34% Cu	1.03% Si	3.69% Si	0.54% Ta	4.37% Ta	4.45% Cb	1.00% Cb	3.96% Mo	1.19% Mo
27.74	27.66	27.58	27.80	27.87	27.91	27.60	27.76	27.48	27.50	27.77	27.75

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

Cumulative Time (Hours)	3.88% V	0.84% V	1% Cu[3]	3.34% Cu	1.03% Si	3.69% Si	0.54% Ta	4.37% Ta	4.45% Cb	1.00% Cb	3.96% Mo	1.19% Mo
2.9	0.8	0.8	1.4	0.8	0.4	0.3	0.6	0.6	0.5	0.7	0.7	0.5
18.5	2.9	3.0	6.0	2.3	1.0	0.6	1.5	1.3	1.2	1.5	1.7	1.1
24.2	3.5	3.9	7.3	2.8	1.1	0.6	1.7	1.5	1.3	1.8	2.0	1.3
71.2	6.8	8.1	16.0	5.0	2.0	1.2	3.1	2.5	2.2	2.9	3.5	2.0
96.1	8.4	10.1	20.2	6.1	2.3	1.3	3.6	2.8	2.5	3.4	4.4	2.2
168.8	13.6	15.6	34.9	8.6	3.0	1.8	4.8	3.6	3.5	4.5	7.8	2.8
191.8	15.4	17.2	39.8	9.5	3.1	1.8	5.1	4.0	3.7	4.8	9.1	2.9
214.3	18.6	20.1	48.8	11.0	3.6	2.1	5.9	4.5	4.2	5.4	12.0	3.3

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B
3 - Intended composition 1% Cu; chemical analysis subsequent to the scaling test indicated no copper present

TABLE 23

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1400°F. (760C.)

CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	0.91% Ni		1.27% Mn		2.95% W		1.05% Cr		4.03% Cr		4.13% Ni		0.93% Fe		4.11%Mn		1.15% W		3.28% Al		1.21% Al		3.76% Fe		Ti
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
2.2	22.7	24.1	20.0	26.4	14.9	14.1	45.0	56.6	134.2	144.8	21.1	20.8	20.9	19.4	31.7	27.2	18.5	17.7	20.7	15.9	20.8	20.6	26.2	32.4	14.0
15.4	71.7	69.6	72.6	72.2	29.2	30.6	225.4	240.5	470.3	478.8	58.4	57.2	63.8	60.2	85.9	89.2	45.9	46.2	44.0	41.3	65.0	63.9	88.0	90.5	47.1
21.1	87.3	87.1	86.0	84.8	33.2	32.0	293.6	309.0	571.2	575.1	72.0	67.5	78.8	77.7	104.1	109.1	49.7	53.6	47.8	50.0	81.3	81.7	105.0	109.1	57.0
39.3	134.1	132.8	127.7	127.5	40.3	43.7	493.3	515.9	851.2	835.1	104.4	101.2	120.5	121.1	152.4	160.8	73.8	77.2	69.4	66.8	138.2	132.9	162.6	171.1	86.3
62.8	189.5	186.8	179.7	171.1	51.4	51.5	720.3	745.6	1146.9	1118.2	143.6	139.8	170.9	177.1	212.2	225.1	96.2	102.5	92.5	87.5	212.9	205.3	225.5	249.4	113.5
86.3	246.3	237.9	221.5	209.7	56.1	54.9	908.2	936.6	1376.5	1342.2	177.2	167.7	213.3	226.7	264.5	282.2	112.6	118.2	102.7	100.2	279.1	266.4	281.2	310.4	149.0

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	0.91% Ni	1.27% Mn	2.95% W	1.05% Cr	4.03% Cr	4.13% Ni	0.93% Fe	4.11%Mn	1.15% W	3.28% Al	1.21% Al	3.76% Fe	Ti
2.2	23.4	23.2	14.5	50.8	139.5	20.9	20.1	29.4	18.1	18.3	20.7	29.3	14.0
15.4	70.6	72.4	29.9	232.9	474.5	57.8	62.0	87.5	46.0	42.6	64.4	89.2	47.1
21.1	87.2	85.4	32.6	301.3	573.1	69.7	78.2	106.6	51.6	48.9	81.5	107.0	57.0
39.3	133.4	127.6	42.0	504.6	843.1	102.8	120.8	156.6	75.5	68.1	135.5	166.8	86.3
62.8	188.1	175.4	51.4	732.9	1132.5	141.7	174.0	218.6	99.3	90.0	209.1	237.4	113.5
86.3	242.1	215.6	55.5	922.4	1359.3	172.4	220.0	273.3	115.4	101.4	272.8	295.8	149.0

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

	0.91% Ni	1.27% Mn	2.95% W	1.05% Cr	4.03% Cr	4.13% Ni	0.93% Fe	4.11%Mn	1.15% W	3.28% Al	1.21% Al	3.76% Fe	Ti
	27.33	27.29	27.75	27.43	27.49	27.55	27.45	27.46	27.66	27.43	27.53	27.58	27.60

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)

Cumulative Time (Hours)	0.91% Ni	1.27% Mn	2.95% W	1.05% Cr	4.03% Cr	4.13% Ni	0.93% Fe	4.11%Mn	1.15% W	3.28% Al	1.21% Al	3.76% Fe	Ti
2.2	0.8	0.8	0.5	1.8	5.1	0.7	0.7	1.1	0.6	0.6	0.7	1.0	0.5
15.4	2.6	2.6	1.1	8.5	17.3	2.1	2.2	3.2	1.6	1.5	2.3	3.2	1.7
21.1	3.2	3.1	1.2	11.0	20.8	2.5	2.8	3.9	1.8	1.8	2.9	3.9	2.0
39.3	4.9	4.7	1.5	18.4	30.6	3.7	4.4	5.7	2.7	2.5	4.9	6.0	3.1
62.8	6.9	6.4	1.8	26.7	41.2	5.1	6.3	7.9	3.6	3.3	7.6	8.6	4.1
86.3	8.8	7.9	2.0	33.6	49.4	6.2	8.0	9.9	4.2	3.7	9.9	10.7	5.4

1- Weight increase of ribbons included
2- Specimens (of the same composition) were employed in duplicate and designated A and B

TABLE 24

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1600 F. (871.1 C.)

CUMULATIVE WEIGHT[1] INCREASE (mg.) OF SPECIMENS[2]

Cumulative Time (Hours)	0.84% V A	0.84% V B	3.34% Co A	3.34% Co B	4.37% Ta A	4.37% Ta B	3.96% Mo A	3.96% Mo B	1.19% Mo A	1.19% Mo B	0.54% Ta A	0.54% Ta B	1.03% Si A	1.03% Si B	3.88% V A	3.88% V B	3.69% Si A	3.69% Si B	4.45% Cb A	4.45% Cb B	1.00% Cb A	1.00% Cb B	Ti
4.5	187.1	177.6	119.4	114.4	43.8	44.5	50.6	54.0	43.3	41.3	49.8	45.7	35.4	32.0	160.9	170.6	20.7	17.9	48.0	44.4	49.8	51.1	105.0
28.7	825.1	792.2	465.0	455.0	108.1	107.5	228.4	220.2	97.2	91.9	195.8	192.0	150.8	149.2	492.1	507.0	83.5	79.6	104.4	102.9	172.2	176.8	468.0
48.5	1134.6	1083.4	584.1	572.7	139.2	141.1	668.8	651.5	150.4	145.0	302.5	296.9	224.4	225.0	623.3	648.6	144.2	137.1	134.1	135.1	253.1	255.3	617.5
98.3	1975.7	1850.0	800.6	800.4	222.4	220.8	1851.7	1837.1	350.3	373.6	479.2	461.8	358.5	366.1	886.8	932.2	278.6		213.3	217.7	423.9	403.0	849.9
168.6	2827.0	2749.9	1108.0	1091.8	328.9	324.4	3420.3	3389.6	1078.1	1073.5	635.3	619.9	464.7	470.6	1312.9	1466.8	442.6		320.8	325.1	620.8	582.0	1336.3

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg.) OF SPECIMENS[2]

Cumulative Time (Hours)	0.84% V	3.34% Co	4.37% Ta	3.96% Mo	1.19% Mo	0.54% Ta	1.03% Si	3.88% V	3.69% Si	4.45% Cb	1.00% Cb	Ti
4.5	182.4	116.9	44.2	52.3	42.3	47.8	33.7	165.8	19.3	46.2	50.5	105.0
28.7	808.6	460.0	107.8	224.3	94.6	193.9	150.0	499.6	81.6	103.7	174.5	468.0
48.5	1109.0	578.4	140.2	660.2	147.8	299.7	224.7	636.0	140.7	134.6	254.2	617.5
98.3	1912.9	800.5	221.6	1844.4	362.0	470.5	362.3	909.5	278.6	215.5	413.5	849.9
168.6	2788.4	1099.9	326.7	3405.0	1075.8	627.6	467.7	1389.9	442.6	323.0	601.4	1336.3

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

0.84% V	3.34% Co	4.37% Ta	3.96% Mo	1.19% Mo	0.54% Ta	1.03% Si	3.88% V	3.69% Si	4.45% Cb	1.00% Cb	Ti
27.65	27.72	27.88	27.73	27.83	27.51	27.86	27.72	27.88	27.47	27.51	27.77

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

Cumulative Time (Hours)	0.84% V	3.34% Co	4.37% Ta	3.96% Mo	1.19% Mo	0.54% Ta	1.03% Si	3.88% V	3.69% Si	4.45% Cb	1.00% Cb	Ti
4.5	6.6	4.2	1.6	1.9	1.5	1.7	1.2	6.0	0.7	1.7	1.8	3.8
28.7	29.2	16.6	3.9	8.1	3.4	7.0	5.4	18.0	2.9	3.8	6.3	16.9
48.5	40.1	20.9	5.0	23.8	5.3	10.9	8.1	22.9	5.0	4.9	9.2	22.2
98.3	69.2	28.9	7.9	66.5	13.0	17.1	13.0	32.8	10.0	7.8	15.0	30.6
168.6	100.8	39.7	11.7	122.8	38.7	22.8	16.8	50.1	15.9	11.8	21.9	48.1

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B

TABLE 25

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1600F.(871. 1C.)

CUMULATIVE WEIGHT[1] INCREASE (mg.) OF SPECIMENS[2]

Cumulative Time (Hours)	3.76% Fe A	3.76% Fe B	4.13% Ni A	4.13% Ni B	0.93% Fe A	0.93% Fe B	1.05% Cr A	1.05% Cr B	4.11% Mn A	4.11% Mn B	0.91% Ni A	0.91% Ni B
1.0	52.5	51.3	41.3	39.0	40.5	43.0	133.3	160.3	99.6	85.0	69.2	78.9
6.2	310.4	307.3	168.1	160.8	242.8	233.8	471.9	502.5	325.4	298.3	320.8	317.8
19.9	751.4	746.9	474.3	464.5	583.4	572.7	924.6	955.1	660.2	626.2	662.1	638.4
47.9	1373.5	1397.0	798.4	796.2	808.7	799.4	1631.5	1558.4	1098.0	1062.3	868.9	833.4
67.7	1728.5	1768.3	894.3	885.5	893.1	884.5	2099.4	1993.8	1333.3	1297.6	950.2	928.3
90.3	2122.0	2192.2	978.0	952.7	1001.7	973.8	2459.2	2362.3	1565.4	1530.3	1078.2	1062.9
100.5	2290.5	2378.0	1019.9	987.6	1064.0	1028.5	2591.8	2509.1	1657.2	1615.0	1153.7	1145.6
139.9	2933.7	3021.8	1274.8	1137.0	1368.9	1301.8	3075.0	3009.1	1960.5	1918.5	1575.1	1547.3

Cumulative Time (Hours)	4.03% Cr A	4.03% Cr B	2.95% W A	2.95% W B	1.13% W A	1.13% W B	1.21% Al A	1.21% Al B	1.27% Mn A	1.27% Mn B	3.28% Al A	3.28% Al B
1.0	280.7	290.2	27.3	27.5	41.7	38.1	100.6	105.6	69.6	76.3	50.2	53.3
6.2	838.8	843.4	51.9	52.3	82.1	76.6	321.8	336.5	187.5	211.8	97.4	97.3
19.9	1424.8	1510.5	93.7	82.5	147.8	148.7	537.6	573.6	443.5	467.2	194.3	182.1
47.9	2024.7	2065.9	164.3	150.9	331.4	346.8	843.1	821.9	691.1	719.7	396.3	370.4
67.7	2355.5	2364.9	207.5	192.5	513.3	492.7	1066.2	994.9	849.4	884.0	498.1	473.2
90.3	2670.4	2728.9	250.7	232.8	650.4	609.0	1267.9	1228.5	1000.2	1041.6	571.7	598.2
100.5	2824.5	2872.0	266.2	255.8	690.1	647.8	1342.3	1328.9	1068.3	1096.7	636.3	610.4
139.9	3279.7	3350.0	345.3	328.1	810.7	798.1	1620.2	1667.2	1287.0	1329.3	784.8	747.5

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg.) OF SPECIMENS[2]

Cumulative Time (Hours)	3.76% Fe	4.13% Ni	0.93% Fe	1.05% Cr	4.11% Mn	0.91% Ni	4.03% Cr	2.95% W	1.13% W	1.21% Al	1.27% Mn	3.28% Al
1.0	51.9	40.2	41.8	146.8	92.3	74.1	285.5	27.4	39.9	103.1	73.0	51.8
6.2	308.9	164.5	238.3	487.2	311.9	319.3	841.1	52.1	79.4	329.2	199.7	97.4
19.9	749.2	469.4	578.1	939.9	643.2	650.3	1467.7	88.1	148.3	555.6	455.4	188.2
47.9	1385.3	797.3	804.1	1595.0	1080.2	851.2	2045.3	157.6	339.1	832.5	705.4	383.4
67.7	1748.4	889.9	888.8	2046.6	1315.5	939.3	2360.2	200.0	503.0	1030.6	866.7	485.7
90.3	2157.1	965.4	987.8	2410.8	1547.9	1070.6	2699.7	241.8	629.7	1248.2	1020.9	584.9
100.5	2334.3	1003.8	1046.3	2550.5	1636.1	1149.7	2848.3	261.0	669.0	1335.6	1082.5	623.4
139.9	2977.8	1205.9	1335.4	3042.1	1939.5	1561.2	3314.9	336.7	804.4	1643.7	1308.2	766.2

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

3.76% Fe	4.13% Ni	0.93% Fe	1.05% Cr	4.11% Mn	0.91% Ni	4.03% Cr	2.95% W	1.13% W	1.21% Al	1.27% Mn	3.28% Al
27.61	27.76	27.57	27.46	27.39	27.47	27.38	27.87	27.75	27.58	27.36	27.80

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

Cumulative Time (Hours)	3.76% Fe	4.13% Ni	0.93% Fe	1.05% Cr	4.11% Mn	0.91% Ni	4.03% Cr	2.95% W	1.13% W	1.21% Al	1.27% Mn	3.28% Al
1.0	1.9	1.4	1.5	5.3	3.4	2.7	10.4	1.0	1.4	3.7	2.7	1.9
6.2	11.2	5.9	8.6	17.7	11.4	11.6	30.7	1.9	2.9	11.9	7.3	3.5
19.9	27.1	16.9	21.0	34.2	23.5	23.7	53.6	3.2	5.3	20.1	16.6	6.8
47.9	50.1	28.7	29.2	58.1	39.4	31.0	73.5	5.7	12.2	30.2	25.8	13.8
67.7	63.3	32.1	32.2	74.5	48.0	34.2	86.2	7.2	18.1	37.4	31.7	17.5
90.3	78.1	34.8	35.8	87.5	56.5	39.0	98.6	8.7	22.7	45.3	37.3	21.0
100.5	84.5	36.2	38.0	92.9	59.7	41.9	104.0	9.4	24.1	48.4	39.6	22.4
139.9	107.9	43.4	48.4	110.8	70.8	56.8	121.1	12.1	29.0	59.6	47.8	27.6

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B

TABLE 26

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1800°F. (982.2°C.)

CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	3.69% Si A	3.69% Si B	1.19% Mo A	1.19% Mo B	Ti A	Ti B	1.00% Cb A	1.00% Cb B	4.45% Cb A	4.45% Cb B	3.88% V A	3.88% V B
4.8	127.2	130.2	125.4	123.7	519.9	532.6	215.4	211.4	122.1	118.8	546.7	543.7
7.3	206.5	215.6	168.9	166.1	639.2	634.4	280.7	283.5	142.4	139.8	687.6	677.1
28.2	711.0	767.4	800.7	826.4	1893.6	1907.2	862.2	887.0	396.2	380.4	2127.4	2059.6
34.4	751.0	812.1	970.4	1024.7	2080.1	2096.5	980.5	996.3	435.2	497.6	2559.2	2462.9
49.3	876.2	964.5	1533.8	1640.3	2555.4	2529.2	1245.6	1269.5	545.4	526.0	3537.9	3346.7
54.7	927.8	1034.9	1780.1	1908.2	2669.3	2647.4	1330.8	1359.5	576.9	557.9	3899.3	3666.0

Cumulative Time (Hours)	1.03% Si A	1.03% Si B	0.54% Ta A	0.54% Ta B	3.96% Mo A	3.96% Mo B	4.37% Ta A	4.37% Ta B	3.34% Cu A	3.34% Cu B	0.84% V A	0.84% V B
4.8	111.3	108.0	269.2	270.8	313.5	341.3	155.4	135.9	567.8	579.8	1022.6	967.2
7.3	144.4	141.3	321.6	321.3	479.6	504.7	193.4	175.2	681.0	704.7	1402.4	1345.6
28.2	331.7	323.3	901.1	843.2	1820.6	1847.3	423.9	389.4	1580.9	1629.3	3971.2	3887.9
34.4	369.3	363.0	998.5	939.0	2225.2	2159.6	475.5	425.5	1770.8	1804.7	4200.1	4133.2
49.3	496.0	478.9	1302.1	1214.7	3604.6	3592.4	603.4	544.3	2274.1	2167.7	4301.1[3]	4275.6[3]
54.7	545.4	526.1	1453.6	1325.2	3727.5	3717.8	654.2	578.4	2463.4	2282.8	3961.0[3]	4000.6[3]

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	3.69% Si	1.19% Mo	Ti	1.00% Cb	4.45% Cb	3.88% V	1.03% Si	0.54% Ta	3.96% Mo	4.37% Ta	3.34% Cu	0.84% V
4.8	128.7	124.5	526.2	213.4	120.4	545.2	109.6	270.0	327.4	145.6	573.8	994.9
7.3	211.0	167.5	636.8	282.1	141.1	682.3	142.6	321.4	492.1	184.3	692.8	1374.0
28.2	739.2	813.5	1900.4	874.6	388.3	2093.5	327.6	872.1	1833.9	406.6	1605.1	3929.5
34.4	781.5	997.5	2088.8	988.4	466.4	2506.5	366.1	968.7	2192.4	450.5	1787.7	4166.6
49.3	920.3	1587.0	2542.3	1257.5	535.7	3442.3	487.4	1258.4	3598.5	573.8	2220.9	4288.3[3]
54.7	981.3	1844.1	2658.3	1345.1	567.4	3782.6	535.7	1389.4	3722.6	616.3	2373.1	3980.8[3]

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

3.69% Si	1.19% Mo	Ti	1.00% Cb	4.45% Cb	3.88% V	1.03% Si	0.54% Ta	3.96% Mo	4.37% Ta	3.34% Cu	0.84% V
26.28	27.68	27.72	27.66	27.63	27.79	27.99	27.70	27.92	27.65	27.89	27.64

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

Cumulative Time (Hours)	3.69% Si	1.19% Mo	Ti	1.00% Cb	4.45% Cb	3.88% V	1.03% Si	0.54% Ta	3.96% Mo	4.37% Ta	3.34% Cu	0.84% V
4.8	4.9	4.5	19.0	7.7	4.4	19.6	3.9	9.7	11.7	5.3	20.6	36.0
7.3	8.0	6.1	23.0	10.2	5.1	24.6	5.1	11.6	17.6	6.7	24.8	49.7
28.2	28.1	29.4	68.6	31.6	14.1	75.3	11.7	31.5	65.7	14.7	57.6	142.2
34.4	29.7	36.0	75.4	35.7	16.9	90.2	13.1	35.0	78.5	16.3	64.1	150.7
49.3	35.0	57.3	91.7	45.4	19.4	123.9	17.4	45.4	128.9	20.8	79.6	155.2[3]
54.7	37.3	66.6	95.9	48.6	20.5	136.1	19.1	50.2	133.3	22.3	85.1	144.0[3]

1 - Weight increase of ribbons included
2 - Specimens (of the same composition) were employed in duplicate and designated A and B
3 - Some scale lost due to spalling in furnace

TABLE 27

DATA OBTAINED FROM SCALING TESTS OF BINARY ALLOYS AT 1800°F. (982.2°C.)

CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	1.27% Mn A	1.27% Mn B	1.21% Al A	1.21% Al B	1.13% W A	1.13% W B	2.95% W A	2.95% W B	4.03% Cr A	4.03% Cr B	0.91% Ni A	0.91% Ni B	4.11% Mn A	4.11% Mn B
4.0	566.7	583.1	765.5	781.3	90.2	110.2	31.7	40.5	1019.4	1009.6	699.4	674.4	662.7	655.3
20.4	1412.4	1398.6	1937.0	1997.6	524.6	571.6	326.6	335.7	2310.5	2225.7	1540.4	1556.7	1495.1	1498.7
27.6	1675.5	1657.8	2282.5	2344.5	755.6	816.6	473.3	488.4	2706.0	2625.2	1833.2	1852.7	1713.1	1725.0
44.8	2184.3	2163.6	3028.4	3166.2	1236.6	1363.0	937.0	959.5	3451.1	3362.6	2349.9	2330.2	2209.4	2232.8
48.2	2276.2	2257.7	3226.7	3327.5	1353.1	1472.8	1041.4	1074.6	3573.9	3484.6	2442.6	2418.8	2306.3	2338.4

Cumulative Time (Hours)	1.05% Cr A	1.05% Cr B	0.93% Fe A	0.93% Fe B	4.13% Ni A	4.13% Ni B	3.76% Fe	3.28% Al A	3.28% Al B	Ti A	Ti B
4.0	679.1	702.9	517.2	484.4	659.9	674.5	688.0	317.2	333.8	429.8	473.0
20.4	1997.5	2134.2	1468.4	1439.4	1377.5	1384.1	2233.6	917.1	926.1	1222.9	1263.1
27.6	2473.1	2609.0	1655.3	1587.7	1527.1	1527.0	2679.4	1087.7	1100.7	1360.2	1400.0
44.8	3451.2	3591.1	2358.2	2204.1	1870.2	1916.1	3824.4	1503.2	1528.6	1791.3	1825.7
48.2	3629.9	3770.2	2521.2	2394.5	1952.5	2013.1	4033.4	1594.3	1623.5	1891.5	1924.6

AVERAGE CUMULATIVE WEIGHT[1] INCREASE (mg) OF SPECIMENS[2]

Cumulative Time (Hours)	1.27% Mn	1.21% Al	1.13% W	2.95% W	4.03% Cr	0.91% Ni	4.11% Mn	1.05% Cr	0.93% Fe	4.13% Ni	3.76% Fe	3.28% Al	Ti
4.0	574.9	773.4	100.2	36.1	1014.5	686.9	659.0	691.0	500.8	667.2	688.0	325.5	451.4
20.4	1405.4	1967.3	548.1	331.2	2268.1	1548.6	1496.9	2065.9	1453.9	1380.6	2233.6	921.6	1243.0
27.6	1666.7	2313.5	786.1	480.9	2660.6	1843.0	1719.1	2541.2	1621.5	1527.1	2679.4	1094.2	1380.1
44.8	2174.0	3097.3	1299.8	948.3	3406.4	2340.1	2221.1	3521.2	2281.2	1893.2	3824.4	1515.9	1808.5
48.2	2267.0	3277.1	1413.0	1058.0	3529.3	2430.7	2322.4	3700.1	2457.9	1982.8	4033.4	1608.9	1908.1

AVERAGE SURFACE AREA (cm^2) OF SPECIMENS[2]

1.27% Mn	1.21% Al	1.13% W	2.95% W	4.03% Cr	0.91% Ni	4.11% Mn	1.05% Cr	0.93% Fe	4.13% Ni	3.76% Fe	3.28% Al	Ti
27.38	27.62	27.82	27.79	27.42	27.37	27.46	27.64	27.67	27.80	27.54	28.30	27.36

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

Cumulative Time (Hours)	1.27% Mn	1.21% Al	1.13% W	2.95% W	4.03% Cr	0.91% Ni	4.11% Mn	1.05% Cr	0.93% Fe	4.13% Ni	3.76% Fe	3.28% Al	Ti
4.0	21.0	27.0	3.6	1.3	37.0	25.1	24.0	25.0	18.1	24.0	25.0	11.5	16.5
20.4	51.3	71.2	19.7	11.9	82.7	56.6	54.5	74.7	52.5	49.7	81.1	32.6	45.4
27.6	60.9	83.8	28.3	17.3	97.0	67.3	62.6	91.9	58.6	54.9	97.3	38.7	50.4
44.8	79.4	112.1	46.7	34.1	124.2	85.5	80.9	127.4	82.4	68.1	138.9	53.6	66.1
48.2	82.8	118.6	50.8	38.1	128.7	88.8	84.6	133.9	88.8	71.3	146.5	56.9	69.7

1 - Weight increase of ribbons included.
2 - Specimens (of the same composition) were employed in duplicate and designated A and B.

TABLE 28

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1200° F. (648.8° C.)

Alloying Element	48 hours	72 hours	96 hours	120 hours	144 hours	168 hours	192 hours	216 hours	240 hours	264 hours	288 hours
1.21% Al	0.66*	0.9	1.0	1.2	1.3	1.5	1.6	1.7	1.9	2.0	2.1
3.28% Al	0.5	0.6	0.7	0.8	0.86	0.93	1.0	1.0	1.1	1.1	1.2
1.13% W	0.77*	1.0	1.1	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0
2.95% W	0.5	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.4	1.5	1.6
0.91% Ni	0.8	1.0	1.3	1.4	1.5	1.7	1.8	2.0	2.2	2.3	2.5
4.13% Ni	1.07*	1.3	1.5	1.6	1.8	1.9	2.0	2.2	2.3	2.4	2.5
1.05% Cr	2.05*	2.8	3.5	4.1	4.7	5.3	5.8	6.5	7.0	7.5	8.0
4.03% Cr	3.6	4.8	5.8	6.8	7.6	8.5	9.2	10.0	10.0	11.0	11.0
1.27% Mn	0.96*	1.2	1.4	1.6	1.8	1.9	2.0	2.2	2.3	2.5	2.6
4.11% Mn	1.22*	1.5	1.9	2.1	2.4	2.7	2.9	3.1	3.3	3.5	3.7
0.93% Fe	0.95*	1.1	1.4	1.5	1.7	1.9	2.0	2.1	2.3	2.4	2.5
3.76% Fe	1.5*	1.9	2.2	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0
3.34% Cu	0.98*	1.2	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.2	2.3
0.84% V	0.96*	1.2	1.4	1.6	1.8	1.9	2.0	2.2	2.3	2.5	2.6
3.88% V	1.3	1.7	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.4
0.54% Ta	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.2	2.4	2.5
4.37% Ta	0.6	0.8	1.0	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0
1.19% Mo	0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
3.96% Mo	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.2	2.4	2.5
1.03% Si	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.4	1.5
3.69% Si	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.3	1.4	1.4	1.5
1.00% Cb	0.9	1.1	1.2	1.4	1.6	1.7	1.8	2.0	2.1	2.2	2.3
4.45% Cb	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7
Ti	0.9	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.5	2.7

* Extrapolated value.

Table 29

AVERAGE CUMULATIVE WEIGHT INCREASE (mg.) PER AVERAGE ORIGINAL UNIT AREA ($cm.^2$)
DATA OBTAINED FROM SCALING TESTS AT 1400° F. (760° C.)

Alloying Element	24 hours	48 hours	72 hours	96 hours	120 hours	144 hours	168 hours
Cu*	7.4	10.2	11.1	20.0	22.7	26.8	30.0
3.34% Cu	2.7	4.1	5.1	6.2	7.0	7.8	8.6
3.88% V	3.3	5.5	7.4	9.1	10.6	12.0	13.5
0.84% V	3.8	6.4	8.6	10.8	12.6	14.5	16.4
3.69% Si	0.7	0.9	1.2	1.3	1.5	1.7	1.8
1.03% Si	1.1	1.6	2.0	2.2	2.5	2.8	3.0
2.95% W	1.2	1.6	1.9				
1.13% W	2.1	3.0	3.8				
4.13% Ni	2.8	4.2	5.4				
0.91% Ni	3.5	5.7	7.5				
3.28% Al	2.0	2.8	3.4				
1.21% Al	3.3	5.9	8.2				
4.11% Mn	4.3	6.7	8.7				
1.27% Mn	3.5	5.4	6.9				
3.76% Fe	4.5	7.0	9.1				
0.93% Fe	3.1	5.2	7.0				
4.03% Cr	22.1	34.1	44.0				
1.05% Cr	12.2	20.8	28.5				
4.45% Cb	1.2	1.8	2.2	2.5	2.8	3.1	3.3
1.00% Cb	1.7	2.4	2.9	3.4	3.8	4.1	4.5
4.37% Ta	1.5	2.1	2.5	2.9	3.2	3.5	3.8
0.54% Ta	1.7	2.5	3.1	3.6	4.0	4.4	4.8
3.96% Mo	1.9	2.8	3.5	4.3	5.5	6.6	7.8
1.19% Mo	1.2	1.6	2.0	2.2	2.4	2.6	2.7
Ti	2.2	3.5	4.6				

* Intended composition 1% Cu; chemical analysis subsequent to the scaling test indicated copper was not present in the desired amount.

Note: The omission of data for half of the alloy specimens for time periods beyond 72 hours was due to a temporary breakdown of the controlling circuit of the scaling furnace.

TABLE 30

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm°)
Data Obtained from Scaling Tests at 1600° F. (871.1° C.)

Alloying Element	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
1.21% Al	21.7	31.9	40.0	47.0	56.0	58.8*	64.0*
3.28% Al	8.1	13.2	17.7	21.6	25.3	28.7*	32.2*
1.13% W	6.4	11.9	17.4	22.6	27.5	38.2*	37.7*
2.95% W	3.6	5.8	7.6	9.3	10.7	12.2*	13.7*
0.91% Ni	25.0	30.8	35.0	42.0	49.0	56.8*	64.4*
4.13% Ni	19.7	26.9	32.1	36.8	40.3	44.0*	47.0*
1.05% Cr	36.2	57.0	73.0	89.8	100.4	117.0*	129.0*
4.03% Cr	57.5	76.0	90.0	100.0	101.0	117.0*	125.0*
1.27% Mn	18.2	26.4	33.0	38.5	43.2	48.0*	52.0*
4.11% Mn	27.3	39.7	49.5	58.0	65.8	72.0*	78.2*
0.93% Fe	22.4	28.5	33.0	36.5	39.5	42.0*	44.8*
3.76% Fe	30.0	49.0	66.0	81.0	96.0	110.0*	122.0*
3.34% Cu	15.5*	20.8	25.0	28.4	31.2	33.9	36.2
0.84% V	23.5	40.0	55.0	69.0	82.0	94.0	100.5
3.88% V	16.5*	23.0	28.0	32.0	35.8	39.0	44.0
0.54% Ta	7.1*	10.6	13.5	16.3	18.5	20.7	23.0
4.37% Ta	3.5*	5.3	6.6	7.9	9.1	10.0	11.0
1.19% Mo	3.1	4.8	8.9	13.7	19.4	25.5	32.5
3.96% Mo	10.0*	24.0	40.0	58.0	79.0	98.0	102.0
1.03% Si	5.3*	8.0	10.0	12.0	13.7	15.3	17.0
3.69% Si	2.6*	4.9	7.2	9.3	11.5	13.5	15.8
1.00% Cb	5.6*	9.0	12.0	14.5	17.0	19.3	21.5
4.45% Cb	3.2*	5.1	6.6	8.0	9.2	10.2	11.4
Ti	15.5*	22.6	28.0	33.0	37.2	41.2	45.0

* Extrapolated value.

TABLE 31

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1800° F. (982.2° C.)

Alloying Element	24 Hours	48 Hours
3.28% Al	36.0	56.9
1.21% Al	77.8	118.6
2.95% W	14.7	38.1
1.13% W	24.1	50.8
4.13% Ni	52.8	71.3
0.91% Ni	62.0	88.8
4.03% Cr	90.0	128.7
1.05% Cr	84.0	133.9
4.11% Mn	58.8	84.6
1.27% Mn	56.2	82.8
3.76% Fe	89.8	146.5
0.93% Fe	56.5	88.8
3.34% Cu	52.0	78.5
3.88% V	68.0	118.0
0.84% V	120.0	205.0*
4.37% Ta	13.5	20.5
0.54% Ta	28.2	44.5
3.96% Mo	57.0	112.0
1.19% Mo	25.5	55.0
3.69% Si	21.0	39.3
1.03% Si	10.5	16.0
4.45% Cb	12.5	19.0
1.00% Cb	26.5	45.0
Ti	57.0	90.1

* Extrapolated value.

TABLE 32

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.

Alloying Element	1200° F. (648.8° C.)	1400° F. (760.0° C.)	1600° F. (871.1° C.)	1800° F. (982.2° C.)
1.21% Al	0.7*	5.9	31.9	118.6
3.28% Al	0.5	2.8	13.2	56.9
1.13% W	0.8*	3.0	11.9	50.8
2.95% W	0.5	1.6	5.8	38.1
0.91% Ni	0.8	5.7	30.8	88.8
4.13% Ni	1.1*	4.2	26.9	71.3
1.05% Cr	2.1*	20.8	57.0	133.9
4.03% Cr	3.6	34.1	76.0	128.7
1.27% Mn	1.0*	5.4	26.4	82.8
4.11% Mn	1.2*	6.7	39.7	84.6
0.93% Fe	1.0*	5.2	28.5	88.8
3.76% Fe	1.5*	7.0	49.0	146.5
3.34% Cu	1.0*	4.1	20.8	78.5
0.84% V	1.0*	6.4	40.0	205.0*
3.88% V	1.3	5.5	23.0	118.0
0.54% Ta	0.8	2.5	10.6	44.5
4.37% Ta	0.6	2.1	5.3	20.5
1.19% Mo	0.5	1.6	4.8	55.0
3.96% Mo	0.8	2.8	24.0	112.0
1.03% Si	0.5	1.6	8.0	16.0
3.69% Si	0.7	0.9	4.9	39.3
1.00% Cb	0.9	2.4	9.0	45.0
4.45% Cb	0.7	1.8	5.1	19.0
Ti	0.8	3.5	22.6	90.1

*Extrapolated value.

TABLE 33

DATA OBTAINED FROM SCALING TESTS OF TERNARY ALLOYS AT 1200°F. (648.8°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si A	4W - 1Si B	4Cr - 1Mn A	4Cr - 1Mn B	1Cr - 1Fe A	1Cr - 1Fe B	1Al - 1W A	1Al - 1W B	4Ta - 1Si A	4Ta - 1Si B	6W - 1C A	6W - 1C B	2Ni - 1Cu A	2Ni - 1Cu B	6Al - 1Si A	6Al - 1Si B	4Ta - 1Cb A	4Ta - 1Cb B	4Al - 1W A	4Al - 1W B	4Ta - 1W A	4Ta - 1W B	4W - 1Mo A	4W - 1Mo B
23.4	7.4	5.8	2.8	28.4	25.7	13.3	11.6	6.7	4.9	2.5	2.1	6.5	4.5	7.0	9.7	0.0	0.0	4.1	3.0	2.3	2.5	4.9	5.3	3.7	1.7
64.8	22.7	9.8	8.3	73.1	71.9	33.2	31.6	13.3	17.3	7.1	7.4	12.4	10.8	21.2	19.7	3.4	3.1	10.5	8.8	8.4	7.7	11.2	12.2	9.5	8.7
90.5	28.7	11.2	9.5	101.0	94.1	42.5	41.0	15.6	18.0	8.9	8.0	14.8	13.5	22.8	24.1	4.7	3.9	12.4	10.4	10.2	9.6	13.4	14.9	11.8	12.5
117.4	34.5	14.5	11.7	125.2	115.5	54.8	51.4	22.2	22.7	10.8	12.5	18.8	16.4	27.6	28.9	5.7	5.6	17.5	13.8	13.2	12.2	16.0	19.3	14.0	15.3
144.4	37.2	16.1	13.4	149.8	133.7	63.8	62.0	22.3	23.1	13.8	14.7	22.1	17.8	32.3	32.2	7.1	5.8	19.2	16.8	13.2	13.3	17.0	19.5	15.8	16.9

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
23.4	7.4	4.3	27.1	12.5	5.8	2.3	5.5	8.4	0.0	3.6	2.4	5.1	2.7
64.8	22.7	9.1	72.5	32.4	15.3	7.3	11.6	20.5	3.3	9.7	8.1	11.7	9.1
90.5	28.7	10.4	97.6	41.8	16.8	8.5	14.2	23.5	4.3	11.4	9.9	14.2	12.2
117.4	34.5	13.1	120.4	53.1	22.5	11.7	17.6	28.3	5.7	15.7	12.7	17.7	14.7
144.4	37.2	14.8	141.8	62.9	22.7	14.3	20.0	32.3	6.5	18.0	12.8	18.3	16.4

Average Surface Area (cm^2) of Specimens

	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
	27.73	28.05	27.60	27.97	27.70	25.79	27.80	27.86	27.89	27.80	27.21	27.75	27.74

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

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
23.4	0.267	0.153	1.0	0.4	0.209	0.09	0.2	0.3	0.0	0.1	0.1	0.2	0.1
64.8	0.819	0.324	2.6	1.2	0.552	0.3	0.4	0.7	0.118	0.3	0.3	0.4	0.3
90.5	1.035	0.371	3.5	1.5	0.606	0.3	0.5	0.9	0.154	0.4	0.4	0.5	0.4
117.4	1.244	0.467	4.4	1.9	0.812	0.5	0.6	1.0	0.204	0.6	0.5	0.6	0.5
144.4	1.342	0.528	5.1	2.2	0.819	0.6	0.7	1.2	0.233	0.6	0.5	0.7	0.6

NOTE: Compositions are intended; see Table 32 for actual compositions.

TABLE 34

DATA OBTAINED FROM SCALING TESTS OF TERNARY ALLOYS AT 1400°F. (760.0°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si A	4W - 1Si B	4Cr - 1Mn A	4Cr - 1Mn B	1Cr - 1Fe A	1Cr - 1Fe B	1Al - 1W A	1Al - 1W B	4Ta - 1Si A	4Ta - 1Si B	6W - 1C A	6W - 1C B	2Ni - 1Cu A	2Ni - 1Cu B	6Al - 1Si A	6Al - 1Si B	4Ta 1Cb A	4Ta 1Cb B	4Al - 1W A	4Al - 1W B	4Ta - 1W A	4Ta - 1W B	4W - 1Mo A	4W - 1Mo B
26.2	90.3	31.2	22.7	601.3	508.0	308.9	282.9	56.7	54.8	27.7	26.9	45.2	44.7	63.0	63.7	29.6	30.5	39.9	44.1	54.7	52.2	47.4	47.4	44.0	40.8
52.8	115.5	35.4	33.9	738.9	716.7	392.3	369.3	78.3	79.0	37.8	35.3	58.6	56.2	79.0	82.2	37.3	38.6	56.0	55.3	61.6	59.8	58.5	56.9	49.7	48.9
73.7	122.7	35.5	34.2	806.5	780.2	425.7	391.2	79.0	79.5	36.1	36.1	59.5	56.3	81.3	82.9	41.8	41.0	57.0	57.6	65.4	65.8	58.5	58.7	53.0	53.0
100.9	127.6	36.8	38.6	895.3	861.9	477.7	442.6	90.7	90.4	39.5	38.6	68.4	71.5	95.6	96.8	42.1	43.6	60.5	61.4	71.4	72.5	64.8	63.6	56.6	56.6
145.8	152.0	42.5	41.2	1033.3	996.3	548.8	510.4	100.5	100.5	39.7	38.8	73.9	77.6	105.6	106.1	44.2	46.4	64.6	66.0	79.0	79.7	67.5	67.1	57.8	61.3

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
26.2	90.3	27.0	590.7	295.9	55.8	27.3	45.0	63.4	30.1	42.0	53.5	47.4	42.4
52.8	115.5	34.7	727.8	377.3	78.7	36.6	57.4	80.6	38.0	55.7	60.7	57.7	49.3
73.7	122.7	34.9	793.4	408.5	79.3	36.1	57.9	82.1	41.4	57.3	65.6	58.6	53.0
100.9	127.6	37.7	878.6	460.2	90.6	39.1	70.0	96.2	42.9	61.0	72.0	64.2	56.6
145.8	152.0	41.9	1014.8	529.6	100.5	39.3	75.8	105.9	45.3	65.3	79.4	67.3	59.6

Average Surface Area (cm^2) of Specimens

Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
27.95	28.03	27.69	27.82	27.64	27.76	27.81	27.85	27.98	27.39	27.35	27.89	27.90

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

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
26.2	3.2	0.96	21.3	10.6	2.0	0.98	1.6	2.3	1.1	1.5	2.0	1.7	1.5
52.8	4.1	1.23	26.3	13.6	2.8	1.32	2.1	2.9	1.4	2.0	2.2	2.1	1.8
73.7	4.4	1.25	28.7	14.7	2.9	1.30	2.1	2.9	1.48	2.1	2.4	2.1	1.9
100.9	4.6	1.34	31.7	16.6	3.3	1.41	2.5	3.5	1.5	2.2	2.6	2.3	2.0
145.8	5.4	1.49	36.6	19.0	3.6	1.42	2.7	3.8	1.6	2.4	2.9	2.4	2.1

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 35

DATA OBTAINED FROM SCALING TESTS OF TERNARY ALLOYS AT 1600° F. (871. 1°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	4W - 1Si A	4W - 1Si B	4Cr - 1Mn A	4Cr - 1Mn B	1Cr - 1Fe A	1Cr - 1Fe B	1Al - 1W A	1Al - 1W B	4Ta - 1Si A	4Ta - 1Si B	6W - 1C A	6W - 1C B	2Ni - 1Cu A	2Ni - 1Cu B	6Al - 1Si A	6Al - 1Si B	4Ta - 1Cb A	4Ta - 1Cb B	4W - 1Mo A	4W - 1Mo B	4Ta - 1W A	4Ta - 1W B	4Al - 1W A	4Al - 1W B
23.6	277.8	40.1	41.1	1229.3	1171.6	799.8	748.4	123.7	127.8	45.2	43.4	84.5	90.7	128.4	137.4	62.5	59.3	78.0	77.9	57.4	57.9	83.4	82.2	94.1	93.1
47.6	465.6	61.9	64.4	1792.7	1692.4	1296.9	1250.7	190.6	222.0	65.6	61.9	142.3	142.3	207.5	236.9	84.3	86.8	108.9	109.5	80.3	88.5	112.7	112.5	132.4	127.9
73.8	649.4	78.1	84.8	2238.2	2114.8	1743.0	1753.6	256.5	330.0	77.4	72.1	178.5	181.8	297.5	346.6	108.8	105.4	131.6	132.2	112.3	121.6	128.7	129.0	170.2	165.6
98.7	817.3	94.2	99.1	2565.7	2441.9	2104.6	2176.2	325.9	412.9	89.4	85.3	219.6	218.7	392.1	447.4	125.2	121.0	143.6	145.7	142.4	156.0	142.2	144.3	197.4	191.6
124.5	965.9	112.2	118.7	2874.7	2751.0	2412.0	2536.7	407.8	489.4	97.1	97.8	258.7	256.9	515.0	561.5	141.7	134.9	159.8	160.8	173.6	196.9	155.8	156.9	223.2	218.5
145.2	1071.1	119.5	124.1	3073.2	2946.9	2635.1	2795.8	471.8	540.7	104.5	105.6	291.5	290.6	618.2	648.2	154.1	149.4	173.0	172.7	205.0	234.2	165.1	167.2	240.2	231.8

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti(115)	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4W - 1Mo	4Ta - 1W	4Al - 1W
23.6	277.8	40.6	1200.5	774.1	125.8	44.3	87.6	132.9	60.9	78.0	57.7	82.8	93.6
47.6	465.6	63.2	1742.6	1273.8	206.3	63.8	142.3	222.2	85.6	109.2	84.4	112.6	130.2
73.8	649.4	81.5	2176.5	1748.3	293.3	74.8	180.2	322.1	107.1	131.9	117.0	128.9	167.9
98.7	817.3	96.7	2503.8	2140.4	369.4	87.4	219.2	419.8	123.1	144.7	149.2	143.3	194.5
124.5	965.9	115.5	2812.9	2474.4	448.6	97.5	257.8	538.3	138.3	160.3	185.3	156.4	220.9
145.2	1071.1	121.8	3010.1	2715.5	506.3	105.1	291.1	633.2	151.8	172.9	219.6	166.2	236.0

Average Surface Area (cm^2) of Specimens

	Ti(115)	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4W - 1Mo	4Ta - 1W	4Al - 1W
	27.68	27.94	27.59	27.91	27.67	27.80	27.76	27.83	27.93	27.44	27.94	27.99	27.61

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

Cumulative Time (Hours)	Ti(115)	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4W - 1Mo	4Ta - 1W	4Al - 1W
23.6	10.0	1.5	43.5	27.7	4.5	1.6	3.2	4.8	2.2	2.8	2.1	3.0	3.4
47.6	16.8	2.3	63.2	45.6	7.5	2.3	5.1	8.0	3.1	4.0	3.0	4.0	4.7
73.8	23.5	2.9	78.9	62.6	10.6	2.7	6.5	11.6	3.8	4.8	4.2	4.6	6.1
98.7	29.5	3.5	90.8	76.7	13.4	3.1	7.9	15.1	4.4	5.3	5.3	5.1	7.0
124.5	34.9	4.1	102.0	88.7	16.2	3.5	9.3	19.3	5.0	5.8	6.6	5.6	8.0
145.2	38.7	4.4	109.1	97.3	18.3	3.8	10.5	22.8	5.4	6.3	7.9	5.9	8.5

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 36

DATA OBTAINED FROM SCALING TESTS OF TERNARY ALLOYS AT 1800°F. (982.2°C)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si A	4W - 1Si B	4Cr - 1Mn A	4Cr - 1Mn B	1Cr - 1Fe A	1Cr - 1Fe B	1Al - 1W A	1Al - 1W B	4Ta - 1Si A	4Ta - 1Si B	6W - 1C A	6W - 1C B	2Ni - 1Cu A	2Ni - 1Cu B	6Al - 1Si A	6Al - 1Si B	4Ta - 1Cb A	4Ta - 1Cb B	4Al - 1W A	4Al - 1W B	4Ta - 1W A	4Ta - 1W B	4W - 1Mo A	4W - 1Mo B
16.3	1334.7	134.9	125.7	2181.1	2196.0	1827.9	2149.7	565.7	614.0	108.0	107.6	292.5	307.3	340.6	320.0	239.3	225.9	181.6	185.6	256.0	262.0	191.2	195.8	234.5	236.5
23.3	1452.8	190.5	169.7	2627.4	2656.1	2436.6	2751.2	764.6	836.3	136.1	134.2	425.1	458.3	438.7	411.7	307.2	286.7	226.9	232.3	328.8	337.7	225.7	221.6	303.1	306.3
40.8	1647.1	334.5	279.8	3460.8	3470.6	3538.3	3849.7	1128.4	1257.7	187.7	185.2	899.7	912.9	694.9	650.9	415.2	387.8	311.0	315.3	519.9	552.6	331.4	331.8	615.9	624.2
47.2	1711.3	384.7	328.4	3724.3	3721.1	3865.5	4177.3	1249.0	1392.6	205.4	202.5	1066.7	1047.3	819.2	772.0	450.7	421.1	344.4	348.3	587.8	624.3	358.2	354.0	804.9	800.3

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
16.3	1334.7	130.3	2188.6	1988.8	589.9	107.8	299.9	330.3	232.6	183.6	259.0	193.5	235.5
23.3	1452.8	180.1	2641.8	2593.9	800.5	135.2	441.7	425.2	297.0	229.6	333.3	223.7	304.7
40.8	1647.1	307.2	3465.7	3694.0	1193.1	186.5	906.3	672.9	401.5	313.2	536.3	331.6	620.1
47.2	1711.3	356.2	3722.7	4021.4	1320.8	204.0	1057.0	795.6	435.9	346.4	606.1	356.1	802.6

Average Surface Area (cm^2) of Specimens

	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
	27.67	27.93	27.54	27.90	27.72	27.83	27.71	27.82	27.94	27.40	28.06	27.93	27.94

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

Cumulative Time (Hours)	Ti	4W - 1Si	4Cr - 1Mn	1Cr - 1Fe	1Al - 1W	4Ta - 1Si	6W - 1C	2Ni - 1Cu	6Al - 1Si	4Ta - 1Cb	4Al - 1W	4Ta - 1W	4W - 1Mo
16.3	48.2	4.7	79.5	71.3	21.3	3.9	10.8	11.9	8.3	6.7	9.2	6.9	8.4
23.3	52.5	6.4	95.9	93.0	28.9	4.9	15.9	15.3	10.6	8.4	11.9	8.0	10.9
40.8	59.5	11.0	125.8	132.4	43.0	6.7	32.7	24.2	14.4	11.4	19.1	11.9	22.2
47.2	61.8	12.8	135.2	144.1	47.6	7.3	38.1	28.6	15.6	12.6	21.6	12.7	28.7

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 37

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Ternary Ti Alloys at 1200° F. (648.8° C.)

Alloy	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
2 Ni, 1 Cu	0.31	0.52	0.70	0.88	1.0	1.2
6 Al, 1 Si	0.05	0.09	0.13	0.17	0.21	0.24
1 Al, 1 W	0.23	0.39	0.53	0.66	0.78	0.88
4 Ta, 1 Si	0.10	0.20	0.30	0.41	0.51	0.61
4 Cr, 1 Mn	1.10	2.00	2.80	3.6	4.4	5.1
4 Ta, 1 Cb	0.12	0.23	0.33	0.42	0.51	0.60
6 W, 1 C	0.20	0.32	0.46	0.53	0.62	0.70
1 Cr, 1 Fe	0.41	0.80	1.20	1.6	1.9	2.3
4 W, 1Si	0.20	0.29	0.35	0.41	0.46	0.50
4 Al, 1W	0.12	0.23	0.33	0.42	0.51	0.60
Titanium	0.42	0.66	0.86	1.0	1.2	1.3
4 Ta, 1 W	0.20	0.32	0.46	0.53	0.62	0.70
4 W, 1 Mo	0.12	0.23	0.33	0.42	0.51	0.60

Note: Compostions are intended; see Table 32 for actual compositions.

TABLE 38

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Ternary Ti Alloys at 1400° F. (760.0° C.)

Alloy	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
2 Ni, 1 Cu		2.8	3.2	3.4	3.7	3.9
6 Al, 1 Si		1.3	1.5	1.6	1.7	1.8
1 Al, 1 W		2.6	2.9	3.2	3.4	3.6
4 Ta, 1 Si		1.15	1.3	1.4	1.47	1.55
4 Cr, 1 Mn		25.5	29.0	31.0	33.0	35.0
4 Ta, 1 Cb		1.8	2.1	2.25	2.4	2.5
6 W, 1C		1.94	2.2	2.4	2.6	2.7
1 Cr, 1 Fe		13.0	15.0	16.4	17.7	19.0
4 W, 1 Si		1.1	1.25	1.34	1.42	1.5
4 Al, 1 W		2.15	2.4	2.6	2.75	2.9
Titanium		3.9	4.4	4.8	5.1	5.4
4 Ta, 1 W		2.0	2.2	2.3	2.45	2.6
4 W, 1 Mo		1.8	1.9	2.0	2.05	2.1

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 39

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Ternary Ti Alloys at 1600° F. (871.1° C.)

Alloy	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
2 Ni, 1 Cu	4.9	8.6	11.9	15.0	18.0	20.8
6 Al, 1 Si	2.2	3.1	3.8	4.4	4.9	5.4
1 Al, 1 W	4.3	7.6	10.5	13.2	15.6	18.2
4 Ta, 1 Si	1.6	2.2	2.7	3.1	3.4	3.7
4 Cr, 1 Mn	44.0	63.0	78.0	91.0	100.0	110.0
4 Ta, 1 Cb	2.85	3.9	4.6	5.2	5.8	6.3
6 W, 1 C	2.95	4.8	6.4	7.8	9.2	10.4
1 Cr, 1 Fe	28.0	46.0	61.0	75.0	88.0	100.0
4 W, 1 Si	1.4	2.2	2.9	3.5	4.0	4.5
4 Al, 1 W	3.4	4.9	6.0	7.0	7.8	8.5
Titanium	10.3	17.0	23.0	28.7	34.0	39.0
4 Ta, 1 W	3.0	3.9	4.6	5.1	5.6	6.0
4 W, 1 Mo	1.7	3.0	4.2	5.4	6.5	7.5

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 40

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Ternary Ti Alloys at 1800° F. (982.2° C)

Alloy	24 Hours	48 Hours
2 Ni, 1 Cu	16.0	29.0
6 Al, 1 Si	10.7	15.7
1 Al, 1 W	30.0	48.0
4 Ta, 1 Si	4.9	7.4
4 Cr, 1 Mn	96.0	135.0
4 Ta, 1 Cb	8.4	12.7
6 W, 1 C	17.0	39.0
1 Cr, 1 Fe	91.0	145.0
4 W, 1 Si	6.6	13.0
4 Al, 1 W	12.3	22.0
Titanium	52.8	62.0
4 Ta, 1 W	8.4	12.7
4 W, 1 Mo	12.5	27.0

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 41

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Ternary Ti Alloys over Period of Forty-Eight Hours
at 1200°, 1400°, 1600°, 1800° F.

Alloy	1200° F. (648.8° C.)	1400° F. (760.0° C.)	1600° F. (871.1° C.)	1800° F. (982.2° C.)
2 Ni, 1 Cu	0.52	2.8	8.6	29.0
6 Al, 1 Si	0.09	1.3	3.1	15.7
1 Al, 1 W	0.39	2.6	7.6	48.0
4 Ta, 1 Si	0.20	1.15	2.2	7.4
4 Cr, 1 Mn	2.0	25.5	63.0	135.0
4 Ta, 1 Cb	0.23	1.8	3.9	12.7
6 W, 1 C	0.32	1.94	4.8	39.0
1 Cr, 1 Fe	0.8	13.0	46.0	145.0
4 W, 1 Si	0.29	1.1	2.2	13.0
4 Al, 1 W	0.23	2.15	4.9	22.0
Titanium	0.66	3.9	17.0	62.0
4 Ta, 1 W	0.32	2.0	3.9	12.7
4 W, 1 Mo	0.23	1.8	3.0	27.0

Note: Compositions are intended; see Table 32 for actual compositions.

TABLE 42

DATA OBTAINED FROM SCALING TESTS OF COMMERCIAL ALLOYS AT 1200°F. (648.8°C.)

(Weight Increase of Ribbons Included)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti A	Ti B	RC-130A A	RC-130A B	RS-70 A	RS-70 B	RS-110A A	RS-110A B	RC-130B A	RC-130B B	MST-3Al,5Cr A	MST-3Al,5Cr B	MST-2.5Fe,2.5V* A	MST-2.5Fe,2.5V* B	MST-2.5Fe,2.5V** A	MST-2.5Fe,2.5V** B	MST-2Al,2Fe A	MST-2Al,2Fe B
19.5	19.6	16.9	32.4	33.3	16.2	20.8	31.9	27.4	18.0	23.8	44.3	38.9	24.3	18.4	20.7	19.5	19.4	17.4
66.8	44.6	45.6	72.5	74.0	46.0	47.8	70.3	68.3	45.4	50.8	107.9	100.8	48.2	43.4	45.7	41.0	45.4	40.0
115.8	64.7	61.5	102.8	100.9	67.2	66.7	99.4	94.1	66.5	70.0	144.9	135.1	71.3	68.1	67.9	69.4	64.2	56.0
145.0	72.1	69.1	112.9	111.4	76.7	75.8	114.3	110.6	75.8	81.1	161.2	153.3	81.1	79.7	80.2	79.7	74.7	70.2

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe
19.5	18.3	32.9	18.5	29.7	20.9	41.6	21.4	20.1	18.4
66.8	45.1	73.3	46.9	69.3	48.1	104.4	45.8	43.4	42.7
115.8	63.1	101.9	67.0	98.3	68.3	140.0	69.7	68.7	60.1
145.0	70.6	112.2	76.3	112.5	78.5	157.3	80.4	80.0	72.5

Average Surface Area (cm^2) of Specimens

	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe
	27.52	26.77	25.15	26.26	27.28	27.25	27.14	26.65	25.14

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

Cumulative Time (Hours)	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe
19.5	0.7	1.2	0.7	1.1	0.8	1.5	0.8	0.8	0.7
66.8	1.6	2.7	1.9	2.6	1.8	3.8	1.7	1.6	1.7
115.8	2.3	3.8	2.7	3.7	2.5	5.1	2.6	2.6	2.4
145.0	2.6	4.2	3.0	4.3	2.9	5.8	3.0	3.0	2.9

* - 2.67% Fe, 2.68% V, Bal. Ti
** - 2.28% Fe, 2.55% V Bal. Ti

TABLE 43

DATA OBTAINED FROM SCALING TESTS OF COMMERCIAL ALLOYS AT 1400°F. (760. 0°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Type 302*	Ti A	Ti B	RC-130A A	RC-130A B	RS-70 A	RS-70 B	RS-110A A	RS-110A B	RC130B A	RC130B B	MST-3Al,5Cr A	MST-3Al,5Cr B	MST-2.5Fe,2.5V** A	MST-2.5Fe,2.5V** B	MST-2.5Fe,2.5V† A	MST-2.5Fe,2.5V† B	MST-2Al,2Fe A	MST-2Al,2Fe B
17.7	5.1	52.2	57.1	125.5	125.9	68.8	63.4	136.4	145.1	108.3	107.9	180.5	179.6	108.2	109.5	103.5	101.0	74.7	80.3
44.7	6.2	95.4	100.5	266.8	260.0	123.4	112.6	253.4	288.5	210.7	206.1	288.4	287.6	204.4	202.1	196.9	189.2	150.7	150.8
68.7	6.2	120.5	128.5	365.5	353.6	170.9	154.2	341.8	378.0	272.5	267.1	380.1	384.6	262.5	263.1	257.5	247.1	201.0	198.0
141.7	10.0	202.5	225.3	613.9	603.9	315.4	282.3	599.2	611.8	431.8	428.7	640.3	658.2	409.4	406.3	392.1	381.4	346.3	338.0
185.1	10.0	243.3	277.2	725.8	715.9	391.7	353.5	708.9	738.7	506.2	504.2	785.8	815.0	473.1	478.8	454.6	443.1	419.1	404.8

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Type 302*	Ti	RC-130A	RS-70	RS-110A	RC130B	MST-3Al,5Cr	MST-2.5Fe,2.5V**	MST-2.5Fe,2.5V†	MST-2Al,2Fe
17.7	5.1	54.7	125.7	66.1	130.8	108.1	180.1	108.9	102.3	77.5
44.7	6.2	98.2	263.4	118.0	271.0	214.0	288.0	203.3	193.1	150.8
68.7	6.2	124.5	359.6	162.6	360.0	269.8	382.4	262.8	252.3	199.5
141.7	10.0	213.9	613.9	298.8	605.5	430.3	649.3	407.9	386.8	342.2
185.1	10.0	260.3	730.8	362.4	723.8	505.2	800.4	475.9	448.9	412.0

Average Surface Area (cm^2) of Specimens

Type 302*	Ti	RC-130A	RS-70	RS-110A	RC130B	MST-3Al,5Cr	MST-2.5Fe,2.5V**	MST-2.5Fe,2.5V†	MST-2Al,2Fe
27.65	27.48	26.85	25.17	26.45	27.54	27.71	26.57	26.65	24.87

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

Cumulative Time (Hours)	Type 302*	Ti	RC-130A	RS-70	RS-110A	RC130B	MST-3Al,5Cr	MST-2.5Fe,2.5V**	MST-2.5Fe,2.5V†	MST-2Al,2Fe
17.7	0 2	2.0	4.7	2.6	4.9	3.9	6.5	4.1	3.8	3.1
44.7	.2	3.6	9.8	4.7	10.9	7.8	10.4	7.7	7.2	6.1
68.7	0.2	4.5	13.4	6.5	13.6	9.8	13.8	9.9	9.5	8.0
141.7	0.4	7.8	22.9	11.9	22.9	15.6	23.4	15.4	14.5	13.8
185.1	0.4	9.5	27.2	14.4	27.4	18.3	28.9	17.9	16.8	16.6

* - Stainless Steel (Republic Steel)
** - 2.67% Fe, 2.68% V, Bal. Ti
† - 2.28% Fe, 2.55% V, Bal. Ti

TABLE 44

DATA OBTAINED FROM SCALING TESTS OF COMMERCIAL ALLOYS AT 1600°F. (871.1°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti A	Ti B	RC-130A A	RC-130A B	RS-70 A	RS-70 B	RS-110A A	RS-110A B	RC-130B A	RC-130B B	MST-3Al,5Cr A	MST-3Al,5Cr B	MST-2.5Fe,2.5V* A	MST-2.5Fe,2.5V* B	MST-2.5Fe,2.5V** A	MST-2.5Fe,2.5V** B	MST-2Al,2Fe A	MST-2Al,2Fe B	Type 302†
34.0	787.3	880.8	984.2	974.4	922.9	1010.6	1009.2	1019.0	947.4	978.2	1043.1	1043.8	740.7	760.8	735.7	743.8	808.3	778.4	126.9
52.2	1021.1	1108.3	1254.0	1230.1	1039.7	1159.0	1318.6	1336.7	1320.9	1363.5	1280.5	1279.2	1054.9	1069.2	981.6	986.1	1120.4	1069.0	166.7
74.2	1160.7	1240.2	1563.2	1497.7	1116.3	1243.6	1644.8	1654.4	1728.0	1729.9	1536.1	1534.1	1410.1	1425.5	1256.3	1258.2	1482.2	1441.3	191.5
96.0	1238.4	1304.7	1976.1	1882.0	1173.0	1302.5	1979.3	1970.6	2089.5	2106.2	1784.9	1793.5	1795.8	1814.9	1530.3	1508.4	1790.1	1820.0	204.0
172.3	1371.2	1419.6	2836.4	2798.9	1370.7	1460.3	2742.5	2769.2	2789.5	2853.3	2383.6	2409.1	2790.6	2596.4	2254.6	2189.1	1889.5	1875.8	233.1

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe	Type 302†
34.0	834.0	979.3	966.7	1014.1	962.8	1043.4	750.8	739.8	793.3	121.9
52.2	1064.7	1242.0	1099.3	1327.6	1342.2	1279.8	1062.0	983.9	1094.7	168.7
74.2	1200.4	1530.6	1179.9	1649.6	1728.9	1535.1	1417.8	1257.2	1461.7	191.5
96.0	1271.5	1929.0	1237.7	1974.9	2097.8	1789.2	1805.3	1519.3	1805.0	204.0
172.3	1395.4	2817.6	1415.5	2755.8	2821.4	2396.3	2693.5	2221.8	1882.6	233.1

Average Surface Area (cm^2) of Specimens

	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe	Type 302†
	27.86	26.84	25.39	26.23	27.49	26.79	26.84	26.56	24.83	27.66

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

Cumulative Time (Hours)	Ti	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V*	MST-2.5Fe,2.5V**	MST-2Al,2Fe	Type 302†
34.0	29.9	36.5	38.1	38.7	35.0	38.9	28.0	27.9	32.9	4.1
52.2	38.2	46.3	43.3	50.6	48.8	47.8	39.6	37.0	44.1	6.1
74.2	43.1	57.0	46.5	62.9	62.9	57.3	52.8	47.3	58.9	6.9
96.0	45.6	71.9	48.8	75.3	76.3	66.8	67.3	51.2	72.7	7.4
172.3	50.1	105.0	55.8	105.1	102.6	89.4	100.4	83.7	75.8	8.4

* - 2.67% Fe, 2.68% V, Bal. Ti
** - 2.28% Fe, 2.55% V, Bal. Ti
† - Stainless Steel (Republic Steel)

TABLE 45

DATA OBTAINED FROM SCALING TESTS OF COMMERCIAL ALLOYS AT 1800°F (982 2°C.)

Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Type 302* A	Type 302* B	Type 302** A	Type 302** B	RC-130A A	RC-130A B	RS-70 A	RS-70 B	RS-110A A	RS-110A B	RC-130B A	RC-130B B	MST-3Al,5Cr A	MST-3Al,5Cr B	MST-2.5Fe,2.5V† A	MST-2.5Fe,2.5V† B	MST-2.5Fe,2.5V‡ A	MST-2.5Fe,2.5V‡ B	MST-2Al,2Fe A	MST-2Al,2Fe B	Ti A	Ti B
4.0	25.9	34.0	41.8	32.8	818.1	847.1	783.8	796.5	880.2	896.6	967.8	981.2	608.7	621.3	448.9	452.2	626.1	617.2	712.5	718.1	651.1	649.0
16.5	317.1	338.5	416.2	424.6	2321.1	2392.5	1270.0	1265.5	2427.6	2485.1	2382.5	2483.0	1056.6	1076.1	1568.4	1576.3	1509.7	1460.7	2051.0	2018.5	1104.7	1106.2
21.2	384.2	401.4	488.2	497.0	2749.1	2791.8	1389.2	1380.6	2564.7	3003.8	2768.6	2800.5	1179.0	1231.8	1893.2	1880.8	1703.4	1703.0	2369.4	2328.7	1202.2	1199.2
41.5	563.5	569.3	684.1	702.5	3775.6	3772.3	1936.5	1887.6	4382.3	4407.0	3278.9	3312.8	1764.6	1742.1	2809.9	3041.5	2453.8	2443.1	2771.9	2780.2	1834.7	1800.0
46.3	594.1	599.1	727.8	747.7	3808.8	3793.2	2078.8	2041.1	4486.1	4464.1	3293.8	3313.0	1856.4	1841.6	3013.4	3296.3	2457.8	2446.0	2772.4	2782.0	2053.1	1978.1

Average Cumulative Weight Increase (mg) of Specimens

Cumulative Time (Hours)	Type 302*	Type 302**	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V†	MST-2.5Fe,2.5V‡	MST-2Al,2Fe	Ti
4.0	30.0	37.3	832.6	790.2	888.4	974.5	616.9	450.6	621.7	715.3	650.1
16.5	327.8	420.4	2356.8	1267.8	2456.4	2432.8	1066.4	1572.4	1485.2	2034.8	1105.5
21.2	392.8	492.6	2770.5	1384.9	2984.3	2784.6	1205.4	1887.0	1703.2	2349.1	1200.7
41.5	566.4	693.3	3774.0	1912.1	4394.7	3295.9	1753.4	2922.2	2448.5	2776.1	1817.4
46.3	596.6	737.8	3801.0	2060.0	4475.1	3303.4	1849.0	3154.9	2451.9	2777.2	2015.6

Average Surface Area (cm ^{2}) of Specimens

	Type 302*	Type 302**	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V†	MST-2.5Fe,2.5V‡	MST-2Al,2Fe	Ti
	27.68	27.40	26.67	25.60	26.26	27.18	27.27	27.16	26.70	25.23	27.70

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

Cumulative Time (Hours)	Type 302*	Type 302**	RC-130A	RS-70	RS-110A	RC-130B	MST-3Al,5Cr	MST-2.5Fe,2.5V†	MST-2.5Fe,2.5V‡	MST-2Al,2Fe	Ti
4.0	1.1	1.4	31.3	30.9	33.8	35.9	22.6	16.6	23.3	28.3	23.5
16.5	11.9	15.4	88.5	49.5	93.6	89.5	39.1	57.9	55.6	80.6	39.9
21.2	14.2	18.0	104.0	54.1	113.7	102.4	44.2	69.7	63.8	93.1	43.4
41.5	20.5	25.3	141.7	74.7	167.4	121.3	64.3	107.7	91.7	110.0	65.6
46.3	21.6	26.9	142.7	80.5	170.4	121.5	67.8	116.2	91.8	110.0	72.8

* - Stainless Steel (Republic Steel)
** - Stainless Steel (United States Steel)
† - 2.67% Fe, 2.68% V, Bal. Ti
‡ - 2.28% Fe, 2.55% V, Bal. Ti

TABLE 46

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1200° F. (648.8° C.)

Alloy	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
MST-2% Fe, 2% Al	0.8	1.3	1.7		2.5	
MST-2.5% Fe, 2.5% V*	0.9	1.4	1.8	2.2	2.5	2.8
MST-2.5% Fe, 2.5% V**	0.91	1.4	1.9	2.2	2.6	2.9
MST-3% Al, 5% Cr	1.9	2.9	3.9	4.7	5.4	6.1
RC-130B	0.9	1.4	1.9	2.2	2.6	2.9
RS-110A	1.3	2.1	2.7	3.3	3.8	4.3
RS-70	0.9	1.5	2.0	2.3	2.8	3.1
RC-130A	1.4	2.2	2.8	3.4	3.8	4.3
Titanium	0.8	1.3	1.7	2.0	2.4	2.6

* - 2.28% Fe, 2.55% V Bal. Ti.
** - 2.67% Fe, 2.68% V Bal. Ti.

TABLE 47

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PERAVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1400° F. (760.0° C.)

Alloy	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
MST-2% Fe, 2% Al	3.9	6.4	8.4	10.5	12.0	14.0	15.5
MST-2.5% Fe, 2.5% V*	5.0	7.6	9.6	11.5	13.0	14.5	16.0
MST-2.5% Fe, 2.5% V**	5.3	8.0	10.0	12.0	14.0	15.5	16.5
MST-3% Al, 5% Cr	6.2	10.5	14.0	17.5	21.0	24.0	27.0
RC-130B	4.8	7.6	10.0	12.0	14.0	16.0	17.0
RS-110A	6.4	10.5	14.0	17.0	20.0	23.0	25.0
RS-70	2.9	5.0	6.8	8.6	10.0	12.0	13.0
RC-130A	5.9	10.0	13.0	17.0	20.0	23.0	26.0
Type 302 S.S. (Republic)	0.2	0.2	0.27	0.30	0.32	0.34	0.35
Titanium	2.4	3.8	4.9	5.9	6.3	7.4	8.2

* - 2.28% Fe, 2.55% V
** - 2.67% Fe, 2.68% V

TABLE 48

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1600° F. (871.1° C.)

Alloy	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
MST-2% Fe, 2% Al	41.0	57.0	72.0	85.0*	98.0*	
MST-2.5% Fe, 2.5% V**	35.0	46.0	56.0	66.0	74.0	82.0
MST-2.5% Fe, 2.5% V***	37.0	51.0	64.0	76.0	88.0	98.0
MST-3% Al, 5% Cr	46.0	57.0	66.0	74.0	81.0	87.0
RC-130B	46.0	59.0	72.0	83.0	94.0	105.0
RS-110A	47.0	61.0	73.0	84.0	94.0	105.0
RS-70	41.0	45.5	48.8	51.0	53.0	55.0
RC-130A	46.0	59.0	72.0	83.0	93.0	103.0
Type 302 S.S. (Republic)	6.0	6.7	7.2	7.6	8.0	8.4
Titanium	35.0	40.0	44.0	48.0	51.0	54.0

* - Extrapolated Value.
** - 2.28% Fe, 2.55% V
*** - 2.67% Fe, 2.68% V

TABLE 49

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Tests at 1800° F. (982.2 °C.)

Alloy	24 Hours	48 Hours*
MST-2% Fe, 2% Al	93.0	110.0
MST-2.5% Fe, 2.5% V**	66.0	96.0
MST-2.5% Fe, 2.5V***	75.0	120.0
MST-3% Al, 5% Cr	48.0	69.0
RC-130B	103.0	130.0
RS-110A	118.0	184.0
RS-70	60.0	78.0
RC-130A	106.0	155.0
Ti	48.0	72.0
Type 302 S.S. (U.S.S.)	19.0	27.0
Type 302 S.S. (Republic)	15.0	22.0

* - Extrapolated value
** - 2.28% Fe, 2.55% V
*** - 2.67% Fe, 2.68% V

TABLE 50

AVERAGE CUMULATIVE WEIGHT INCREASE (mg) PER AVERAGE ORIGINAL UNIT AREA (cm^2)
Data Obtained from Scaling Commercial Ti and Ti Alloys over Period of Forty-Eight Hours at 1200°, 1400°, 1600°, and 1800° F.

Alloy	1200° F. (648.8° C.)	1400° F. (760.0° C.)	1600° F. (871.1° C.)	1800° F. (982.2° C.)
MST-2% Fe, 2% Al	1.3	6.4	41.0	110.0
Titanium	1.3	3.8	35.0	72.0
MST-2.5% Fe, 2.5% V*	1.4	7.6	35.0	120.0
MST-2.5% Fe, 2.5% V**	1.4	8.0	37.0	96.0
RS-130B	1.4	7.6	46.0	130.0
RS-70	1.5	5.0	41.0	78.0
RS-110A	2.1	10.5	47.0	184.0
RC-130A	2.2	10.0	46.0	155.0
MST-3% Al, 5% Cr	2.9	10.5	46.0	69.0
Type 302 S.S (Republic)	0.15	0.24	6.0	22.0
Type 302 S.S. (U.S.S.)				27.0

* 2.67% Fe, 2.68% V
** 2.28% Fe, 2.55% V

TABLE 51

SHORT TIME SCALING DATA OBTAINED AT 1200° F. (648.8° C.)
(Non-Commercial Titanium - Heat 115)

Time (Min.)	Initial Specimen Weight (gm)	Final Specimen Weight (gm)	Specimen Area $(dm)^2$	Cumulative Weight Increase (mg) Per Original Unit Area (dm^2)
10	7.2181	7.2188	0.2814	2.5
20	7.0640	7.0657	0.2819	6.0
30	7.2235	7.2260	0.2816	8.9
40	7.9470	7.9508	0.2836	13.4
50	7.9245	7.9286	0.2833	14.5
60	7.0894	7.0945	0.2815	18.0
90	7.9159	7.9218	0.2837	20.8
120	7.1395	7.1465	0.2814	25.0
180	7.9080	7.9163	0.2837	29.3
210	7.9748	7.9839	0.2832	32.0
240	6.9279	6.9378	0.2836	34.8

TABLE 52

DATA UTILIZED IN PLOTTING WEIGHT INCREASE RAISED TO 0.93 POWER AS A FUNCTION OF TIME AT 1200° F. (648.8° C.)
(Heat Number 115 - - Non-Commercial Ti)

W	K	t	X	$W^{\frac{1}{x}}$	$\frac{1}{x}$
2.49	13.76	0.17	1.08	2.34	0.93
6.03	15.65	0.33	1.08	5.32	0.93
8.88	15.24	0.50	1.08	7.62	0.93
13.40	16.50	0.68	1.08	11.2	0.93
14.47	14.12	0.83	1.08	12.0	0.93
18.00	14.70	1.00	1.08	14.7	0.93

$W = (Kt)^x$

Where:

W = Weight Increase (mg per dm^2)

K = Constant

t = time (hours)

x = slope

TABLE 53

DATA UTILIZED IN PLOTTING WEIGHT INCREASE RAISED TO 2.0 POWER AS A FUNCTION OF TIME AT 1200° F. (648.8° C.)
(Heat Number 115 - - Non-Commercial Ti)

W	K	t	x	$W^{\frac{1}{x}}$	$\frac{1}{x}$
20.80	288.67	1.50	0.5	433	2.0
25.00	312.50	2.00	0.5	625	2.0
29.26	286.10	3.00	0.5	858.5	2.0
32.00	291.00	3.50	0.5	1020	2.0
34.8	302.5	4.00	0.5	1210	2.0

$W = (Kt)^x$

Where:

W = Weight increase (mg per dm^2)

K = Constant

t = time (hours)

x = slope

TABLE 54

DATA UTILIZED IN PLOTTING WEIGHT INCREASE RAISED TO 1.54 POWER AS A FUNCTION OF TIME AT 1200° F. (648.8° C) (Heat Number 115 - - Non-Commercial Ti)

W	K	t	x	$W^{\frac{1}{x}}$	$\frac{1}{x}$
41.1	13.08	23.4	0.65	306.0	1.54
81.9	13.64	64.8	0.65	884.0	1.54
103.5	14.14	90.5	0.65	1280.0	1.54
124.4	14.95	117.4	0.65	1670.0	1.54
134.2	14.61	144.4	0.65	2110.0	1.54

$W = (Kt)^x$

Where:

W = Weight increase (mg per dm^2)

K = Constant

t = time (hours)

x = slope

TABLE 55

DATA EMPLOYED IN PLOTTING INDICATED TRANSITION IN SLOPE OF TITANIUM AT 1800° F. (982.2° C.)

Cumulative Time (Hours)	Average Cumulative Weight Increase (mg) Per Average Original Unit Area (cm^2)	
	Heat No. 7	Heat No. 8
4.8	19.0	23.6
7.3	23.0	34.6
28.2	68.6	105.9
34.4	75.4	116.9
49.3	91.7	136.5
54.7	95.9	143.2

TABLE 56

VARIATION OF SLOPE OF TITANIUM CURVES AT TEMPERATURES OF 1200°, 1400°, 1600°, and 1800° F.

	Temperature and Corresponding Slope				Percent Difference of Specific and Average Values of Slope			
	1200° F.	1400° F.	1600° F.	1800° F.	1200° F.	1400° F.	1600° F.	1800° F.
Heat Number 7[a]	0.66	....	....	0.33	+6.5%	....	....	-13.2%
Heat Number 8[a]	0.57	0.74	0.35	0.45	-8.1%	+19.4%	-18.6%	+15.6%
Heat Number 21[a]	0.55	0.70	0.55	....	-11.3%	+12.9%	+27.9%	....
Heat Number 82[b]	0.59	....	....	....	-4.8%	....	....	....
Heat Number 112[a]	....	0.68	0.28	0.57	....	+9.7%	-34.9%	+33.3%
Heat Number 115[a]	0.65	0.26	0.75	0.23	+4.8%	-41.9%	+74.4%	-39.5%
RS-70[c]	0.71	0.71	0.21	0.37	+14.5%	+14.5%	-51.1%	-2.6%

a. Non-commercial
b. Non-commercial; melted five times
c. Commercial

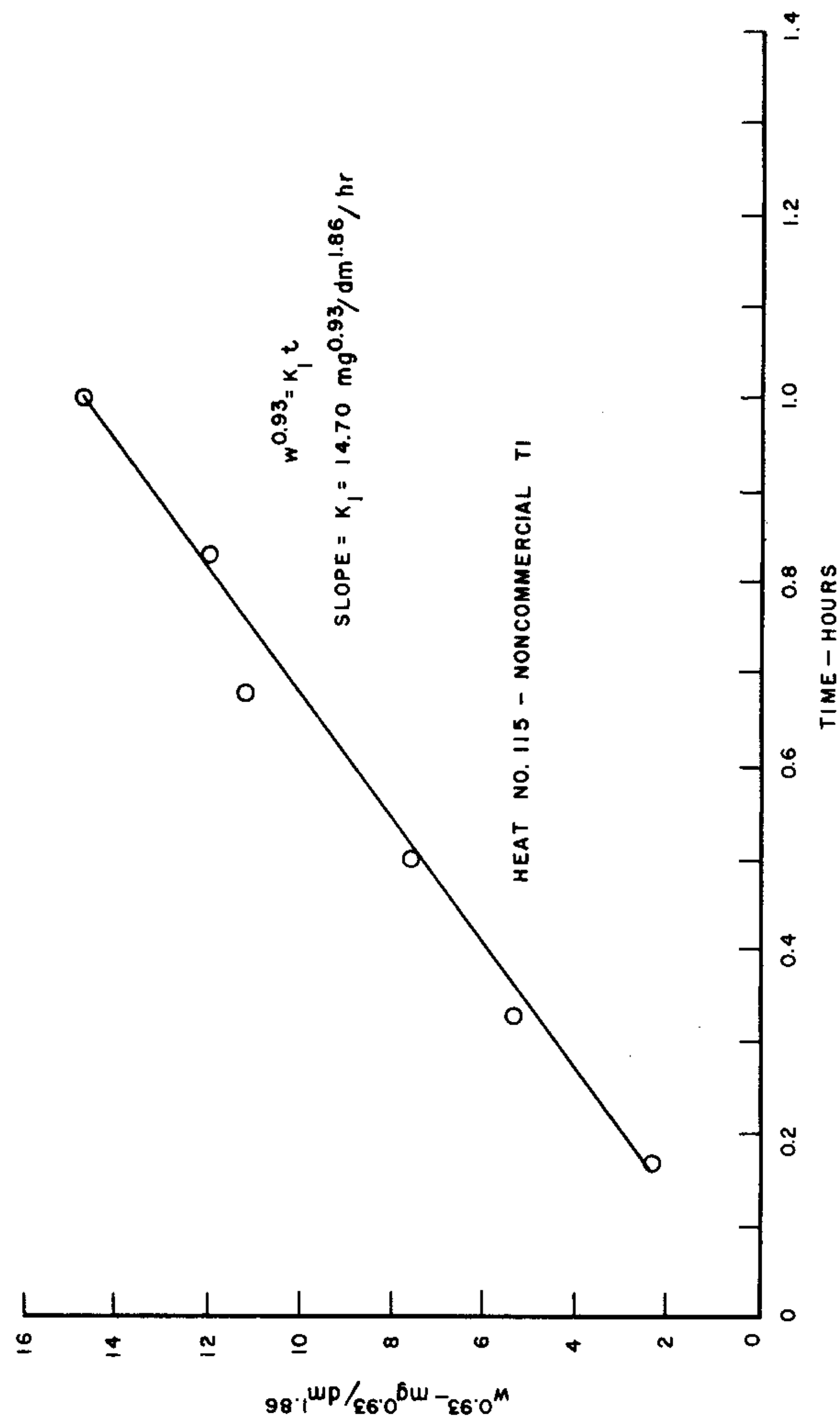

FIG.18 WEIGHT INCREASE RAISED TO 0.93 POWER AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

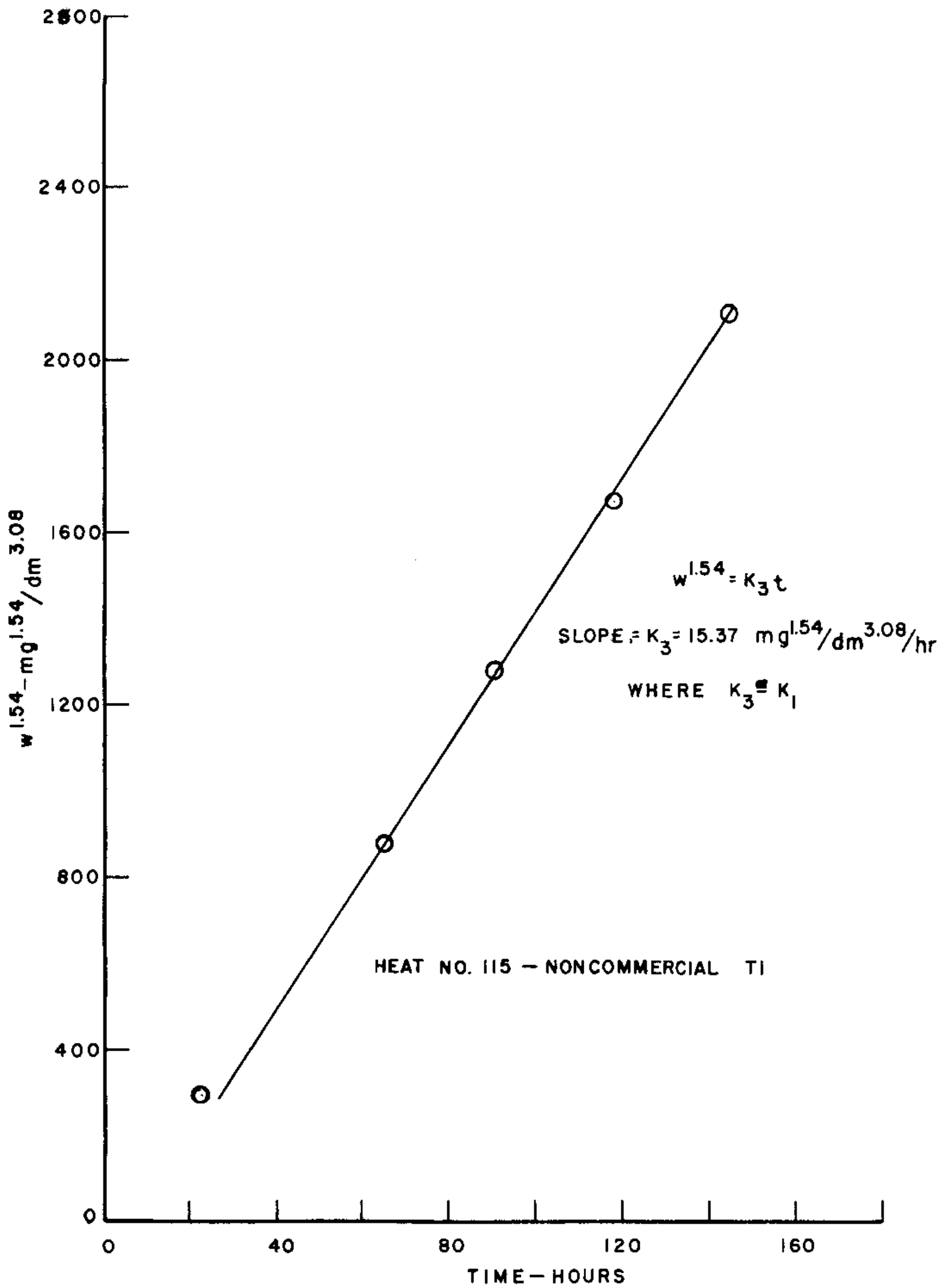

FIG. 19 WEIGHT INCREASE RAISED TO 1.54 POWER AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

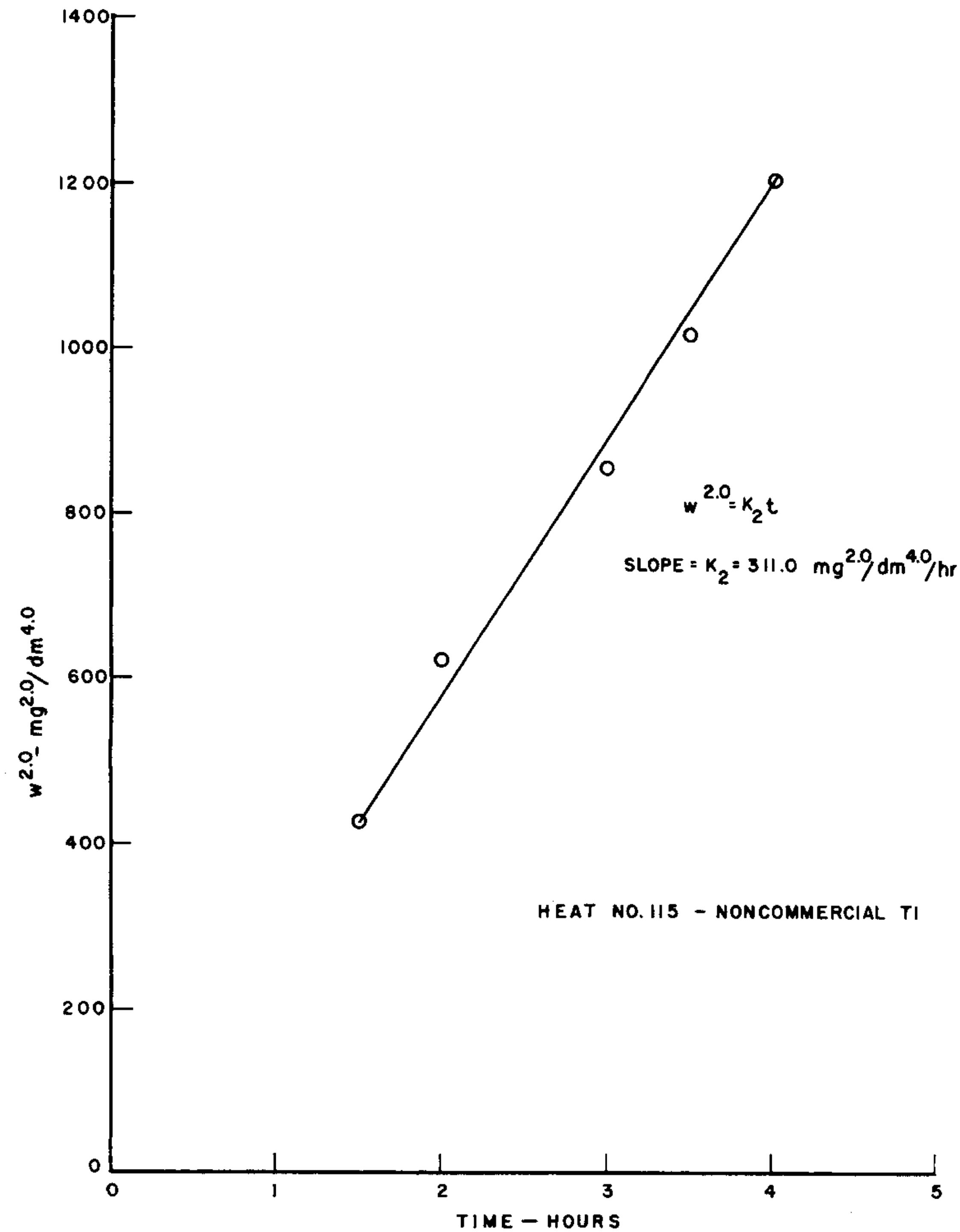

FIG. 20 WEIGHT INCREASE RAISED TO 2.0 POWER AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

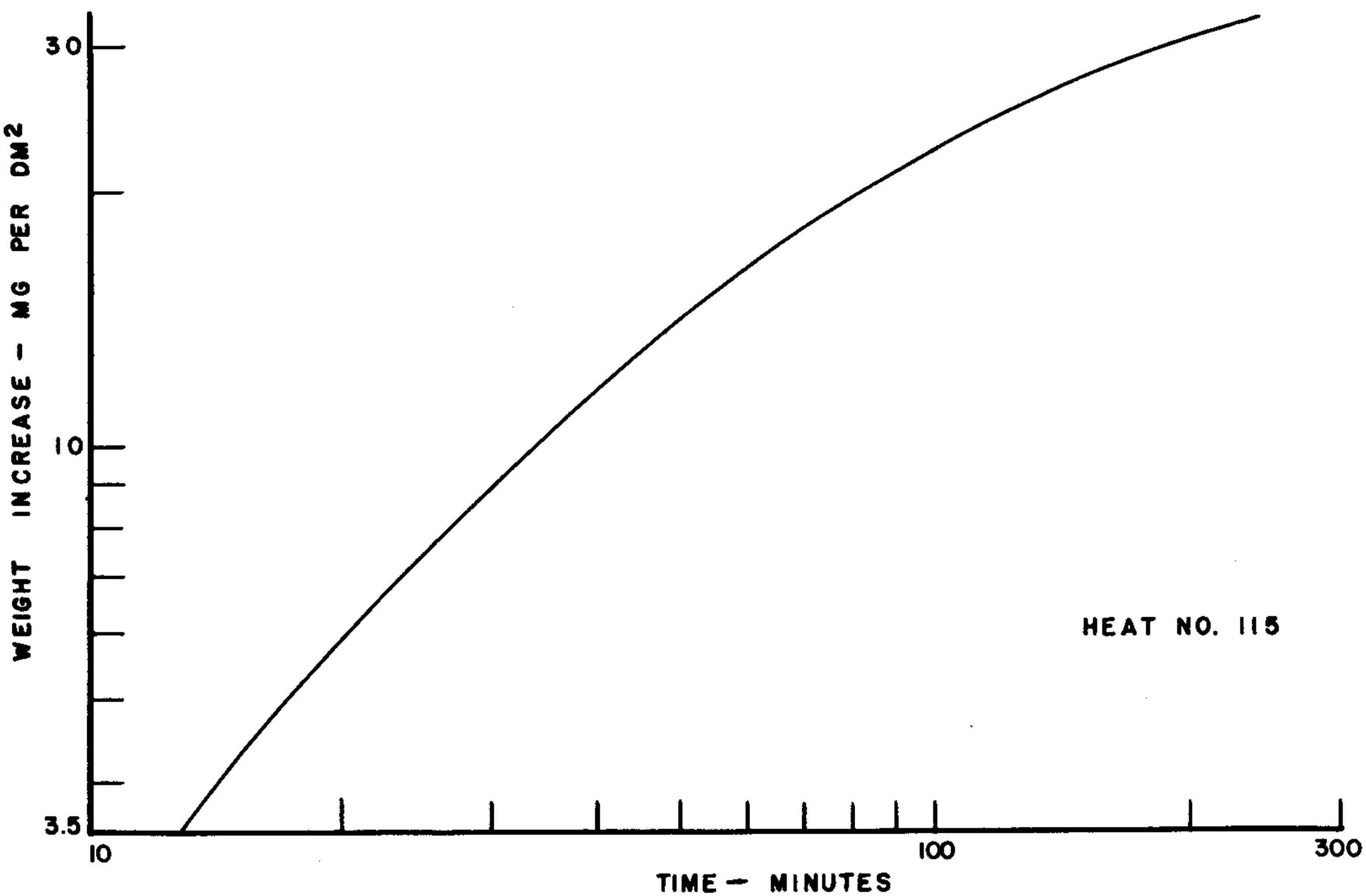

FIG.21 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

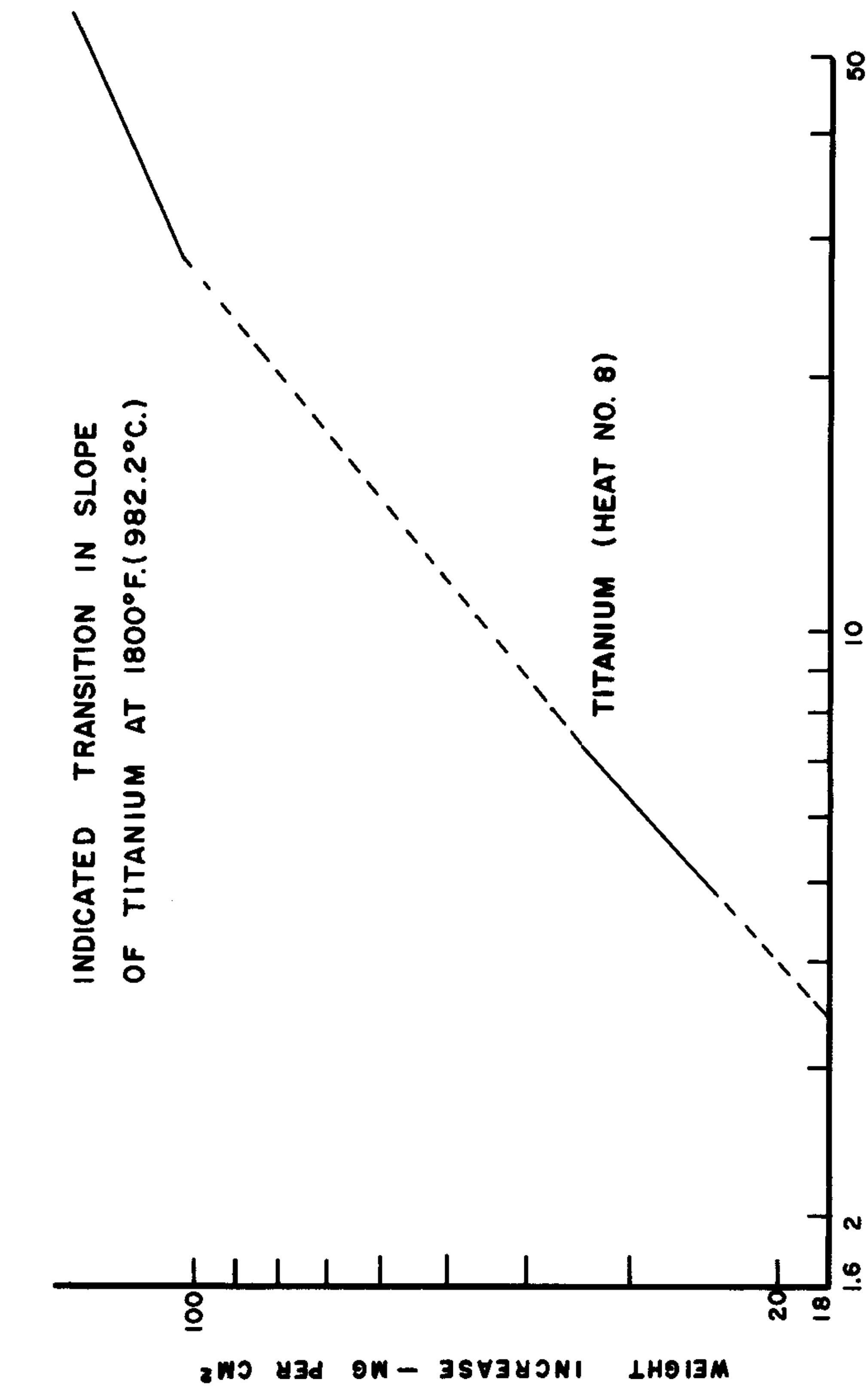

FIG.22 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F.(982.2°C.)

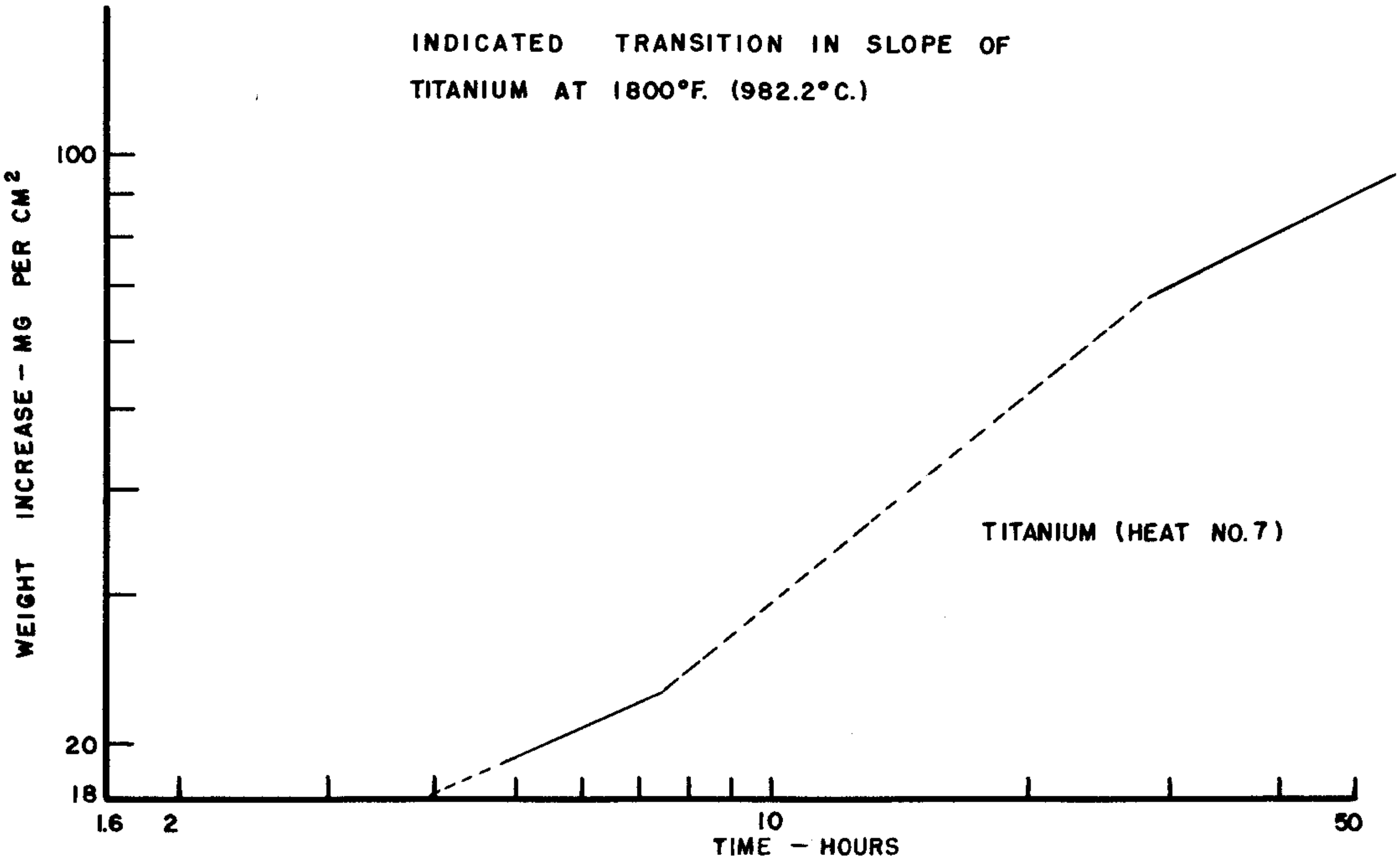

FIG. 23 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

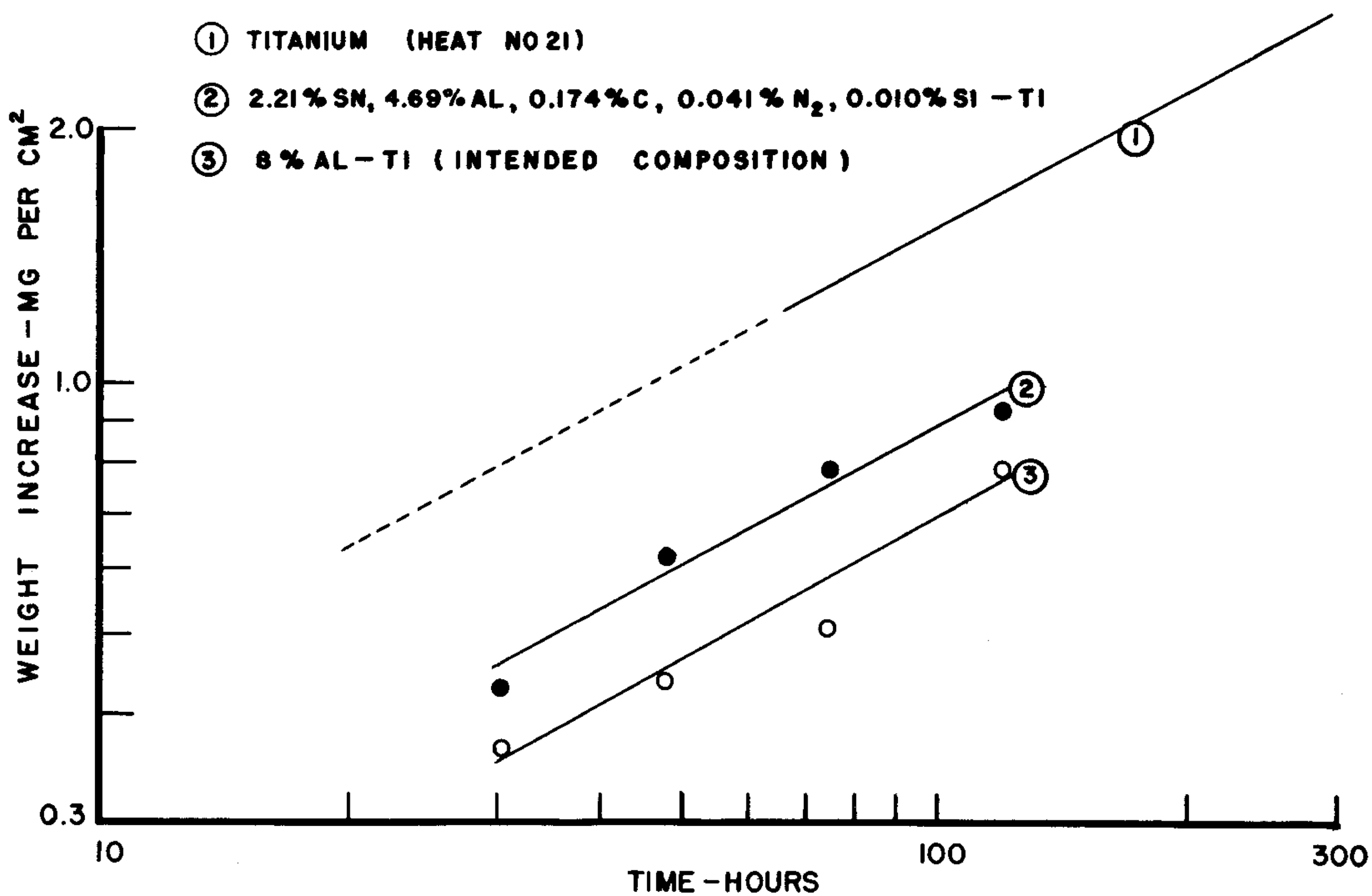

FIG. 24 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

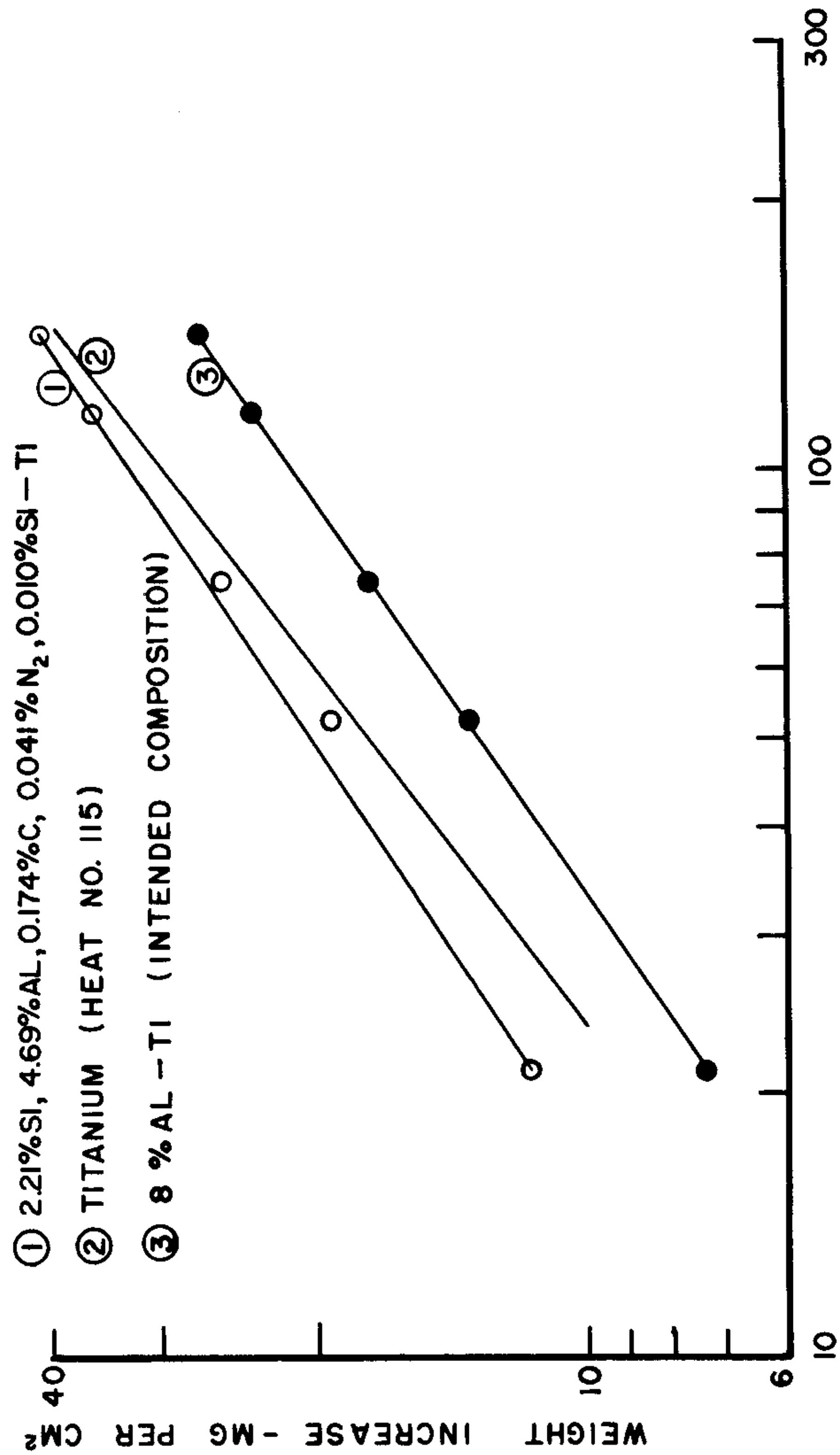

FIG.25 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

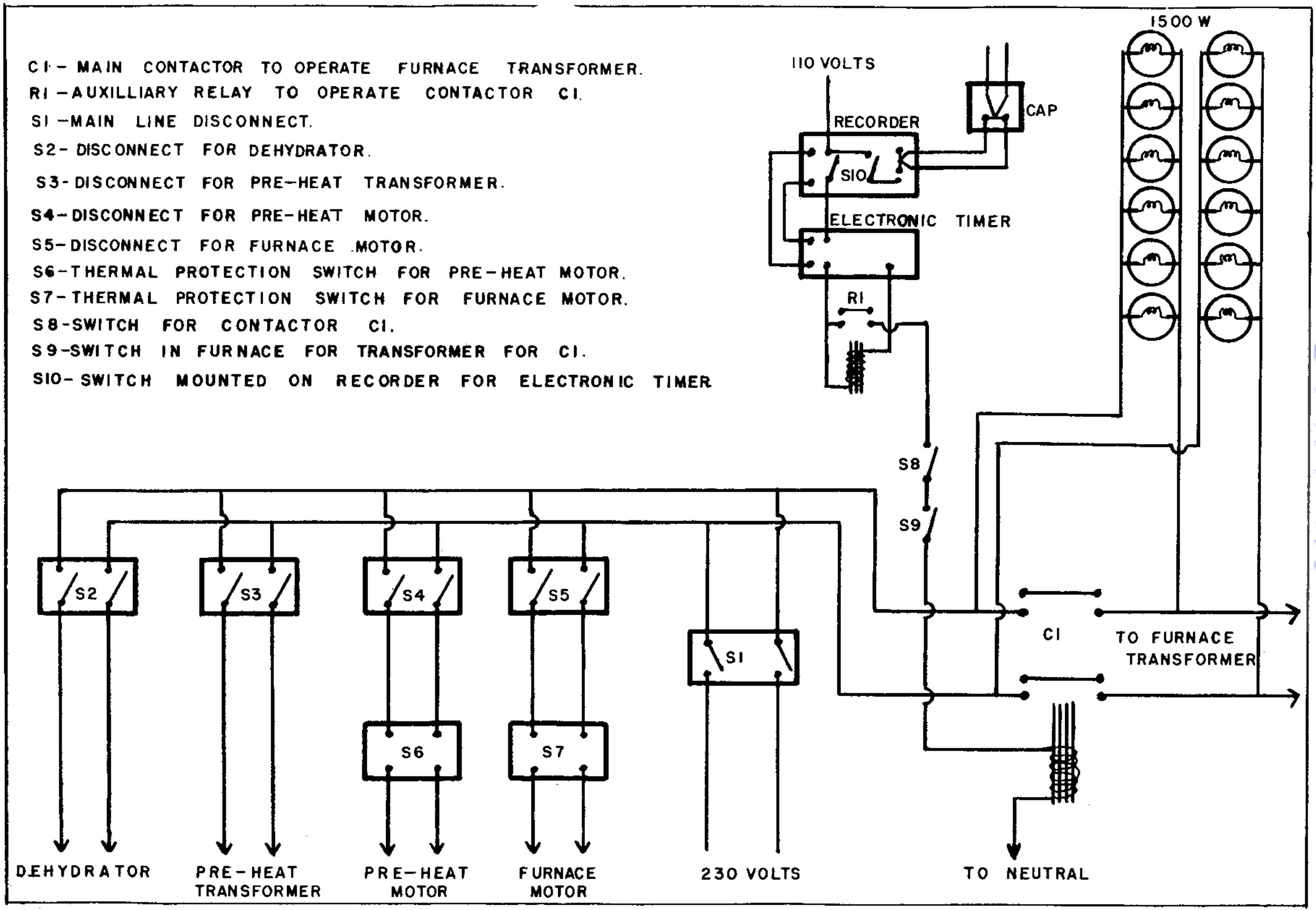

FIGURE 26 CIRCUIT DIAGRAM FOR SCALING FURNACE

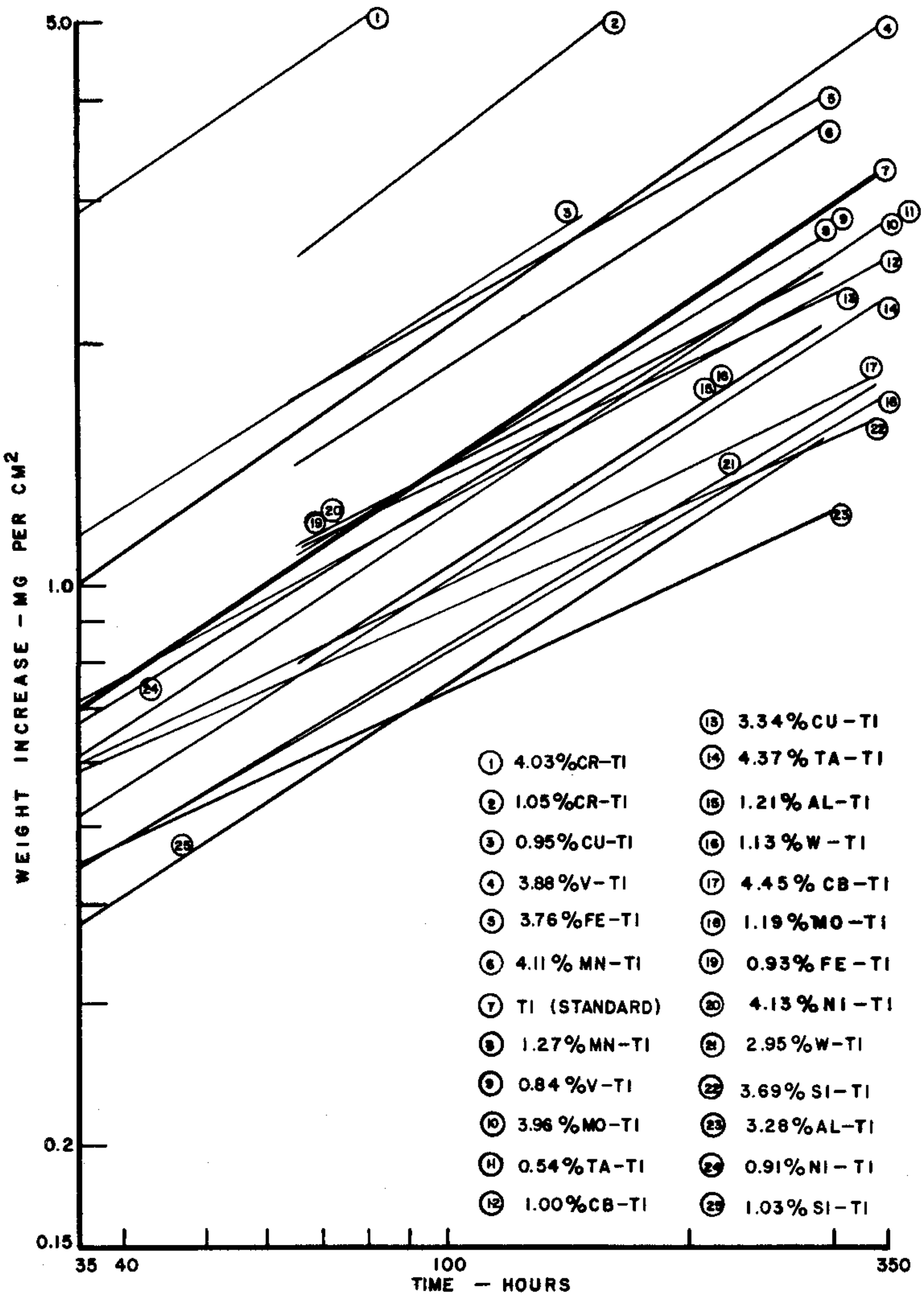

FIG. 27 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

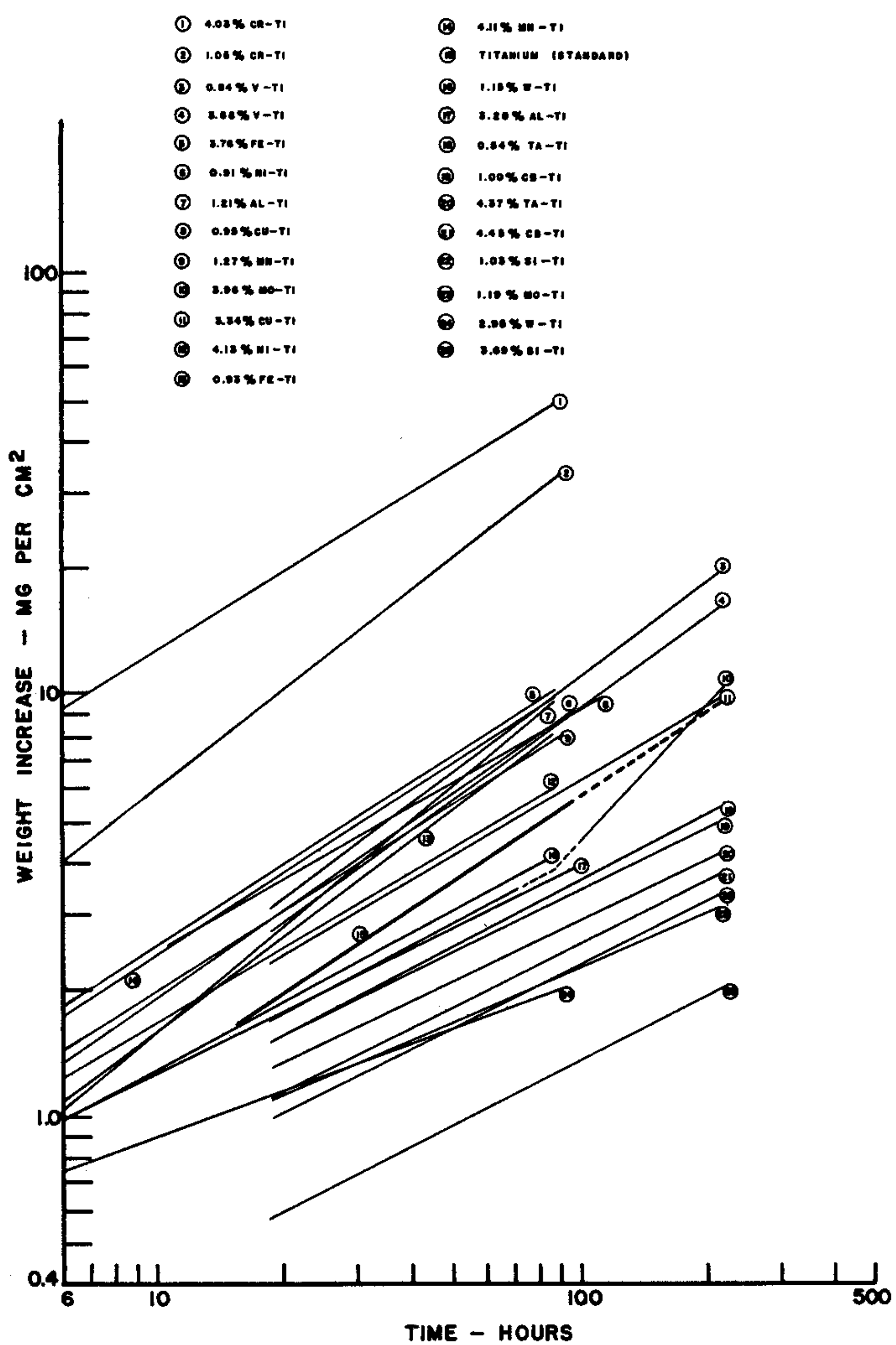

FIG. 28 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (648.8°C.)

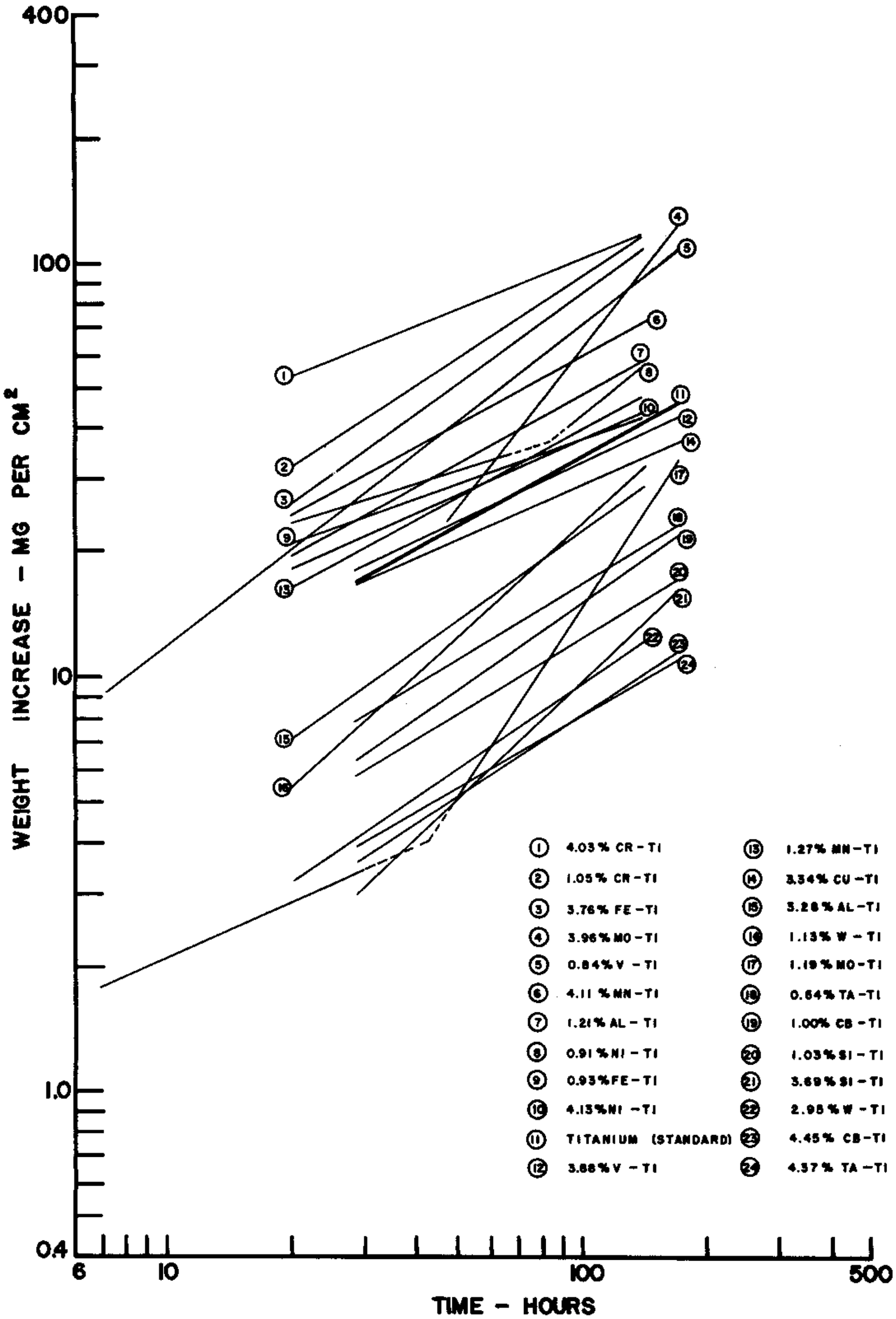

FIG. 29 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

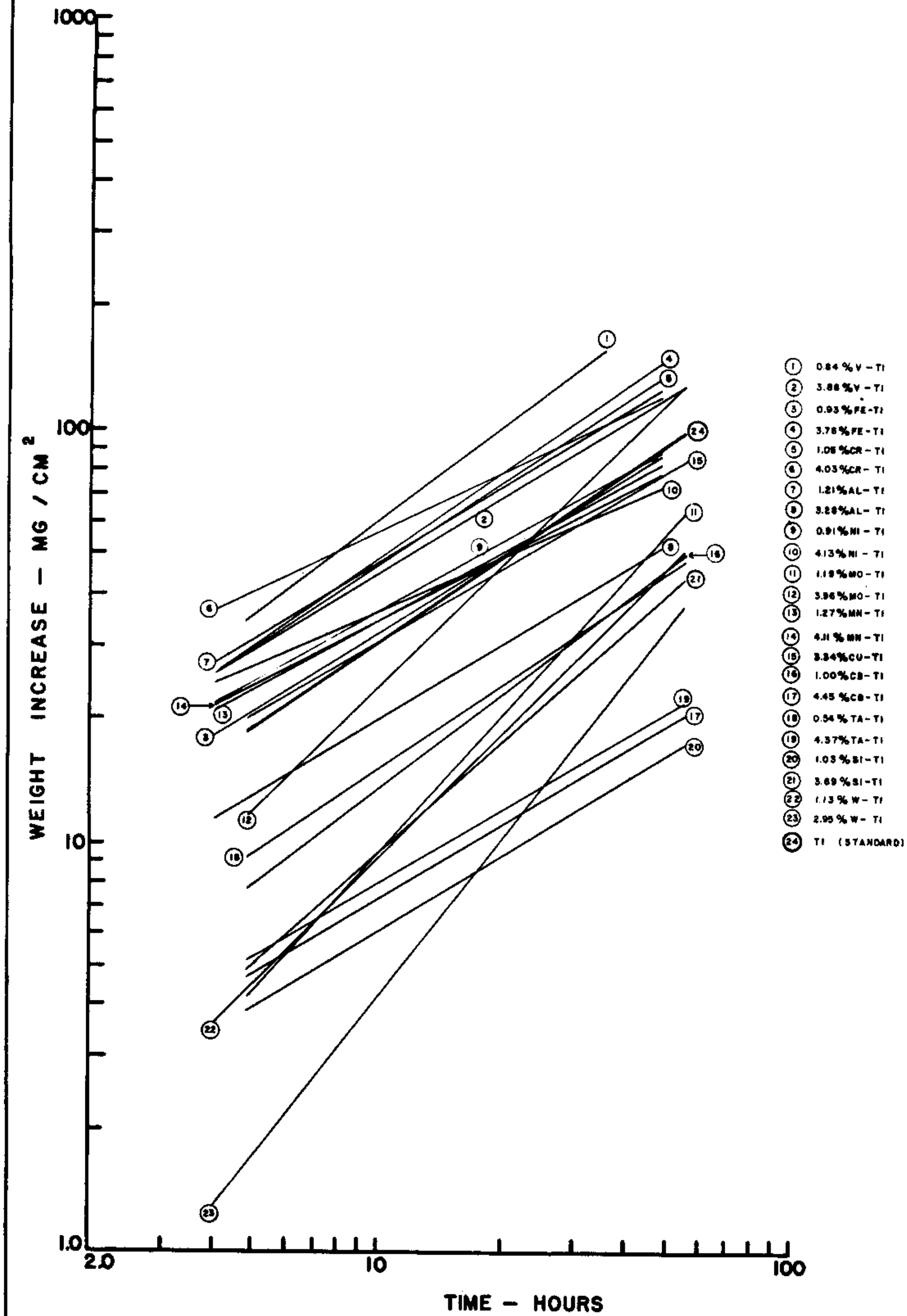

FIG. 30 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800° F. (982.2° C.)

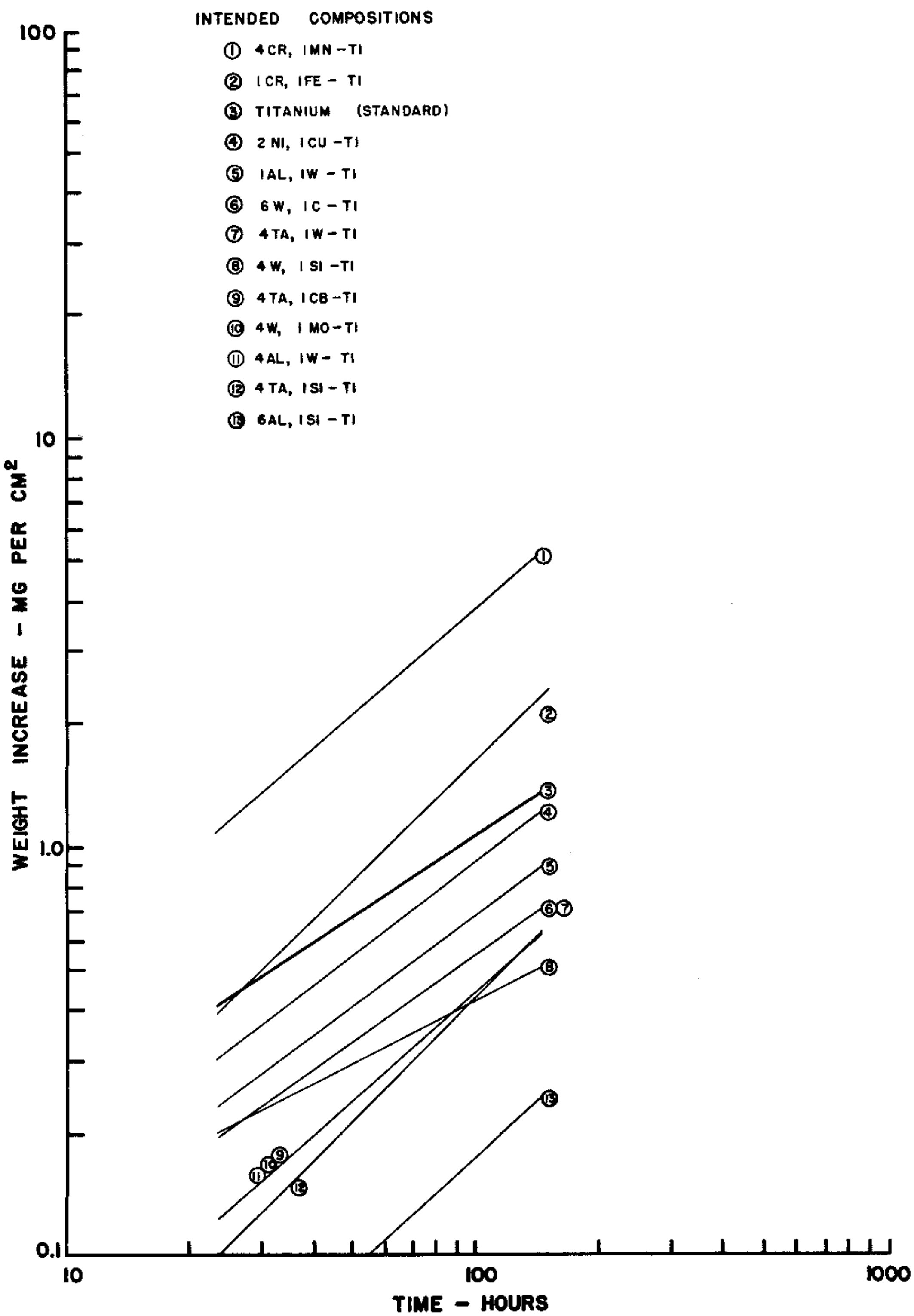

FIG. 31 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

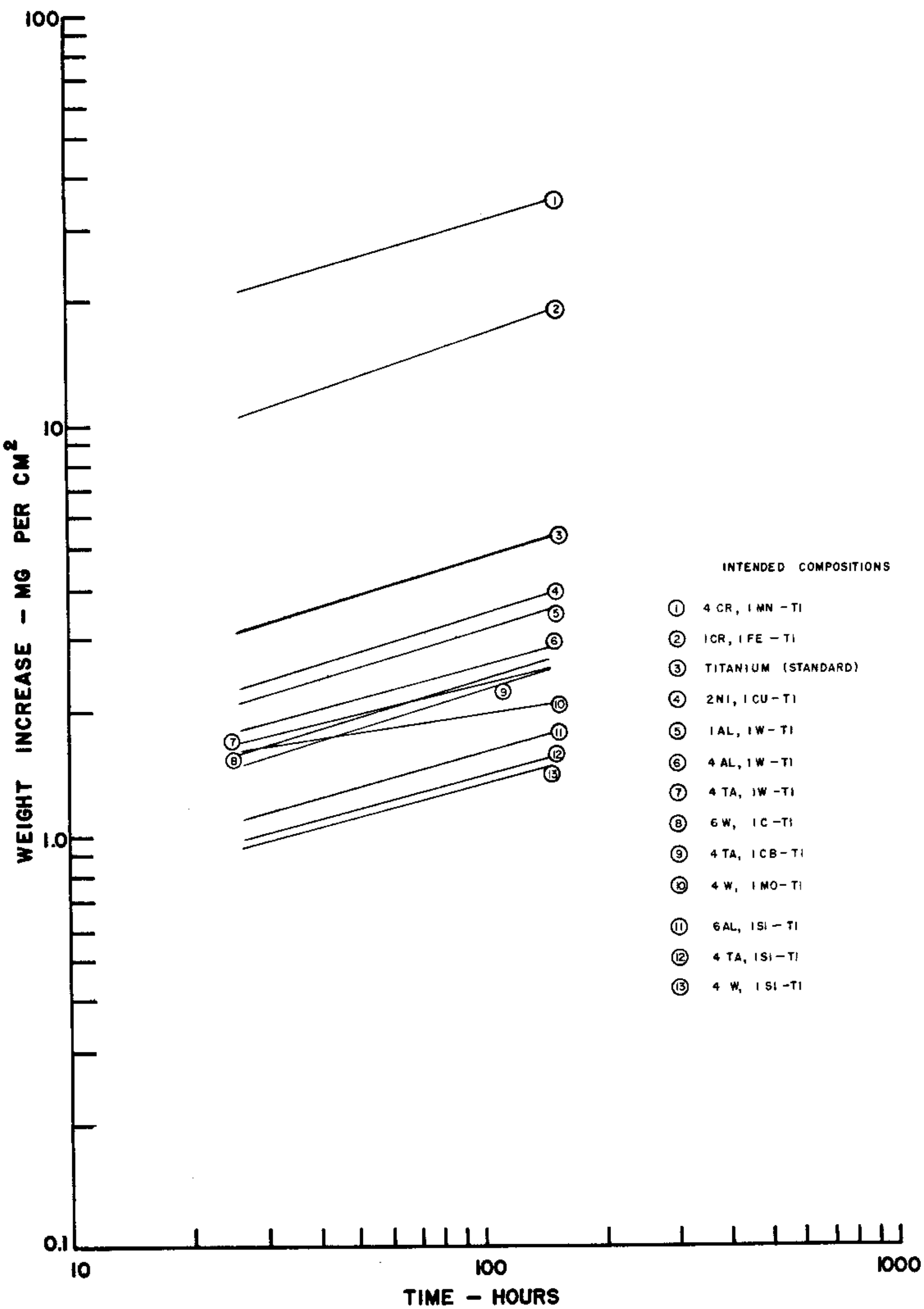

FIG. 32 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

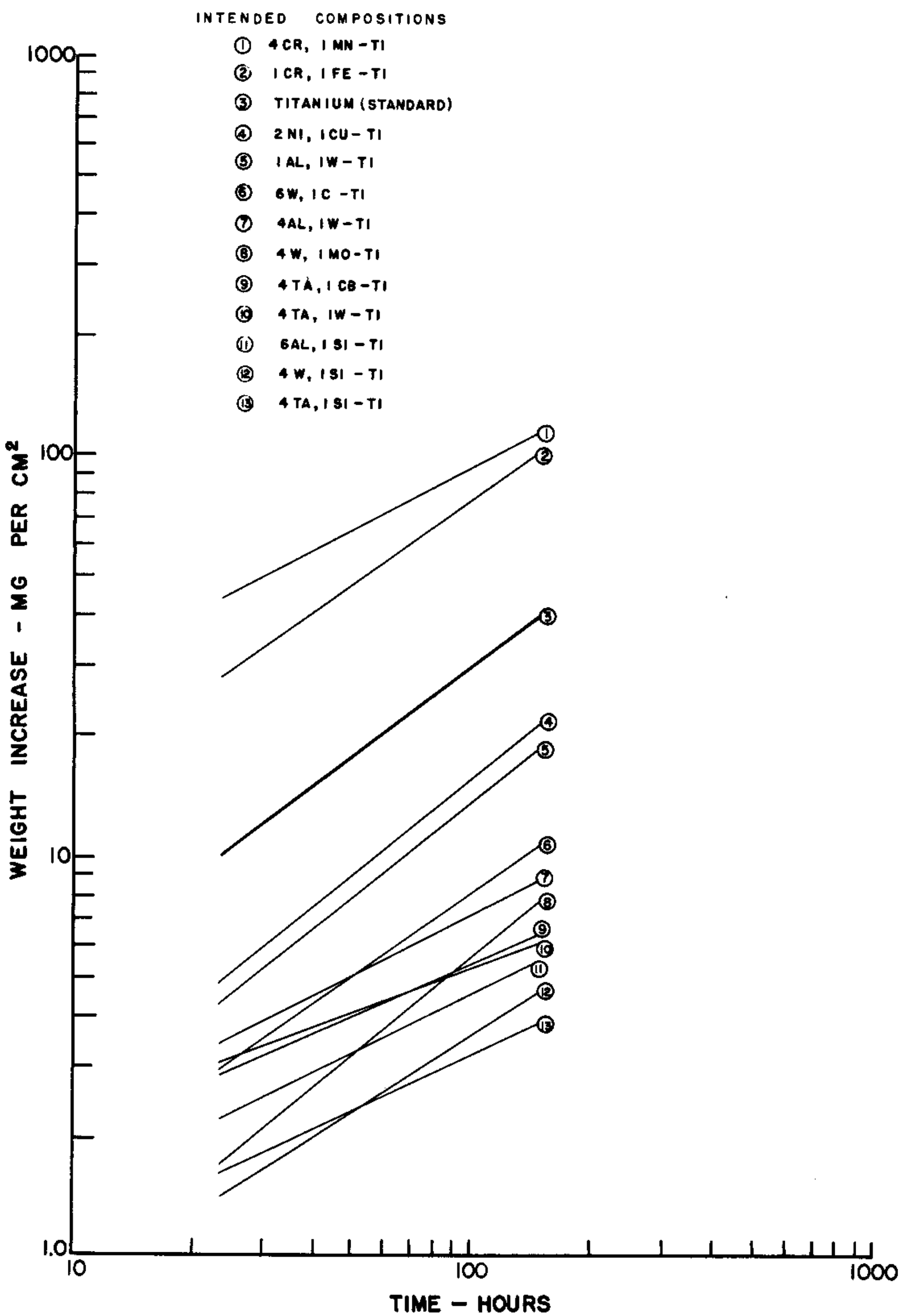

FIG. 33 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

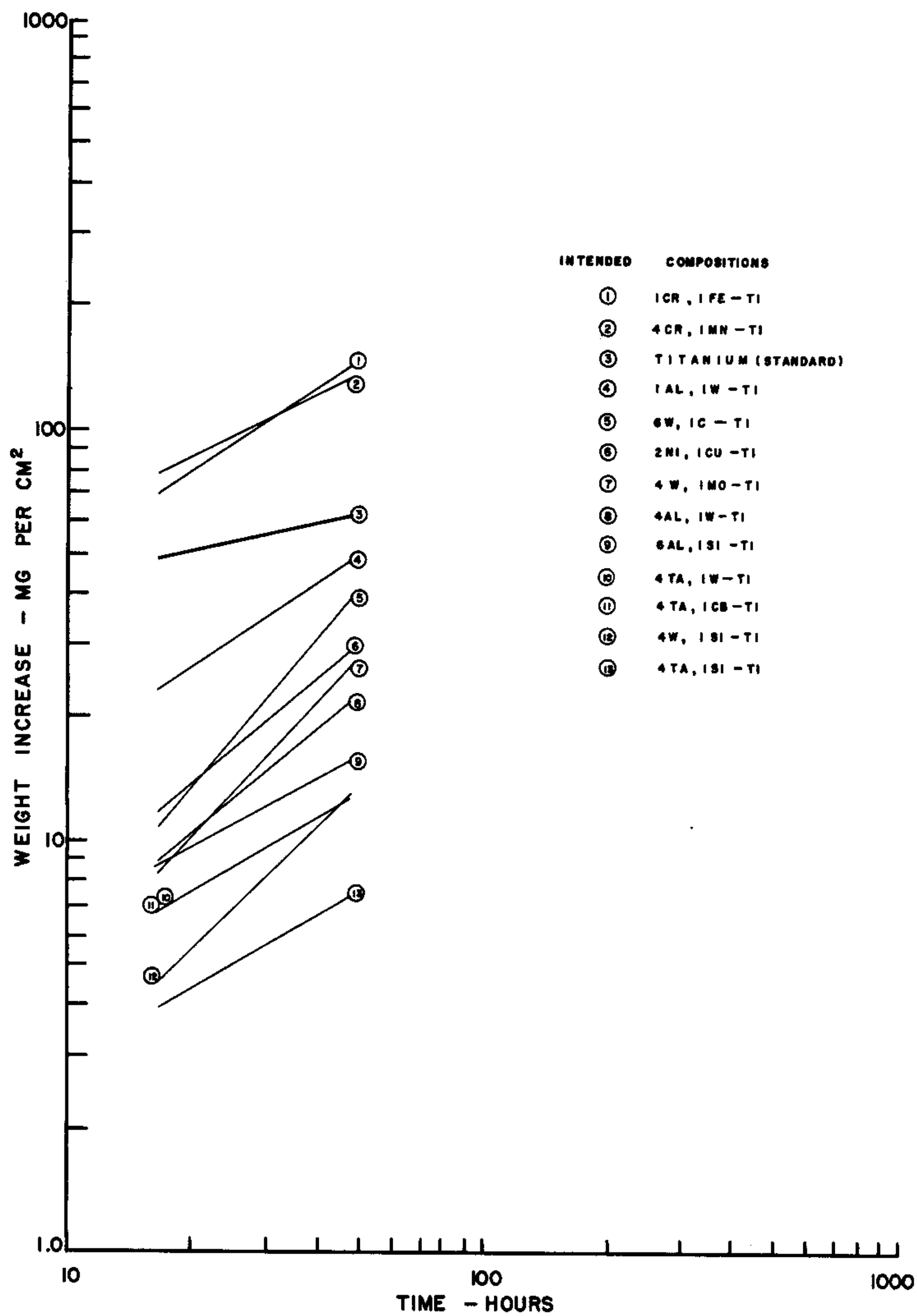

FIG. 34 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

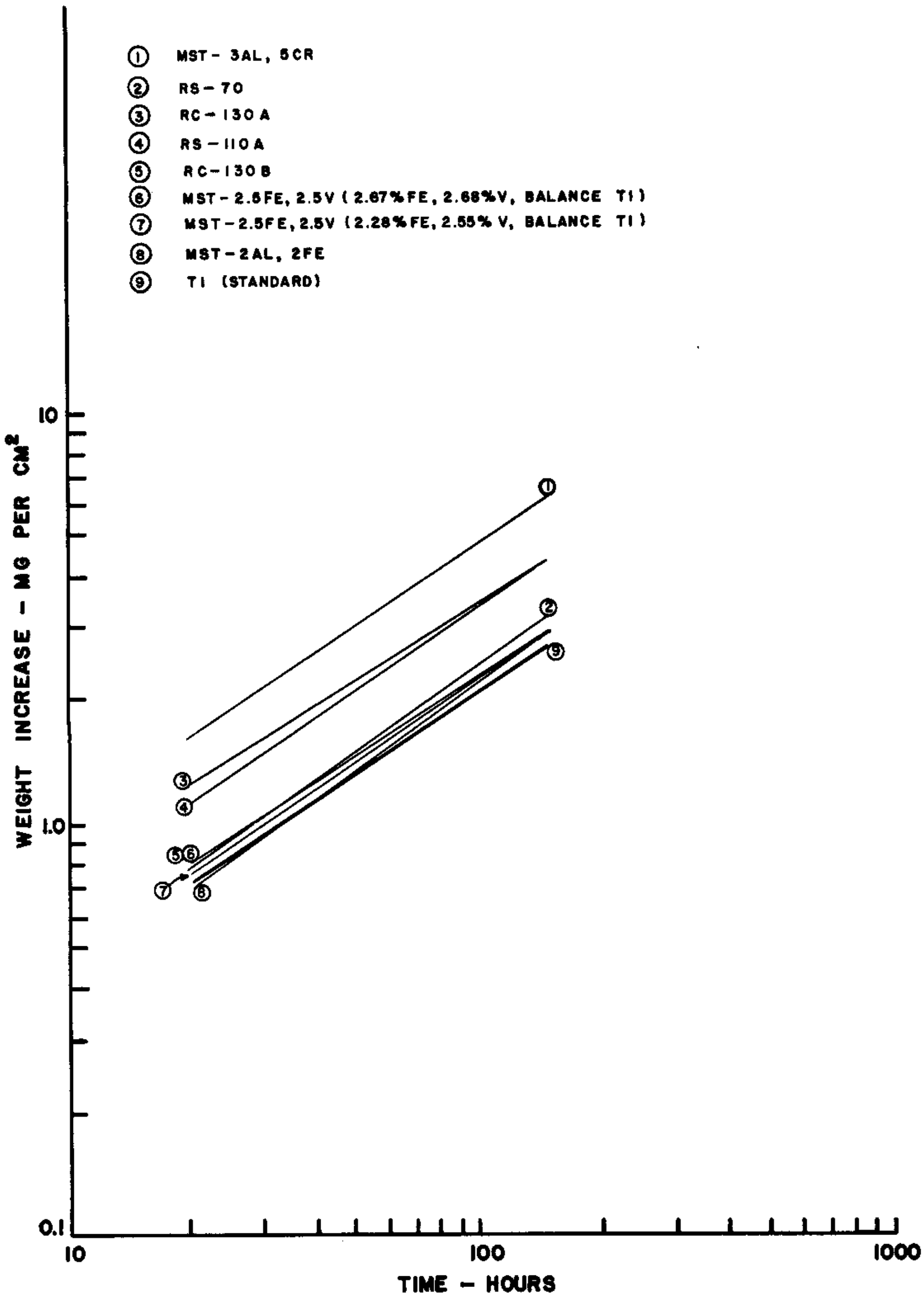

FIG.35 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

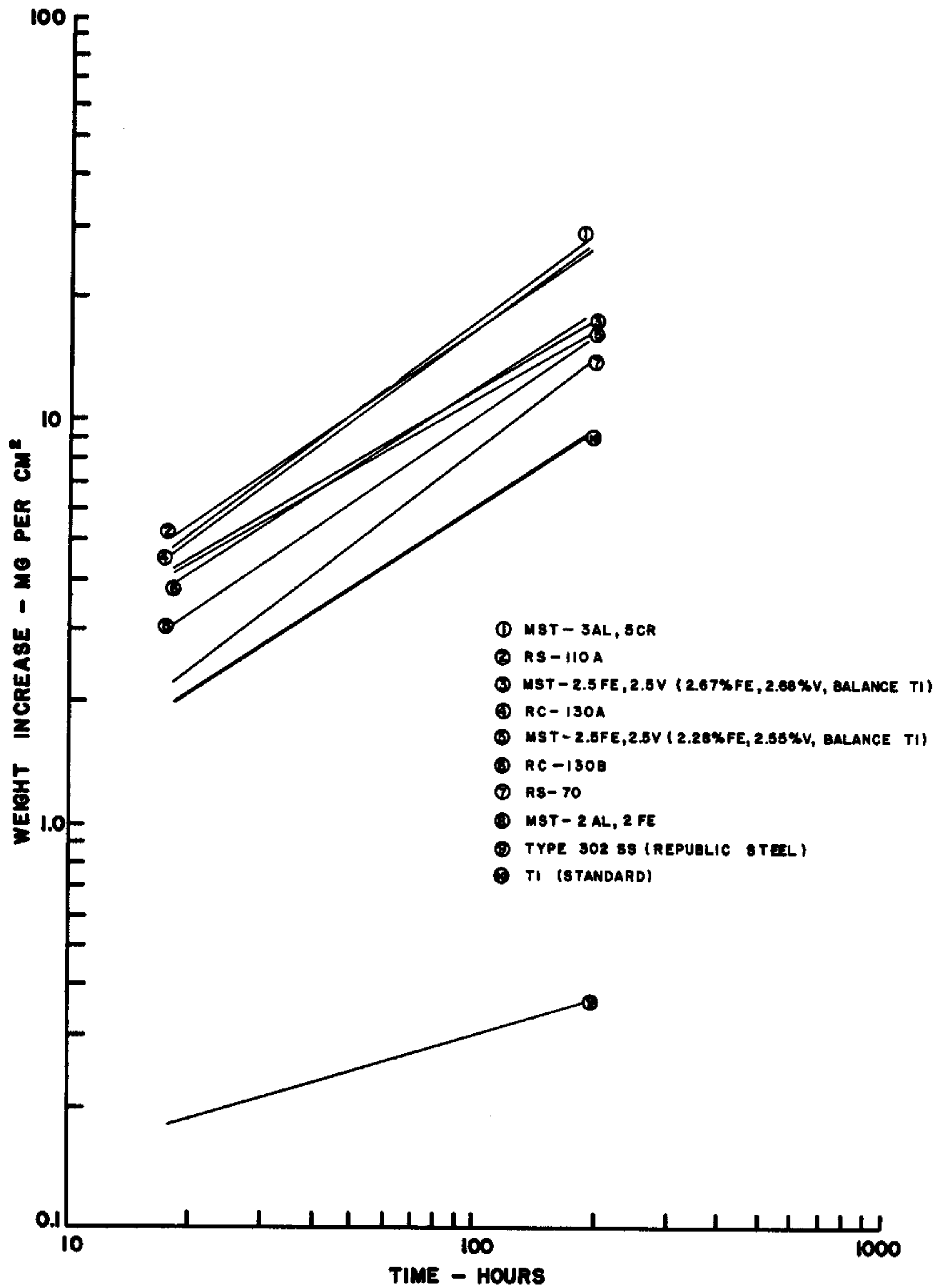

FIG. 36 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

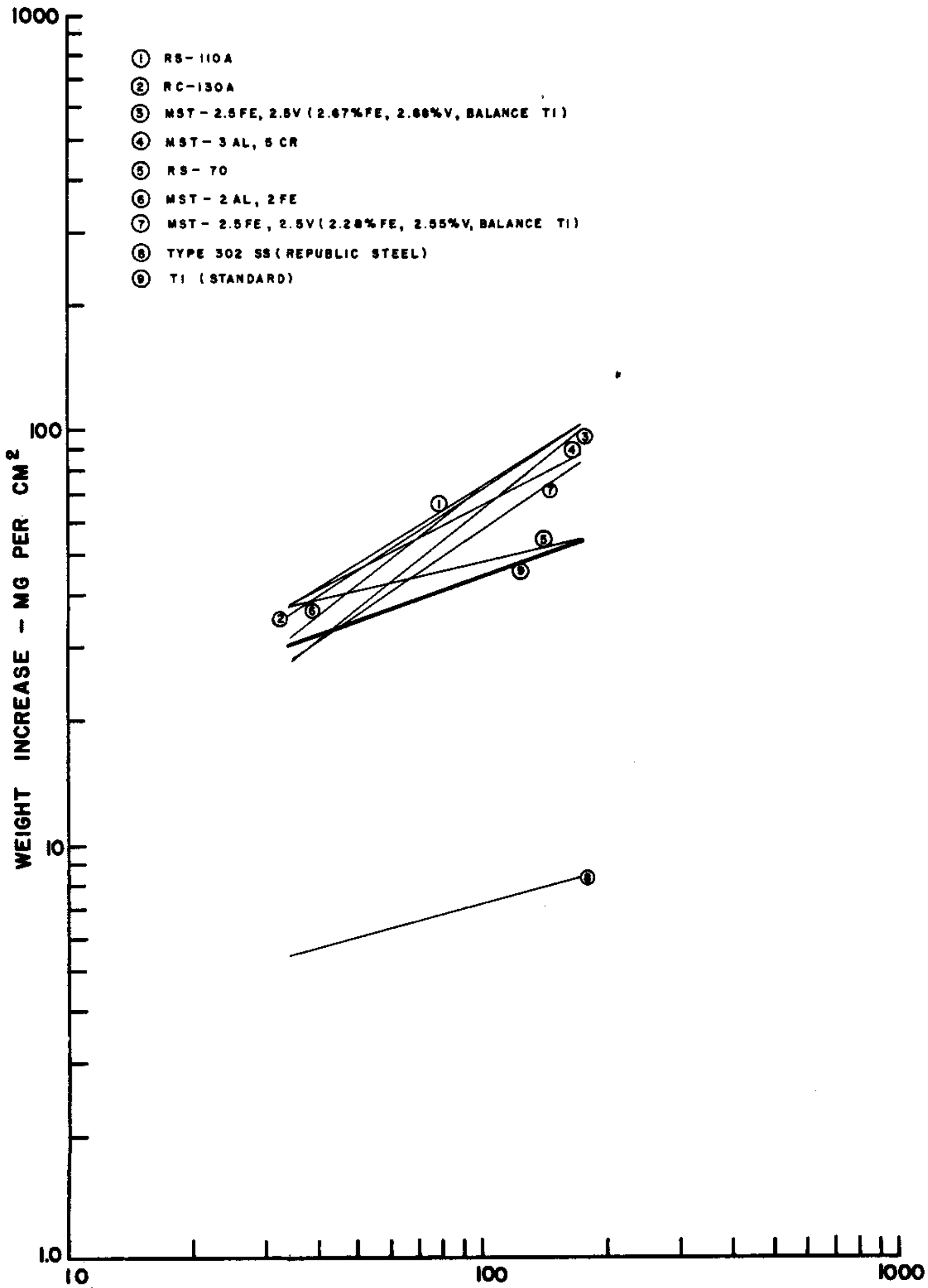

FIG. 37 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

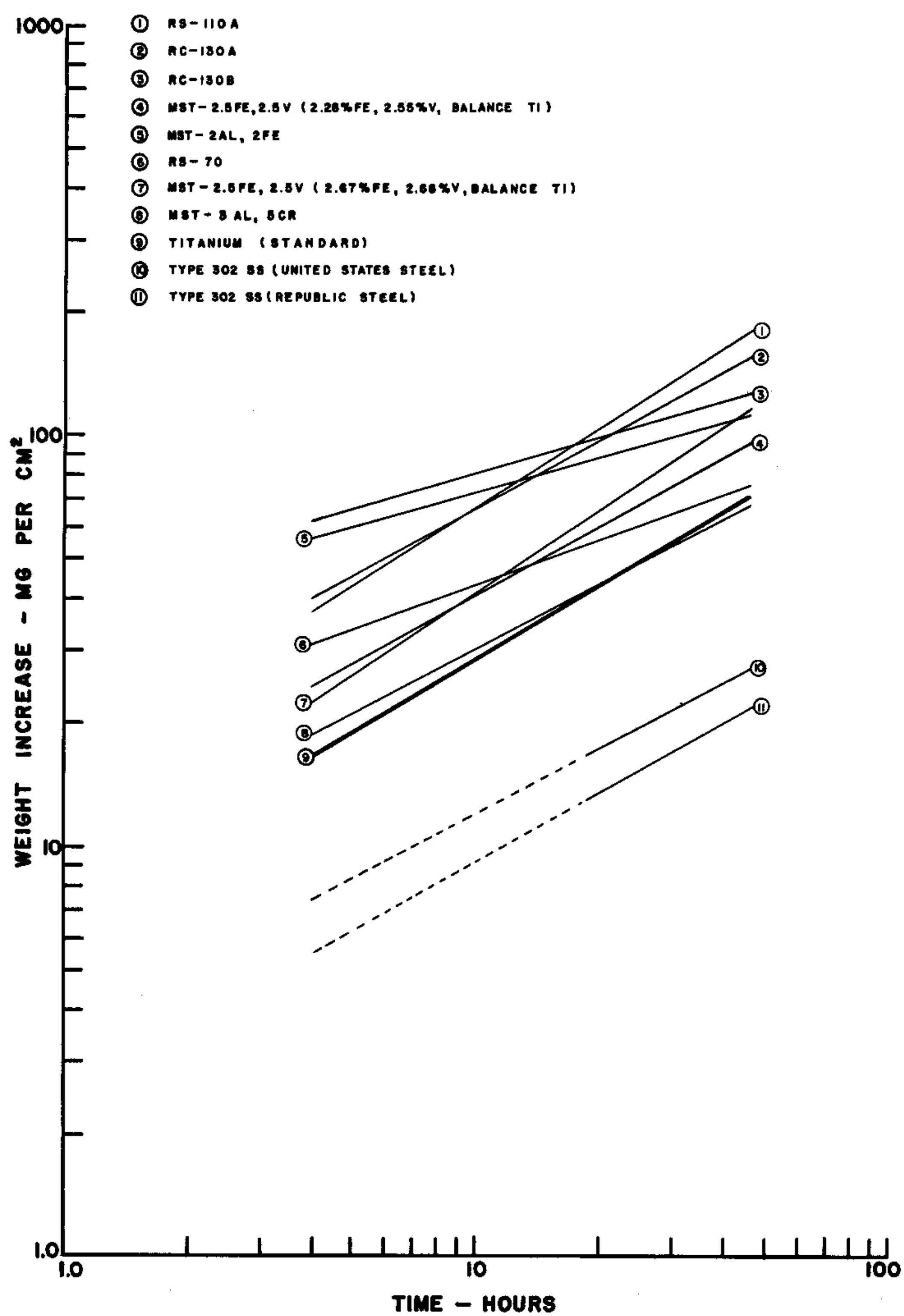

FIG. 38 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

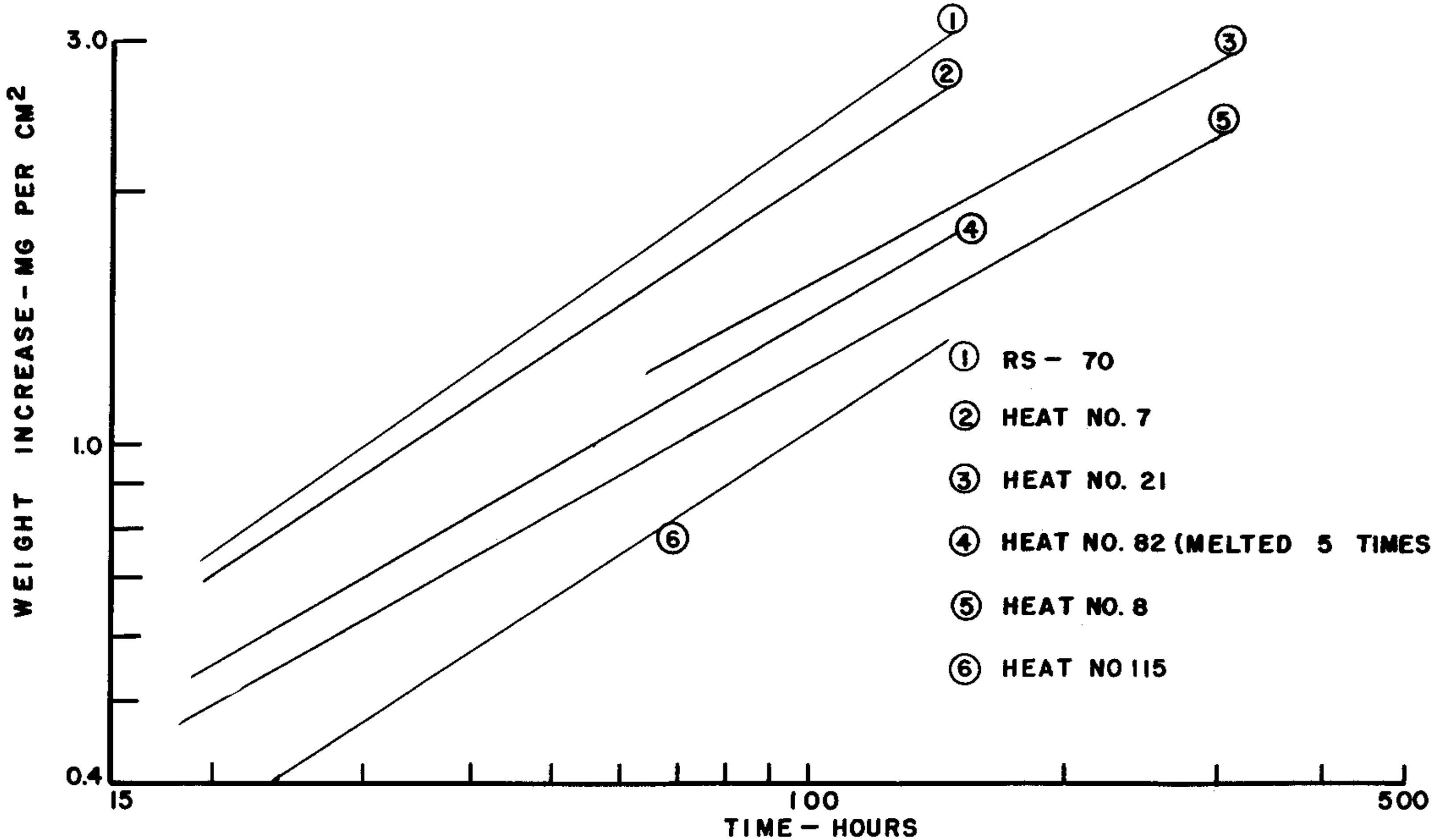

FIG. 39 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

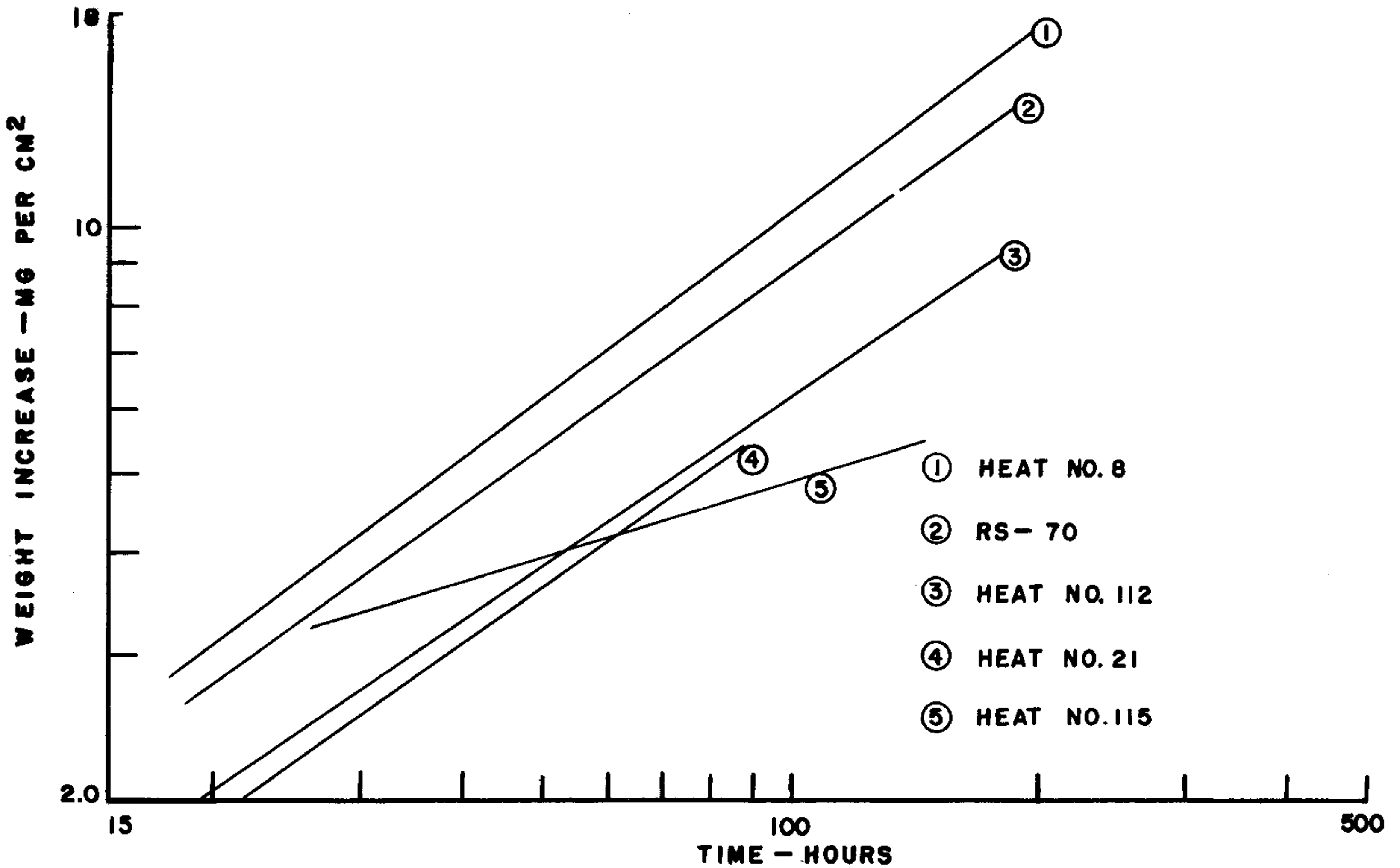

FIG. 40 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

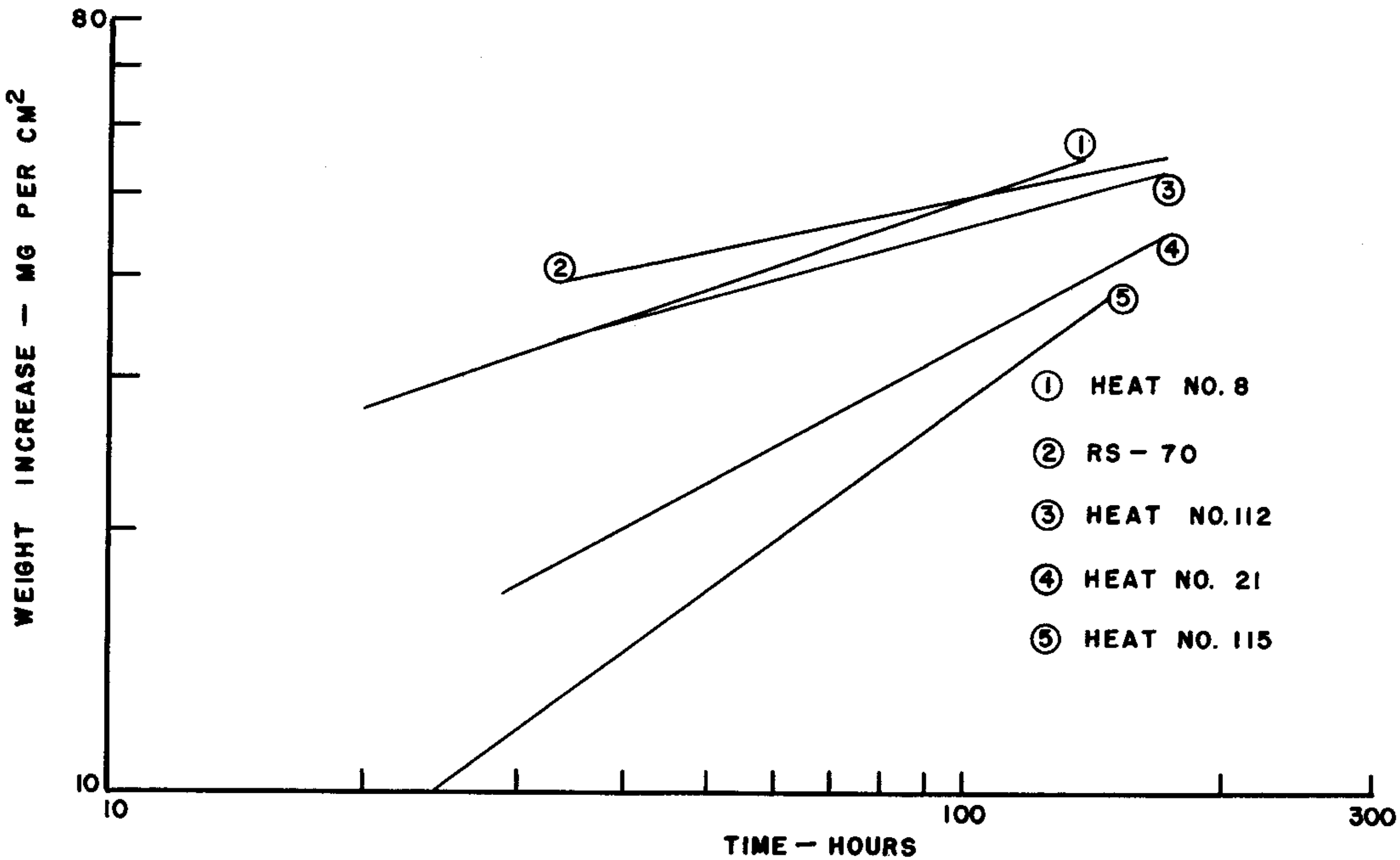

FIG. 41 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1600° F. (871.1 °C.)

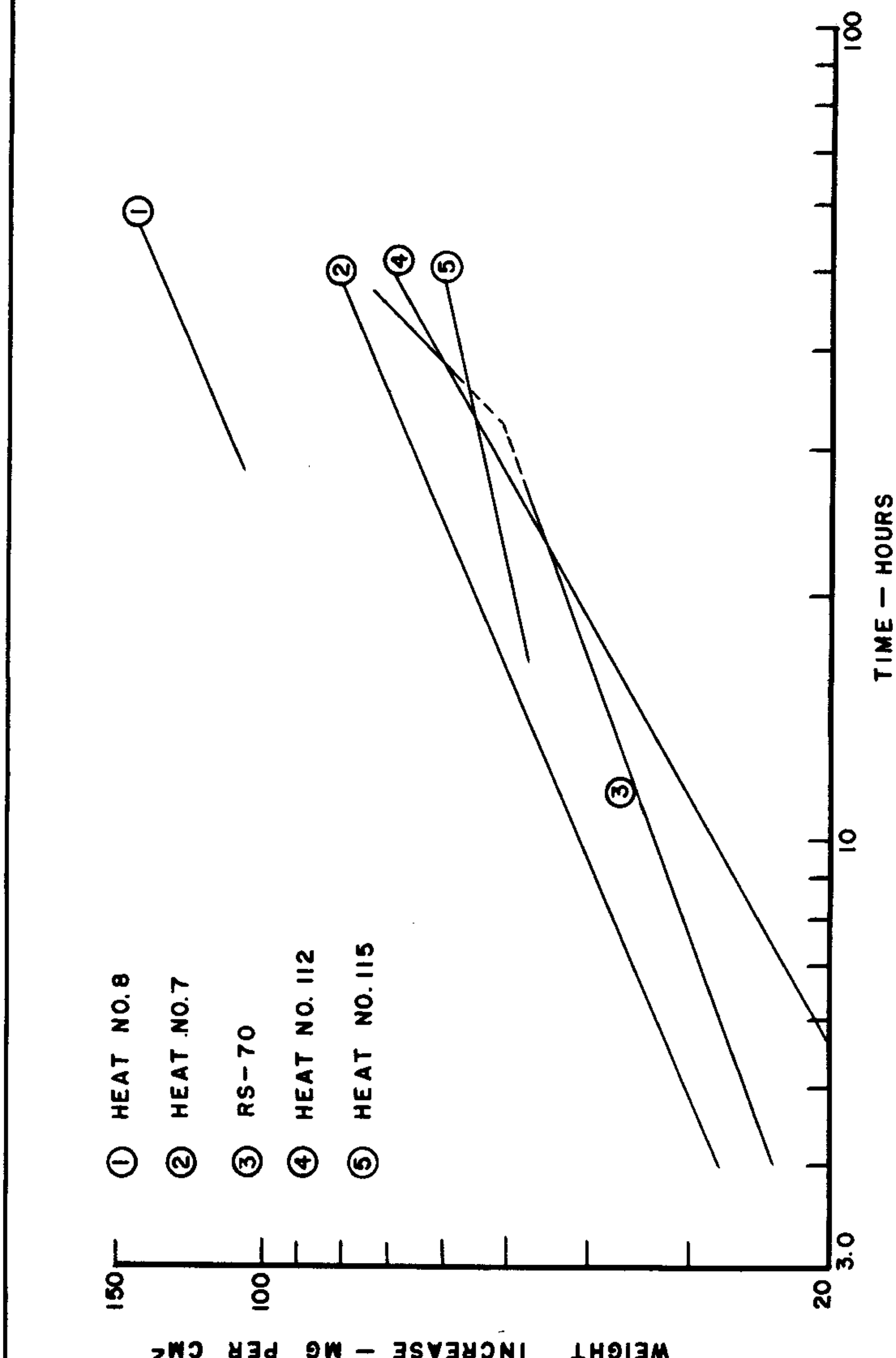

FIG. 42 AVERAGE CUMULATIVE WEIGHT INCREASE PER AVERAGE UNIT OF ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)

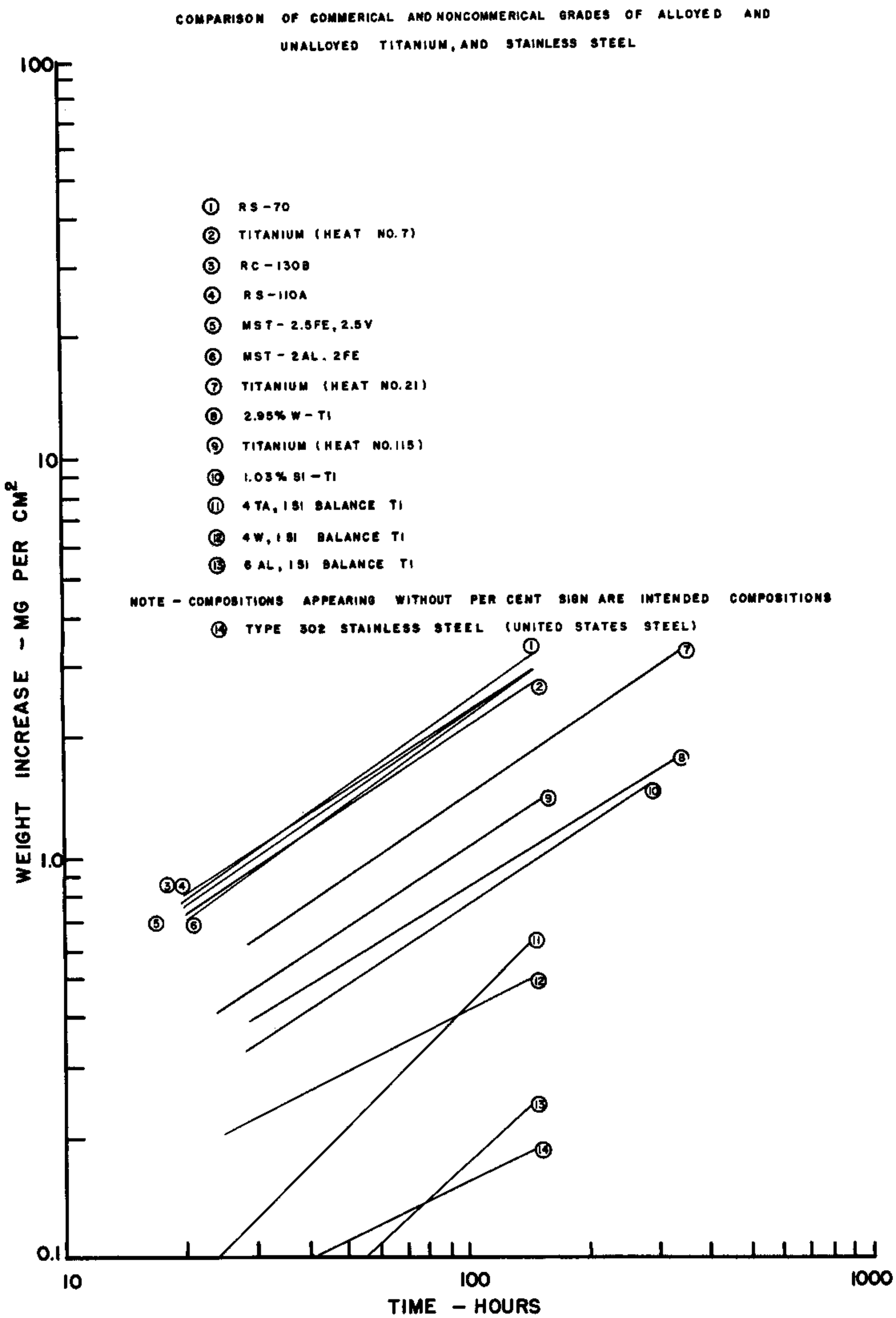

FIG. 43 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1200°F. (648.8°C.)

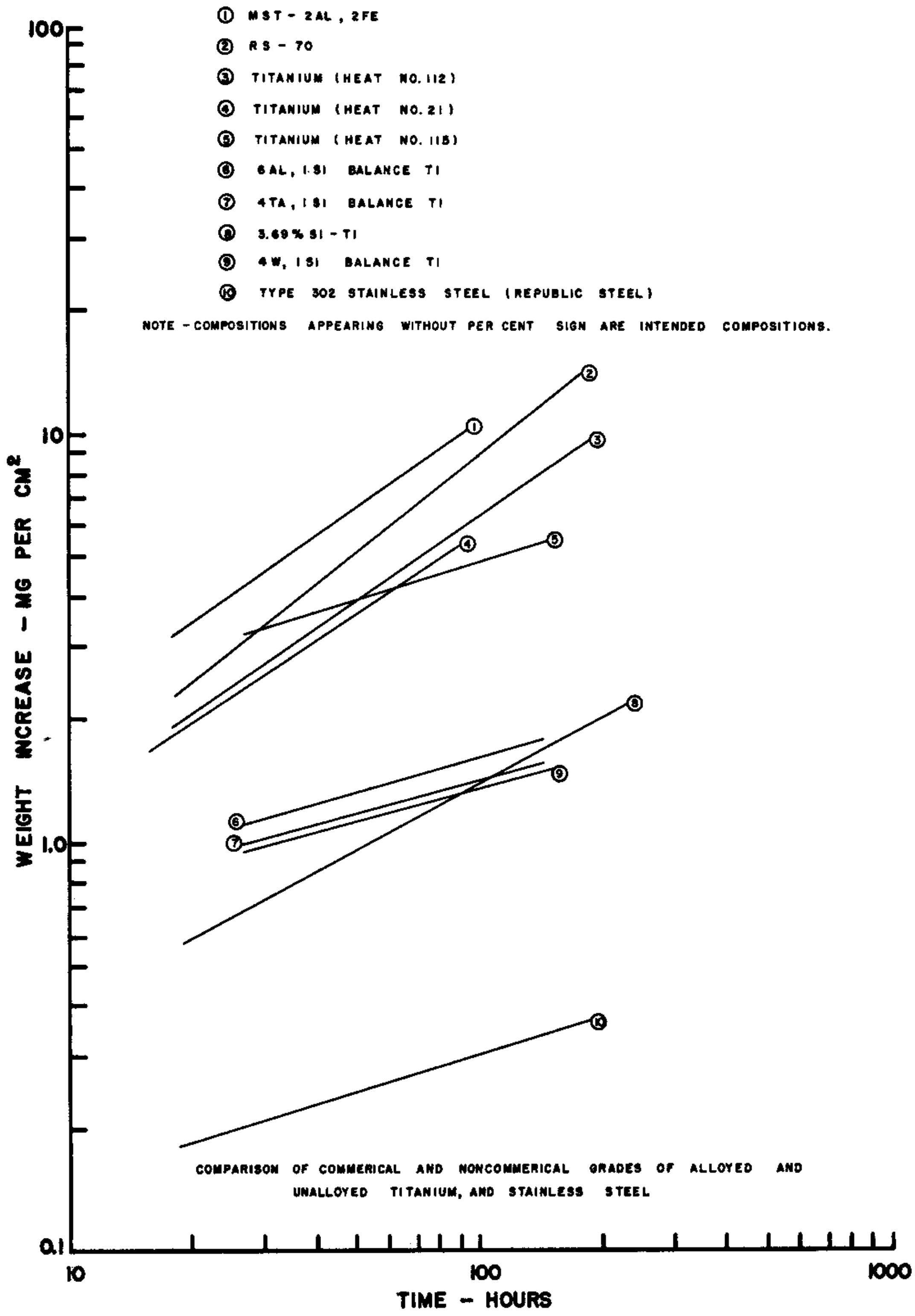

FIG. 44 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1400°F. (760.0°C.)

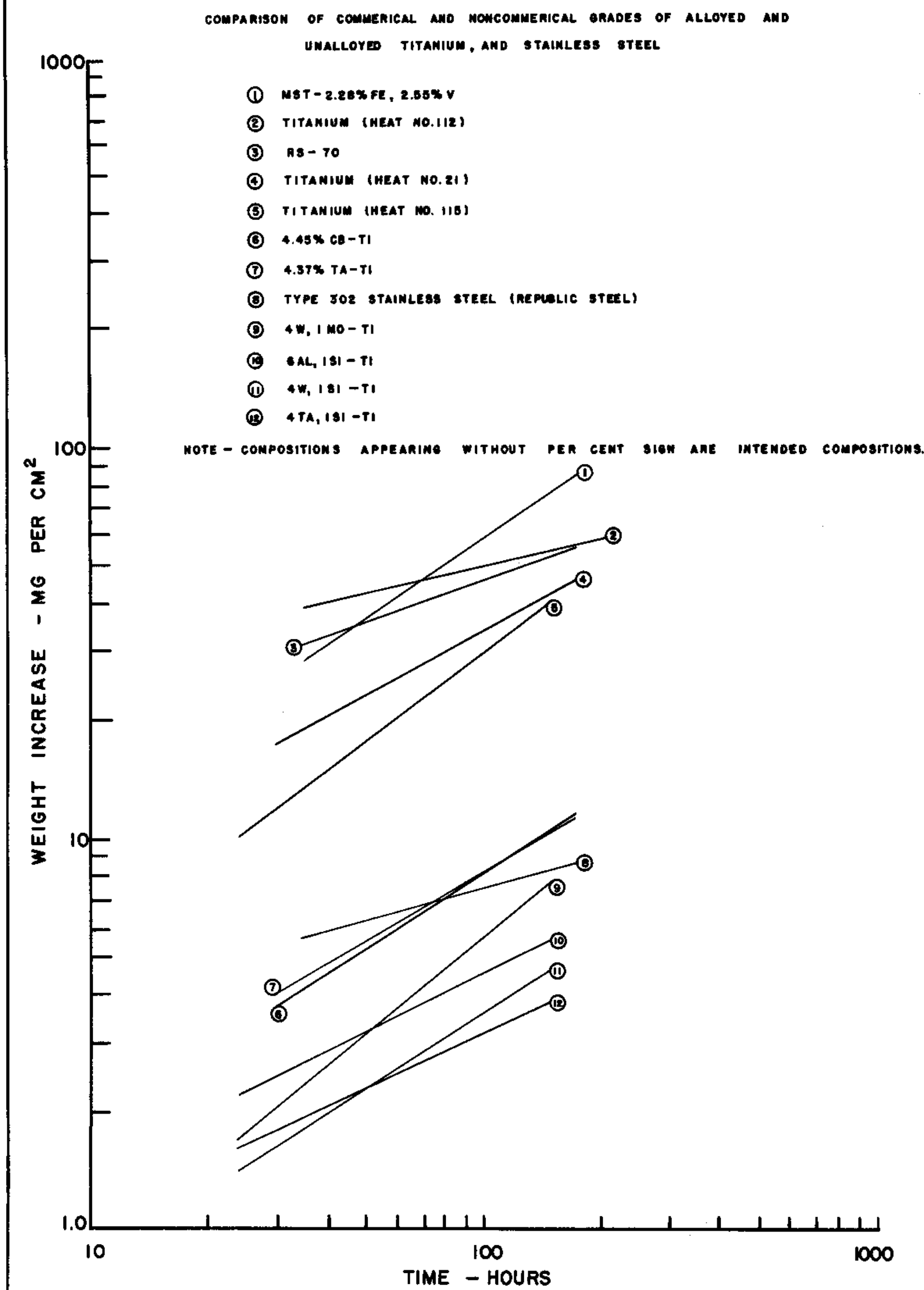

FIG. 45 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1600°F. (871.1°C.)

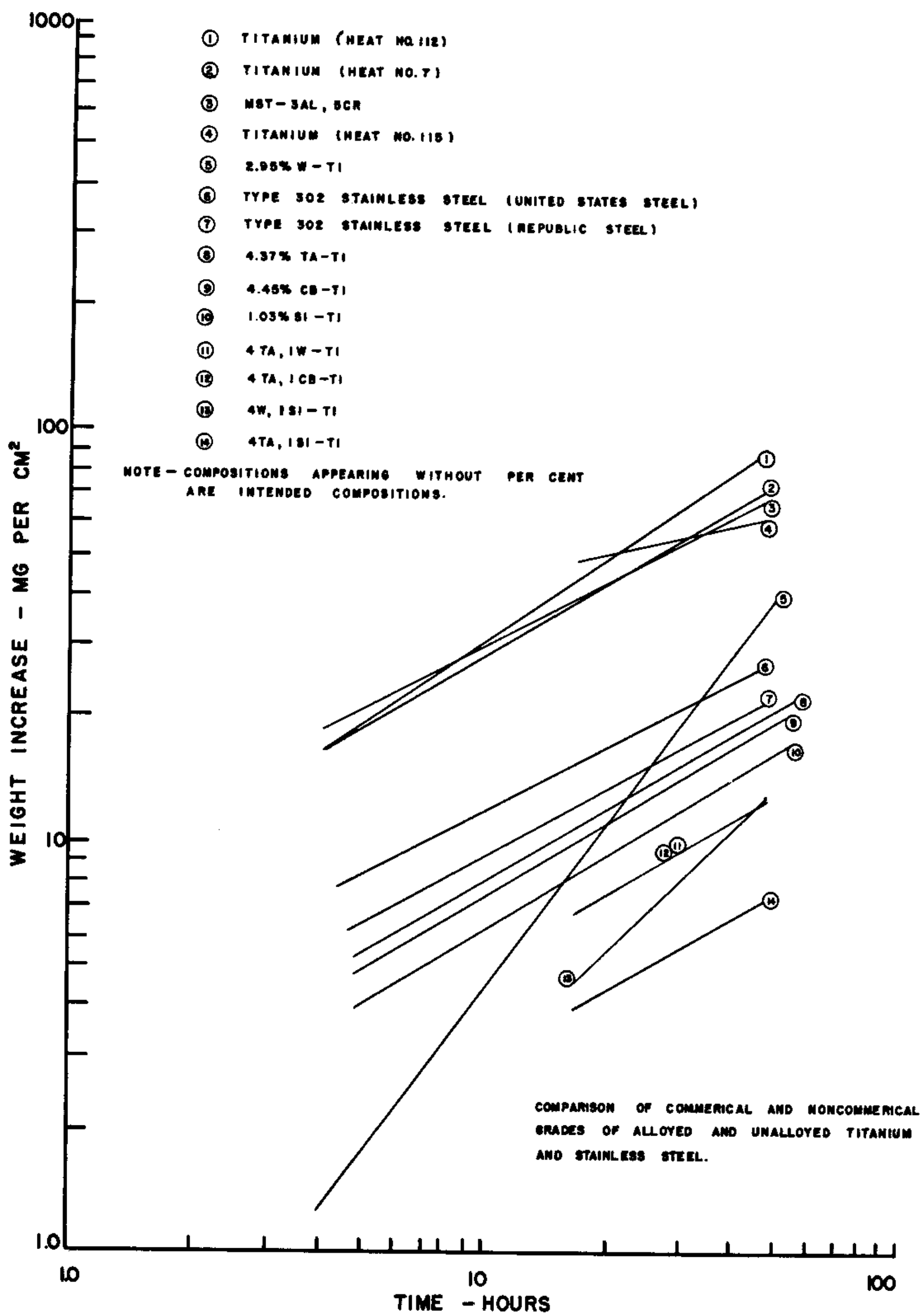

FIG. 46 WEIGHT INCREASE PER UNIT ORIGINAL AREA AS A FUNCTION OF TIME AT 1800°F. (982.2°C.)