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A STATISTICAL ANALYSIS OF HOT-CORROSION TESTS OF SOME EXPERIMENTAL AND COMMERCIAL SUPERALLOYS

R. Field, et al

Naval Ship Research and Development Center
Washington, D.C.

January 1969

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A STATISTICAL ANALYSIS OF HOT-CORROSION TESTS OF SOME EXPERIMENTAL AND COMMERCIAL SUPERALLOYS

By
R. Field, D. J. Fisk, and
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MATERIALS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

January 1969

Report 2833

47

A Statistical Analysis of Hot-Corrosion Tests of Some Experimental and Commercial Superalloys

by

R. Field, D. J. Fisk, and
H. von E. Doering

nuary 1969 MATLAB 243 Report 2833

ABSTRACT

The use of gas turbines in marine power plants depends in part on the development of superalloys which not only possess high temperature mechanical properties but also resist the corrosive effects of sea salt.

As part of a program to develop such alloys, a total of 137 experimental and commercial superalloys, both nickel and cobalt based, were exposed in burner rigs where controlled amounts of sea salt were added to the combustion products of sulfur-containing diesel fuel. Test temperatures ranged from 1600° to 2125° F. Times ranged from 86 to 100 hours with 200 parts per million, and from 489 to 1100 hours with 5 parts per million salt. Corrosion was measured by recording both surface loss and maximum penetration. This experimental work was performed by the General Electric Company under contract to the Naval Ship Research and Development Center.

For each group of alloys tested under similar conditions, a linear regression equation was found that shows the average contribution of each alloying element to the amount of corrosion. The effects of the alloying elements were found to vary with changes in temperature, salt concentration, and whether or not the particular element was part of a simple binary or tertiary alloy, or a complex alloy.

Analyses of variance methods were applied to two sets of factorially designed compositions, one of nickel-base alloys and one of cobalt-base alloys, to determine the possible significance on corrosion of various proportions of single elements and interactions among elements. It was found that in the cobalt alloys significant interactions existed between heat treatment and temperature as well as between heat treatment and chromium content.

RATIVE INFORMATION

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EDGMENT

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ns.

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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

A STATISTICAL ANALYSIS OF HOT-CORROSION TESTS OF SOME EXPERIMENTAL AND COMMERCIAL SUPERALLOYS

by
R. Field, D. J. Fisk, and
H. von E. Doering

INTRODUCTION

The effects of alloying elements on the hot-corrosion resistance of nickel- and cobalt-base superalloys has been a subject of interest to gas turbine manufacturers for a number of years. The application of gas turbines in marine environments has necessitated the development of alloys, for hot section components, which are resistant to the molten salts ingested by the engine. A knowledge of the behavior of alloying elements in either increasing or decreasing corrosion resistance is necessary for future alloy development.

In two recent studies of hot-corrosion resistance of superalloys,[1,2] statistical analysis was employed to establish a multiple linear regression equation relating the weight percent of alloying elements present with the amount of corrosion observed.

It is the purpose of this study to treat statistically the data which was generated for this laboratory in four studies, under contract with the General Electric Company.[3,4,5,6,7,8]

Linear regression coefficients and their significance are computed for all alloying elements used in simple experimental (up to four elements) alloys, experimental complex alloys, and commercial alloys. The effects of temperature, the concentration of sea salt, and the type of alloy on the behavior of each element have, where possible, been examined.

Since it was felt that alloying elements do not behave independently but interact, two factorially designed sets of experimental alloys are examined using analysis of variance methods.[9,10]

---

[1] Superscripts refer to similarly numbered entries in Appendix B.

EXPERIMENTAL PROCEDURE

ecimens of all 137 alloys were exposed in a burner rig
d to simulate the environment within the hot section of a
bine which was operated while ingesting aerosol sea salt.
l is a schematic view of the equipment. Diesel fuel
ing 1% sulfur was atomized and burned within a ceramic
ion tube. To the flame sea salt was added at either 5 ppm
ppm by weight of air.* Tests with 5 ppm salt were run for
1000 hours, whereas tests with 200 ppm salt were run for
p to 100 hours only. Thermal cycling was effected by
g the rotating specimen holder and allowing the specimens
for 5 minutes every 50 hours during the 500- and 1000-hour
The shorter tests were not thermally cycled.

e specimens, nominally 1/8 inch in diameter and 1 5/8 inches
th, were sectioned after exposure; two measurements, surface
d maximum penetration, were taken as shown in Figure 2.

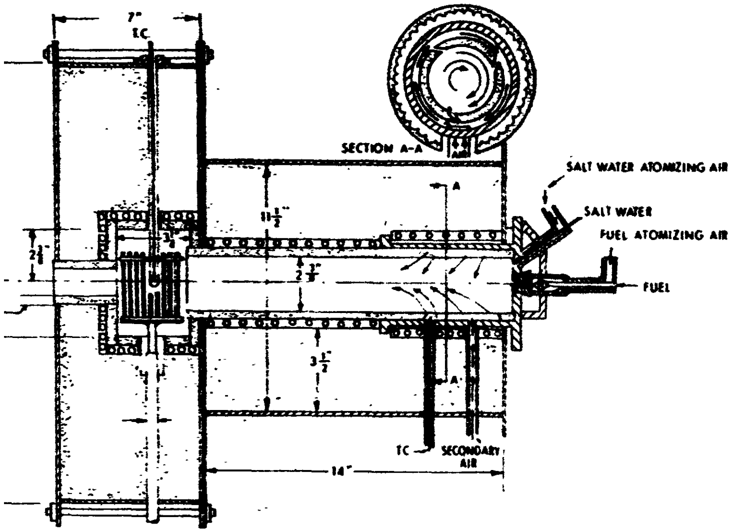

Figure 1
Schematic Cross-Section of Burner Rig

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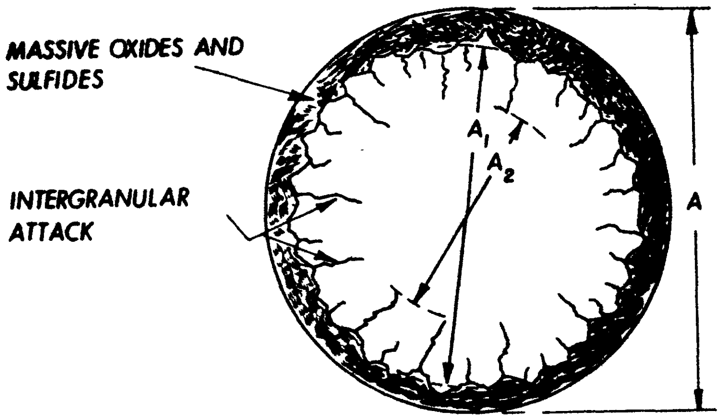
iations used in this text are from the GPO Style Manual,
unless otherwise specified.



A = ORIGINAL DIAMETER, MEASURED WITH A MICROMETER.

A_1 = DIAMETER OF STRUCTURALLY USEFUL METAL. MEASURED AT 100X

A_2 = DIAMETER OF METAL UNAFFECTED BY OXIDES AND SULFIDES, MEASURED AT 100X

SURFACE LOSS: $A-A_1$ LOSS IN DIAMETER DUE TO MASSIVE OXIDES AND SULFIDES.

MAXIMUM ATTACK: $A-A_2$ LOSS IN DIAMETER DUE TO ALL FORMS OF OXIDATION AND SULFIDATION.

Figure 2

Method of Measuring Hot-Corrosion Attack

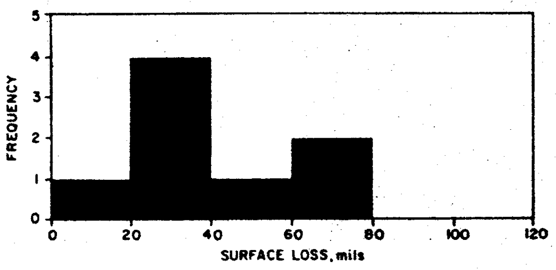
RESULTS AND DISCUSSION

CORROSION MEASUREMENTS

To assess the consistency and accuracy with which corrosion behavior can be measured in the burner rig used in the study, measurements were taken from eight specimens of one heat from an alloy, PA 1 (Heat 1). Each specimen was originally intended as a control to determine the similarity of nominal operating conditions between runs. Therefore, each specimen comes from a different test run, although each test was performed under the same specified conditions of temperature (1750° F), salt concentration (200 ppm) and operating time (100 hours). Thus, the

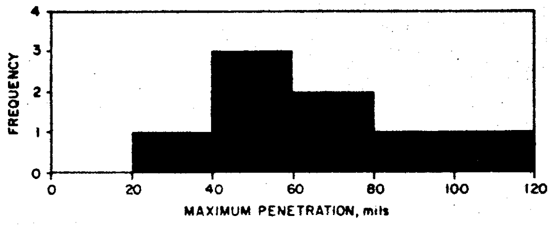
nce, σ^2, for the specimens represents dispersion in test
tions as well as variation in behavior of the alloy from
men to specimen.

A comparison of the data for the surface loss and maximum
ration measurements indicate an average difference of about
ls. There is, at the 5% significance level, a significant
r correlation between the surface loss and maximum penetra-
measurements, see Figure 3.



Ranges : 16.1–76.1 mils
Mean : 42.1 mils
Std Dev : 21.1 mils
* Sample Size 8

NOTE: CORRELATION BETWEEN SURFACE LOSS AND MAXIMUM PENETRATION MEASUREMENTS r = 0.8871 (SIGNIFICANT AT 5% LEVEL)



Ranges : 34.1–115.4 mils
Mean : 63.8 mils
Std Dev 26.6 mils
* Sample Size 8

* TESTED AT 1750° F, FOR 100 HOURS OF OPERATION AND 200 PPM SALT

Figure 3
Frequency Distributions (Surface Loss and Maximum Penetration) for Hot-Corrosion Measurements Taken of Alloy PA 1 (Heat 1)

Alloy PA 1 (Heat 1) was the only alloy in the study for which the results of a sufficient number of tests performed under similar conditions were available to evaluate the distribution parameters of surface loss and maximum penetration. These estimated measures of dispersion and correlation between surface loss and maximum penetration should not be applied to other alloys, however, or to PA 1 (Heat 1) when they are tested under other conditions.

REGRESSION ANALYSIS

An intensive regression analysis of the 137 alloys included in the development program was completed.

The alloys analyzed included 47 experimental cobalt-base alloys, 73 experimental and 17 commercial nickel-base alloys. The test temperatures ranged from 1600° to 2125° F. Times ranged from 86 to 100 hours with 200 ppm salt and from 439 to 1100 hours with 5 ppm salt. A total of 969 tests were examined in the regression analyses. The compositions by weight percent of simple experimental, complex experimental, and commercial nickle-base alloys, plus experimental cobalt-base alloys, are given in Appendix A, Tables 1-A through 4-A.* The analyzed composition is given when available, otherwise the nominal is shown. The General Electric Research Laboratory series designated as RL nickel-base alloys are simple experimental alloys, while the Thomson Engineering Laboratory (TEL) series and the Marine Engineering Laboratory nickel (MELNI) alloys are the complex nickel-base alloys. The RL series of the cobalt-base alloys, the Marine Engineering Laboratory cobalt-base (MELCO) series, and the experimental DISCO series comprise the experimental cobalt alloys. The DISCO alloys were intended to be a matrix for dispersion strengthening.

Table 5-A shows the ranges of concentration in weight percent for each element in each group of alloys. The regression equation for the group will be valid only for an element whose concentration lies within the specified interval.

For each group of alloys within a series and tested under similar conditions, a multiple linear regression equation showing the average contribution of each alloying element to the amount of corrosion was found. Tables 6-A and 7-A give the regression coefficients for the equations representing the different groups of alloys at various conditions. Coefficients in Table 6-A are

---

All tables mentioned in this text will appear in Appendix A.

on the measurement of surface loss, whereas those in Table
e based on maximum penetration measurements. A positive
sion coefficient indicated a tendency for a given element
rease corrosion whereas a negative coefficient indicated a
sed tendency toward corrosion. Other pertinent facts
ning each regression equation are the multiple correlation
cient, R, and the standard error of estimate, S_E.

nspection of Tables 6-A and 7-A indicates the contribution
rosion of relatively few coefficients with a high level of
ence (95%). The confidence level of many of the coefficients
be accurately measured due principally to the few tests
ted of any given alloy. In addition, the coefficients of
lements do not consistently indicate that the element has
a beneficial or detrimental effect. Also, it was not
le, with the number of tests used in the studies,[3,4,5,6,7,8]
mine all the possible interactions. Tables 3-A through 17-A
e the behavior of each element as it may be affected by test
ature, by time and salt concentration, by whether or not
ement is a constituent of a simple or complex alloy, and by
ncentration range of the element present.

he effect of temperature in 100-hour tests of the simple
-base experimental alloys (RL 1 through 9, and 20 through
shown in Table 8-A. It can be seen that Y, Zr, and Ce
nsistently detrimental with respect to maximum penetration
the three temperatures, and that C, Si, Cb, Mo, and W are
singly detrimental with increasing temperature. On the
hand, Cr, Fe, and Co are consistently beneficial while Al
eficial with increasing temperatures; Ti is detrimental at
F. The highest degree of confidence (95%) in the above
sions is indicated for Ti (1675° F), for Zr (1750° F), for
Ce (1675° and 1750° F), for Cb, Mo, W, and Ta (1900° F),
r Cr (all temperatures).

he effects of temperature on the behavior of elements with
t to maximum penetration of the complex experimental nickel-
lloys (MELNI 1, 2, 4, 5, and 7 through 24) in 1000-hour
are summarized in Table 9-A. It can be seen that Cr, Fe,
, Mo, W, and Re have consistent, but not highly significant,
ental effects and that only Al, Ti, Y, La, and Ta seem to
beneficial effect on corrosion. Boron seems to promote
sion with increasing temperature, in contrast to the effects
nd Cb. However, only the effect of Al and Y on corrosion
be considered highly significant (at the 90% confidence
).

n comparison of Tables 8-A and 9-A, it appears that the
on maximum penetration of Zr was consistently duplicated

in both the RL alloys for 100 hours and the MELNI alloys for 1000 hours.

Thus, the projection of the behavior of elements in simple alloys under one set of conditions and ranges of concentration cannot predict their behavior in complex alloys at other sets of conditions. In addition, from Table 5-A it can be seen that C, Cr, Co, Zr, and W were present in different concentration ranges in each series of alloys. This fact may have added to the discrepancy.

A more direct comparison between simple and complex alloys is summarized in Table 10-A. Under precisely the same conditions, 1750° F and 200 ppm salt for 100 hours, consistant agreement is found in Al, Ti, Fe, Y, and Zr with respect to maximum penetration. The discrepancy in C, Cr, Co, and W can again be suspected to be due to the differing concentration ranges in both sets of alloys. The beneficial behavior of Mo at 1750° F in the MELNI series in the 100-hour test, in contrast to the 1000-hour test, or in the simple alloys with increasing temperature may indicate that this element contributes to corrosion resistance in a highly sulfidizing environment, but not in a more oxidizing one associated with higher temperatures and lower salt concentrations.

Similar comparisons can be made from Tables 8-A through 10-A with respect to surface loss. In the RL series, the beneficial (or detrimental) influence of C, Ti, Cr, Fe, Co, Cb, and Mo on corrosion was the same for both surface loss and maximum penetration. On the other hand, the influence of B, Y, Zr, and Ce on surface loss was opposite to that for maximum penetration.

A similar lack of agreement exists for the MELNI series at 1600° and 1800° F (Table 9-A). Only C, Fe, Zr, Mo, W, and Re had the same influence on both surface loss and maximum penetration. The disagreement is not surprising in view of the lack of correlation between the two measurements, and thus gives added support for the use of both measurements in hot-corrosion tests.

The test effects of time and salt concentration at 1750° F on the MELNI 1 through 13 series is shown in Table 11-A. It is interesting to note that the effect of time does not change the sign of any regression coefficient although the values do differ. Also, the influence of each element is the same for both surface loss and maximum penetration. A comparison of the effects of the simple RL alloys and the complex TEL and MELNI alloys is given in Table 12-A.

t is interesting to note that none of the effects are con-
t, either for surface loss or for maximum penetration. The
s on corrosion for the elements common to the three groups
s the same for both types of measurements.

similar comparison is made between the TEL alloys and the
cial alloys tested at 1600° F, for 500 hours with 5 ppm
Table 13-A). Of the elements common to both series of
, all but C, Ti, and Cr show the same beneficial, or
iental, effect. With the exception of W, all elements had
me effect with respect to both surface loss and maximum
. With regard to the surface loss of the commercial alloys,
fects of Cr, Mo, and W agree with results of Ryan[2] for tests
med at 1800° F.

n contrast to the simple nickel-base RL series, the cobalt
(RL 10 through 15 and 52 through 64) in Table 14-A show
loying elements to have the same type of effect on both
e loss and maximum penetration. Carbon is always
iental, while Ni, Mo, and W show an increase in corrosion
with increasing temperatures. Titanium, Cr, Y, Zr, Cb, La,
d Ta show a beneficial effect with increasing temperature.

he behavior of alloying elements in the complex MELCO 1
h 11 series is compared with their behavior in the simple
ies at two temperatures, 1750° and 1900° F, for the 100-
nd 200 ppm salt tests. The elements common to both sets of
exhibit a lack of consistent behavior, with the exception
whereby the set of alloys used and the temperature tested
ave an effect on surface loss and maximum penetration.
m shows a beneficial effect (sometimes significant, some-
not) under all the conditions described above.

he effects of temperature on the behavior of elements common
CO 3, 4, 5, 7, 8, 9, 10, and 11 can be examined in Table
Boron is consistently detrimental at all temperatures and
h surface loss and maximum penetration, although the sig-
ance is questionable. Chromium, Ni, Ta, and W show reduction
rosion with increasing temperature, and C, Cu, and Y show
sistent test results. However, because of the few tests
ted on each alloy, the validity of these conclusions is
ionable.

he nature of the tests conducted on MELCO 1 through 11
s us to examine the behavior of the alloying elements in
at more detail than can be done with most of the other
s examined. In addition to the sign of the regression
icient, its numerical value may be examined in Tables 17a-A

through 17h-A to determine the sensitivity to corrosion of a given element under two test-times and two temperatures.

Boron

With the exception of 1000-hour tests at 1750° F, B seems to be detrimental with respect to surface loss. Maximum penetration is more dramatically enhanced at 1900° F than surface losses at that temperature, even with the lower salt concentration.

Carbon

The effect of carbon appears to vary most with test conditions at 1900° F, although the significance of the coefficients is questionable.

Chromium

Although Cr is accepted as beneficial in hot corrosion, it appears from the tests that there are cases at the high concentration ranges where it is not. For example, based on maximum penetration values, Cr appears beneficial at both 1750° and 1900° F with the higher salt concentration and 100 hours of operation. However, a longer period of test operation (1000 hours) shows a detrimental effect at a low salt concentration. This seems to indicate that test conditions, oriented more toward oxidizing than sulfidizing conditions, cause Cr to be less helpful.

Nickel

Nickel appears to be the most detrimental at the highest temperature and longest test even with the low salt concentration.

Copper

Copper appears to be beneficial, expecially at high temperatures and long times, with the exception of the test at 1750° F for 1000 hours.

Yttrium

The effect of Y at all conditions, except the detrimental effect on surface loss in 1000-hour tests, is beneficial. These observations, at least with respect to maximum attack, support the contention that if Y is helpful in oxidation resistance of cobalt-base alloys, then it should be of similar help in corrosion resistance.

alum

In the concentrations present in MELCO 1 through 11, Ta ars to be innocuous (neither beneficial nor detrimental).

sten

Like Ta, W, too appears innocuous or at least inconclusive in behavior.

YSIS OF VARIANCE

el-Base Alloys

Table 18-A illustrates the testing of three sample specimens ight nickel-base alloys at each of three temperature levels otal of nine specimens per alloy).

The analysis of variance (Table 19a-A), using all the given results for maximum penetration, seems to indicate that only ferences in the proportion of chromium used (15% or 20%) made ignificant contribution to differences in corrosion measure- ts.

However, a further examination of the data in Table 18-A icates that certain test runs (e.g., Nos. 3 and 8) resulted in exaggerated corrosive effect on certain alloys, as compared other specimens of the same alloys tested under the same ditions but in different test runs.

Examples in Table 18-A of these particular test specimens lude Alloy RL 46, when tested at 1675° and at 1750° F, and oys RL 47 and 51, when tested at 1750° F.

Therefore, a new analysis of variance was performed (Table -A) in which Tests 3, 8, and 13 were eliminated; the remaining t measurements for each alloy obtained under similar conditions e averaged together. In the new analysis, besides the ferences in corrosion due to differences in chromium, those cerning titanium and temperature levels also seemed to make nificant contributions to corrosive behavior.

It should be noted that variations in the proportion of kel used in these nickel-base alloys, although not specifically ted in Table 18-A, may also contribute to an increase or rease in corrosive effects.

Cobalt-Base Alloys

Hot-corrosion tests were performed on two specimens each of nine cobalt-base alloys, at each of three temperature levels, as shown in Table 20-A. For each two specimens, one specimen was placed in the test chamber as cast, while the other specimen was given a special heat treatment before being placed in the test chamber.

An analysis of variance using the maximum penetration measurement is presented in Table 21-A to determine the relative effect on corrosion of heat treatments or lack of heat treatments versus the proportions of chromium, nickel, and tantalum used within each alloy. The results of these analyses are presented graphically as well as in analysis-of-variance tables, according to statistical methods described by Hoel[9] and Brownlee.[10]

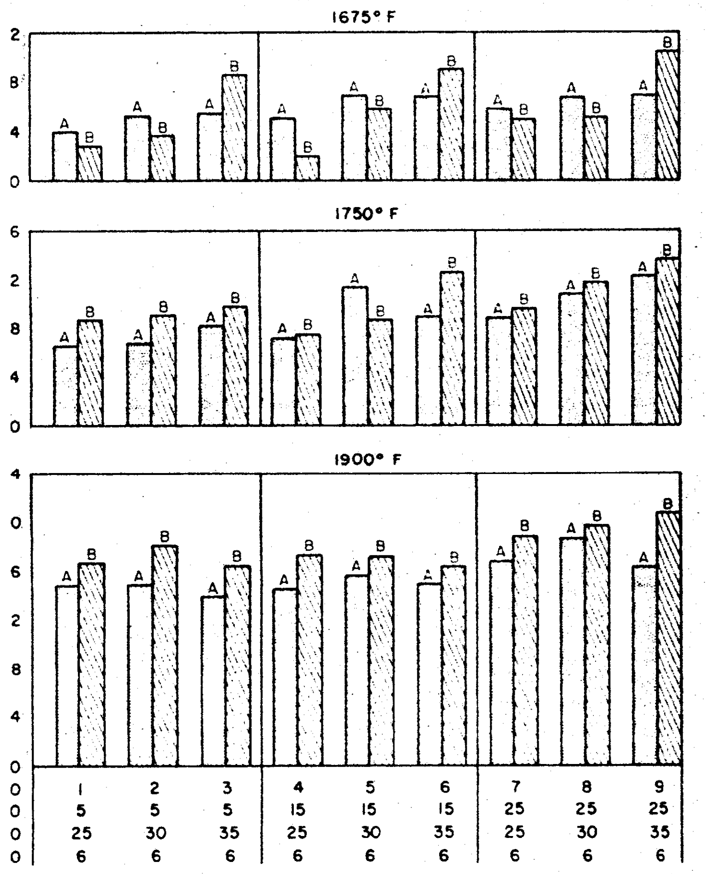
Taking into consideration all the given factors, there seems to be considerable interaction between (H) (heat treatment or lack of heat treatment) and the test temperatures used (T), as well as between (H) and the proportion of chromium used in an alloy (Cr). A significant interaction indicates that a specific combination of factors may possibly affect the outcome of a test in a somewhat different fashion than would each of the factors considered by itself (called a main effect). This analysis also indicates a possible interaction between test temperatures and the proportion of chromium used, as well as significant main effects of temperature and nickel considered independently.

Because of the highly significant effect of temperature on most of the other factors, a separate analysis of variance was performed in reference to each separate temperature level (1675°, 1750°, and 1900° F). The result of this analysis is also presented in Table 21-A and shown graphically in Figures 4 and 5.

As can be readily seen on examining Figures 4 and 5, there is an increase in corrosion due to higher test temperatures for all proportions of nickel and chromium used in the alloys and in respect to both the heat-treated (B) and nonheat-treated specimens (A).

At an operating temperature of 1900° F, heat-treated specimens (B) show a consistent increase in corrosion over nonheat-treated specimens (A). At 1750° F, one set of specimens out of nine sets shows a reverse relationship (a decrease in corrosion for the heat-treated specimen), while heat-treated specimens tested at 1675° F show about a 50-50 chance of either increasing or decreasing the corrosive effect.

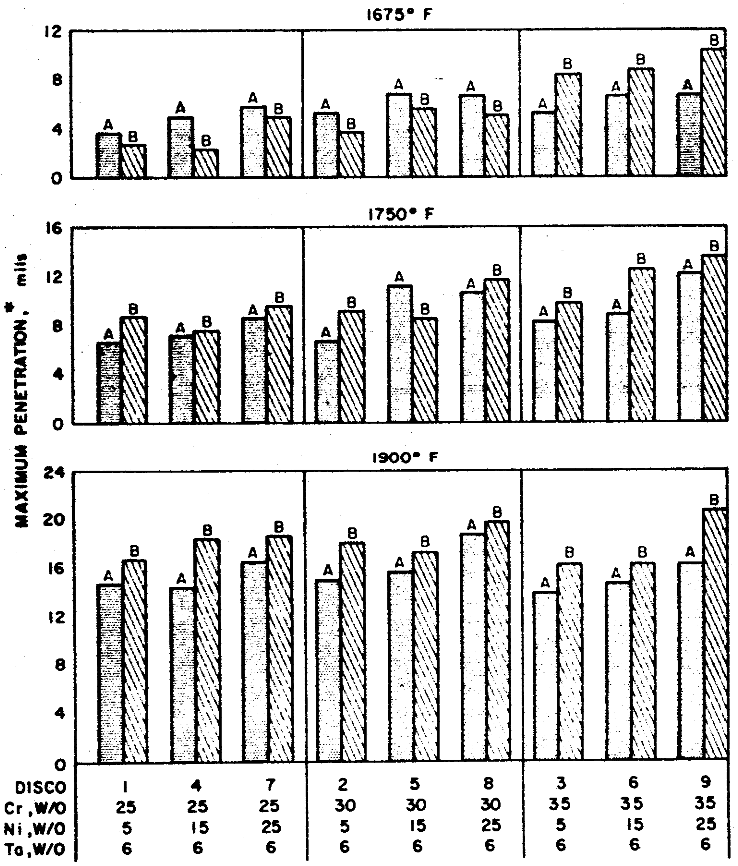
A = Nonheat-treated
B = Heat treated



imum penetration values from Table 20-A.

Figure 4
Corrosion of DISCO Alloys Arranged by Nickel Content

A = Nonheat-treated
B = Heat treated



*Maximum penetration values from Table 20-A.

Figure 5
Hot Corrosion of DISCO Alloys Arranged by Chromium Content

a similar fashion, the general increase in corrosion test
due to increases in nickel content (Figure 4) at each
ture level is evident, as is also the general decrease in
on measurements due to increases in chromium content
5) at each temperature level. However, an increase (or
se) in nickel content has less apparent effect on corrosion
sted at 1900° F, while a change in chromium content has
parent effect on corrosion when tested at 1675° F. The
of nickel, chromium, and temperature on corrosion test
may thus be considered main effects at various tempera-
evels. As shown in Table 21-A, nickel seems to be very
icant at all three temperatures, while chromium is most
icant at 1750° F and least significant at 1675° F.

ius, the analysis of variance presented in Table 21-A and
aphical representations in Figures 4 and 5 indicate that
reatment has no significant effect on corrosion when
ens are tested for 100 hours at 1675° F, a somewhat greater
icance when tested at 1750° F, and a very significant effect
ested at 1900° F. However, the direction of change
ase or decrease in test results) versus the change in test
ions is not presented in an analysis of variance, but must
ermined by further examination of the data.

n addition to changes in corrosion test results due to
s in chromium and nickel content, the experimenter should
glect the possible effects of tantalum (6%) and the
ses or decreases in cobalt content which depend on the
proportion of other metals used in each alloy.

SUMMARY AND CONCLUSIONS

he hot-corrosion behavior of a number of experimental and
cial nickel- and cobalt-base superalloys was statistically
ed. Tests were made in a burner rig using diesel fuel to
controlled quantities of sea salt were added. The
icant results of the study are as follows:

- In general no one-to-one correspondence could be
between surface loss and maximum penetration for all the
tested under various conditions. Therefore, in studies
such a spread of alloy compositions, both measurements are
ended.

- Projection of the behavior of elements in simple
under one set of conditions and ranges of concentration
always predict their behavior in complex alloys at other
f conditions.

- Although Cr is considered a beneficial constituent, this analysis indicates that additions greater than about 20% in nickel-base MELNI alloys had a tendency to increase corrosion slightly.

- The lack of consistency in the effect of various elements on corrosion indicates the possible existence of interactions among elements as well as the need for testing a greater number of specimens of any given alloy.

- In a series of cobalt-base DISCO alloys with factorially designed compositions, it was found that there were significant interactions between Cr and temperature, between heat treatment and Cr, and between heat treatment and temperatures.

- Alloying elements, which show effects of doubtful significance, should be investigated by designed experiments, using a sufficient number of replications.

80
35
66
32

Appendix A

Tables

---

nl

DUPLEX - RwB3

Table 1-A

Chemical Composition of Simple Experimental Nickel-Base Alloys*

RL Designation	Element, %																				
		C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re
1		0.01									B											
2		0.02					10.2															
3		0.01					15.0															
4		0.02					25.5															
5		0.01					15.1														3.05	
6		0.02					15.4														24.00	
7		0.01					15.0									6.01						
8		0.01			4.96		15.4															
9		0.04	8.03				15.4															
20		0.02					15.0			10.0												
21		0.02					15.0									1.00						
22		0.02					15.0									3.00						
23		0.02	2.00				15.0															
24		0.02	5.00				15.0															
25		0.02	9.99				15.0															
26		0.02			2.00		15.0															
27		0.02			3.00		15.0															
28		0.02	9.99				15.0															
29		0.02					15.0														3.00	
30		0.02					15.0														12.00	
31		0.02					15.0													3.00		
32		0.02					15.0													8.00		
33		0.02					15.0													12.00		
34		0.02					15.0						0.15									
35		0.02					15.0							0.15								
36		0.02					15.0											1.00				
37		0.02		0.50			15.0															
38		0.02		2.00			15.0															
39		0.02					15.0								2.00							
40		0.02					15.0								7.00							
41		0.02					15.0		10.0													
42		0.02					15.0		20.0													
43	0.150	0.02					15.0							0.500								
44		0.02	2.50		4.50		15.0															
45		0.02	2.50		9.00		15.0															
46		0.02	5.00		4.50		15.0															
47		0.02	5.00		9.00		15.0															
48		0.02	2.50		4.50		20.0															
49		0.02	2.50		9.00		20.0															
50		0.02	5.00		4.50		20.0															
51		0.02	5.00		9.00		20.0															

*Composition in weight percent. B = Balance

Table 2-A

l Composition of Complex Experimental Nickel-Base Alloys*

Element, %																				
C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re
TEL																				
0.12	4.00		2.00		25.0			10.0	BA				0.50	1.9					4.00	
0.14	4.00		2.00		20.0			10.0					0.50	1.9					4.00	
0.14	4.18		1.65		15.2			10.0					0.51	1.5					4.14	
0.15	4.00		2.00		10.1			10.0					0.50	1.9					4.00	
0.16	6.16		0.02		15.1			10.0					0.50	1.8					4.00	
0.17	5.27		2.96		15.0			10.0					0.50	1.5					4.00	
0.12	2.65		3.96		15.0			10.0					0.50	1.7					4.00	
0.11	4.00		2.00		15.0			10.0					0.50	0.1					7.49	
0.12	4.00		2.00		15.0			10.0					0.50	2.2					1.77	
0.15	4.00		2.00		15.0								0.50	1.0					4.00	
0.15	4.17		1.98		15.1			24.2					0.50	1.0					4.73	
0.13	6.20		3.98		15.0			0.1					0.50	1.7						
MEINI																				
0.09	3.68		1.90		18.7		0.2	14.9				0.092		4.0						
0.09	3.50		1.80		18.3		0.2	14.8				0.081								4.58
0.10	3.64		2.08		20.8		0.2	15.8				0.059		0.1						
0.10	2.93		1.82		18.7		0.2	14.9			0.200	0.095		4.0						
0.10	3.50		2.16		18.8		0.2	23.4			0.200	0.049		3.9						
0.10	3.68		1.82		19.8		0.2	15.2				0.091		4.1	0.08					
0.08	2.24		3.12		24.8			11.8				0.088			0.25				6.00	
0.08	1.90		2.66		24.5			13.8				0.084			0.26			1.20	6.10	
0.08	2.00		4.13		22.0			13.0				0.063			0.12			2.40	5.90	
0.08	1.54		3.54		24.5			12.3				0.083			0.31				5.90	
0.05	2.20		3.10		25.0			12.3				0.084			0.17				6.00	
0.05	2.02		3.10		24.8			12.3				0.093			0.67				6.00	
0.05	2.18		3.10		24.4			12.7				0.091			1.45				5.90	
0.14	2.26		4.22		19.8			9.4				0.100			0.16				5.65	
0.14	2.23		3.93		19.8			9.4				0.015		2.0	0.17			1.50	1.95	
0.14	4.08		1.95		19.7			9.4				0.140			0.17				5.75	
0.12	2.50		4.40		19.5			9.6				0.094		3.9	0.17					
0.14	4.12		2.84		18.3			7.9				0.160		2.2	0.16				2.05	
C.11	3.08		2.90		19.2							0.120	2.10	3.3	0.12				3.20	
0.14	3.08		1.37		18.3			7.6				0.090	2.00	2.1	0.15			1.39	1.30	

in weight percent. BA = Balance

Table 3-A

Chemical Composition of Commercial Nickel-Base Alloys*

Designation	Element, %																					
	B	C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re
AMS 5397	0.014	0.18	5.50		4.70	1.00	10.0			15.0	BA			0.060		3.0						
PA 2	0.015	0.14	4.86		1.80		8.8		0.3	10.2					1.20						12.30	
AMS 5391A (Heat 1)	0.007	0.12	5.69		1.01		13.4		1.7						2.37	3.7				0.17		
AMS 5399		0.08	1.60		3.15		19.1			11.1						9.9						
AMS 5384 (Heat 1)	0.005	0.08	3.02		3.05		19.4									3.9						
AMS 5384 + Ce	0.005	0.08	2.97		2.98		18.8		0.2	19.4						4.2		0.50				
AMS 5384 (Heat 2)	0.006	0.07	3.00		3.00		18.5			18.5						4.0						
PA 7 (Heat 1)	0.013	0.12	4.70		3.63		14.8			18.9				0.050		5.0						
PA 7 (Heat 2)	0.027	0.09	4.35		3.18		15.2			18.6						5.0						
PA 7 (Heat 3)	0.015	0.12	4.28		3.48		14.6			15.2						4.1						
PA 7 (Heat 4)	0.015	0.12	4.27		3.41		14.8			15.1						4.2						
PA 7 + 0.5 Ce	0.020	0.07	4.30		3.35		14.8			15.0				0.080		4.2		0.50				
PA 7 + 0.2 Ce	0.020	0.07	4.30		3.35		14.8			15.0						4.2		0.20				
PA 1 (Heat 1)	0.014	0.10	4.48		2.07		15.2		0.2	24.8						4.6						
PA 1 (Heat 2)	0.014	0.08	4.50		2.51		15.0			25.8						4.5						
PA 5	0.015	0.07	5.40		2.50		11.0			15.0					0.45	6.5					1.50	
PA 6	0.018	0.05	6.30		0.10		16.7							0.100	1.00					1.90	1.95	

*Composition in weight percent.
PA = Proprietory alloy
BA = Balance

Table 4-A

Chemical Composition of Experimental Cobalt-Base Alloys*

Element, %																					
B	C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re
RL																					
	0.01					25.6			BA												
	0.02																				
	0.03					25.7														7.88	
	0.01					26.2									6.0						
	0.02					25.0													7.08		
	0.02					26.4				10.2											
	0.45					15.0				10.0											
	0.45					25.0				10.0											
	0.45					35.0				10.0											
	0.45					25.0				10.0									8.00		
	0.45					25.0				10.0									15.00		
	0.45					25.0				10.0										8.00	
	0.45					25.0				10.0										15.00	
	0.45			4.00		25.0				10.0											
	0.45					25.0				10.0		0.150									
	0.45					25.0				10.0						0.15					
	0.45					25.0				10.0							1.00				
	0.45					25.0				10.0			0.500								
	0.45					25.0				10.0				4.00							
MELCO																					
.015	0.23					27.3				10.7										7.00	
.012	0.25					30.0				0.5		0.150								8.10	
.012	0.26					30.7				9.7									1.80	7.80	
.014	0.27					29.8				9.8									3.45	7.80	
.013	0.26					29.8				9.8		0.130							3.60	8.00	
.012	0.40					29.8				9.8		0.190							3.65	8.10	
.013	0.28					33.0				9.3		0.180							3.80	8.25	
.012	0.26					34.7				9.5		0.170							4.00	6.50	
.008	0.27					31.8				9.9	2.95	0.130								7.85	
	0.42					31.8				9.9		0.010								7.85	
.013	0.26					30.5				9.9		0.120							2.35	8.00	
.013	0.44		0.23			23.9	0.62	0.2		10.4		0.250							3.10	7.80	
.013	0.44		0.24			23.3	0.36	0.2		10.0		0.200	0.150						3.45	7.80	
.016	0.40		0.21			23.7	0.30	0.3		10.7		0.180						0.15	3.10	7.40	
.017	0.42		0.23			23.6	0.32	0.3		11.1		0.550							3.40	8.00	
.015	0.42		0.27			23.5	0.35	0.2		20.2		0.110							3.50	7.90	
.014	0.51		0.13			28.5	0.31	0.2		10.3		0.180							3.20	10.50	
.017	0.43		0.22			23.8	0.09	0.3		10.7		0.110							3.10	7.40	
DISCO																					
						25.9			BA	5.2									5.77		
	0.01					31.0				5.2									6.00		
	0.01					35.7				5.2									6.00		
						25.3				14.8									6.00		
	0.01					30.9				14.6									6.00		
	0.01					36.3				14.7									6.00		
	0.02		0.30			25.9	0.10			23.3									5.85		
	0.04					31.0				24.2									6.00		
	0.03					35.9				24.6									6.00		
	0.01					25.6				14.3		0.290							6.00		

ition in weight percent.
lance

lloy	Element, %																				
	B	C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W
										Nickel Base Alloys											
0-51		0.01-0.04	0.0-9.99	0.0-2.00	0.0-9.00		0.0-25.5		0.0-20.0	0.0-10.0			0.0-0.15	0.0-0.50	0.0-7.00	0.0-6.01		0.0-1.0		0.0-12.0	0.0-24.
		0.11-0.17	2.65-6.16		0.02-3.96		10.1-25.0			0.0-10.0					0.50-0.51	0.1-2.2					1.77-7.
		0.11-0.17	2.65-6.20		0.02-3.98		10.1-25.0			0.0-24.2					0.50-0.51	0.1-2.2					1.77-7.
3	0.006-0 017	0.05-0.10	1.84-3.68		1.80-4.13		18.3-25.0		0.0-0.2	11.8-23.4			0.0-0.200	0.063-0.095		0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.1
4	0.006-0.024	0.05-0.14	1.84-4.12		1.80-4.40		18.3.25.0		0.0-0.2	0.0-23.4			0.0-0.200	0.015-0.160	0.0-2.10	0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.1
2, 4, 5, 7-24	0.008-0.024	0.05-0.14	1.84-4.12		1.80-4.40		18.3-25.0		0.0-0.2	0.0-23.4			0.0-0.200	0.015-0.160	0.0-2.10	0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.1
1s	0.0-0.027	0.05-0.13	1.60-6.30		0.10-4.70	0.0-1.00	3.3-19.4		0.0-1.7	0.0-25.8				0.0-0.100	0.0-2.37	0.0-6.5		0.0-0.50		0.0-1.90	0.0-12.
										Cobalt Base Alloys											
52-64	0.01-0.45				0.0-4.00		0.0-35.0				0.0-10.2		0.0-0.150	0.0-0.500	0.0-4.00	0.0-6.0	0.0-0.15	0.0-1.00		0.0-15.00	0.0-15.
1	0.008-0.015	0.23-0.40					27.8-34.7				0.5-10.7	0 0-2.95	0.0-0.190							0.0-4.00	6.30-8.
, 7-11	0.0-0.018	0.26-0.42					29.8-34.7				9.3-9.9	0.0-2.95	0.0-0.180							0.0-4.00	6.30-3.
1	0.0-0.014	0.26-0.42		0.0-0.27			29.8-34.7				0.5-9.9	0.0-2.95	0.0-0.190							0.0-4.00	6.30-8.
, 7-18	0.0-0.018	0.26-0.61					28.5-34.7	0.0-0.62	0.0-0.3		9.3-20.2	0.0-2.95	0.0-0.550	0.0-0.105					0.0-0.15	0.0-4 00	6 30-
8	0.0-0.018	0.23-0.61		0.0-0.27			27.8-34.7	0.0-0.62	0.0-0.3		0.5-20.2	0.0-2.95	0.0-0.550	0.0-0.105					0.0-0.15	0.0-4.00	6.30-1

	T °F	Time hour	Sea Salt ppm	Element																						R
				B	C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re	
														Nickel Base Alloys												
51	1675	100	200	+190.0 c	-265.0 c	+4.78 a	-6.33c	-1.73 b		-3.66 a		-0.707c	-0.492c			-77.3 c	-79.6 c	-1.69 c	-2.54 c		-11.7 c		-1.17 c	-1.21 c		0.56
	1750	100	200	4.42c	+217.0 c	+5.50 a	+4.32c	+0.811c		-2.52 a		-0.053c	-0.005c			-2.69 c	-1.13c	+1.56 c	+0.827c		-1.07c		+0.059c	+0.414c		0.53
	1900	100	200	+152.6 c	+696.0 c	+1.24 c	-1.17c	-0.735c		-3.13 a		-0.067c	-0.619c			-84.7 c	-71.4 c	+14.5 a	+2.47 c		-12.7 c		+1.19 c	+3.27 a		0.67
	1600	100																								
	1750	100	200		+614.0 c	-29.6 c		-23.0 c		-2.54 c			+6.73 c					-1363.0 c	-56.7 c					-25.7c c		0.36
	1600	500	5		+220.0 c	-9.61 c		-7.95 c		-3.43 b			+0.864c					-1922.0 c	+21.6 c					+5.22 c		0.85
	1750	100	200		-441.6 c	-4.25 c		-9.25 c		-4.63 a			+0.130c					+57.0 c	+9.44 c					-3.02 c		0.93
	1600	500	5		-673.0 a	+20.9 a		+10.2 c		-4.15 a			-0.420c					-931.0 c	+10.7 c					-3.88 c		0.85
	1750	1100	5		-282.0 c	+1.79 c		-2.50 c		-3.96 a			-0.023c					+2134.0 c	+17.5c c					+0.366c		0.91
	1750	100	200	+3249.0 c	-112.0 c	+12.9 c		+18.2 c		+5.42 c		-54.9 c	+1.79 a			+52.1 b	+538.0 c		-3.27 b	-9.33 c			+11.7 c	-12.5 c		0.93
	1750	1000	5	+6068.5 c	-223.2 c	+32.0 c		+34.2 c		+14.6 c		-2062.7 c	+5.4 c			+95.3 c	+1569.5 c		-6.37 c	-24 1 c			+29.3 c	-89.9 c		0.93
	1600	1000	5	-233.0 a	+14.1 c	-1.79 b		-0.302c		-0.437c		-3.60 c	+0.111c			-6.01 c	+20.2 c	+1.27 a	-0.420c	+0.210c			-0.712c	-0.037c	-0.30	0.39
,5,7-24	1600	1000	5	+38.7 c	+13.4 c	-0.519c		+0.753c		+0.158c		+21.2 c	-0.036c			-2.63 c	+2.55 c	+0.833c	+1.54 c	+0.352c			+0.336c	+1.08 b	+1.44 c	0.39
	1300	1000	5	+59.2 c	-15.5 c	+0.737c		+0.774c		-0.055c		+8.46 c	-0.053c			+5.05 c	+3.54 c	+0.632c	+1.14 c	-0.724c			+0.613c	-0.372c	[illegible]	0.36
	1600	500	5	-1108.0 c	+99.5 c	+70.0 c		-6.66 c	+33.9c	+4.73 c		-9.94 c	-10.6 b				-1140.0 a	-108.0 c	+2.23 c		+3.46c		-56.5 c	-0.316c		0.39
														Cobalt Base Alloys												
2-64	1675	100	200		+47.9 b			-6.49 a		-4.65 a				-0.600c		-180.0 a	-54.4 a	-6.72 a	-1.01 c	-2713.9 a	-27.1 a		-2.10 a	-1.93 a		0.33
	1750	100	200		+47.4 c			-6.44 a		-4.64 a				-0.568c		-178.0 a	-54.0 a	-6.65 a	+4.07 b	-2676.0 a	-27.2 a		-2.08 a	-2.01 a		0.96
	1900	100	200		+33.0 c			-4.32 c		-2.30 a				+0.033c		-127.0 c	-37.5 c	-4.04 c	+21.5 a	-1383.0 c	-19.1 c		-1.37 c	+1.21 c		0.32
	1750	100	200	+465.0 c	-1.30 c					+0.213c				+0.544c	-2.12 c	-0.323c							-1.66 c	+1.41 c		0.92
	1900	100	200	+556.0 c	+8.46 c					+0.417c				-0.207c	+0.059c	-33.0 a							+0.437c	+0.965c		0.35
	1750	1000	5	-168.0 c	-3.01 c					+0.021c				+0.080c	-0.177c	+5.01 c							+0.077c	+0.001c		0.96
	1900	1000	5	+445.0 c	-15.1 c					-0.942b				+1.30 a	-3.55 a	+25.6 b							-2.31 a	-2.33 a		0.32
	1600	500	5	-17.6 c	-1.30 b					-0.021c				-0.009c	+0.027c	+0.850b							+0.040c	+0.045c		0.99
7-11	1600	500	5	+19.3 c	+0.501c					+0.022c				+0.294c	+0.008c	+0.647c							+0.047c	+0.001c		1.0
	2050	500	5	+555.0 c	+15.0 c					-0.320c				-6.63 c	+0.041c	-31.9 c							+0.242c	-0.255c		0.90
	2125	500	5	+1341.0 c	-93.0 c					-10.7 c				-54.1 c	-16.3 c	+46.1 c							-13.9 c	-17.4 c		0.99
	2050	500	5	+858.0 a	+22.2 a					+0.846a				-0.183c	-0.133c	-40.4 a							+0.968c	+1.52 a		0.95
7-18	2125	500	5	+11511.0 c	+474.0 c		-1599.0 a			-0.032c	+117.0 c	+416.0 c		+21.7 c	-20.4 b	-21.4 c	+579.0 c					-197.0c	-10.0 c	-3.33 c		[illegible]
	1900	1000	5	+413.0c c	+0.933c		-52.6 c			-0.589c	+3.55c	+20.7 c		+0.771a	-2.14 c	+0.485 c	+25.1 c					-19.6c	-1.61 b	-0.124c		[illegible]

fidence level, b - 90% confidence level, c - Confidence level is equal to or greater than 60% but less than 90%

ture, R - Multiple correlation coefficient, S_E - Standard error of estimate, N - Number of tests per regression analysis, I - Intercept value for regression equation

Table 5-A

Ranges for Each Alloying Element

Element, %												
o	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re
el Base Alloys												
10.0			0.0-0.15	0.0-0.50	0.0-7.00	0.0-6.01		0.0-1.0		0.0-12.0	0.0-24.0	
10.0					0.50-0.51	0.1-2.2					1.77-7.49	
24.2					0.50-0.51	0.1-2.2					1.77-7.49	
-23.4			0.0-0.200	0.063-0.095		0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.10	0.0-4.52
23.4			0.0-0.200	0.015-0.160	0.0-2.10	0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.10	0.0-4.52
23.4			0.0-0.200	0.015-0.160	0.0-2.10	0.0-4.1	0.0-1.45			0.0-2.40	0.0-6.10	0.0-4.52
25.8				0.0-0.100	0.0-2.37	0.0-6.5		0.0-0.50		0.0-1.90	0.0-12.3	
t Base Alloys												
	0.0-10.2		0.0-0.150	0.0-0.500	0.0-4.00	0.0-6.0	0.0-0.15	0.0-1.00		0.0-15.00	0.0-15.00	
	0.5-10.7	0.0-2.95	0.0-0.190							0.0-4.00	6.30-8.10	
	9.3-9.9	0.0-2.95	0.0-0.180							0.0-4.00	6.30-8.25	
	0.5-9.9	0.0-2.95	0.0-0.190							0.0-4.00	6.30-8.25	
	9.3-20.2	0.0-2.95	0.0-0.550	0.0-0.105					0.0-0.15	0.0-4.00	6.30-10.50	
	0.5-20.2	0.0-2.95	0.0-0.550	0.0-0.105					0.0-0.15	0.0-4.00	6.30-10.50	

Table 6-A

Regression Coefficients for Surface Loss

Element												R	Sg	N	I
Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re				
kel Base Alloys															
		-77.3 c	-79.6 c	-1.69 c	-2.54 c		-11.7 c		-1.17 c	-1.21 c		0.56	26.9	111	72.5
		-2.69 c	-1.13c	+1.56 c	+0.827c		-1.07c		+0.059c	+0.414c		0.53	25.6	111	35.2
		-84.7 c	-71.4 c	+14.5 a	+2.47 c		-12.7 c		+1.19 c	+3.27 a		0.67	26.1	108	32.7
				-1863.0 c	-56.7 c					-25.7c c		0.86	22.3	12	1216.0
				-1922.0 c	+21.6 c					+5.22 c		0.85	12.9	20	994.0
				+57.0 c	+9.44 c					-3.02 c		0.83	16.2	16	161.0
				-931.0 c	+10.7 c					-3.88 c		0.85	20.2	23	533.0
				+2134.0 c	+17.5c c					+0.366c		0.91	14.1	12	-1003.0
		+52.1 b	+538.0 c		-3.27 b	-9.33 c			+11.7 c	-12.3 c		0.93	0.67	31	-251.0
		+95.8 c	+1569.5 c		-6.97 c	-24.1 c			+29.8 c	-39.9 c		0.93	0.44	13	-267.4
		-6.01 c	+20.2 c	+1.27 a	-0.420c	+0.210c			-0.712c	-0.087c	-0.304c	0.88	0.61	46	18.6
		-2.63 c	+2.55c	+0.383c	+1.54 c	+0.352c			+0.336c	+1.08 b	+1.44 c	0.89	0.59	42	-10.7
		+5.05 c	+3.54c	+0.682c	+1.14 c	-0.724c			+0.613c	+0.972c	+1.35 c	0.96	0.50	25	-5.4
			-1140.0 a	-103.0 c	+2.23 c		+3.46c		-56.5 c	-0.316c		0.89	26.3	42	-91.7
lt Base Alloys															
-0.600c		-130.0 a	-54.4 a	-6.72 a	-1.01 c	-2713.9 a	-27.1 a		-2.10 a	-1.98 a		0.88	14.3	43	128.0
-0.563c		-178.0 a	-54.0 a	-6.65 a	+4.07 b	-2676.0 a	-27.2 a		-2.08 a	-2.01 a		0.86	16.2	48	128.0
+0.085c		-127.0 c	-37.5 c	-4.04 c	+21.5 a	-1883.0 c	-19.1 c		-1.37 c	+1.21 c		0.82	24.2	49	74.1
+0.544c	-2.12 c	-0.323c							-1.66 c	+1.41 c		0.92	1.69	11	-18.9
-0.207c	+0.053c	-33.0 a							+0.437c	+0.965c		0.85	1.48	15	1.86
+0.080c	-0.177c	+5.01 c							+0.077c	+0.001c		0.96	0.290	11	2.76
+1.30 a	-3.55 a	+25.6 b							-2.81 a	-2.83 a		0.82	2.60	28	47.9
-0.009c	+0.027c	+0.350b							+0.040c	+0.045c		0.99	0.031	11	1.03
+0.294c	+0.003c	+0.647c							+0.047c	+0.091c		1.0	0.013	8	-4.44
-6.68 c	+0.041c	-31.9 c							+0.242c	-0.255c		0.90	1.73	16	+75.9
-54.1 c	-16.3 c	+46.1 c							-13.9 c	-17.4 c		0.996	2.62	8	+1073.0
-0.183c	-0.133c	-40.4 a							+0.963c	+1.52 a		0.95	1.04	20	-43.2
+21.7 c	-20.4 b	-21.4 c	+579.0 c					-197.0c	+10.0 c	-3.38 c		0.91	5.22	22	-358.0
+0.771a	-2.14 c	+0.435 c	+25.1 c					-19.6c	-1.61 b	-0.124c		0.63	2.93	42	+15.7

ysis, I - Intercept value for regression equation

C

Table 7-A

Regression Coefficients for Maximum Penetration

oy	T °F	Time hour	Sea Salt ppm	Element																			
				B	C	Al	Si	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta
Nickel-Base Alloys																							
1	1675	100	200	-271.0 c	-117.0 c	+3.57 a	-1.24c	-2.01 a		-3.61 a		-0.867c	-0.875 c			+76.5 c	+61.6 c	-1.54c	-3.09 c		+36.3 a		-0.943c
	1750	100	200	-883.4 a	+322.0 c	+3.87 a	+1.69c	+0.309c		-3.90 a		-0.445c	-0.629 c			+170.0 c	+267.0 a	+2.98c	+0.255 c		+49.4 a		-0.002c
	1900	100	200	-457.0 c	+723.0 c	-0.772c	+19.1 b	-1.47 b		-3.10 a		-0.055c	-0.670 c			+38.5 c	+127.0 c	+12.2 a	+8.58 a		+23.6 c		+3.08 a
	1600	100	200		+345.0 c	-13.9 c		-7.15 c		-2.24 c			-0.008 c					-320.0 c	+26.6 c				
	1750	100	200		+330.0 c	-27.1 c		-27.1 c		-8.12 c			+3.95c c					-2852.0 c	-8.93 c				
	1600	500	5		-15.4 c	+3.10 c		-2.02 c		-5.70 a			-0.262 c					-2522.0 c	+38.3 c				
	1750	100	200		-448.0 c	-3.56 c		-13.1 c		-9.21 a			+0.445 c					-1511.0 c	+17.2 c				
	1600	500	5		-597.0 b	+23.5 a		-10.2 b		-6.07 a			-0.808 c					-1925.0 c	+26.8 b				
	1750	1100	5		-87.0 c	+1.75 c		+0.437c		-4.70 a			+0.0006c					+3054.0 c	+17.6 c				
	1750	100	200	+1583.0 c	-59.6 c	+12.0 c		+17.2 c		+5.47 c		-39.7 c	+2.97 a			+67.3 c	+705.0 c		-3.55 c	-5.15 c			+9.32 c
	1750	1000	5	+15084.1 c	-302.9 c	+78.5 c		+72.2 c		+31.81 c		-3889.7 c	+8.05 c			+232.4 c	+2731.3 c		-14.1 c	-51.7 c			+52.4 c
	1600	1000	5	-1023.0 c	+50.1 c	-7.00 c		-3.62 c		+1.14 c		-40.0 c	+1.22 c			-29.7 c	+151.0 c	+4.55c	-1.00 c	-2.36 c			-2.97 c
4, 5, 7-24	1600	1000	5	-512.0 c	+108.0 c	-3.85 c		-1.25 c		+3.14 c		+53.1 c	+0.780 c			-54.3 c	+95.6 c	+3.35c	+2.47 c	-0.962c			-0.331c
	1800	1000	5	+250.0 c	-5.20c	-6.64 b		-4.48 c		+1.44 c		+7.27 c	+0.249 c			-37.1 b	+21.0 c	-1.32c	+3.89 c	-0.313c			-0.374c
	1600	500	5	-790.0 c	+408.0 c	+71.0 c		-8.27 c	+14.5c	+7.14 c		-5.70 c	-8.836 b				-974.0 a	-98.7 c	+4.06 c		-0.656c		-40.4 c
Cobalt-Base Alloys																							
-64	1675	100	200		+51.3 a			-6.43 a		-4.48 a				-0.410c		-194.0 a	-56.6 a	-7.22a	-1.01 c	-2940.0 a	-26.6 a		-2.15 a
	1750	100	200		+47.0 b			-6.37 a		-4.40 a				-0.210c		-193.0 a	-56.9 a	-6.64a	+4.00 b	-2909.0 a	-25.3 a		-2.05 a
	1900	100	200		+37.3 c			-3.55 c		-2.53 a				+0.205c		-141.0 c	-33.1 c	-2.93c	+19.9 a	-2248.0 c	-13.1 c		-1.27 c
	1750	100	200	+796.0 c	-10.4 c					-2.67 c				+0.376c	-2.87c	-10.4 c							-2.75 c
	1900	100	200	+1094.0 c	+29.2 c					-1.14 c				+0.824c	-1.35c	-27.0cc							-0.318c
	1750	1000	5	+76.0 c	-7.74c					+0.533c				+0.163c	+1.43c	-43.6 a							+1.91 b
	1900	1000	5	+1820.0 a	+15.6 c					+0.583c				+1.43 a	-2.87b	-41.1 a							-2.06 b
	1600	500	5	+484.0 c	+2.71c					+0.156c				+0.168c	-1.36c	+3.98c							-0.647c
-11	1600	500	5	+434.0 c	-6.60c					+1.55 c				+7.69 c	-1.22c	-7.30c							+0.131c
	2050	500	5	+878.0 c	-52.6 c					-2.23 c				-20.3 c	-3.23c	-47.0 c							-1.88 c
	2125	500	5	+579.0 c	+6.84c					-10.7 c				-44.2 c	-7.46c	+16.6 c							-5.29 c
	2050	500	5	+2531.0 a	+27.0 c					+1.56 b				+1.61 a	-3.39b	-73.3 a							+0.010c
-18	2125	500	5	-542.0 c	-61.3 c		-787.0 c			-1.36 c	+138.0c	+567.0 c		+4.43 c	-5.35c	-72.5 c	+452.0 c					-272.0c	+1.06 c
	1900	1000	5	+1152.0 a	-7.29c		-161.0 a			+0.189c	+26.9a	+66.5 c		+1.72 a	-3.00a	-20.0 a	+87.3 a					-51.3a	-2.05 b

dence level, b - 90% confidence level, c - Confidence level is equal to or greater than 60% but less than 90%

re, R - Multiple correlation coefficient, S_E - Standard error of estimate, N - Number of tests per regression analysis, I - Intercept value for regression equation

b

Table 7-A

Regression Coefficients for Maximum Penetration

	Element															R	S_E	N	I
	Mn	Fe	Co	Ni	Cu	Y	Zr	Cb	Mo	La	Ce	Hf	Ta	W	Re				
			Nickel-Base Alloys																
a		-0.867c	-0.875 c			+76.5 c	+61.6 c	-1.54c	-3.09 c		+36.3 a		-0.943c	-0.996c		0.560	26.5	111	82.5
a		-0.445c	-0.629 c			+170.0 c	+267.0 a	+2.98c	+0.255 c		+49.4 a		-0.002c	+0.600c		0.562	26.4	111	74.3
a		-0.055c	-0.670 c			+38.5 c	+127.0 c	+12.2 a	+8.58 a		+23.6 c		+3.08 a	+4.42 a		0.752	23.5	108	75.0
c			-0.008 c					-320.0 c	+26.6 c					+10.6c c		0.95	10.0	20	145.0
c			+3.95c c					-2852.0 c	-3.93 c					-8.49 c		0.87	35.7	12	1742.0
a			-0.262 c					-2522.0 c	+38.3 c					+9.20 c		0.89	15.7	20	1280.0
a			+0.445 c					-1511.0 c	+17.2 c					-0.735c		0.85	26.3	16	1026.0
a			-0.308 c					-1925.0 c	+26.8 b					-1.40 c		0.90	18.3	23	1012.0
a			+0.0006c					+3054.0 c	+17.6 c					-0.940c		0.92	17.3	12	-1422.0
c		-39.7 c	+2.97 a			+67.3 c	+705.0 c		-3.55 c	-5.15 c			+9.32 c	-9.91 c		0.97	0.98	31	-265.0
c		-3889.7 c	+8.05 c			+232.4 c	+2731.3 c		-14.1 c	-51.7 c			+62.4 c	-174.7 c		1.00	0.94	13	-640.7
c		-40.0 c	+1.22 c			-29.7 c	+151.0 c	+4.56c	-1.00 c	-2.36 c			-2.97 c	-1.11 c	+0.200c	0.68	7.40	46	13.8
c		+53.1 c	+0.780 c			-54.3 c	+95.6 c	+3.95c	+2.47 c	-0.962c			-0.831c	+0.891c	+2.00 c	0.71	7.49	42	-63.4
c		+7.27 c	+0.249 c			-37.1 b	+21.0 c	-1.32c	+3.89 c	-0.313c			-0.374c	+1.61 c	+2.83 c	0.97	2.47	25	5.6
c		-5.70 c	-8.83b b				-974.0 a	-98.7 c	+4.06 c		-0.656c		-40.4 c	+2.45 c		0.91	29.9	42	-197.0
			Cobalt-Base Alloys																
a				-0.410c		-194.0 a	-56.6 a	-7.22a	-1.01 c	-2940.0 a	-26.6 a		-2.15 a	-2.00 a		0.89	13.4	48	127.0
a				-0.210c		-193.0 a	-56.9 a	-6.64a	+4.00 b	-2909.0 a	-25.8 a		-2.05 a	-2.05 a		0.86	15.6	48	126.0
a				+0.205c		-141.0 c	-33.1 c	-2.93c	+19.9 a	-2248.0 c	-13.1 c		-1.27 c	+1.21 c		0.82	21.7	49	76.5
c				+0.376c	-2.87c	-10.4 c							-2.75 c	-0.654c		0.94	3.67	11	24.6
c				+0.824c	-1.35c	-27.0cc							-0.318c	+2.77 c		0.57	5.95	15	-64.9
33c				+0.163c	+1.43c	-43.6 a							+1.91 b	+2.79 c		0.99	1.29	11	-25.9
33c				+1.43 a	-2.87b	-41.1 a							-2.06 b	+0.460c		0.85	3.31	28	-26.8
56c				+0.168c	-1.3[illegible]	+3.98c							-0.647c	-0.762c		0.97	0.727	11	0.100
c				+7.69 c	-1.22c	-7.30c							+0.131c	+1.47 c		0.98	0.635	8	-132.0
c				-20.3 c	-3.23c	-47.0 c							-1.88 c	-0.791c		0.96	3.04	16	+318.0
c				-44.2 c	-7.46c	+16.6 c							-5.29 c	-14.8 c		0.998	1.72	8	+931.0
b				+1.61 a	-3.39b	-73.3 a							+0.010c	+4.97 a		0.97	2.61	20	-98.5
c	+138.0c	+567.0 c		+4.43 c	-5.35c	-72.5 c	+452.0 c					-272.0c	+1.06 c	+1.46 c		0.95	3.66	22	+58.7
39c	+26.9a	+66.5 c		+1.72 a	-3.00a	-20.0 a	+37.3 a					-51.3a	-2.05 b	+1.37 c		0.82	3.16	42	-17.8

n 60% but less than 90%

of tests per regression analysis, I - Intercept value for regression equation

Table 8-A
Comparison of Signs of Regression Coefficients of RL Nickel Alloys as a Function of Temperature

emperature °F	Time hour	Sea Salt ppm	Alloy Series	Elements														
				B	C	Al	Si	Ti	Cr	Fe	Co	Y	Zr	Cb	Mo	Ce	Ta	W
				Surface Loss														
1675	100	200	RL	+c	-c	+a	-c	-b	-a	-c	-c	-c	-c	-c	-c	-c	-c	-c
1750	100	200	RL	+c	+c	+a	+c	+c	-a	-c	-c	-c	-c	+c	+c	-c	+c	+c
1900	100	200	RL	+c	+c	+c	-c	-c	-a	-c	-c	-c	-c	+a	+c	-c	+c	+a
				Maximum Penetration														
1675	100	200	RL	-c	-c	+a	-c	-a	-a	-c	-c	+c	+c	-c	-c	+a	-c	-c
1750	100	200	RL	-a	+c	+a	+c	+c	-a	-c	-c	+c	+a	+c	+c	+a	-c	+c
1900	100	200	RL	-c	+c	-c	+b	-b	-a	-c	-c	+c	+c	+a	+a	+c	+a	+a

- 95% confidence level
- 90% confidence level
- Confidence level is equal to or greater than 60% but less than 90%

Table 9-A
Comparison of Signs of Regression Coefficients of MELNI Alloys as a Function of Temperature

Temperature °F	Time hour	Sea Salt ppm	Alloy Series	Elements														
				B	C	Al	Ti	Cr	Fe	Co	Y	Zr	Cb	Mo	La	Ta	W	Re
				Surface Loss														
1600	1000	5	MELNI	+c	+c	-c	+c	+c	+c	-c	-c	+c	+c	+c	+c	+c	+b	+c
1800	1000	5	MELNI	+c	-c	+c	+c	-c	+c	-c	+c	+c	+c	+c	-c	+c	+c	+c
				Maximum Penetration														
1600	1000	5	MELNI	-c	+c	-c	-c	+c	+c	+c	-c	+c	+c	+c	-c	-c	+c	+c
1800	1000	5	MELNI	+c	-c	-b	-c	+c	+c	+c	-b	+c	-c	+c	-c	-c	+c	+c

a - 95% confidence level
b - 90% confidence level
c - Confidence level is equal to or greater than 60% but less than 90%

Table 10-A
Comparison of Signs of Regression Coefficients in RL and MELNI Alloys at 1750° F for 100-Hour Test

perature °F	Time hour	Sea Salt ppm	Alloy Series	Elements											
				B	C	Al	Ti	Cr	Fe	Co	Y	Zr	Mo	Ta	W
			Surface Loss												
1750	100	200	RL Nickel	+c	+c	+a	+c	-a	-c	-c	-c	-c	+c	+c	+c
1750	100	200	MELNI	+c	-c	+c	+c	+c	-c	+a	+b	+c	-b	+c	-c
			Maximum Penetration												
1750	100	200	RL Nickel	-a	+c	+a	+c	-a	-c	-c	+c	+a	+c	-c	+c
1750	100	200	MELNI	+c	-c	+c	+c	+c	-c	+a	+c	+c	-c	+c	-c

95% confidence level
90% confidence level
Confidence level is equal to or greater than 60% but less than 90%

Table 11-A
Comparison of Signs of Regression Coefficients of ELNI 1-13 at 1750° F as a Function of Exposure Time

rature F	Time hour	Sea Salt ppm	Alloy Series	Elements												
				B	C	Al	Ti	Cr	Fe	Co	Y	Zr	Mo	La	Ta	W
			Surface Loss													
'50	100	200	MELNI	+c	-c	+c	+c	+c	-c	+a	+b	+c	-b	-c	+c	-c
'50	1000	5	MELNI	+c	-c	+c	+c	+c	-c	+c	+c	+c	-c	-c	+c	-c
			Maximum Penetration													
'50	100	200	MELNI	+c	-c	+c	+c	+c	-c	+a	+c	+c	-c	-c	+c	-c
750	1000	5	MELNI	+c	-c	+c	+c	+c	-c	+c	+c	+c	-c	-c	+c	-c

5% confidence level
0% confidence level
onfidence level is equal to or greater than 60% but less than 90%

Table 12-A
Comparison of Signs of Regression Coefficients of Simple and Complex Nickel Alloys at 1750° F for 100 Hours

Temperature °F	Time hour	Sea Salt ppm	Alloy Series	Elements						
				C	Al	Ti	Cr	Co	Mo	W
			Surface Loss							
1750	100	200	RL	+c	+a	+c	-a	-c	+c	+c
1750	100	200	TEL	-c	-c	-c	-a	+c	+c	-c
1750	100	200	MELNI	-c	+c	+c	+c	+a	-b	-c
			Maximum Penetration							
1750	100	200	RL	+c	+a	+c	-a	-c	+c	+c
1750	100	200	TEL	-c	-c	-c	-a	+c	+c	-c
1750	100	200	MELNI	-c	+c	+c	+c	+a	-c	-c

a - 95% confidence level
b - 90% confidence level
c - Confidence level is equal to or greater than 60% but less than 90%

Table 13-A
Comparison of Signs of Regression Coefficients of TEL Alloys and Commercial Alloys at 1600° F for 500 Hours

Temperature °F	Time hour	Sea Salt ppm	Alloy Series	Elements							
				C	Al	Ti	Cr	Co	Cb	Mo	W
			Surface Loss								
1600	500	5	TEL 1-12	-a	+a	+c	-a	-c	-c	+c	-c
1600	500	5	COM	+c	+c	-c	+c	-b	-c	+c	-c
			Maximum Penetration								
1600	500	5	TEL 1-12	-b	+a	+b	-a	-c	-c	+b	+c
1600	500	5	COM	+c	+c	-c	+c	-b	-c	+c	+c

a - 95% confidence level
b - 90% confidence level
c - Confidence level is equal to or greater than 60% but less than 90%

Table 14-A

Comparison of Signs of Regression Coefficients of RL Cobalt Alloys as a Function of Temperature

perature °F	Time hour	Sea Salt ppm	Alloy Series	Elements											
				C	Ti	Cr	Ni	Y	Zr	Cb	Mo	La	Ce	Ta	W
			Surface Loss												
1675	100	200	RL	+b	-a	-a	-c	-a	-a	-a	-c	-a	-a	-a	-a
1750	100	200	RL	+c	-a	-a	-c	-a	-a	-a	+b	-a	-a	-a	-a
1900	100	200	RL	+c	-c	-a	+c	-c	-c	-c	+a	-c	-c	-c	+c
			Maximum Penetration												
1675	100	200	RL	+a	-a	-a	-c	-a	-a	-a	-c	-a	-a	-a	-a
1750	100	200	RL	+b	-a	-a	-c	-a	-a	-a	+b	-a	-a	-a	-a
1900	100	200	RL	+c	-c	-a	+c	-c	-c	-c	+a	-c	-c	-c	+c

95% confidence level
90% confidence level
Confidence level is equal to or greater than 60% but less than 90%

Table 15-A

Comparison of Signs of Regression Coefficients in Simple and Complex Cobalt Alloys at Two Temperatures in 100-Hour Tests

Carbon

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	+c	+c	+b	+c	0.01-0.45
Complex	+c	+c	-c	+c	0.23-0.42

Chromium

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	-a	-a	-a	-a	15.0-35.0
Complex	+c	+c	-c	-c	27.8-34.7

Nickel

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	-c	+c	-c	+c	0-10.2
Complex	+c	-c	+c	+c	0.5-10.7

Yttrium

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	-a	-c	-a	-c	0-0.150
Complex	-c	-a	-c	-c	0-0.190

Tantalum

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	-a	-c	-a	-c	0-15.0
Complex	-c	+c	-c	-c	0-4.0

Tungsten

Alloys	Surface Loss		Maximum Penetration		Concentration Range w/o
	1750° F	1900° F	1750° F	1900° F	
Simple	-a	+c	-a	+c	0-15.0
Complex	+c	+c	-c	+c	6.30-8.25

Note: Simple alloys are RL 10-15, 52-64
Complex alloys are MELCO 1-11

Table 16-A

Comparison of Signs of Regression Coefficients of MELCO 3, 4, 5, 7-11 as a Function of Temperature

Temperature °F	Time hour	Sea Salt ppm	Alloy Series	Elements							
				B	C	Cr	Ni	Cu	Y	Ta	W
Surface Loss											
1600	500	5	MELCO	+c	+c	+c	+c	+c	+c	+c	+c
2050	500	5	MELCO	+c	+c	-c	-c	+c	-c	+c	-c
2125	500	5	MELCO	+c	-c	-c	-c	-c	+c	-c	-c
Maximum Penetration											
1600	500	5	MELCO	+c	-c	+c	+c	-c	-c	+c	+c
2050	500	5	MELCO	+c	-c	-c	-c	-c	-c	-c	-c
2125	500	5	MELCO	+c	+c	-c	-c	-c	+c	-c	-c

a - 95% confidence level
b - 90% confidence level
c - Confidence level is equal to or greater than 60% but less than 90%

Table 17a-A

Comparison of the Regression Coefficients of Boron MELCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	+465.0 c	+556.0 c	+796.0 c	+1094.0 c
1000 hours 5 ppm	-168.0 c	+445.0 c	+76.0 c	+1820.0 a

Cencentration range of B is 0% to 0.015%.

Table 17b-A

Comparison of the Regression Coefficients of Carbon in MELCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	+1.30 c	+8.46 c	-10.4 c	+29.2 c
1000 hours 5 ppm	-8.01 c	-15.1 c	-7.74 c	+15.6 c

*Concentration range of C is 0.23% to 0.42 %.

Table 17c-A

Comparison of the Regression Coefficients of Chromium in MELCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	+0.213 c	+0.417 c	-2.67 c	-1.14 c
1000 hours	+0.021 c	-0.942 b	+0.533 c	+0.583 c

*Concentration range of Cr is 27.8% to 34.7%.

Table 17d-A

Comparison of the Regression Coefficients of Nickel in MELCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	+0.544 c	-0.207 c	+0.376 c	+0.324 c
1000 hours 5 ppm	+0.080 c	+1.30 a	+0.163 c	+1.43 a

*Concentration range of Ni is 0.50% to 10.7%.

Table 17e-A
mparison of the Regression Coefficients of Copper LCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	-2.12 c	+0.058 c	-2.87 c	-1.35 c
000 hours 5 ppm	-0.177 c	-3.55 a	+1.43 c	-2.87 b

oncentration range of Cu is 0% to 2.95%.

Table 17f-A
mparison of the Regression Coefficients of Yttrium LCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	-0.823 c	-33.0 a	-10.4 c	-27.0 c
000 hours 5 ppm	+5.01 c	+25.6 b	-43.6 a	-41.1 a

oncentration range of Y is 0% to 0.190%.

Table 17g-A
mparison of the Regression Coefficients of Tantalum LCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	-1.66 c	+0.437 c	-2.75 c	-0.318 c
1000 hours 5 ppm	+0.077 c	-2.81 a	+1.91 b	-2.06 b

Concentration range of Ta is 0% to 4.00%.

Table 17h-A
Comparison of the Regression Coefficients of Tungsten in MELCO 1-11 at Two Temperatures and Two Test Conditions*

	Surface Loss		Maximum Penetration	
	1750° F	1900° F	1750° F	1900° F
100 hours 200 ppm	+1.41 c	+0.965 c	-0.654 c	+2.77 c
1000 hours 5 ppm	+0.001 c	-2.83 a	+2.79 c	+0.460 c

*Concentration range of W is 6.30% to 8.25%.

Table 18-A
Hot-Corrosion Results for Factorial Alloys[1]
(Nickel-Base, 100 Hours of Test Operation)

RL Alloy No.	Chemical Composition of Alloys %				Maximum Penetration, mils[2]								
					1675° F			1750° F			1900° F		
					Test[3]								
	Ni	Cr	Al	Ti	2	3	4	7	8	9	12	13	14
44	Bal	15.0	2.5	4.5	54.6	97.9	10.7	36.6	39.9	50.1	34.9	22.2	58.6
45	Bal	15.0	2.5	9.0	8.6	8.9	7.5	15.3	51.1	11.4	11.5	12.2	21.6
46	Bal	15.0	5.0	4.5	15.8	>130.0	5.9	10.8	>130.0	43.7	46.7	21.5	63.3
47	Bal	15.0	5.0	9.0	7.7	9.9	6.5	9.4	>130.0	8.9	44.5	15.5	56.4
48	Bal	20.0	2.5	4.5	12.5	18.5	9.0	11.5	17.9	12.6	17.0	12.4	33.4
49	Bal	20.0	2.5	9.0	7.1	7.0	6.6	9.6	8.0	8.7	13.6	16.8	14.1
50	Bal	20.0	5.0	4.5	8.6	7.7	7.9	10.0	10.4	28.7	27.1	28.3	45.5
51	Bal	20.0	5.0	9.0	6.6	5.4	6.1	8.2	>130.0	8.9	31.1	11.5	14.4

[1] Temperature - as given; Time - 100 hours; Fuel - diesel (1% sulfur); Air/Fuel - 30/1; Sea Salt - 200 ppm of air; Specimen Size - approximately 0.130 inch in diameter by 1.25 inches in length.

[2] A maximum penetration >130 mils indicates that the specimen has been corroded all the way through.

[3] Each test number represents a separate test run in which one specimen of each alloy is placed in a hot corrosion test chamber, which is then operated under specified conditions.

Bal - Balance.

Table 19a-A
Analysis of Variance for Hot-Corrosion Results for Factorial Alloys
ıl-Base, 100 Hours of Test Operation, All Data Included)

ource of riance	Sums of Squares	Degrees of Freedom	Mean Squares	'F' Ratio
rature (T)	2378.39	2	1189.28	1.45
ium (Cr)	6367.56	1	6367.56	7.78*
num (Al)	1833.15	1	1833.15	2.24
ium (Ti)	2704.80	1	2704.80	2.31
ual	53998.18	66	818.15	
Total	67282.08	71		

ficant at the 1% level.

Table 19b-A
Analysis of Variance for Hot-Corrosion Results for Factorial Alloys (Nickel-Base, 100 Hours of Test Operation Test Runs 3, 8, and 13 Eliminated)

ource of riance	Sums of Squares	Degrees of Freedom	Mean Squares	'F' Ratio
rature (T)	2033.32	2	1016.66	12.31*
ium (Cr)	826.75	1	823.75	10.00*
num (Al)	19.93	1	19.93	<1.00
ium (Ti)	1007.06	1	1007.06	12.24*
ual	1488.99	18	82.72	
Total	5376.05	23		

ficant at the 1% level.
The following test results have been averaged in Table 19b for each alloy: Tests 2 and 4, 7 and 9, and 12 and 14.

Table 20-A

Hot-Corrosion Results for Factorial Alloys[1] (Cobalt-Base, 100 Hours of Test Operations)

DISCO Alloy No.(2)	Chemical Composition of Alloys %				Maximum Penetration, mils					
					1675° F		1750° F		1900° F	
					Test 1(2)		Test 2(2)		Test 3(2)	
	Co	Cr	Ni	Ta	A	B	A	B	A	B
1	Bal	25	5	6	3.9	2.8	6.5	8.6	14.7	16.6(3)
2	Bal	30	5	6	5.3	3.8	6.8	9.2	14.9	18.0
3	Bal	35	5	6	5.4	8.3	8.2	9.9	13.9	16.1
4	Bal	25	15	6	4.8	2.0	7.2	7.6	14.3	17.2
5	Bal	30	15	6	6.8	5.8	11.3	8.6	15.6	17.1
6	Bal	35	15	6	6.6	8.9	8.9	12.4	14.8	16.2
7	Bal	25	25	6	5.9	5.0	8.4	9.6	16.5	18.7
8	Bal	30	25	6	6.6	5.1	10.7	11.8	18.6	19.7
9	Bal	35	25	6	6.8	10.3	12.1	13.6	16.1	20.7

[1] Temperature - as given; Time - 100 hours; Fuel - diesel (1% sulfur); Air/Fuel - 30/1; Sea Salt - 200 ppm of air; Specimen Size - approximately 0.130 inch in diameter by 1.25 inches in length.

[2] DISCO 1A to 9A - Specimens are used, as cast. DISCO 1B to 9B - Specimens are heat treated, 1200° C (2192° F), 24 hours, WQ. Heat-treated (B) and nonheat-treated (A) specimens of each alloy were tested at one time, under a specified temperature condition.

[3] Estimated value.

Table 21a-A
Analysis of Variance for Hot-Corrosion Results for Factorial Alloys (Cobalt-Base, Overall Factors)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares	'F' Ratio Line	Line
DISCO, A vs B(H)	18.96	1	18.96	1/5 = 3.09	1
Temperature (T)	1097.21	2	548.60	2/5 = 89.35*	2
Chromium (Cr)	43.34	2	21.67	3/6 = 3.74	3
Nickel (Ni)	54.72	2	27.36	4/8 = 28.21*	4
H x T	12.28	2	6.14	5/8 = 6.33*	5
H x Cr	14.26	2	7.13	6/8 = 7.35*	6
T x Cr	26.11	4	6.53	7/8 = 6.73*	7
Residual	36.93	38	0.97		8
Total	1303.81	53			

*Significant at the 1% level (very significant).
'F' - Fisher's ratio.

Table 21b-A
Analysis of Variance for Corrosion Results for Factorial Alloys (Cobalt-Base, Over 3-Temperature Levels)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares	'F' Ratio Line	Line
Temperature - 1675° F					
DISCO, A vs B(H)	0	1	0	1/4 = 0	1
Chromium (Cr)	40.39	2	20.20	2/4 = 2.11	2
Nickel (Ni)	8.68	2	4.34	3/5 = 9.04*	3
H x Cr	19.12	2	9.56	4/5 = 19.91*	4
Residual	4.79	10	0.48		5
Total	72.98	17			
Temperature - 1750° F					
DISCO, A vs B(H)	6.95	1	6.95	1/4 = 5.27**	1
Chromium (Cr)	25.06	2	12.53	2/4 = 9.49*	2
Nickel (Ni)	24.41	2	12.20	3/4 = 9.24*	3
Residual	15.85	12	1.32		4
Total	72.27	17			
Temperature - 1900° F					
DISCO, A vs B(H)	24.22	1	24.22	1/4 = 48.44*	1
Chromium (Cr)	4.01	2	2.00	2/4 = 4.00**	2
Nickel (Ni)	27.13	2	13.56	3/4 = 27.12*	3
Residual	5.99	12	0.50		4
Total	61.35	17			

*Significant at the 1% level (very significant).
**Significant at the 5% level.

Appendix B

Technical References

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UPPLEMENTARY NOTES iven as a paper at AIME on 6 Oct 1968.	12. SPONSORING MILITARY ACTIVITY NAVSHIPS

BSTRACT

The use of gas turbines in marine power plants depends in part on the
velopment of superalloys which not only possess high temperature
chanical properties but also resist the corrosive effects of sea salt.
part of a program to develop such alloys, a total of 137 experimental
d commercial superalloys, both nickel and cobalt based, were exposed
burner rigs where controlled amounts of sea salt were added to the
mbustion products of sulfur-containing diesel fuel. Test temperatures
nged from 1600° to 2125° F. Times ranged from 86 to 100 hours with
0 parts per million, and from 489 to 1100 hours with 5 parts per
llion salt. Corrosion was measured by recording both surface loss
d maximum penetration. This experimental work was performed by the
neral Electric Company under contract to the Naval Ship Research and
velopment Center. For each group of alloys tested under similar con-
tions, a linear regression equation was found that shows the average
ntribution of each alloying element to the amount of corrosion. The
fects of the alloying elements were found to vary with changes in
mperature, salt concentration, and whether or not the particular
ement was part of a simple binary or tertiary alloy, or a complex

(Over)

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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sion						
stical analysis						
ne blades						
r rig						
l fuel						
dation						
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t loss						
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tions						
idence levels						

Analyses of variance methods were applied to two sets of fac-
ly designed compositions, one of nickel-base alloys and one of
-base alloys, to determine the possible significance on
ion of various proportions of single elements and interactions
elements. It was found that in the cobalt alloys significant
ctions existed between heat treatment and temperature as well
tween heat treatment and chromium content.