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NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Final Report

on

HEAT-RESISTANT ALLOYS FOR ORDNANCE MATERIEL AND AIRCRAFT AND NAVAL ENGINE PARTS (N-102): PART II - COBALT AND NICKEL IN 26% Cr ALLOYS

by

F. S. GARDNER, H. S. AVERY, AND EARNSHAW COOK
AMERICAN BRAKE SHOE COMPANY

OSRD No. 5334
Serial No. M-516
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[redacted]

July 12, 1945

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[redacted]

July 12, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Final Report on "Heat-resistant Alloys for Ordnance Materiel and Aircraft and Naval Engine Parts (N-102): Part II - Cobalt and Nickel in 26% Cr Alloys"

The attached final report submitted by Earnshaw Cook, Technical Representative on NDRC Research Project NRC-84A, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of a study of the properties at elevated temperatures of two groups of 26% Cr alloys containing varying amounts of cobalt and nickel. One group of alloys was essentially non-ferrous, the other contained about 50% iron.

This project was financed by the American Brake Shoe Company and was carried out as a correlation project under the supervision and direction of the War Metallurgy Committee. I recommend acceptance as a satisfactory final report on a phase of the work done on this project.

Respectfully submitted,

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

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PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as N-102, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-84A.

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Final Report
for
National Research Council Project No. 84-A

HEAT RESISTANT ALLOYS FOR ORDNANCE MATERIEL AND AIRCRAFT AND NAVAL ENGINE PARTS: PART II - COBALT AND NICKEL IN 26%Cr ALLOYS

Departmental Report No. 7-M-95

Case Report No. 385-1

by

Frank S. Gardner
Metallurgist

Howard S. Avery
Research Metallurgist

Mahwah, New Jersey
April 16, 1945

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Table of Contents

Index of Tables

Index of Figures

SUMMARY

The effects of cobalt and nickel have been studied in two groups of 26%Cr alloys, one series being essentially non-ferrous, the other containing about 50% iron. The results of stress-strain-rupture tests at 1600 and 1800°F are presented. Additional data from room temperature tension tests are included for materials as-cast or after exposure to one of several aging treatments. Photomicrographs of as-cast structures are appended.

In the absence of iron, the substitution of cobalt for nickel produces a marked strengthening at elevated temperatures. Creep testing of several compositions is in progress to supplement the indications of stress-strain-rupture tests; two creep tests at 1800°F are completed for this report.

C.R.-385-1

HEAT RESISTANT ALLOYS FOR ORDNANCE MATERIEL AND AIRCRAFT AND NAVAL ENGINE PARTS: COBALT AND NICKEL IN 26% CHROMIUM ALLOYS

Introduction

This project was established in April 1944, as NDRC Correlation Project NRC-84A with the following general objectives:

1. To determine the elevated temperature characteristics of heat-resisting alloys used in national defense applications.
2. To conduct experiments directed toward the improvement of these alloys where present properties are inadequate.
3. To clarify the possibilities of substitutions that will permit savings in strategic alloying elements.
4. To adapt knowledge of the heat-resisting alloys to the specialized applications that have developed because of the war.

The project is being financed by the American Brake Shoe Company and is being conducted under the general supervision of the War Metallurgy Committee. This is the second report submitted on the project.

The requirements of turbo-superchargers, gas turbines and similar devices involve alloys with great strength at elevated temperatures. As most commercial Cr-Ni-Fe heat resistant grades lack this requisite strength, complex materials of related types that are considered appropriate for such service up to 1600°F have been developed. Since increased efficiency results from operating gas turbines at even higher temperatures, the solution of material problems at 1600°F will undoubtedly be followed by engineering demands for alloys that will operate satisfactorily up to 1800°F and beyond.

In the development of improved alloys, an understanding of the role of each chemical element is desirable. This report relates to an exploration of the comparative behavior of nickel and cobalt, which are included, with and without iron, in alloys containing 26% chromium as a base. This chromium level was chosen to provide reasonable assurance of adequate hot gas corrosion resistance in the temperature range from 1600 to 2000°F.

It is proposed to study a number of additional elements in combination with cobalt, nickel, iron, and 26% chromium, although present research is confined to the determination of optimum proportions of cobalt and nickel in these alloys in the absence of significant amounts of other metals.

Since strength, life expectancy, and ductility are of chief concern, the research has depended largely upon the evidence of stress-strain-rupture and creep tests. These have been supplemented by room temperature tension tests and microscopic examination, while oxidation and X-ray diffraction studies are projected. The program of creep testing is currently in progress.

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COMPOSITION

Two series (Table 1) of nickel-cobalt alloys, all containing 26% chromium, have been investigated. In the first series, which is essentially non-ferrous, the cobalt plus nickel content is maintained at 70%, with cobalt progressively replacing nickel. Approximately 50% iron is present in the second series, the total of cobalt and nickel being held at 20%.

Table 1

Cobalt and Nickel in 26% Chromium Alloys
Chemical Analyses

Heat No.	C%	Mn%	P%	S%	Si%	Cr%	Ni%	Co%	Fe%	N%	Balance (by Diff.)%
44-278	.35	.41	.013	.014	1.41	26.22	70.60	.43	.73	.042	-.219
-274	.35	.59	.021	.014	1.35	26.25	45.95	24.10	.93	.045	+.400
-275	.31	.61	.014	.018	1.37	26.38	34.60	35.50	.97	.036	+.192
-261	.30	.60	.012	.014	1.29	26.42	23.83	45.65	1.29	.051	+.543
-279	.31	.46	.011	.021	1.21	26.55	.42	69.00	1.21	.040	+.768
XJ-142	.30	.53	--	--	1.21	26.26	19.71	--	(51.+)	.105	--
XK-100	.30	.58	--	--	1.62	26.65	20.06	--	(51.±)	.099	--
44-287	.34	.62	.011	.022	1.29	26.10	9.90	9.85	51.43	.146	+.291
-280	.30	.58	.011	.021	1.21	26.70	.28	19.40	51.38	.116	+.002

The compositions of the two groups were intended to be univarient. Only carbon and nitrogen are considered significant as chemical variables that may modify the effects of the cobalt-nickel comparison. The carbon contents are 0.325 ± 0.025% in the non-ferrous group and 0.32 ± 0.02% in the 50% iron base alloys. As carbon usually has a pronounced strengthening effect, the 0.35% values in the low iron series may have operated to reduce the apparent magnitude of the spread of high temperature properties. The nitrogen range in the same group is considered insignificant as a variable.

The carbon levels are similar to those of commercial alloys containing 26% chromium. The nitrogen levels selected differ appreciably. Two alloys, XJ-142 and XK-100, were available at the start of this program; their nitrogen content was therefore used as a base for the 50% iron group. Both the carbon and nitrogen of heat 44-287 are somewhat high and an increment in strength would be expected from this cause. It was not detected in the elevated temperature tests, however, this heat being the weakest and most ductile of the 50% iron group.

Previous experience with high nickel alloys has indicated difficulty in attaining high nitrogen contents. Rather than risk unexpected variations during the substitution of cobalt for nickel, a relatively low nitrogen content was selected. Comparison between the ferrous and non-ferrous groups should therefore be made with caution. By interpolation it would be possible to compare the relative effects of about 50% iron vs. 50% cobalt as a base in 26%Cr: 20%Ni alloys except that one group contains twice as much nitrogen as the other.

Experimental Procedure

Melting was performed in an induction furnace, all heats being deoxidized with ferrosilicon, followed by a ladle addition to the cobalt bearing alloys of 0.04%Ca as CaSi. These were poured at approximately 250°F above the solidus into castings (Figure 1) that have been developed as a source of radiographically sound creep, stress-strain rupture, and tension test bars.

Elevated temperature characteristics have been determined by stress-strain rupture tests at 1600°F and 1800°F, which are summarized in Table 2, and are being supplemented by creep tests that are in progress. The techniques employed are described in A.I.M.E. Technical Publications 1443-C and 1480. The precision of initial applied stresses is within ±1%, nominal temperatures are well within A.S.T.M.* limits of ±10°F, and life or rate values are believed to be reproducible within ±20%. Structural heterogeneity among different castings of the same analysis is a possible source of erratic results. Its extent in the alloys reported herein has not yet been investigated, however.

Data from two available compositions of commercial 26%Cr:20%Ni alloy are included in Table 2 for comparison, and in Tables 5 and 6 in the appendix.

Tension tests at room temperature were conducted on these alloys in the as-cast condition, and after aging at several temperatures, to appraise roughly their toughness and susceptibility to precipitation hardening. The yield strength values reported are approximate.

The microstructures of these alloys have been examined, and representative photomicrographs are presented.

Elevated Temperature Properties

The strengthening effect of cobalt in the non-ferrous series as it replaces nickel up to 70% is apparent in Figures 2 and 3. Confirmation at lower stresses of this trend is dependent on current and future creep tests. The extrapolation of the stress vs. rate data for heat 44-274 (46%Ni:24%Co) at 1600°F suggests superior strength at low stresses but this trend cannot be accepted without additional tests as it may arise from structural differences within the heat. This should be considered in the interpretation of Figures 4 and 5 which show graphically the effect of composition on the stress required to produce various minimum strain rates; as detailed in Table 7 of the appendix. A summary of time elongation data at 1, 2, and 5 per cent deformation (Table 2A) affords further evidence of the enhanced creep strength accompanying cobalt substitution for nickel.

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*A.S.T.M. Designation E22-41

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In the presence of 50% iron the 20% cobalt alloy is strongest, 20% nickel intermediate, and 10%Co:10%Ni weakest and most ductile at the relatively high stresses employed. Whether these differences are significant and relatively independent of other variables has not been determined. Figures 6 and 7 portray the relationship of stress vs. creep rate and fracture time.

The stress vs. fracture time and stress vs. minimum creep rate relationships can usually be represented by straight lines when plotted logarithmically, as in Figures 2 and 3. Departures of austenitic heat resistant alloys from this correlation are customarily within the experimental errors. Some high strength materials may change their behavior at a critical stress, however, which is indicated graphically by an abrupt change in slope of the line.* The 69% cobalt and the 35%Ni:36%Co heats, as plotted in Figure 3, suggest this, which occurrence will require additional tests for clarification.

For convenience in comparing with the stress-rupture data of the NRC-8 program the stresses required to produce rupture at various times are summarized in Table 3.

In all creep and stress-rupture tests, control variations have been limited to less than ±2°F by a throttling device in the furnace control mechanism. The minimum creep rate values obtained are not expected to characterize these materials if they are heated and cooled through larger temperature ranges. Much higher creep rates are expected in cyclic service if the nominal maximum temperature is above 1600°F.

Room Temperature Mechanical Properties

The as-cast tensile strength of these alloys at room temperature, which ranges from 72,000 to 100,000 psi., is ample for ordinary industrial utilization. Specialized requirements, as for turbine service, have not been clarified. The ductility values are more significant as they provide some indication of the deformation latitude in fabrication. Ductility is also desirable for resistance to fracture from hindered contraction. After aging at either 1600 or 1800° F tensile elongation falls to about half of the original value, as shown in Table 4. This is usually accompanied by a moderate increase in tensile strength.

Metallography

Microscopical examination suggests that all alloys contain a carbide phase in an austenitic, qualitatively non-magnetic matrix. The former, which is frequently eutectiform, tends to outline a dendritic pattern. Nitrogen or nitrides may be associated but positive means of identification are lacking. An unclassified fine lamellar structure resembling pearlite also appears in

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*A.I.M.E. Technical Publication 1480

some of the alloys. Judging from etching behavior it could be an unusual aggregate of austenite and carbide. Photomicrographs are included in the appendix. (Figures 8 to 18).

Inspection of as-cast specimens discloses no dispersed phase and suggests that considerable carbon is probably in solid solution. The increase of strength and drop in ductility that follows aging are attributed to carbide precipitation, which is also evident microscopically after creep testing (Figures 13 and 14).

Discussion

It is evident that increased elevated temperature strength results from the substitution of cobalt for nickel in these non-ferrous alloys. This per se is not an economic development, however, as strengthening of similar magnitude may be obtained at lower cost by the addition of 1.5% columbium to a 26%Cr:14%Ni base. The chief interest in this series is in its relationship to more complex materials that are produced by adding high melting point and carbide forming elements such as molybdenum and tungsten. With tungsten the cobalt rich alloy becomes one of the Stellites, while with molybdenum the Vitallium type is developed. These grades, together with similar alloys containing nickel up to 30%, have been extensively studied under the program for NDRC Research Project NRC-8.

It is planned to add a long term oxidation test at 1940°F to this test program. The strengthening effect of columbium mentioned above is partially off-set by greater susceptibility to oxidation at the higher temperatures, which behavior is apparently associated with formation of a relatively brittle scale. While this report is concerned with the strength of alloys at high temperatures, the establishment of satisfactory resistance to hot gases is also important.

The mechanism of strengthening as cobalt replaces nickel requires clarification. Inhibiting creep of the solid solution by changes in crystal lattice character and slip interference by precipitation hardening are both possibilities. Strengthening by carbon increments is usually possible up to some critical range. Whether a non-carbide forming element like cobalt operates by modifying the solid solution, or by changing carbide solubility, thereby making a given amount of carbon more effective, is an interesting question. Proposed X-ray diffraction studies may provide an insight into these possibilities.

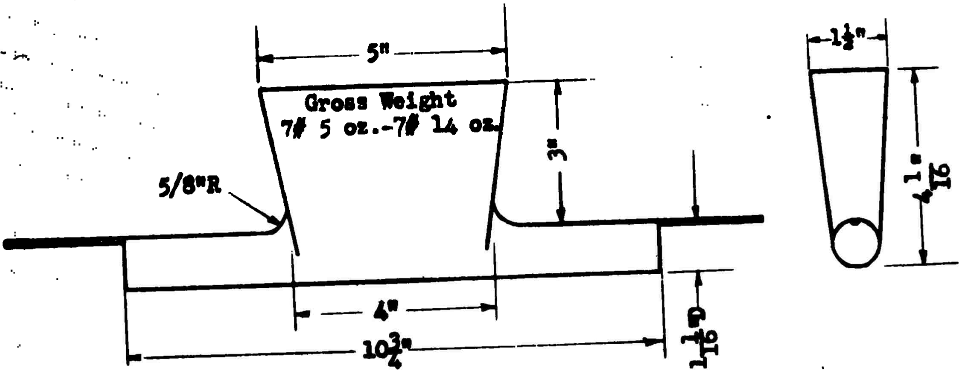
Projected work includes the addition of carbon to the 0.30% carbon, 26% chromium, 69% cobalt alloy; investigation of 0.50% carbon in a 10% nickel, 60% cobalt, 26% chromium base; and separate additions of 7% tungsten, 7% molybdenum, and 7% columbium to the bases above on the 0.50% carbon level.

This program will partially duplicate some of the NDRC Research Project NRC-8 activities, with which it is being coordinated.

FRANK S. GARDNER
Metallurgist

HOWARD S. AVERY
Research Metallurgist

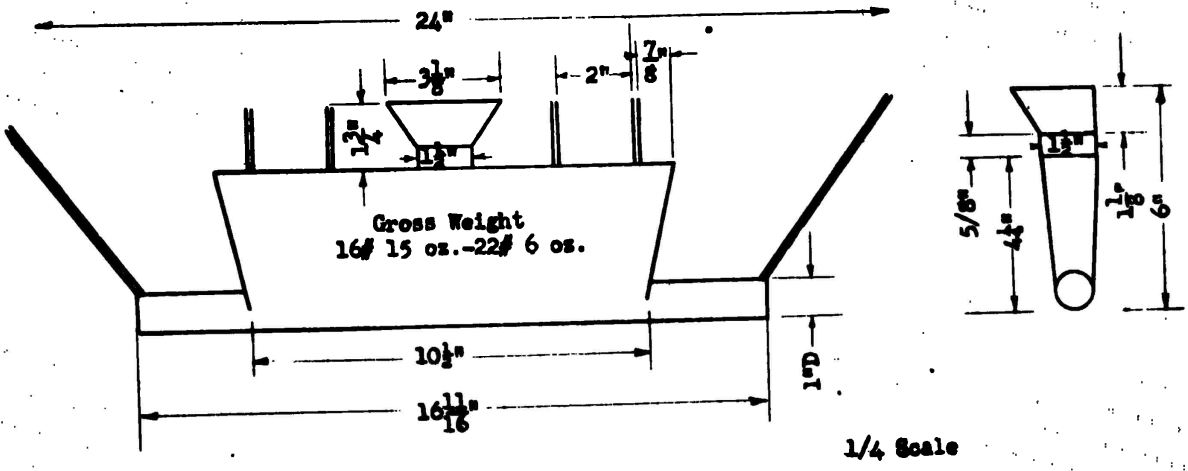
STANDARD HEAT RESISTANT ALLOY CORE SAND TEST CASTINGS



1/3 Scale

Standard D-14 Tensile Test Bar Casting

Figure 1A



1/4 Scale

Standard D-17 Creep Test Bar Casting

Figure 1B

Table 2

COBALT AND NICKEL IN 26% CHROMIUM ALLOYS
Elevated Temperature Properties

									1800°F.					1600°F.				
Heat No.	C%	Mn%	Si%	Ni%	Co%	Cr%	Fe%	N%	Stress P.S.I.	Life Hrs.	Rate %/Hr.	Elong. %	R.A. %	Stress P.S.I.	Life Hrs.	Rate %/Hr.	Elong. %	R.A. %
44-278	.35	.41	1.41	70.6	0.4	26.2		.73	.042	8000	2.0	11.7	37.	43.	12000	4.8	4.4	30.	46.
									6000	13.4	1.6	35.	33.	10000	28.4	0.72	34.	47.
44-274	.35	.59	1.35	46.0	24.1	26.3		.93	.045	8000	9.6	1.19	21.	35.	12000	37.0	.37	20.	27.
									6000	58.4	.19	19.	31.	10000	277.	.003	6.	12.
44-275	.31	.61	1.37	34.6	35.5	26.4		.97	.036	8000	14.7	.21	32.	38.	16000	4.4	1.8	16.	28.
									6000	124.	.0035	4.	10.	12000	54.	.071	8.	12.
									4000	876.	.00027	1.	5.					
44-261	.30	.60	1.29	23.8	45.7	26.4		1.33	.051	8000	21.7	.17	16.	35.	16000	14.3	.16	5.	6.
									6000	142.	.0020	3.	7.	12000	119.	.0050	3.	4.
									4000									
44-279	.31	.46	1.21	0.4	69.0	26.6		.97	.040	8000	37.0	.046	9.	12.	16000	49.5	.037	5.	8.
									6000	267.	.0015	7.	22.	12000	366.	.0014	2.	3.
									4000	1765.	.00010	1.25	2.					
KJ-142	.30	.53	1.21	19.7	—	26.3	(51.±)	.105										
									6000	16.9	.38	15.	22.	10000	18.3	.23	6.	12.
									4000	194.	.006	6.	7.	8000	83.+	.029	3.	6.
									3000	539.+	.0023	3.	16.	4000	809.(d)	.00014	-	-
									2000	1002.(d)	.00003	-	-					
KK-100	.30	.58	1.62	20.1	—	26.7	(51.±)	.099										
									6000	13.4	.35	12.	21.					
									4000	157.	.009	10.	7.					
									2000	880.(d)	.00008	-	-					
44-287	.34	.62	1.29	9.9	9.9	26.1	51.4	.146										
									6000	13.7	1.1	24.	32.	10000	13.3	.42	11.	12.
									4000	73.8	.16	19.	23.	8000	45.6	.14	12.	14.
44-280	.30	.58	1.21	.3	19.4	26.7	51.4	.116	8000	7.0	1.6	21.	20.	10000	40.7	.069	6.	5.
									6000	42.9	.13	8.	12.	8000	116.	.013	4.	4.

d Discontinued before fracture

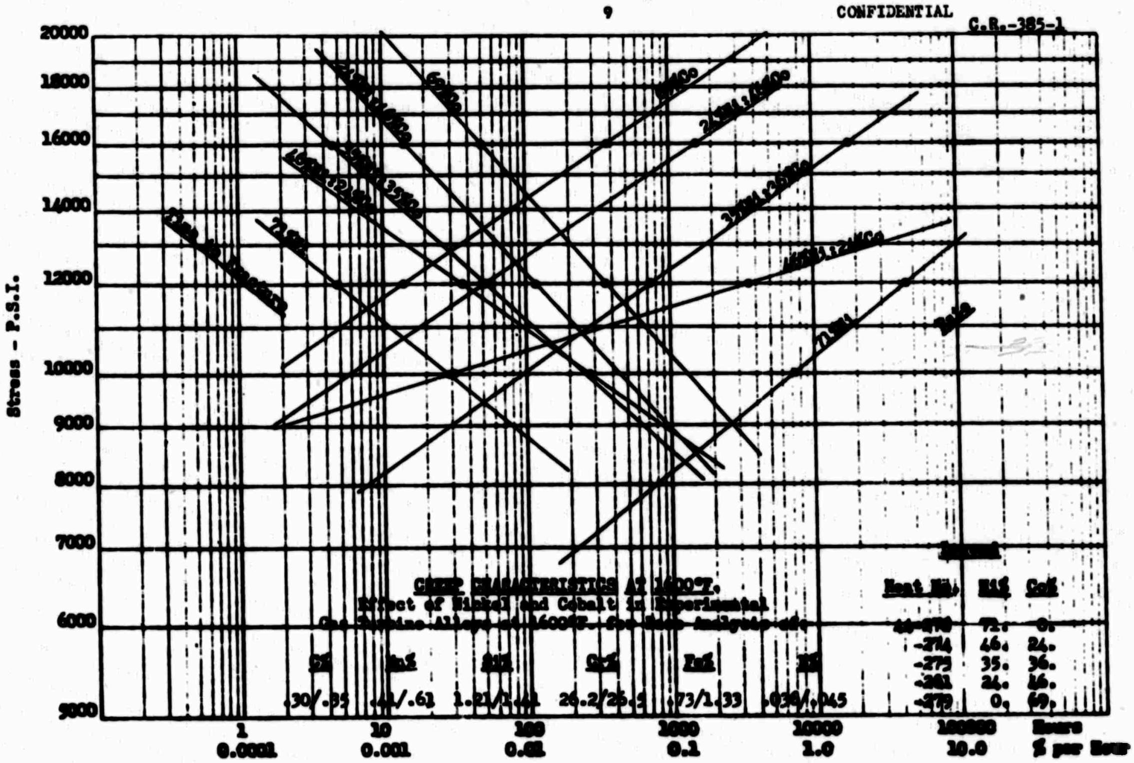


Figure 2

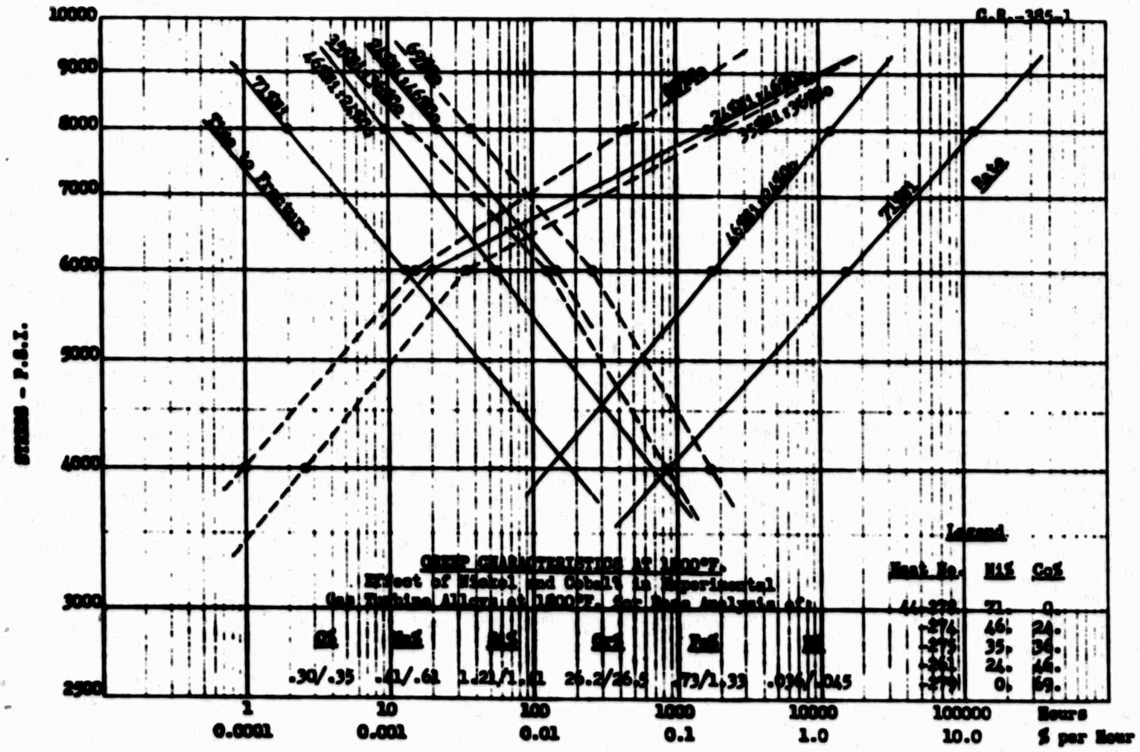


Figure 3

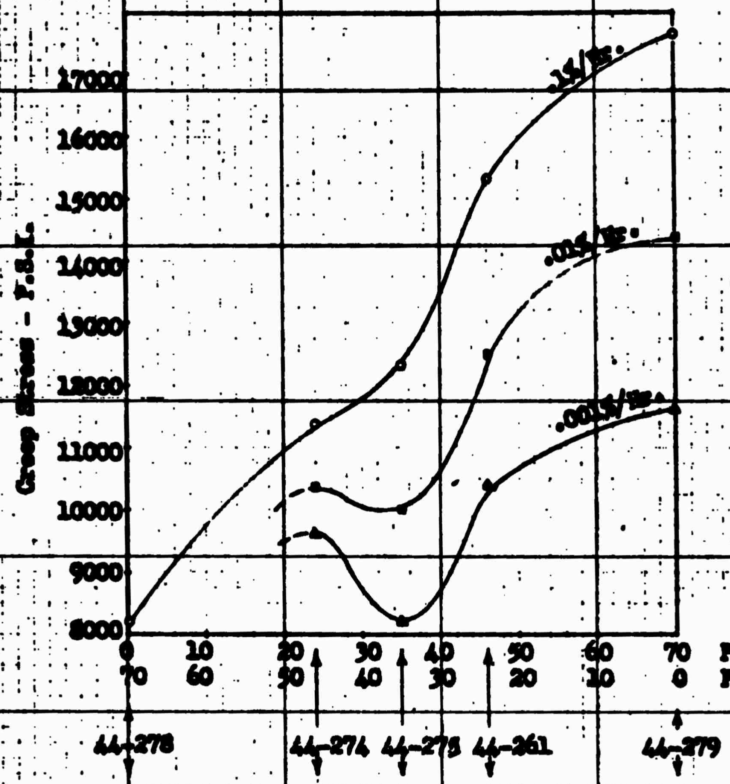


Figure 4

CREEP STRESS AT 1600°F.
Vs.
NICKEL-COBALT CONTENT

(for Stage II rates of 0.1, 0.01, and 0.001%/Hr.)

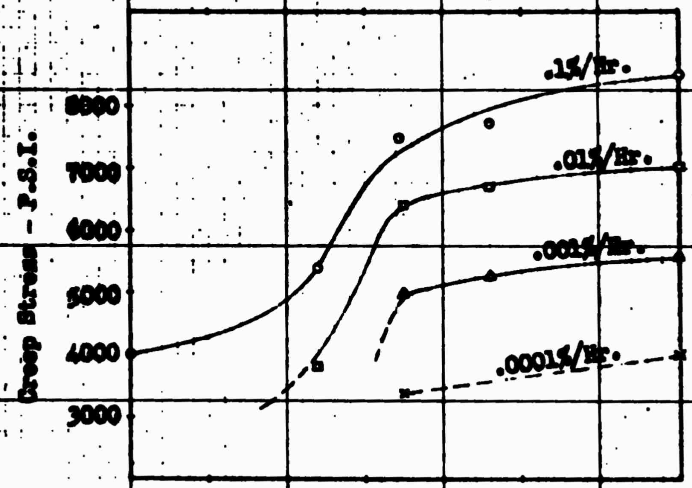


Figure 5

CREEP STRESS AT 1800°F.
Vs.
NICKEL-COBALT CONTENT

(for Stage II rates of 0.1, 0.01, and 0.001%/Hr.)

Nickel vs. Cobalt as a Base in 26% Cr Heat Resistant Alloys
for Minor Element Range of:

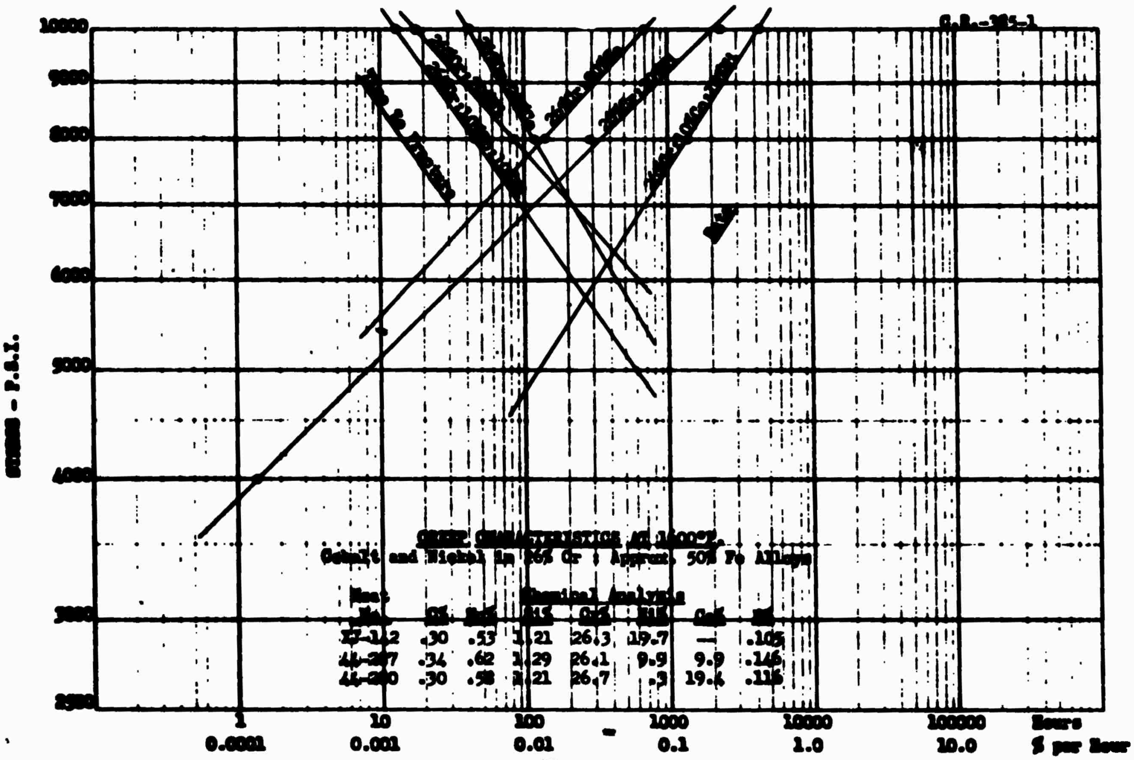
C%	Mn%	Si%	Cr%	Fe%	N%
.30/.35	.41/.61	1.21/1.41	26.2/26.5	.73/1.33	.036/.051

Table 2A

COBALT AND NICKEL IN 26% CHROMIUM ALLOYS
Time-Elongation Data

	Chemical Analysis							
Heat No.	**C%**	**Mn%**	**Si%**	**Ni%**	**Co%**	**Cr%**	**Fe%**	**N%**
44-278	.35	.41	1.41	70.6	0.4	26.2	.73	.042
44-274	.35	.59	1.35	46.0	24.1	26.3	.93	.045
44-275	.31	.61	1.37	34.6	35.5	26.4	.97	.036
44-261	.30	.60	1.29	23.8	45.7	26.4	1.33	.051
44-279	.31	.46	1.21	0.4	69.0	26.6	.97	.040

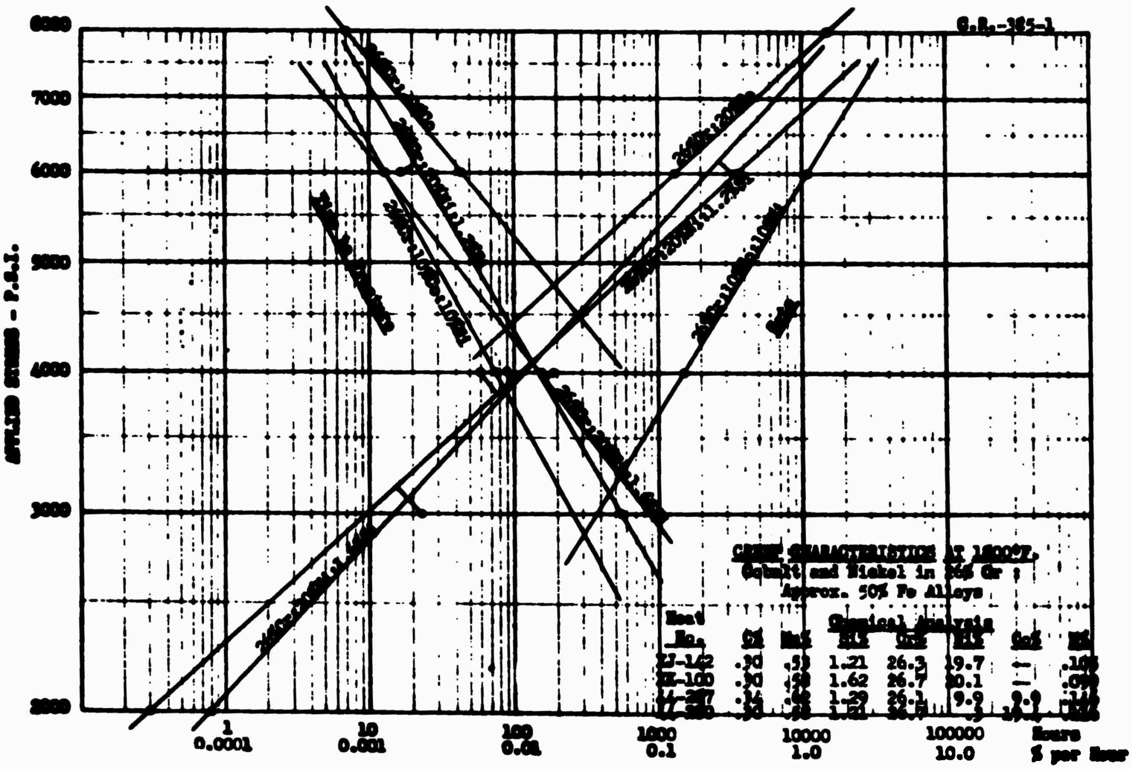
			1800°F.						1600°F.					
	Nominal		**Stress**	**Elong.**	**Time (Hrs.) for:**			**Life**	**Stress**	**Elong.**	**Time (Hrs.) for:**			**Life**
Heat No.	**Ni%**	**Co%**	**P.S.I.**	**%**	**1%**	**2%**	**5%**	**Hrs.**	**P.S.I.**	**%**	**1%**	**2%**	**5%**	**Hrs.**
44-278	71.	0.	8000	37.	.05	.13	.37	2.0	12000	30.	.08	.28	.97	4.8
			6000	35.	.28	.72	2.3	13.4	10000	34.	.42	1.1	4.1	28.4
44-274	46.	24.	8000	21.	.75	1.6	4.0	9.6	12000	20.	1.3	3.3	11.	37.0
			6000	19.	1.8	5.5	17.	58.4	10000	6.	26.	238.	270.	277.
44-275	35.	36.	8000	32.	1.8	3.0	5.8	14.7	16000	16.	.25	.76	2.3	4.4
			6000	4.	110.	115.	—	124.	12000	8.	10.	24.	52.	54.
			4000	1.0	876.	—	—	876.						
44-261	24.	46.	8000	16.	3.3	6.0	12.	21.7	16000	5.	2.7	7.4	14.	14.3
			6000	3.	130.	140.	—	142.	12000	3.	110.	115.	—	119.
44-279	0.	69.	8000	9.	9.5	22.	29.	37.0	16000	5.	3.3	30.	49.	49.5
			6000	7.	200.	250.	260.	267.	12000	2.	290.	360.	—	366.
			4000	1.25	1720.	—	—	1765.						



CREEP CHARACTERISTICS AT 1600°F.
Cobalt and Nickel in 26% Cr : Approx. 50% Fe Alloys

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	N%
ZJ-142	.30	.53	1.21	26.3	19.7	—	.105
44-287	.34	.62	1.29	26.1	9.9	9.9	.146
44-280	.30	.58	1.21	26.7	.3	19.4	.115

Figure 6



CREEP CHARACTERISTICS AT 1600°F.
Cobalt and Nickel in 26% Cr :
Approx. 50% Fe Alloys

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	N%
ZJ-142	.30	.53	1.21	26.3	19.7	—	.105
ZK-100	.30	.58	1.62	26.7	20.1	—	.09[illegible]
44-287	.34	.62	1.29	26.1	9.9	9.9	.14[illegible]
44-280	.30	.58	1.21	26.7	.3	19.4	[illegible]

Figure 7

Table 3

CR-385-1

COBALT AND NICKEL IN 26%CR ALLOYS

Fracture Time Characteristics at 1600°F. and 1800°F.

	Chemical Analysis							
Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-278	.35	.41	1.41	26.2	70.6	0.4	.73	.042
44-274	.35	.59	1.35	26.3	46.0	24.1	.93	.045
44-275	.31	.61	1.37	26.4	34.6	35.5	.97	.036
44-261	.30	.60	1.29	26.4	23.8	45.7	1.33	.051
44-279	.31	.46	1.21	26.6	0.4	69.0	.97	.040
XJ-142	.30	.53	1.21	26.3	19.7	-	(51.+)	.105
XJ-100	.30	.58	1.62	26.7	20.1	-	(51.+)	.099
44-287	.34	.62	1.29	26.1	9.9	9.9	51.4	.146
44-280	.30	.58	1.21	26.7	.3	19.4	51.4	.116

			Stress (P.S.I.) For Fracture in:				Stress (P.S.I.) For Fracture in:			
	Nominal		10	100	500	1000	10	100	500	1000
Heat No.	Ni%	Co%	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.
			1600°F.				1800°F.			
44-278	71.	0.	11000	8700	7500	7000	6200	4400	-	-
44-274	46.	24.	13300	10900	9400	8900	8000	5500	4200	3800
44-275	35.	36.	14500	11100	9200	8500	8300	6200	4400	3900
44-261	24.	46.	16600	12200	9800	8900	9000	6400	-	-
44-279	0.	69.	20000	14400	11400	10300	9600	6900	5200	4500
XJ-142	20.	0.	10800	7800	6100	-	7100	4300	3000	2600
XK-100	20.	0.	-	-	-	-	6200	4300	3200	3000
44-287	10.	10.	10400	6900	5100	-	6400	3600	2500	-
44-280	0.	19.	13500	8200	5800	-	7500	5200	4100	-

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Table 4

C.R.-385-1

COBALT AND NICKEL IN 26% CHROMIUM ALLOYS

As-Cast and Aged Room Temperature Properties

	Chemical Analysis							
Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-278	.35	.41	1.41	26.2	70.6	0.4	.73	.042
44-274	.35	.59	1.35	26.3	46.0	24.1	.93	.045
44-275	.31	.61	1.37	26.4	34.6	35.5	.97	.036
44-261	.30	.60	1.29	26.4	23.8	45.7	1.33	.051
44-279	.31	.46	1.21	26.6	0.4	69.0	.97	.040
XJ-142	.30	.53	1.21	26.3	19.7	—	(51.+)	.105
XK-100	.30	.58	1.62	26.7	20.1	—	(51.+)	.099
44-287	.34	.62	1.29	26.1	9.9	9.9	51.4	.146
44-280	.30	.58	1.21	26.7	.3	19.4	51.4	.116

Heat No.	Ni%	Co%	Yield* Strength P.S.I.	Ult.Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	BHN	Yield* Strength P.S.I.	Ult.Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	BHN
			As Cast									
44-278	71.	0.	44000	73250	15.	15.	179					
44-274	46.	24.	46000	74000	13.	12.	181					
44-275	35.	36.	47000	74750	15.	17.	187					
44-261	24.	46.	54000	90500	21.	17.	196					
44-279	0.	69.	64000	82500	6.	7.	269					
			1600°F.-48 Hrs.-F.C.					1800°F.-48 Hrs.-F.C.				
44-278	71.	0.	44000	85250	8.	7.	199	43000	84500	8.	10.	196
44-274	46.	24.	47000	87500	7.	6.	235	46000	83750	7.	6.	217
44-275	35.	36.	44000	92250	8.	6.	235	46000	92000	8.	7.	228
44-261	24.	46.	61000	104250	8.	7.	252	59000	98750	8.	8.	241
44-279	0.	69.	64000	99750	3.	4.	302	64000	102250	5.	6.	302
			As Cast					1400°F.-24 Hrs.-F.C.				
								(50000	77000	8.	10.	207
XJ-142	20.	0.	43000	71750	16.	31.	170	(53000	79000	8.	10.	202
								73500)	88000	10.	15.	194
XK-100	20.	0.	60000	79500	23.	23.	156	72000)	83500	8.	12.	196
44-287	10.	10.	54000	99500	10.	9.	228	57000	98250	10.	7.	228
44-280	0.	19.	64000	100000	11.	10.	241	71000	107750	9.	10.	262

* Approximate

APPENDIX

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Table 5

G-140
G-277

Heat Resistant Alloy Data Sheet
26%Cr:20%Ni Type

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
XY142	.30	.53	1.21	19.71	26.26	.105

Creep Characteristics

Test No.	Temp. °F.	Stress(1) P.S.I.	Duration Hrs.	Min. Creep Rate % Per Hr.	Elong. %	R.A. %
9	1800	6000	16.92	.38	14.5	21.6
10	"	4000	193.5	.0060	5.5	7.0
6	"	2000	2002.	.000033	-	-
4	"	3000	534/546	.00226	3.0	15.8
14	1600	10000	18.33	.23	6.0	12.2
11	"	8000	75/90	.029	3.3	5.5
5	"	4000	809.(2)	.000136	-	-
8	1400	20000	23.03	.17	8.0	13.4
7	"	15000	97.17	.047	6.5	10.0
3	"	6000	1606.(2)	.000123	-	-

Room Temperature Mechanical Properties

Test No.	Yield Strength P.S.I.	Tensile Strength P.S.I.	Elong. in 2" %	Red. Area %	Hardness BHN	Heat Treatment °F.-Hrs.-Coolant
2	42500	71750	16.0	30.5	170	As Cast
12	52500	79000	7.5	10.4	202	1400-24-F.C.
13	50000	77000	7.5	10.4	207	" " "
6	50000	66000	3.0	3.9		1800°F.-C.T.
5	47500	70900	3.0	5.1		1600°F.-C.T.
3	47500	71000	3.5	8.4		1400°F.-C.T.

(1) Unit stress based on 0.505" diameter gage length and constant load. Unit stresses in Creep Stage II may be higher because of reduction in area.

(2) Discontinued before fracture to obtain residual properties.

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Table 6

G-140

HEAT RESISTANT ALLOY DATA SHEET
26%Cr:20%Ni Type

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
XX-100	.30	.58	1.62	20.06	26.65	.099

CREEP CHARACTERISTICS

Test No.	Temp. °F.	Stress (1) P.S.I.	Duration Hrs.	Min. Creep Rate % per Hr.	Elong. %	R.A. %
7	1800	6000	13.4	.35	12.0	20.7
8	"	4000	157.4	.009	10.0	7.
3	"	2000	577. (2)	.000086	—	—
4	"	2000	571. (2)	.0000696	—	—
6	"	2000	880. (2)	.0000752	—	—

ROOM TEMPERATURE MECHANICAL PROPERTIES

Test No.	Yield Strength P.S.I.	Tensile Strength P.S.I.	Elong. in 2" %	Red. Area %	Hardness BHN	Heat Treatment °F.-Hrs.-Coolant
2	60000	79500	22.5	23.4	156	As Cast
12	73500	86000	9.5	14.5	194	1400 - 24 - F.C.
13	72000	83500	8.0	12.2	196	" " "
3	45000	62100	3.0	7.0		1900°F. - Creep Test
4	50000	61000	2.5	5.3		" " "
6	50000	66250	4.5	3.2		" " "

(1) Unit stress based on 0.505" diameter gage length and constant load. Unit stresses in Creep Stage II may be higher because of reduction in area.

(2) Discontinued before fracture to obtain residual properties.

Table 7

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[illegible]

COBALT AND NICKEL IN 26%Cr ALLOYS

Creep Stress and Time for Fracture for Several Stage II Rates

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
	Chemical Analysis							
44-278	.35	.41	1.41	26.2	70.5	0.4	.73	.042
44-274	.35	.59	1.35	26.3	46.0	24.1	.93	.045
44-275	.31	.61	1.37	26.4	34.6	35.5	.97	.036
44-261	.30	.60	1.29	26.4	23.8	45.7	1.33	.051
44-279	.31	.46	1.21	26.6	0.4	69.0	.97	.040
XY-142	.30	.53	1.21	26.3	19.7	-	(51.+)	.105
XX-100	.30	.58	1.62	26.7	20.1	-	(51.+)	.099
44-287	.34	.62	1.29	26.1	9.9	9.9	51.4	.146
44-280	.30	.58	1.21	25.7	3	19.4	51.4	.116

Heat No.	Nominal Ni%	Nominal Co%	.001%/Hr. Stress P.S.I.	.001%/Hr. Life Hrs.	.01%/Hr. Stress P.S.I.	.01%/Hr. Life Hrs.	.1%/Hr. Stress P.S.I.	.1%/Hr. Life Hrs.
			1600°F.					
44-278	71.	0.	-	-	-	-	8200	200.
44-274	46.	24.	9600	450.	10400	170.	11400	55.
44-275	35.	36.	8200	1300.	10000	230.	12300	40.
44-261	24.	46.	10400	300.	12700	75.	15300	19.
44-279	0.	69.	11600	450.	14300	110.	17500	26.
XY-142	20.	0.	5200	-	6900	220.	9200	35.
XX-100	20.	0.	-	-	-	-	-	-
44-287	10.	10.	-	-	4700	800.	7500	60.
44-280	0.	19.	5700	600.	7700	140.	10500	30.
			1800°F.					
44-278	71.	0.	-	-	-	-	4000	170.
44-274	46.	24.	-	-	3800	900.	5400	100.
44-275	35.	36.	5000	300.	6400	70.	7500	21.
44-261	24.	46.	5300	250.	6700	70.	7700	27.
44-279	0.	69.	5600	330.	7000	90.	8500	23.
XY-142	20.	0.	3000	550.	3900	160.	5100	45.
XX-100	20.	0.	2800	-	3900	180.	5300	25.
44-287	10.	10.	-	-	2200	800.	3600	100.
44-280	0.	19.	-	-	4400	280.	5800	50.

F.R.G.-4/5/45

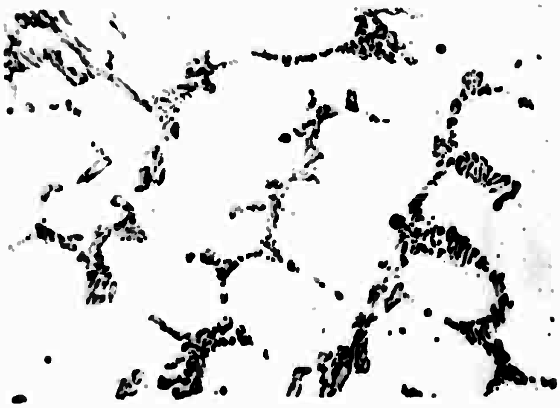


Plate No.
M2601

Bar No.
5

Figure 8

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

	Chemical Analysis							
Heat No.	**C%**	**Mn%**	**Si%**	**Cr%**	**Ni%**	**Co%**	**Fe%**	**N%**
44-278	.35	.41	1.41	26.2	70.6	0.4	.73	.042

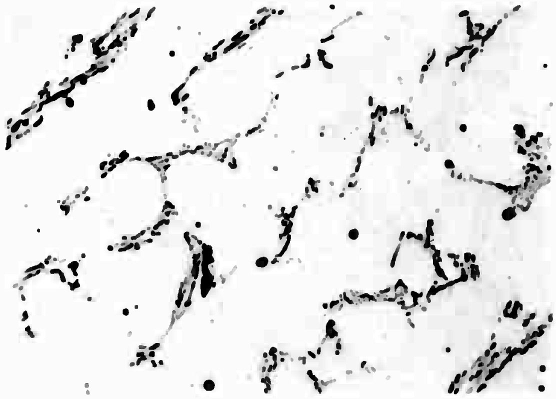


Plate No.
M2801

Bar No.
5

Figure 9

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

	Chemical Analysis							
Heat No.	**C%**	**Mn%**	**Si%**	**Cr%**	**Ni%**	**Co%**	**Fe%**	**N%**
44-274	.35	.59	1.35	26.3	46.0	24.1	.93	.045

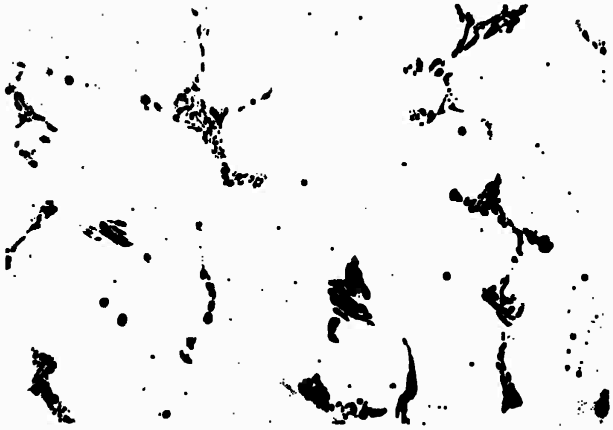


Plate No.
M3001

Bar No.
5

Figure 10

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

------------Chemical Analysis------------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-275	.31	.61	1.37	26.4	34.6	35.5	.97	.036

Compare with Figure 13, noting the precipitation of carbides after creep testing at 1800°F.

Plate No.
M3601

Bar No.
10

Figure 11

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

------------Chemical Analysis------------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-261	.30	.60	1.29	26.4	23.8	45.7	1.33	.051

Plate No.
M3201

Bar No.
5

Figure 12

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
	Chemical Analysis							
44-279	.31	.46	1.21	26.6	0.4	69.0	.97	.040

Compare with Figure 14, observing the development of dispersed carbides after creep testing at 1800°F.

Plate No.
M16001

CT
241

Bar No.
8

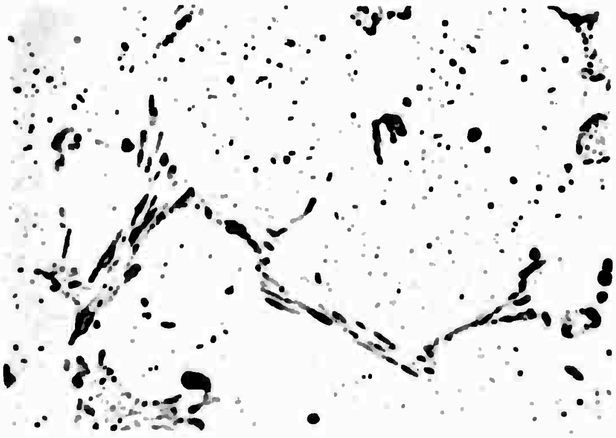


Figure 13

250X

From D17 casting after creep testing at 1800°F.-4000 PSI. for 876 hours.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

	Chemical Analysis							
Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-275	.31	.61	1.37	26.4	34.6	35.5	.97	.036

Observe the dispersed carbides produced during creep testing. See Figure 10 for as-cast structure.

Plate No.
M13701

CT
222

Bar No.
8

Figure 14

250X

From D17 casting after creep testing at 1800°F.-4000 PSI. for 1765 hours.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

	Chemical Analysis							
Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-279	.31	.46	1.21	26.6	0.4	69.0	.97	.040

Note the precipitated carbides which are absent in the as-cast condition. (Figure 12).

COBALT AND NICKEL IN 26%CR : APPROXIMATELY 50% FE ALLOYS

Plate
No.
M11301

Bar No.
15

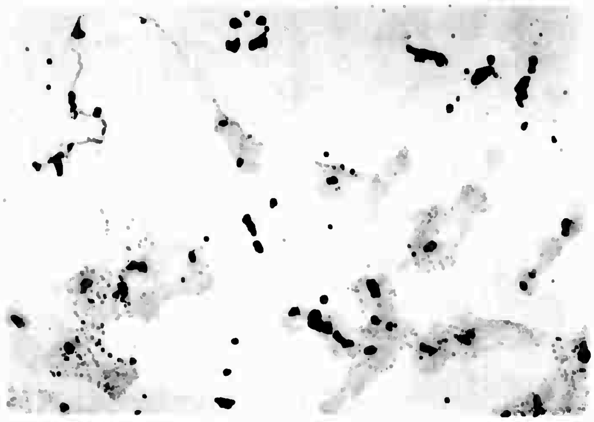


Figure 15

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

--------------Chemical Analysis--------------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
XJ-142	.30	.53	1.21	26.3	19.7	-	(51.±)	.105

The grey colonies are the lamellar constituent, resolvable at higher magnification.

Plate
No.
M12003

Bar No.
9

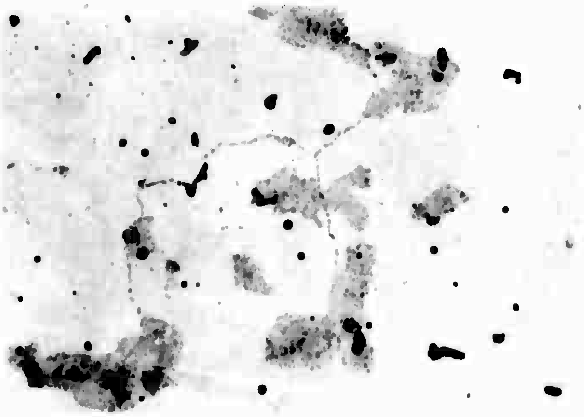


Figure 16

250X

From As-Cast
D-14 Bar.

Etched: 1:1 HCl - 15 secs.
Hot Alk. $K_3Fe(CN)_6$ - 15 secs.

-----------Chemical Analysis--------------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
XK-100	.30	.58	1.62	26.7	20.1	-	(51.±)	.099

Note the lamellar structure, generally adjacent to the grain boundaries.

COBALT AND NICKEL IN 26%CR : APPROXIMATELY 50%FE ALLOYS

Plate No. M3502

Bar No. 5

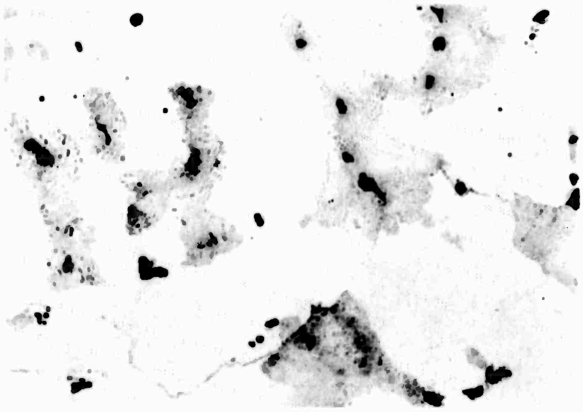


Figure 17

250X

From As-Cast D-14 Bar.

Etched: 1:1 HCl - 15 secs. Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

---------Chemical Analysis---------------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-287	.34	.62	1.29	26.1	9.9	9.9	51.4	.146

Lamellae are here partially resolved in the unidentified constituent.

Plate No. M3401

Bar No. 5

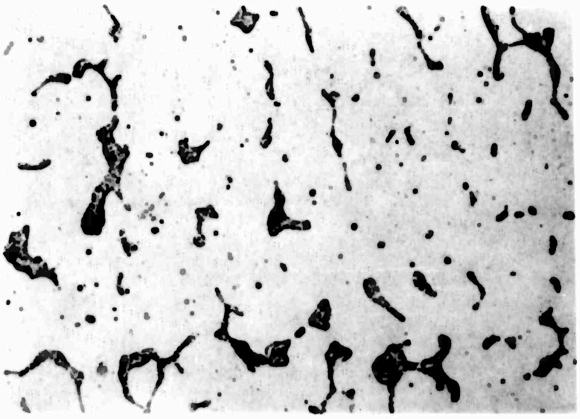


Figure 18

250X

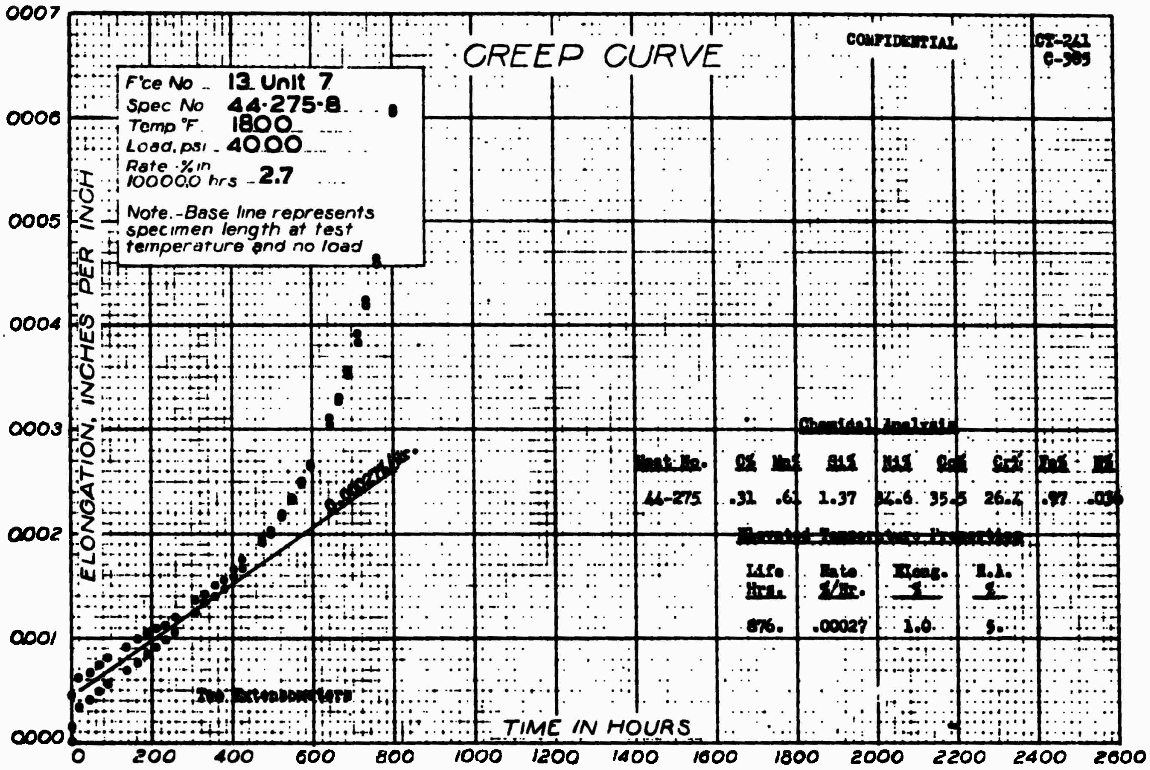
From As-Cast D-14 Bar.

Etched: 1:1 HCl - 15 secs. Hot Alk. $K_3Fe(CN)_6$ - 30 secs.

-----------Chemical Analysis-----------

Heat No.	C%	Mn%	Si%	Cr%	Ni%	Co%	Fe%	N%
44-280	.30	.58	1.21	26.7	.3	19.4	51.4	.116

Eutectic carbides have replaced the lamellar structure in the nickel-bearing alloys.



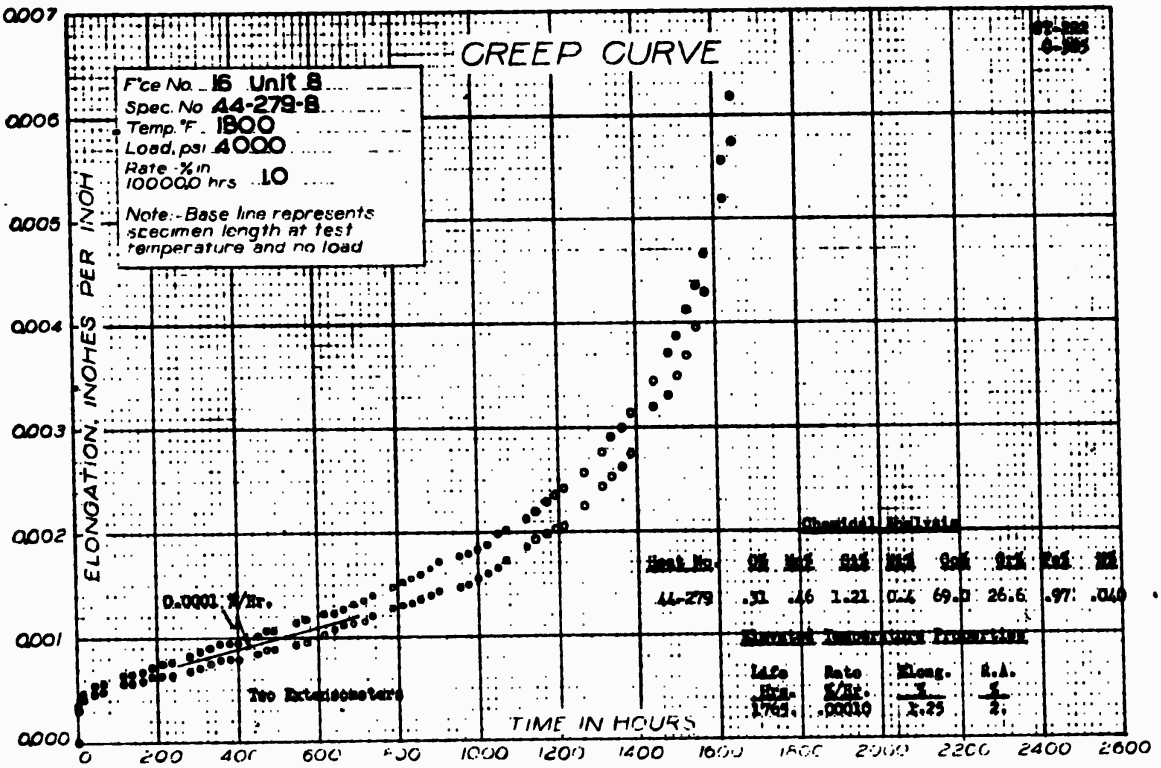
Chemical Analysis

Heat No.	C%	Mn%	Si%	Ni%	Co%	Cr%	Fe%	N%
44-275	.31	.61	1.37	34.6	35.5	26.4	.97	.036

Elevated Temperature Properties

Life Hrs.	Rate %/Hr.	Elong. %	R.A. %
876.	.00027	1.0	5.

Figure 19



Chemical Analysis

Heat No.	C%	Mn%	Si%	Ni%	Co%	Cr%	Fe%	N%
44-279	.31	.46	1.21	0.4	69.0	26.6	.97	.040

Elevated Temperature Properties

Life Hrs.	Rate %/Hr.	Elong. %	R.A. %
1765.	.00010	1.25	2.

CONFIDENTIAL

Figure 20

REEL – C

1091

A.T.I.

28102

23

TITLE: Heat-Resistant Alloys for Ordnance Materiel and Aircraft and Naval Engine Parts (N-102): Part II - Cobalt and Nickel in 26 percent Cr Alloys
AUTHOR(S): Gardner, F. S.; Avery, H. S.; Cook, E.
ORIGINATING AGENCY: American Brake Shoe Co., Mahwah, N. J.
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DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
July'45	Unclass.	U.S.	Eng.	30	photos, graphs, tables

ABSTRACT:

In the investigation of heat-resisting alloys, the effects of nickel and cobalt have been studied in two groups of 26% Cr alloys, one series being essentially nonferrous and the other containing about 50% iron. The results of stress-strain-rupture tests at 1600° and 1800°F are giver.. Data from room temperature tension tests are included for materials as cast or after exposure to one of several aging treatments. In the absence of iron, the replacement of nickel by cobalt produces a marked strengthening at elevated temperatures. Creep testing of several compositions has been initiated to supplement the indications of stress-strain-rupture tests; two tests at 1800°F having been completed for this report. The microstructures of these alloys have been examined, and representative photomicrographs are shown.

P 20/13

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DIVISION: Materials ~~(8)~~ 8 14
SECTION: General Data ~~(15)~~ 6

ATI SHEET NO.: R-8-15-2

SUBJECT HEADINGS: High temperature alloys (49326)

P 11/6

Air Documents Division, Intelligence Department
Air Materiel Command

AIR TECHNICAL INDEX

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(23) HIGH TEMPERATURE

(23) ★ ALLOYS