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NATIONAL DEFENSE RESEARCH COMMITTEE
of
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
WAR METALLURGY DIVISION

ATI No. 6912

Progress Report

on

HEAT RESISTING METALS FOR GAS TURBINE PARTS

M-102

by

Howard C. Cross
Supervisor of High Temperature Metals Research
War Metallurgy Committee

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11-A
April 12, 1943

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: Progress Report on Heat Resisting Metals for Gas Turbine Parts

The attached progress report by Howard C. Cross, Research Supervisor on NDRC Research Project NRC-8, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report covers the test data obtained to date by the twelve cooperating laboratories in this program on the development and testing of heat-resisting alloys for gas turbine parts. Data made available by others than the contracting laboratories are included in the report. Many different types of tests were used in evaluating these heat-resisting alloys. Of particular interest are the experiments on development of new alloy systems for use in higher temperature ranges than are now feasible. The future plan of the test program to produce information needed by designers in industry and the Armed Forces is discussed.

I recommend acceptance as a satisfactory progress report under the following Contracts:

OEMsr-478	American Brake Shoe and Foundry Company
OEMsr-447	Battelle Memorial Institute
OEMsr-457	Climax Molybdenum Company
OEMsr-482	Crane Company
OEMsr-459	Federal Shipbuilding and Dry Dock Company
OEMsr-509	Lunkenheimer Company
OEMsr-508	Massachusetts Institute of Technology
OEMsr-505	The Midvale Company
Sym.-934	National Bureau of Standards
OEMsr-466	University of Michigan
OEMsr-527	Vanadium Corporation of America
OEMsr-840	Research Laboratory, Westinghouse Electric and Manufacturing Company

Respectfully submitted,

(signed) Louis Jordan

Louis Jordan
Technical Aide to the Chief
War Metallurgy Division, NDRC

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-B-

PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research & Development, Navy Department, as E-102, and to the project designated by the War Metallurgy Division as NDRC Research Project NRC-8.

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PROGRESS REPORT

on

NDRC Research Projects NRC-8 and 41

HEAT-RESISTING METALS FOR GAS TURBINE PARTS (X-102)

From September 20, 1942, to April 2, 1943

<u>From</u>	American Brake Shoe and Foundry Company	OEMsr-478 (NRC-8)
	Battelle Memorial Institute	OEMsr-447 "
	Climax-Molybdenum Company	OEMsr-457 "
	Crane Company	OEMsr-462 "
	Lunkenheimer Company	OEMsr-509 "
	Massachusetts Institute of Technology	OEMsr-508 "
	Midvale Company	OEMsr-505 "
	National Bureau of Standards	Grant of funds.
	United States Steel Corporation	OEMsr-459 "
	University of Michigan	OEMsr-466 "
	Vanadium Corporation of America	OEMsr-527 "
	Westinghouse Electric and Manufacturing Company	OEMsr-840 (NRC-41)

by

Howard C. Cress

Research Supervisor

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SUMMARY

The compositions of forty-seven alloys supplied for test and the results of experimental heat treatments on these alloys are shown. Seven additional alloys are now being prepared for test in the form of castings. Density determinations have been made on some of the alloys.

Complete examination of the microstructures of the different alloys has been made and for those with promising high-temperature properties as determined by stress-rupture and creep tests, structures before and after heat treatment and aging and after testing are shown. All of these alloys are of the precipitation-aging type and most of them are indicated to be quite stable at 1500°F.

None of the promising alloys show very high impact resistance, and those with the best load carrying ability show the lowest values. Impact specimens tested with "V" notches showed better impact resistance than bars with keyhole notches and the values for all alloys were higher at 1800°F. than at room temperature, indicating low ductility at room temperature is not necessarily indicative of low ductility at 1500°F.

Stress-rupture tests have been made or are in progress at 1800°F. on most of the alloys listed. Widely differing properties are shown with fracture times at 20,000 p.s.i. at 1500°F., varying from 2.5 to 84.5 hours. For the more promising alloys, fracture times between 500 and 1000 hours and in a few cases over 1000 hours have been obtained, as follows: Eighteen of the alloys show fracture times of 100 hours at stresses above 15,000 p.s.i. at 1500°F., and three alloys show fracture times of 500 hours at stresses of 15,000 p.s.i. at 1500°F. Two of the alloys (8295 and 8497)

show a fracture time of 1000 hours at 14,000 p.s.i. at 1500°F. The best alloys are as-cast X-19, S495, S497, N-153, N-154, N-155, 4275, and alloys identified as NR-36 and NR-40. Compositions of these alloys are shown in Table 1. of the text.

Cold-worked and hot-worked Cr-Ni-Co-Fe alloy, and alloy heat treated and aged after either cold (1200°F.) or hot (1700°F.) work, was found to be inferior in stress-rupture properties at 1500°F. as compared with solution heat-treated and aged alloy.

A few stress-rupture tests are in progress at 1350°F. For S497 alloy, fracture times of 100, 500, and 1000 hours are indicated at stresses of about 29,000, 24,500, and 23,000 p.s.i.

Stress-rupture tests are in progress at 1600°F. on Gamma Columbium, S495, and S497 alloys. On S495 alloy at 1600°F., fracture times at 100, 500, and 1000 hours are indicated at stresses of 13,200, 10,300, and 9,200 p.s.i. Additional pertinent stress-rupture data at 1500°F., made available by the U. S. Naval Engineering Experiment Station and the Westinghouse Electric and Manufacturing Company, are included in the report.

Creep tests are in progress at 1500°F. on twenty of the alloys tested in stress-rupture. The alloys with best creep resistance are S495 and S497, with Gamma Columbium, NR-37, N-156, NR-43, NR-57, and NR-58, having slightly lower creep resistance. Alloys S495 and S497 show a creep rate of .00001% per hour at a stress above 7,000 p.s.i., while the others are close to 7,000 p.s.i. for .00001% per hour. Creep tests are in progress at 1600°F. and 5,000 p.s.i. on S495 and S497 alloys.

Most of the alloys tested in stress-rupture and creep tests at 1500°F. show very little change in hardness as compared with their hardness

as heat treated. Izod impact tests (0.450-inch diameter - "V" notch) after creep and stress-rupture tests at 1600°F. show values of 4 to 14 foot-pounds for some of the alloys with best load carrying ability.

Short-time tension test data over a range of temperatures have been made available by the U. S. Naval Engineering Experiment Station for some of the alloys tested in the NRC program.

Fatigue test data at 1200 to 1500°F. on heat-resisting alloys were made available by the U. S. Naval Engineering Experiment Station and Westinghouse Electric and Manufacturing Company. At 1200°F. some of the materials show endurance limits at 2.5×10^8 cycles over 40,000 p.s.i. and some do not. Some of the well-known alloys such as Timken 16-26-6, Gamma Columbian, 19-9 W-Mo and S497 show stresses producing rupture in 1000 hours at stresses at or near 40,000 p.s.i. This means that in designing parts for a limited service life in which the stresses used are consequently high, it is well to remember that if the part is subjected to fatigue stresses, the endurance limits should be taken into consideration. When the heat-resisting alloys are to be used for types of service in which long service life is desired, the lower stresses dictated by the low creep rates allowable usually give an ample margin of safety as compared with the endurance limit and in these cases the creep rate rather than the endurance limit is the limiting factor in design.

Corrosion tests at 1500°F. in an air-sulphur dioxide atmosphere as performed at U. S. N. E.E.S. show no significant attack on the Cr-Ni-Fe types of alloys discussed in this report.

The research on chromium-tungsten alloys has developed materials with excellent stress-rupture properties at 1600°F. in that alloys with

approximately 23 to 26% tungsten, 8 to 15% iron, balance chromium show tests of 850 to 1150 hours duration at 20,000 p.s.i. without fracture. The ductility is practically nil and efforts are being made to improve the ductility. Centrifugal casting in vacuum of supercharger blades for test purposes is to be attempted.

Tungsten-rich alloys containing 25 to 30% tungsten and with balance principally chromium, nickel, and cobalt show Brinell hardness at 1500°F. of about 400. These are to be tested in stress-rupture at 1500°F. soon.

Experiments are in progress on the effect of heat treatment variables on the structures and high-temperature properties of Timken Alloy 16-25-6, Gamma Columbium, and S495 alloys.

The future work planned is discussed in detail.

COOPERATING LABORATORIES

Research laboratories of the following organizations, operating under NDRC contracts, are cooperating in the research program.

American Brake Shoe and Foundry Company

Battelle Memorial Institute

Climax Molybdenum Company

Crane Company

Lunkenheimer Company

Massachusetts Institute of Technology

Midvale Company

National Bureau of Standards
United States Steel Corporation
University of Michigan
Vanadium Corporation of America
Westinghouse Electric and Manufacturing Company.

Of these laboratories operating under an NDRC contract, stress-rupture tests are being conducted by American Brake Shoe and Foundry Company, Battelle Memorial Institute, and University of Michigan.

Creep tests are being conducted by American Brake Shoe and Foundry Company, Battelle Memorial Institute, Crane Company, Lunkenheimer Company, Massachusetts Institute of Technology, Midvale Company, National Bureau of Standards, and the United States Steel Corporation, using 30-40 creep test units.

The Climax-Molybdenum Company and the Vanadium Corporation are engaged in fundamental research on the development of new and improved alloy systems suitable for high-temperature service. Both companies are conducting experiments on the melting and casting of the various alloys developed for preparation of both test specimens and blades for testing in a turbo-supercharger under gas turbine operating conditions.

Westinghouse Electric and Manufacturing Company is engaged in research on the effect of heat-treatment variables on the structure and high-temperature properties of some of the alloys being studied in this research program.

In addition to the above-noted companies, the following companies are cooperating by supplying test materials either gratis or under purchase order either to reimburse them for out-of-pocket expense or because of

existing priority restrictions on the use of raw materials when not covered by a proper and certified purchase order.

Allegheny-Ludlum Steel Corporation
Crucible Steel Company
Driver Harris Company
General Electric Company
Haynes-Stellite Company
International Nickel Company
Stoody Company
Universal Cyclops Steel Corporation

INTRODUCTION

This research has as its object the development of better heat-resisting metals for use as gas turbine parts. The research is being carried out at the request of the Navy Department.

The initial temperature of interest was stated to be 1500°F. and alloys that will withstand 7,000 p.s.i. with a creep rate not exceeding .00001% per hour are presently required.

Present activities of the Bureau of Aeronautics of the Navy Department have developed the need for alloys suitable for use at higher stresses but with shorter useful life. The research has been directed toward development of alloys of the desired low creep rate, but at the same time considerable data of direct value and interest to the second application are being obtained.

This report will serve to present all of the test data obtained to date in this research program. Subsequent reports will present additional data as they become available.

EXPERIMENTAL WORK

Test Materials

Table 1 shows the forty-seven alloys that have been supplied for test. Some test data are available on all except NR-26, NR-47, and NR-56. The Alloys NR-26 and NR-47 are to be supplied in the as-cast condition and, to date, sound bars have not been received for test. NR-56 is being forged and will soon be ready for heat treatment and testing.

Table 1 also shows the composition of seven alloys which are being prepared for test. NR-10 and NR-12 are to be prepared in the form of castings by Haynes-Stellite Company. These are alloys for which sound test bars have been prepared in small sizes, but for 0.505-inch diameter test bars it has been necessary to do considerable research work on gating and feeding in order to insure sound cast test specimens. Recent trials have indicated that sound material of the size desired may soon be available for test. NR-13 and NR-14 have been delayed until a suitable nickel-titanium alloy for introducing titanium into the melt was obtained. These heats are to be made soon. NR-23 is to be cast by the General Electric Company and lack of soundness in the as-cast bars has delayed these tests. NR-10, NR-23, NR-24, NR-57, and NR-58 are to be cast centrifugally by the Stoddy Company. Cast bars of Alloys NR-10, NR-57, and NR-58 have just been received from the Stoddy Company but have not yet been radiographed for soundness.

TABLE 1. HEAT-RESISTING ALLOYS UNDER TESTS IN HRC-6 PROGRAM

Material	Alloy Number	Chemical Composition, Per Cent											Remarks
		C	Mn	Si	Cr	Ni	Co	Mo	W	Os	Ta	Nb	
L17	HR-1	.29	.59	.61	13.9	33.9	10.78	5.51	2.28	-	-		
S497	HR-2	.47	.68	.98	14.04	19.57	20.03	3.84	4.69	5.10			
H418	HR-3	.40	1.47	.87	16.59	24.30	25.07	5.30	9.03	-			
H385	HR-4	.30	1.47	.60	20.57	25.10	25.74	5.03	-	-			
H359	HR-5	.35	1.60	.52	20.84	25.37	25.49	2.98	5.01	-			
H439	HR-6	.36	1.54	.55	20.39	29.59	31.33	5.01	-	-			
H495 (Low C)	HR-7	.18	.71	.97	14.30	20.94	-	5.57	3.84	5.79			
H495	HR-8	.50	.75	.88	14.44	20.52	-	4.38	3.99	2.78			
Gamma Columblum	HR-9	.38	.74	1.21	14.51	24.04	-	4.41	-	4.34			
1370	HR-10	.15	.75	1.0	15	15	5	15	5	1.65 Ti			.07
Ti-80	HR-15	.08	1.64	.85	15.55	25.2	-	5.45	-	-			
10-9 W-Mo	HR-16	.11	.90	.42	18.27	8.63	-	.40	1.56	.28	0.48 Ti		
Refractaly	HR-17	.07	2.0	-	24.4	30.0	-	5.0	-	-			
70 Co - 30 Cr	HR-18	.45	1.09	.15	30.04	-	67.81	-	-	-			
H153	HR-19	.58	1.78	.52	15.20	14.98	12.85	3.01	2.19	1.08			.07
H154	HR-20	.32	1.69	.65	15.17	25.95	20.95	3.06	2.20	1.03			.07
H155	HR-21	.52	1.84	.89	21.08	20.50	20.64	5.00	2.12	0.95			.11
H156	HR-22	.35	1.45	.97	15.64	23.23	23.59	5.02	2.10	1.03			.08
I-19	HR-24	.10	-	-	25	20	45	5	-	-			
I-37	HR-25	.60	-	-	25	69	-	-	2	-			
Refractaly A	HR-29	.07	.50	.30	20.10	49.50	-	14.4	-	-			
Nimonic 80	HR-29	.04	.54	.47	91.12	74.25	-	-	-	-			
Tyconium	HR-31	.08	.84	.51	26.85	51.05	50.15	5.0	-	-			
Gamma Columblum	HR-32	.05	.96	.24	19.27	24.1	-	3.28	-	1.08			
H495	HR-33	.40	.54	.25	15.22	24.50	-	4.14	-	3.20			
H495	HR-34	.41	.55	.34	15.99	19.71	-	4.55	3.57	4.20			
HR-35	HR-35	-	-	-	-	-	-	-	-	-			
Contra-Acid	HR-35	.054	.65	-	14.77	50.11	-	7.95	-	-			
H559-2	HR-37	.55	9.1	1.64	15.7	15.1	19.7	2.7	-	1.25	.91		
H559	HR-38	.39	5.15	1.79	17.5	25.0	19.7	3.7	-	1.83	.88		
4274	HR-39	1.06	.61	.22	12.66	18.09	-	.50	5.41	-			
4275	HR-40	.95	4.47	.71	18.20	4.45	-	2.33	-	-			
4277	HR-41	1.15	12.62	.44	19.75	-	-	2.02	1.57	-			
22a22	HR-42	1.45	-	1.15	25.77	29.01	-	-	3.72	-			
H550-1	HR-43	.35	2.1	1.55	19.1	15.1	19.9	2.5	-	.72	.35		
Replacement HR-3	HR-44	.64	1.64	.75	15.10	24.15	24.20	5.22	1.95	-			
S497	HR-45	.42	.47	.51	15.55	19.50	19.0	3.94	4.25	4.41			
10-9 W-Mo (mod.)	HR-46	.25	.52	.57	15.95	9.05	-	1.22	1.19	.59			
I-41	HR-47	.30	.60	.50	25	25	55	5	7.5	-			
Ti-80	HR-49	.08	1.65	.69	15.72	25.23	-	6.25	-	-			
4275 (mod.)	HR-50	.35	4.17	.50	18.22	4.55	-	1.25	1.54	.27			
ATV-5	HR-51	.49	1.19	1.24	14.40	27.40	-	-	2.89	-			
H152 (no Co)	HR-52	.55	1.54	.68	15.4	14.9	-	2.9	2.2	1.04			.15
H154 (no Co)	HR-53	.52	1.54	.68	15.4	25.5	-	2.9	2.2	1.00			.15
H155 (no Co)	HR-54	.54	1.54	.61	21.4	20.9	-	2.9	2.5	1.05			.16
H156	HR-55	.59	1.75	.69	21.5	20.7	-	2.9	2.5	1.05	1.05		.12
H359	HR-56	.32	1.60	.53	21.5	24.9	25.0	2.3	3.05	-			
TE	HR-57	.09	.70	.52	20	20	-	4	4.1	-	1.5		.15
TE-O	HR-58	.04	.70	.72	20	20	-	1	5.27	-	5.57		
Heat-Resisting Alloys Not Yet Available													
Vitalium W	HR-10	.20	-	-	25	65	2	-	-	-			
422-10 W	HR-12	.45	-	-	31	15	46	2	-	-			
Modified H30 W	HR-13	.10	.75	1.0	15	55	5	15	5	-			Ti 5
Modified H16 W	HR-14	.04	.54	.70	10	25	2	5	2	-			Ti 2.55
1067 W	HR-23	.15	-	-	15	45	20	30	-	-			
72 A	HR-57	.10	1.59	.36	5.7	52.1	4.22	17.25	5.15	-			Fe 15
51 A	HR-58	.40	-	.52	95.2	55.9	-	-	4.12	-			Pu 1.64

W = Type analysis
 N = Not yet available
 A = Centrifugally cast bars received but not yet examined for soundness prior to test

Density determinations have been made on some of the alloys. Heat-treated and aged specimens were used for the density determinations, except in the case of Cast Alloy NR-11 and Alloys NR-49 and NR-51. At the time, no heat-treated NR-49 (Timken alloy) was available and NR-51 was tested in stress-rupture and creep in the cold-rolled condition so density was determined on similar material.

The specimens were carefully cleaned, weighed in air, and then weighed immersed in water. All weighings were carried out in a constant-temperature, constant-humidity room. The density was computed according to the formula

$$\text{density} = \frac{w \times (d_w - \rho)}{w - (w_w - w_s)} + \rho$$

- in which ρ = density of the air
 d_w = density of the water
 w = weight in air
 w_w = weight in water
 w_s = weight of sling used to suspend sample in water.

The values obtained are shown below:

NR-11	8.9183	NR-34	8.2600
NR-16	8.0386	NR-44	8.1966
NR-17	8.0221	NR-45	8.5698
NR-19	8.1450	NR-46	7.9328
NR-20	8.1889	NR-49	8.0586
NR-21	8.2690	NR-51	8.0816
NR-22	8.3710	NR-52	8.0384
NR-29	8.1922	NR-53	8.0964
NR-33	8.0636	NR-54	8.0586
		NR-55	8.0532

Metallographic Examination and Heat Treatment of Test Materials

All test materials were sent to Battelle Memorial Institute for examination and heat treatment before testing. Structures of the alloys as-received, as-forged, or as-cast were determined. Some alloys were tested in the as-received condition. For those alloys tested as-heat-treated, a series of experimental heat treatments were used to develop the structures thought most suitable for good load-carrying ability at high temperatures. Heat treatment temperatures, times at temperature, and modes of cooling were chosen to produce the maximum carbide solution without objectionable grain growth or grain boundary conditions. The formation of a continuous heavy carbide network in the grain boundaries was avoided.

Table 2. shows the heat treatments thought most suitable for the various alloys and to which the alloys were subjected before test. As a result of the various experimental heat treatments, as will be seen in Table 2., many different combinations of solution heat-treatment temperature, times at temperature, and methods of cooling from the heat-treatment temperature have been used. Specimens of the alloys to be tested at 1350°F. were aged 50 hours at 1400°F. prior to test. Specimens to be tested at 1500 or 1600°F. were aged 50 hours at the test temperature prior to test. The heat treatments used may not have produced the structures with the most desirable high-temperature properties in every case. Recent data made available by an alloy manufacturer indicate that higher solution heat-treatment temperatures can be used in some cases even though the microstructures may not appear as desirable. Such indications are being given careful consideration and experiments to evaluate their effect are being planned. As will be related later in this report, experiments on the

TABLE 2. DETAILS OF HEAT TREATMENTS USED ON BR ALLOYS

Material	Alloy Number	Condition	Heat Treatment		Aging	
			Preheat	Solution Treatment		
L ₁ 2 2467	BR-1	1	None	2150°F.-45 min.-Air cooled	None	
	BR-2	1	None	2250°F.-45 min.-Air cooled	50 hrs.-1500°F.	
	BR-3	1	None	2250°F.-10 min.-Air cooled	None	
	BR-4	1	None	2150°F.-10 min.-Air cooled	None	
	BR-5	2	None	2250°F.-25 min.-Oil quenched	50 hrs.-1500°F.	
		1	1600°F.	2000°F.-5 min.-Air cooled	None	
	BR-6	1	None	2250°F.-2 min.-Air cooled	None	
		2	None	2250°F.-1½ hrs.-Oil quenched	50 hrs.-1500°F.	
	Gamma Columbium	BR-7	2	1/2 hr.-1550°F.	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.
		BR-8	2	None	None	None
Vitalium	BR-9	9	None	None	None	
	BR-10	9	None	None	None	
Titanium	BR-11	9	None	None	None	
	BR-12	1	1/2 hr.-1550°F.	2150°F.-45 min.-Air cooled	50 hrs.-1500°F.	
19-9 Ti-40	BR-13	5	1/2 hr.-1550°F.	2150°F.-45 min.-Water quenched	50 hrs.-1500°F.	
	BR-14	4	None	None	50 hrs.-1500°F.	
Bisfractaloy B 70 Co - 30 Cr	BR-15	2	None	2250°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	BR-16	1	None	1850°F.-1 hr.-Oil quenched	50 hrs.-1500°F.	
BR-17	2	None	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.		
	1	1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.		
BR-18	2	None	1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	1	1/2 hr.-1550°F.	1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
BR-19	4	None	(A)	2150°F.-30 min.-Air cooled	50 hrs.-1500°F.	
	5	None	(A) then 1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
BR-20	6	None	(B)	2150°F.-30 min.-Oil quenched	None	
	7	None	(B) then 1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
BR-21	2	None	(B) then 1/2 hr.-1550°F.	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	4	None	(C)	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
BR-22	7	None	(D) then 1/2 hr.-1550°F.	2150°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	2	None	(D) then 1/2 hr.-1550°F.	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
BR-23	5	None	(E) then 1/2 hr.-1550°F.	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	9	None	None (tested as cast)	None (tested as cast)	50 hrs.-1500°F.	
X-19	2	None	None (tested as cast)	None (tested as cast)	None	
	3	None	2250°F.-30 min.-Oil quenched	1950°F.-4 hrs.-Water quenched	50 hrs.-1500°F.	
Bisfractaloy A	BR-24	2	None	2250°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	BR-25	3	None	2000°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
Himmet 80	BR-26	2	None	2000°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	BR-27	2	None	2000°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
Tycorium	BR-28	2	None	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	
	BR-29	2	1/2 hr.-1550°F.	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	
Gamma Columbium	BR-30	3	None	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	
	BR-31	3	None	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	
Gamma Columbium	BR-32	3	None	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	
	BR-33	3	None	2250°F.-45 min.-Oil quenched	50 hrs.-1500°F.	

Material	Alloy Number	Condition	Preheat	Heat Treatment		Aging
				Solution Treatment	Agging	
Gamma Columbium	NR-33	1	1/2 hr.-1550°F.	2250°F.-45 min.-Air cooled	50 hrs.-1500°F.	
	NR-34	3	None	2250°F.-2 hrs.-Water quenched	50 hrs.-1500°F.	
Contra-Acid	NR-35	2	None	2000°F.-30 min.-Oil quenched	50 hrs.-1500°F. (F)	
	NR-36	2	None	2000°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-37	2	None	2250°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-38	2	None	2250°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-39	2	None	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-40	2	None	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-41	2	None	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
	NR-42	1	None	2050°F.-1 hr.-Air cooled	50 hrs.-1500°F.	
	NR-43	1	None	2250°F.-30 min.-Air cooled	50 hrs.-1500°F.	
	NR-44	1	None	2250°F.-10 min.-Air cooled	50 hrs.-1500°F.	
	NR-45	2	None	2250°F.-2 hrs.-Air cooled	50 hrs.-1500°F.	
	NR-46	2	None	2250°F.-2 hrs.-Water quenched	50 hrs.-1500°F.	
19-9 W-Mo (mod.)	NR-47	9	None	2250°F.-30 min.-Oil quenched	50 hrs.-1500°F. (F)	
X-41	NR-48	3	1/2 hr.-1550°F.	None (tested as cast)	None	
Tinkun (1)	NR-49	3	None	2150°F.-45 min.-Water quenched	50 hrs.-1500°F.	
4275 (mod.)	NR-50	2	None	2200°F.-30 min.-Oil quenched	50 hrs.-1500°F.	
ATV-3	NR-51	1	None	2250°F.-30 min.-Air cooled	50 hrs.-1500°F.	
ATV-3	NR-52	4	None	(G)	None	
N155 (no Co)	NR-53	2	1/2 hr.-1550°F.	2200°F.-30 min.-Oil quenched	50 hrs.-1550°F.	
N154 (no Co)	NR-54	2	1/2 hr.-1550°F.	2200°F.-30 min.-Oil quenched	50 hrs.-1550°F.	
N155 (no Co)	NR-55	2	1/2 hr.-1550°F.	2250°F.-30 min.-Oil quenched	50 hrs.-1550°F.	
plus Ta.	NR-56	2	1/2 hr.-1550°F.	2250°F.-30 min.-Oil quenched	50 hrs.-1550°F.	

- (A) 2100°F.-air cooled
25.6% reduction at 1200°F.
Stress-relieved at 1200°F.
- (B) 2100°F.-air cooled
21.7% reduction at 1700°F.
Stress-relieved at 1200°F.
- (C) 2100°F.-air cooled
25.8% reduction at 1200°F.
Stress-relieved at 1200°F.
- (D) 2100°F.-air cooled
26.3% reduction at 1700°F.
Stress-relieved at 1200°F.
- (E) 2100°F.-air cooled
24.2% reduction at 1200°F.
Stress-relieved at 1200°F.
- (F) Specimens tested at 1600°F.
Aged 50 hrs. at 1600°F.
Specimens tested at 1550°F.
Aged 50 hrs. at 1400°F.
- (G) Forged and rolled at 2100°F.,
then quenched at 1400°F.
40% reduction at 1100°F.
- (H) Replacement for NR-3
- (I) Replacement for NR-15

effect of heat-treatment variables on several of the well-known alloys are in progress.

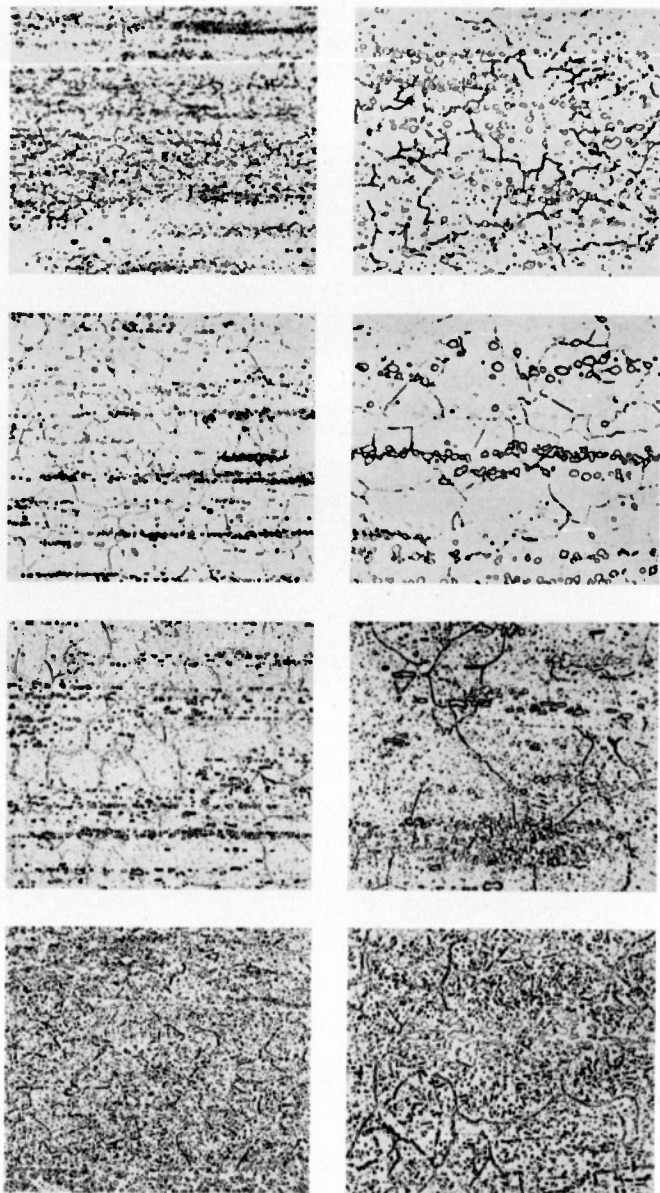
Figures 1 to 9 show photomicrographs of some of the alloys which have shown promising stress-rupture and creep properties in the tests at 1500°F.

Rather complete examination of the structures of the various NR alloys has been made as-heat-treated and before test, but space does not permit the reproduction of the structures of all of the alloys in this report. Those that are shown serve to illustrate the types of structures typical of these types of precipitation-hardening, heat-resisting alloys. Considerable work is in progress at the moment on examination of the structures of the alloys after test and determination of the type of fracture obtained in the stress-rupture tests, but only a portion of this work is in shape for presentation in this report. A subsequent report in several months will be more complete in this respect.

The structures for each alloy are shown on a single page. Four conditions are shown for 2 magnifications each, at 200 and 500. The two photomicrographs at the top show the structure as-received; the next two, the structure after the solution heat treatment, as noted; the next, the structure after aging 50 hours at 1500°F.; and the bottom two, the structure after stress-rupture or creep test.

Photomicrographs are shown for Alloys NR-19, 20, 21, 33, 34, 43, 44, 46, and 49. All of these alloys are of the precipitation-aging type.

Alloys NR-19, 20, and 21 (Figures 1, 2, and 3) had been air-cooled from 2100°F. before receipt. Solution heat treatment at a slightly higher temperature effected a more complete carbide solution and with not too much



Alloy-NR-20
(N-154)

Forged
2100°F.
Air-cooled

Heat-treated
Preheat - 1550°F.
High Heat
2150°F. - 30 min.
Oil-quenched

Aged
1500°F. - 50 hrs.

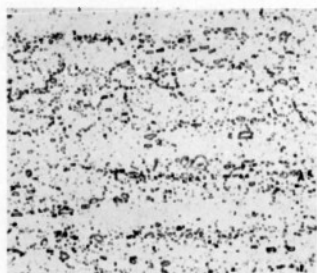
Creep Test Bar
NR-20-1
Temp. 1500°F.
Stress 10,000 p.s.i.
Time 1500 hrs.

200 X

500 X

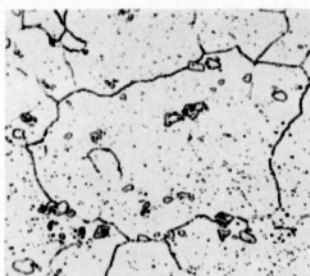
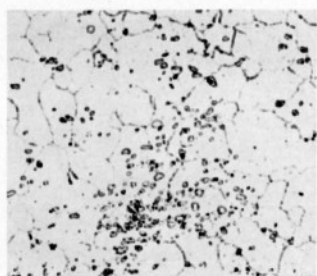
Etchant—Aqua Regia in Glycerine

Figure 2.

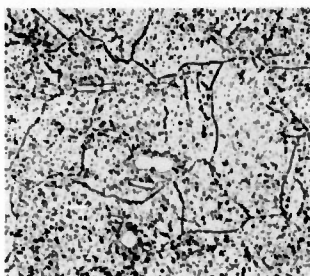
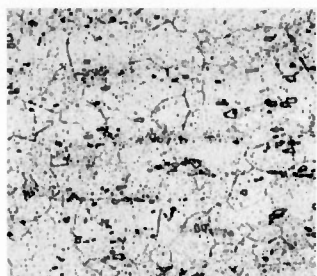


Alloy NR-21
(N-155)

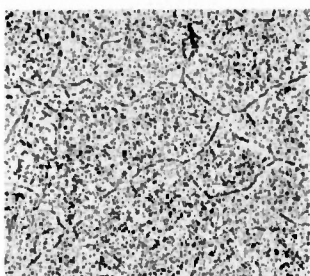
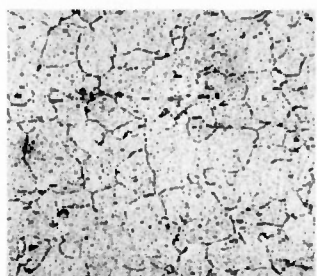
Forged
2100°F.
Air-cooled



Heat-treated
Preheat - 1550°F.
High Heat
2200°F. - 30 min.
Oil-quenched



Aged
1500°F. - 50 hrs.



Creep Test Bar
NR-21-1

Temp. 1500°F.
Stress 10,000 p.s.i.
Time 2160 hrs.

200 X

500 X

Etchant—Aqua Regia in Glycerine

Figure 3.

grain growth. Aging produced considerable precipitation, but for NR-19 apparently the time at temperature in the solution treatment was not sufficient to allow diffusion of the carbide to eliminate the initial segregation of carbon. Structures for specimens tested at 1500°F. are shown for Alloys NR-20 and 21. The time at test temperature of 1500°F. produced coalescence of the carbides particularly at the grain boundaries; yet, as shown in Table 8., little or no change in hardness was noted as compared with the original heat-treated and aged material.

The Gamma Columbian alloy (NR-33) is shown in Figure 4. Appreciable carbide solution was effected in the solution heat treatment. Aging did not precipitate so much carbide as for NR-19, 20, and 21, and testing for 2050 hours at 1500°F. did not appear to produce much more precipitate except in the grain boundaries. Table 8. shows only a small decrease in hardness.

The S495 alloy (NR-34) is shown in Figure 5. Very substantial carbide solution was effected but the massive carbides were not affected much. Aging produced uniform precipitation, and testing for 2280 hours at 1500°F. coarsened the carbides in both the grains and the grain boundaries. The hardness was reduced from Rockwell "A" 61 to 59.

The 8658-1 alloy (NR-43) which is a Cr-Ni-Co-Fe alloy with Mo, W, and Ta added is shown in Figure 6. and this material reacted somewhat similarly to S495 in Figure 5., except that the matrix carbides were not coarsened quite so much.

The replacement alloy for NR-3 (NR-44), Figure 7., showed the greatest amount of precipitation on aging but when tested 418 hours at 1500°F. the hardness was reduced from Rockwell "A" 88 to 59.5. The structure of this alloy as-tested is not yet available.

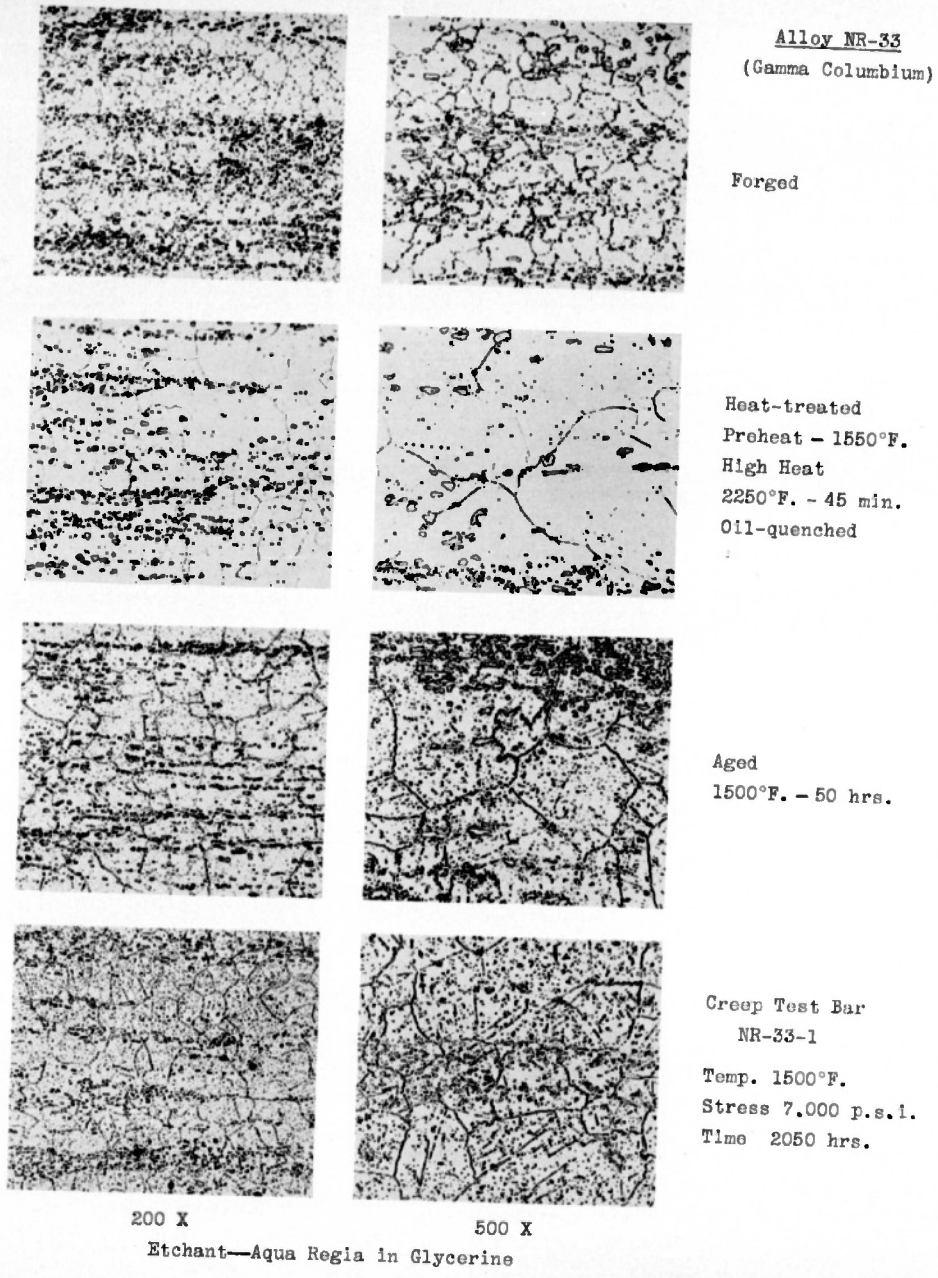
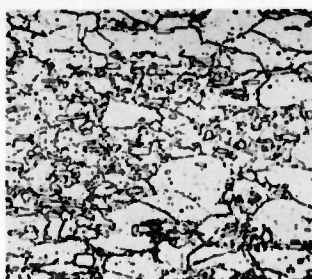
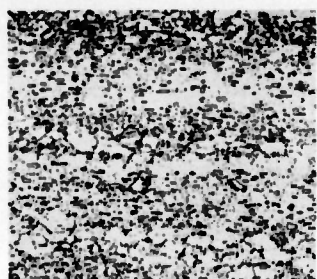
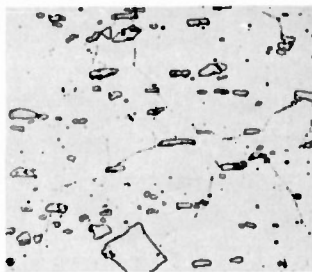
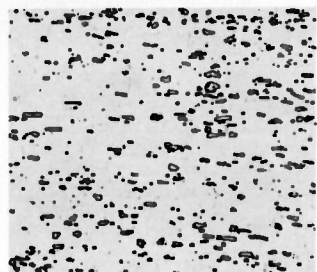


Figure 4.

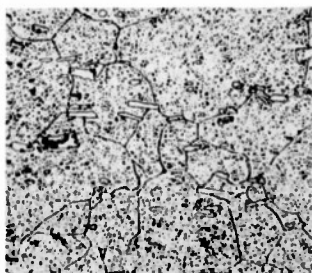
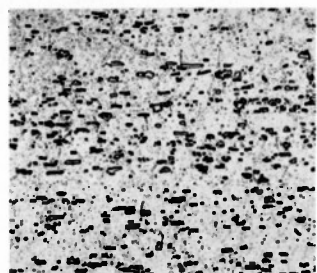


Alloy NR-34
(S495)

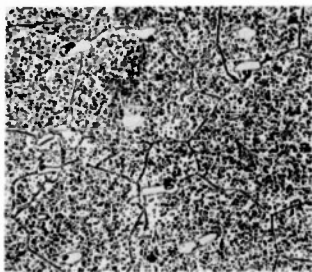
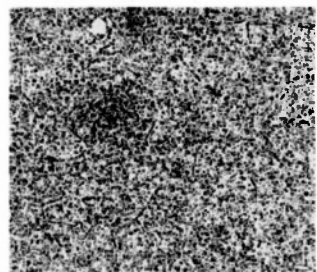
Forged



Heat-treated
2250°F. - 2 hrs.
Water-quenched



Aged
1500°F. - 50 hrs.



Creep Test Bar
NR-34-9

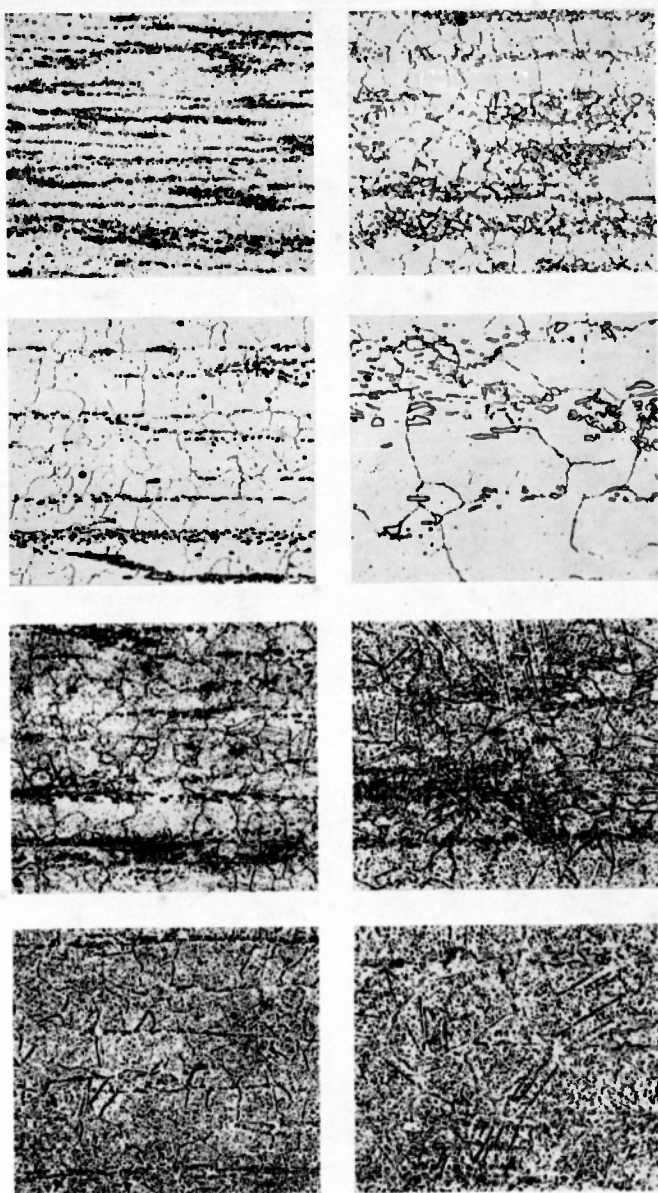
Temp. 1500°F.
Stress 10,000 p.s.i.
Time 2280 hrs.

200 X

500 X

Etchant—Aqua Regia in Glycerine

Figure 5.



Alloy NR-43
(8658-1)

Forged

Heat-treated
2250°F. - 30 min.
Oil-quenched

Aged
1500°F. - 50 hrs.

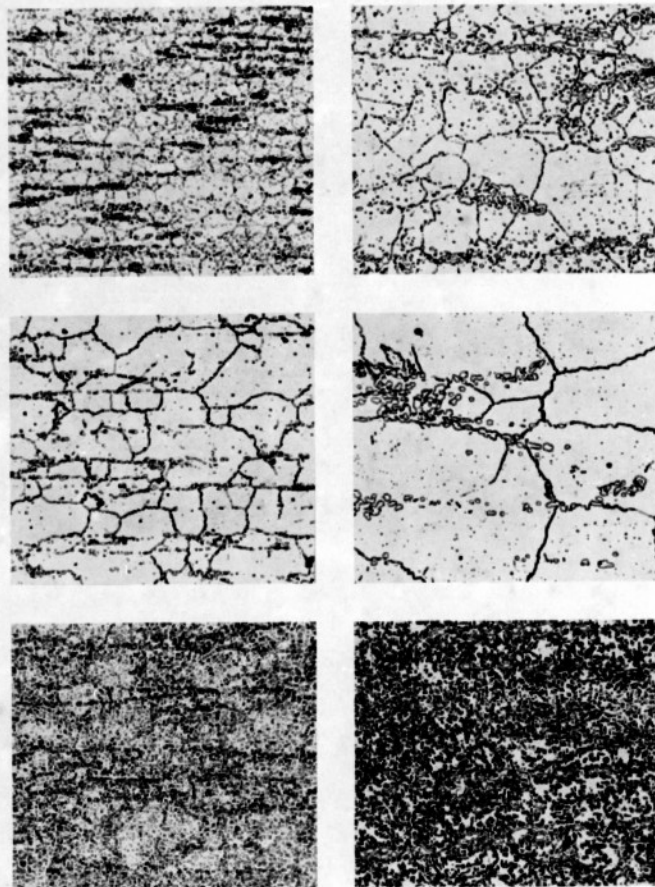
Creep Test Bar
NR-43-3
Temp. 1500°F.
Stress 10,000 p.s.i.
Time 1601 hrs.

200 X

500 X

Etchant—Aqua Regia in Glycerine

Figure 6.



Alloy NR-44
(Replacement NR-3)

Forged

Heat-treated
2250°F. - 10 min.
Air-cooled

Aged
1500°F. - 50 hrs.

200 X

500 X

Etchant—Aqua Regia in Glycerine

Figure 7.

The S497 alloy (NR-45) is shown in Figure 8. and the structures are similar to those for S495 alloy (NR-34).

The Timken 16-25-6 alloy (NR-49) is shown in Figure 9. Solution heat treatment effects almost complete carbide solution, and appreciable precipitation is produced by aging at 1500°F.

Charpy Impact Resistance of Test Materials

Charpy keyhole and "V" notch impact test specimens of some of the alloys have been tested at room temperature and at 1500°F. The results obtained are shown in Table 3.

At room temperature none of the alloys possess very high impact resistance. The alloys showing the best stress-rupture and creep properties at 1500°F. (NR-34 and NR-45) show the lowest impact resistance excepting Alloy NR-17. These were 5 foot-pounds for NR-34 and 7 foot-pounds for NR-45, using the keyhole notch. Although it was suggested that the "V" notch might show still lower values for these alloys in the heat-treated condition, the 3 alloys tested with "V" notch at room temperature showed considerably higher values than with the keyhole notch. The alloys with highest impact resistance were NR-29 (Nimonic-80) and NR-33 (Gamma Columbian).

At 1500°F., all alloys showed higher impact resistance than when tested at room temperature, and when tested with a "V" notch at 1500°F. the values were higher than with a keyhole notch. This is assuring in that alloys with low ductility at room temperature will possess better ductility at the operating temperature. The impact resistance of the Gamma Columbian alloy (NR-33) continues outstanding.

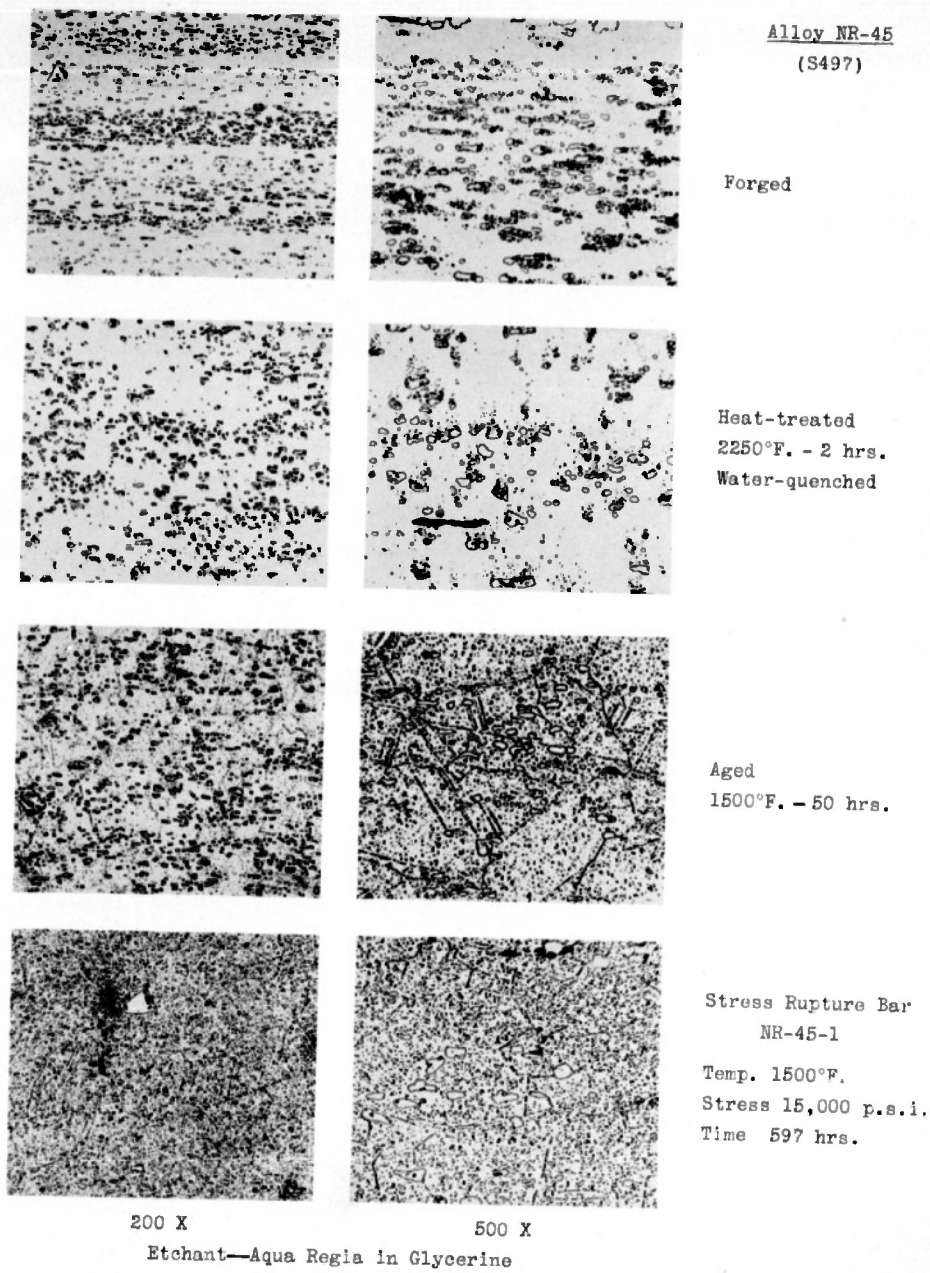
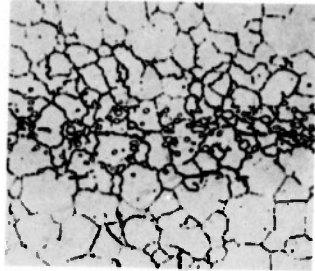
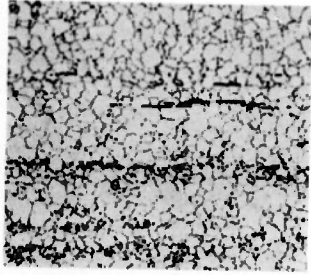
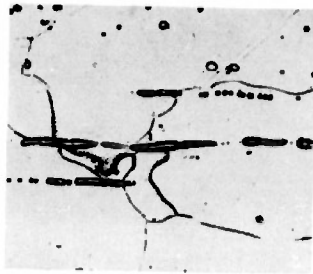
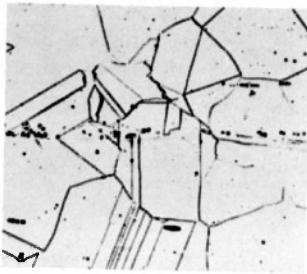


Figure 8.

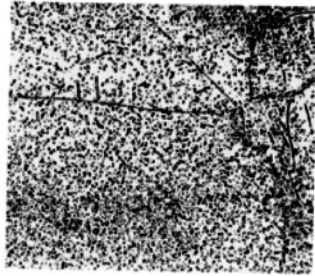


Alloy NR-49
(Timken 16-25-6)

Forged



Heat-treated
Preheat - 1550°F.
High Heat
2150°F. - 45 min.
Water-quenched



Aged
1500°F. - 50 hrs.

200 X

500 X

Etchant—Aqua Regia in Glycerine

Figure 9.

TABLE 3. CHARPY NOTCHED-BAR IMPACT RESISTANCE OF HEAT-RESISTING ALLOYS AT ROOM TEMPERATURE AND AT 1500°F.

Material	Alloy Number	Charpy Impact Resistance - Foot-Pounds			
		Room Temperature		1500°F.	
		Keyhole Notch	"V" Notch	Keyhole Notch	"V" Notch
Timken 16-25-8	NR-15	15	15	27	
Refractaloy B	NR-17	1		(a)	
N153	NR-19	11		24	
N155	NR-21	13		24	
Refractaloy A	NR-28	4		(a)	
Kimonic 80	NR-29	24		(a)	
Gamma Columbian	NR-33	15	24	21	42
8495	FR-34	5	7	13	19
8658-2	NR-37	11	22	19	24
8659	NR-38	7		(a)	
Replacement NR3	NR-44	6		(a)	
8497	NR-45	7		14	
19-9 W-Mo (mod.)	NR-46	27		39	

(a) To be tested later.

Stress-Rupture Tests

Stress-Rupture Tests at 1500°F.

Stress-rupture tests have been run at 1500°F. on test specimens of 0.505-inch diameter and approximately 2-inch gage length. The complete stress-rupture data are shown in Table 4, and the stress fracture-time curves are shown in Figures 10, 11, 12, and 13. The curves for Alloys NR-1 through NR-18 are shown in Figure 10. The curves for Alloys NR-19 through NR-56 are shown in Figure 11, and the curves for NR-57 through NR-58 are shown in Figure 12. This is an arbitrary division merely to prevent crowding of the data on one graph, and therefore, to make inspection of the curves easier.

Most of the alloys have been tested at 20,000 p.s.i. at 1500°F. As available test equipment and the supply of the various alloys permitted, tests were run at lower stresses than 20,000 p.s.i. and with consequent longer fracture times.

In addition to the fracture times for the various stresses employed for the alloys, values for elongation, reduction of area, and the minimum rates of deformation measured from the time-deformation curves are shown in Table 4.

Table 5 also shows the time in hours required at each stress used in the tests to produce total deformations of 1, 2, and 5%. For some of the better alloys, the time-deformation curves are shown so that the types of deformation characteristics and deformations or rates at periods other than those chosen for the various alloys may be more easily seen than can be obtained from tabular data.

TABLE 4. STRESS-RUPTURE PROPERTIES AT 1350, 1500, AND 1800°F. OF HEAT-RESISTING ALLOYS

Alloy and Specimen Number	Condition	Temp. of Test, °F.	Stress, P.s.i.	Time for Rupture, Hours	Elong., %	Reduction of Area, %	Minimum Rate % Per Hr.	Time in Hours for Deformation of		
								1%	2%	5%
HR-1-1	1	1500	20,000	5.41	3.5	6.2	.36	2	4.7	5.2
HR-1-2	1	"	12,000	88.0	1.0	3.0	.012	66	-	-
HR-1-3	1	"	9,000	428.6	1.0	1.0	.0015	428	-	-
HR-2-1	1	1500	20,000	14.1	28.0	21.3	.51	Flaw	-	-
HR-3-2	1	1500	30,000	3.78	5.0		1.23	.4	1.2	3.0
HR-3-1	1	"	20,000	81.8	3.5	3.1	.03	11.5	34.5	-
HR-3-3	1	"	14,000	181.0	1.7	1.79	.0042	180	-	-
HR-3-A1	1	"	17,000	317.0	.69	1.1	.00189	-	-	-
HR-3-A2	1	"	9,000	981.0	1.42	1.1	.00076	-	-	-
HR-4-1	1	1500	14,000	418.0	3.0	1.1	.0017	290	415	-
HR-4-1	1	1500	20,000	24.0	12.0	13.0	-	Not available	-	-
HR-4-2	1(A)	"	14,000	94.8	8.0	2.6	.026	11	43	92
HR-4-3	1	"	9,000	834.0	5.0	4.3	.0032	215	592	538
HR-5-1	2	1500	20,000	21.3	1.0	2.7	.027	Flaw	-	-
HR-5-4	2	"	14,000	92.4	0.9	1.28	.006	92	-	-
HR-6-3	1	1500	20,000	22.0	34.5	26.5	0.54	.8	1.7	8.5
HR-6-2	1	"	15,000	114.6	22.8	23.0	.067	5.2	15.8	50.2
HR-6-4	1	"	10,000	630.0	8.0		.001	-	-	-
HR-7-1	1	1500	20,000	2.8	18.0	21.8	.155	Not available	-	-
HR-7-2	1	"	9,000	207.6	8.5	7.7	.09	81	150	195
HR-8-1	2	1500	20,000	18.0	8.5	11.9	.168	3.5	7.8	15.6
HR-8-2	2	"	17,000	121.5	8.0	7.3	.0115	59	106	121
HR-8-3	2	"	15,000	326.0	7.0	5.1	.005	140	246	320
HR-34-1	5	1500	20,000	29.36	29.0	43.4	.21	4	5.4	18.5
HR-34-7	3	"	15,000	674.0	21.0	33.6	.00118	-	-	-
HR-34-8	3	"	15,500	1423.0	20.0	30.5	.0009	620	1130	1350
HR-34-17	3	1500	14,000	72.5	23.0	34.1	-	Not available	-	-
HR-34-18	3	"	11,500	264.5	8.0			28	50	248
HR-34-12	3	"	9,500	844.5	9.0	14.4	.0053	40	285	540
HR-9-1	2	1500	15,500	183.0	16.0	17.0	.012	47	82	127
HR-9-2	2	"	11,000	863.0	5.0	10.7	.0002	646	800	563
HR-33-3	2	1500	20,000	23.5	24.0	29.9	-	Not available	-	-
HR-33-2	2	"	17,000	83.8	24.0	28.8	.064	17	31	58
HR-33-4	2	"	13,500	502.0	14.0	22.8	.012	107	187	242
HR-33-21	2	"	12,000	In progress				-	-	-
HR-33-19	2	"	10,000	1905.0	8.0	11.1	.00018	1260	1650	1900
HR-33-22	1	1500	20,000	8.44	29.8	26.5	1.5	.3	.5	2.9
HR-33-25	1	"	15,000	67.5	17.5	26.5	.11	5.0	14	34
HR-33-34	2	1500	12,000	38.0	25.0	55.0	.24	5.3	7.4	20
HR-33-35	2	"	9,500	406	In progress			-	-	-
HR-10-1	8	1500	15,000	325.5	9.21	12.4	.0055	75	147	288
HR-11-1	2	1500	20,000	33.2	15.4	18.2	.05	2	-	-
HR-11-2	8	"	15,000	150.5	15.1	15.2	.092	2	6	23
HR-15-23	3	1500	20,000	3.1	19.5	19.9	2.82	.3	.6	1.5
HR-15-4	3	"	10,000	110.4	2.86	10.4	.0276	35	61	-
HR-15-12	3	"	7,000	580.0	3.1	4.6	.001	100	150	325
HR-18-12	1	"	15,000	68.0	52.0	51.7	-	Not available	-	-
HR-18-13	1	"	10,000	404.0	17.5	19.2	.02	28	78	220
HR-15-14	1	"	7,000	935.0	3.5	-	-	432	216	-

TABLE 4. (Continued)

Alloy and Specimen Number	Condition	Temp. of Test, °F.	Stress, P.s.i.	Time for Rupture, Hours	Elong., %	Reduction of Area, %	Minimum Rate % Per Hour	Time in Hours for Deformation of		
								1%	2%	5%
NR-49-1	3	1500	20,000	5.06	56.5	47.6	3.2			
NR-49-3	3	"	10,000	In progress						
NR-49-11	1	"	20,000	7.25	73.0					
NR-49-14	1	"	10,000	In progress						Not available
NR-16-1	4	1500	20,000	3.6	46.0	77.6	1.7			
NR-16-2	4	"	13,000	40.5	57.0	70.7	.225	0.6	1.14	2.2
NR-46-1	2	1500	13,000	114.5	4.0	5.8	.002	4.75	9.0	16.5
NR-17-1	2	"	"					100	110	-
NR-17-2	2	1500	20,000	8.33	29.0	43.4	.75			
NR-17-3	2	"	12,000	172.5	14.0	16.4	.02	1.2	2.4	5.2
	2	"	10,000	441.0	9.0	13.0	.011	45	90	148
NR-18-1	1	1500	20,000	11.7	11.0	13.0		125	290	415
NR-18-2	1	"	12,000	72.5	19.0	16.8	.07			
NR-19-2	2	1500	20,000	84.5	28.0	47.9	.06	10	25	50
NR-19-3	2	"	17,000	251.5	12.5	24.7	.014	60	120	198
NR-19-4	2	"	14,000	574.9	13.2	25.4	.007	90	205	412
NR-20-2	2	1500	20,000	55.0	33.0	40.7	.19	5	15	29
NR-20-3	2	"	16,000	361.5	27.0	37.5	.017	50	110	233
NR-20-4	2	"	14,000	657.0	33.1	21.0	.00656	100	217	425
NR-20-10	1	1500	15,000	155.0	42.5	36.0				
NR-20-11	4	1500	15,000	30.0	30.0	32.1	-			Not available
	4	"	10,000	124.5	24.0	34.7	.0105			
NR-20-5	5	1500	16,000	93.5	34.0	44.9		44	66	98
NR-20-7	6	"	15,000	42.5	17.0	31.8				
NR-20-6	7	"	15,000	195.5	25.0	27.7	-			Not available
NR-21-2	2	1500	20,000	40.5	11.0	13.7	.04	7	46	105
NR-21-3	2	"	15,500	293.0	4.0	8.1	.1			
NR-21-7	4	1500	15,000	10.0	40.0	46.3	.0043	6	16	32
NR-21-6	7	"	15,500	161.5	20.5	27.5		160	290	-
NR-22-2	2	1500	20,000	20.39	5.0	8.1	.14			Not available
NR-22-3	2	"	14,000	241	1.5	2.7	.0016			Not available
NR-22-4	5	1500	14,000					3.8	11.2	20.4
NR-24-5	9	1500	20,000	35.87	14.0	27.6	0.27			
NR-24-4	9	"	16,000	342.5	34.0	44.9	.038	1.3	3.5	15.5
NR-25-1	2	1500	20,000	7.9	20.5	18.8	1.33	8	28	100
NR-29-2	3	1500	30,000	8.4	2.0	1.9	.039	.6	1.4	3.4
NR-29-1	3	"	20,000	53.0	1.5	1.1	.0019			
NR-29-6	3	"	15,000	180.0	<40	1.31	.00088	5.3	-	-
NR-29-13	3	"	13,000	<40				52	-	-
NR-29-11	3	"	12,000	101.3				176	-	-
NR-29-14	3	"	10,000	<66	Broken in threads					
NR-31-1	2	1500	15,000	130.5	22.6	23.3	.07	5	9.5	29.0
NR-32-2	2	1500	20,000	5.58	29.5	27.5	3.0	.2	.5	1.4
NR-35-3	2	1500	20,000	22.6	0.82	H11	-			
NR-35-1	2	"	11,000	121.6	0.43	H11	.0015			Not available
NR-36-1	2	1500	20,000	12.5	30.75	40.4	.56	1	1.5	2.24

TABLE 4. (Continued)

Alloy and Specimen Number	Condition	Temp. of Test, °F.	Stress, p.s.i.	Time for Rupture,		Reduction of Area, %	Minimum Rate % Per Hour	Time in Hours for Deformation of		
				Hours	Elong., %			1%	2%	3%
NR-37-1	3	1500	20,000	14.0	45.0	36.2	-	Not available		
NR-37-6	3	"	15,000	98.3	40.4	44.8	.14	2.3	7.3	26
NR-37-6	2	"	11,500	In progress						
NR-38-1	2	1500	20,000	13.15	37.5	26.5	.77	.3	1.3	3.4
NR-38-2	2	"	13,000	324.6	11.3	13.7	.019	33	66	175
NR-39-1	2	1500	20,000	13.05	3.0	4.7	.077	9.3	13.3	-
NR-39-2	3	"	15,000	In progress						
NR-40-1	3	1500	20,000	23.0	33.0	51.1	-	Not available		
NR-40-2	3	"	15,000	172.0	35.0	36.0	.032	15	36	100
NR-41-1	2	1500	20,000	17.0	36.0	50.4	-	Not available		
NR-41-2	2	"	13,000	60.3	30.0	54.7	-	Not available		
NR-42-1	1	1500	20,000	9.37	16.3	30.3	1.0	.3	.93	3.3
NR-43-1	1	1500	20,000	14.0	31.0	40.4	-	Not available		
NR-43-2	1	"	13,000	213.0	12.0	14.4	.009	33	93	170
NR-45-2	3	1500	20,000	43.3	34.0	29.3	-	Not available		
NR-45-3	3	"	15,500	131.5	15.3	35.4	.031	30	60	127
NR-45-1	3	"	15,000	597.0	13.3	23.4	.0034	313	313	500
NR-45-10	3	"	13,500							
NR-45-9	3	"	13,500	449.3	14.0	17.3	.0116	80	164	360
NR-45-13	1	1500	20,000	21.35	36.9	43.4	.345	1	2	3
NR-45-14	1	"	13,000	309.3	33.1	42.3	.060	14.3	33	37
NR-45-18	3	1500	14,000	In progress						
NR-43-7	2	"	10,000	423.0	7.5	3.3	.0024	73	283	400
NR-45-13	3	"	9,000	In progress						
NR-45-20	3	1380	33,000	29.0	25.0	33.3	-	Not available		
NR-45-21	3	"	23,000	482.0	31.0	41.9				
NR-46-1	2	1500	13,000	114.3	4.0	5.3	.003	100	110	
NR-49-1	3	1500	20,000	3.03	36.3	47.3	3.2	Not available		
NR-49-2	3	"	15,000	In progress						
NR-49-3	3	"	10,000	In progress						
NR-49-11	1	1500	20,000	7.23	75.0	37.0	2.04			
NR-49-13	1	"	13,000	In progress						
NR-49-14	1	"	10,000	In progress						
NR-50-1	2	1500	20,000	3.37	23.0	37.0	4.3	.14	.33	.33
NR-51-2	1	1500	13,000	17.3	3.3	3.3	.173	3	3	13
NR-51-5	1	"	13,000	13.9						
NR-51-3	1	1380	35,000	21.3	6.5	9.66	.203	.5	3.3	15.3
NR-51-4	1	"	13,000	213				In progress		
NR-52-1	2	1500	20,000	20.0	33.0	50.3				

TABLE 4. (Continued)

Alloy and Specimen Number	Condition *	Temp. of Test, °F.	Stress, p.s.i.	Time for Rupture, Hours	Elong., %	Reduction of Area, %	Minimum Rate % Per Hour	Time in Hours for Deformation of		
								1%	5%	50%
HR-53-1	2	1800	20,000	42.5	27.5	44.6				
HR-54-1	2	1800	20,000	11.0	41.5	55.6				
HR-55-2	2	1800	15,000	64.2	6.5	9.3	.033	13	26.5	68

- (1) - Air cooled
- (2) - Oil quenched
- (3) - Water quenched
- (4) - Cold-worked and aged
- (5) - Cold-worked, oil-quenched, and aged
- (6) - Hot-worked
- (7) - Hot-worked, oil-quenched, and aged
- (8) - Aged
- (9) - Tested as-cast

For details of processing, solution heat treatment and aging, see Table 2

(A) - Not aged

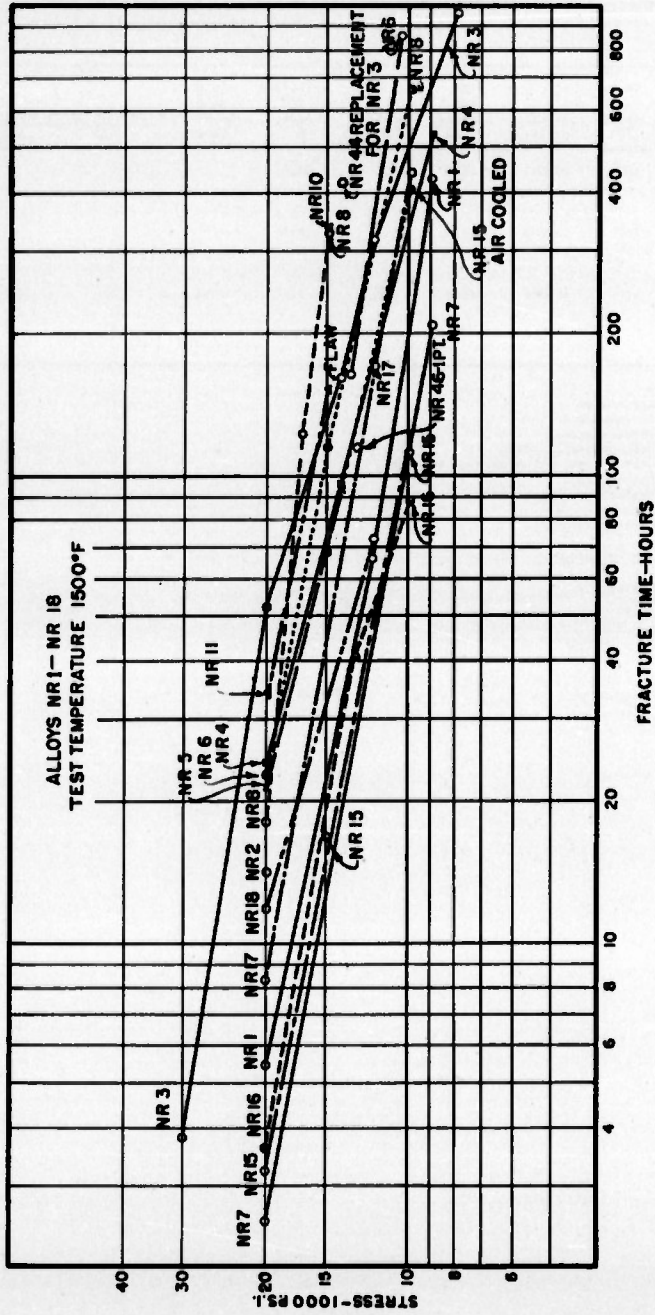


FIG. 10

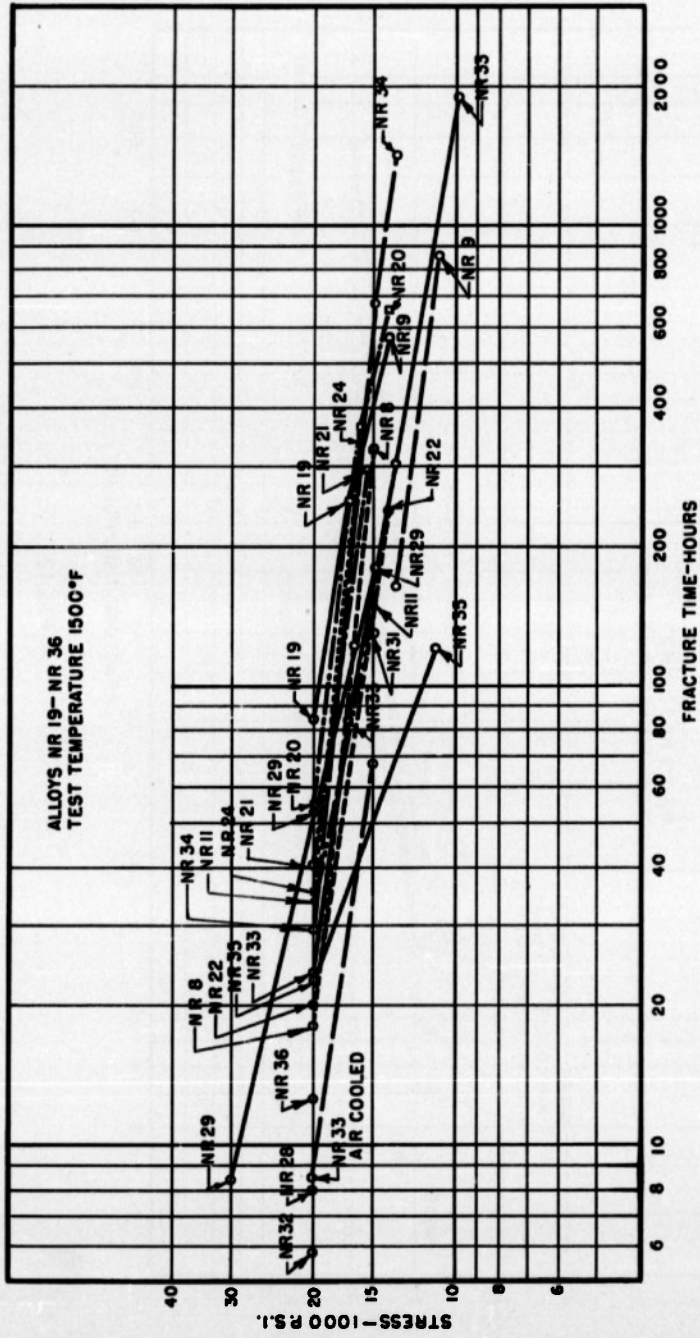


FIG. 11

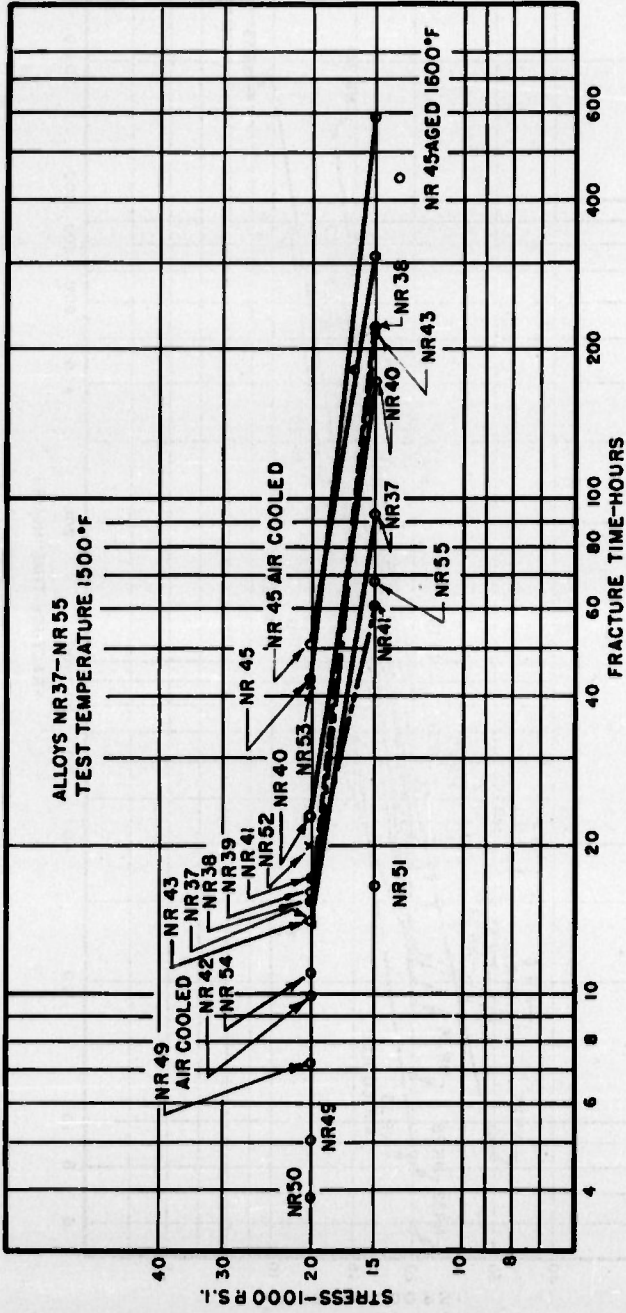


FIG 12

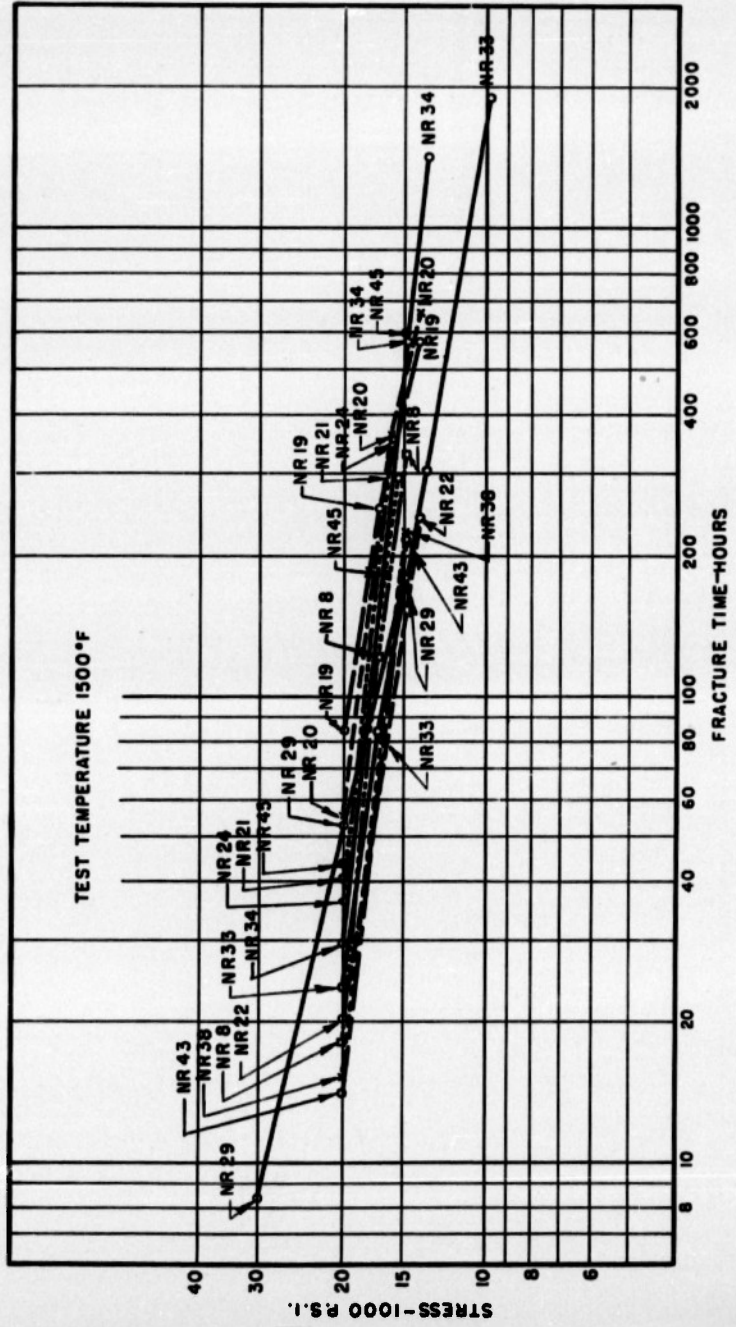


FIG. 13

Table 5. shows the stresses estimated to produce fracture in 10, 100, 500, and 1,000 hours. These data for times to produce certain deformations and stresses to produce fractures in certain time periods are data of value for use by the designing engineer.

Fracture times of 2.5 to 84.5 hours were obtained at 20,000 p.s.i. at 1500°F. In some cases the longer fracture times were the result of large elongations taking place before fracture, but some of the weaker alloys showed both low fracture time and low elongation and several of the alloys showed long fracture times with relatively low elongation.

Alloys NR-1 to NR-8 were prepared from small induction furnace melts and were limited in quantity. The forging of these heats was attempted on small-capacity hammer equipment and numerous cracks and flaws were produced by this forging operation. For this reason the tests on these alloys in several cases were not representative of their composition. For instance, Alloy NR-3, which showed promising fracture times at 30,000 and 20,000 p.s.i., showed a change in slope of the curve in Figure 10 below 20,000 p.s.i. Intergranular appearing fractures were obtained in specimens tested at 14,000, 12,000 and 9,000 p.s.i. Flaws resulting from forging were observed in the specimen tested at 14,000 p.s.i. and may have been present in the specimens tested at higher loads. A duplicate heat (NR-44) has been melted and this heat was forged in a production mill. Note in Table 4 and Figure 10, the fracture time of 418 hours for Alloy NR-44 at 14,000 p.s.i. as compared with the 161 hours for Alloy NR-3. A replacement heat for NR-5 has been melted and is now being forged preparatory to testing.

Alloy NR-8 (S495 alloy) was one of the small experimental heats produced at first, and while its stress-rupture properties were better than the others, it was not quite the equal of bar stock later supplied by

TABLE 5. DATA FROM STRESS-RUPTURE TESTS AT 1800°F.

Material	Alloy Number	Condition*	Stress, P.S.I., For Fracture In			
			10 Hrs.	100 Hrs.	500 Hrs.	1000 Hrs.
L1T2	NR-1	1	17,500	11,500	8,700	7,700*
S497	NR-2	1	-	-	-	-
H418	NR-3	1	25,800	18,300	10,000	7,900
H355	NR-4	1	25,000	13,800	9,200	7,500
H359	NR-5	2	24,000*	13,500	-	-
H439	NR-6	1	23,000*	15,400	10,600	9,000*
S495 (Low C)	NR-7	1	15,600	10,300	-	-
S495	NR-8	2	21,000	17,000	14,500	-
Gamma Columbium	NR-9	2	-	14,300*	11,500	10,600*
Vitallium	NR-10	9	-	>15,000	-	-
1320	NR-11	9	-	16,200	11,700*	-
Tincken	NR-15	3	16,000	10,200	-	-
Tincken	NR-15	1	-	13,800	9,500	-
19-9 W-Mo	NR-16	4	16,700	-	-	-
Refractaloy B	NR-17	2	19,500	13,000	9,900	8,600*
70 Co - 30 Cr	NR-18	1	21,000	11,000	7,000*	-
N153	NR-19	2	-	18,500	14,500	12,000*
N154	NR-20	2	-	18,500	15,000	12,500
N155	NR-21	2	-	17,800	14,500*	-
N156	NR-22	2	22,000*	15,800	12,500	-
X-19	NR-24	9	22,500*	18,000	15,000	-
X-37	NR-26	9	-	(Not available yet)	-	-
Refractaloy A	NR-28	2	-	-	-	-
Nimonic 80	NR-29	3	29,000	17,200	-	-
Tyconium	NR-31	2	-	-	-	-
	NR-32	2	-	-	-	-
Gamma Columbium	NR-33	2	22,500	16,700	12,500	11,000
Gamma Columbium	NR-33	1	19,500	14,100	-	-
S495	NR-34	3	22,500	16,000	15,300	14,000
	NR-35	2	-	11,700	-	-
Contra-Acid	NR-36	2	-	-	-	-
8658-2	NR-37	2	21,000	14,500	-	-
8659	NR-38	2	21,000	16,300	13,500*	-
4274	NR-39	2	-	(In progress)	-	-
4275	NR-40	2	-	16,000	-	-
4277	NR-41	2	-	13,500*	-	-
22422	NR-42	1	-	-	-	-
8658-1	NR-43	1	20,500	16,200	-	-
N(a)	NR-44	1	-	-	13,500*	-
S497	NR-45	3	-	18,000	15,100	14,000
S497	NR-45	1	-	18,000	13,800	-
19-9 W-Mo (mod.)	NR-46	2	-	13,200*	-	-
X-41	NR-47	9	-	(Not available yet)	-	-

TABLE 5. (Continued)

Material	Alloy Number	Condition*	Stress, P.S.I., For Fracture In			
			10 Hrs.	100 Hrs.	500 Hrs.	1000 Hrs.
Timken (b)	HR-49	3				(In progress)
Timken	HR-49	1				(In progress)
4275 (mod.)	HR-50	2				(In progress)
ATV-3	HR-51	1				(In progress)
ATV-3	HR-51	4				(In progress)
N153 (no Co)	HR-52	2				(In progress)
N154 (no Co)	HR-53	2				(In progress)
N155 (no Co)	HR-54	2				(In progress)
N155 (no Co plus Ta)	HR-55	2				(In progress)

(a) - Replacement for HR-3
 (b) - Replacement for HR-15

- *1 - Air cooled
- 2 - Oil quenched
- 3 - Water quenched
- 4 - Cold-worked and aged
- 5 - Cold-worked, oil quenched, and aged
- 6 - Hot-worked
- 7 - Hot-worked, oil quenched, and aged
- 8 - Aged
- 9 - Tested as cast

(For details of processing, solution heat treatment and aging, see Table 2.)

Allegheny-Ludlum and assigned the number NR-34. This can be seen in Table 4 and in Figure 10. In Table 4, alloys duplicating a particular composition have been grouped together to facilitate comparisons. Note the better fracture times of Alloy NR-34 as compared with NR-8.

Figure 13 shows the stress fracture-time curves for those NR alloys with the best stress-rupture properties and it can be seen that while the curves for NR-8 and NR-34 show the same slopes, the values for fracture times for NR-8 are a little lower than for NR-34.

Attention is called to the difference in properties shown by Alloys NR-7 and NR-8. Alloy NR-7 is a low carbon modification of Alloy NR-8 which was intended to be the S495 alloy composition of the S495 alloy. Alloy NR-7 with low carbon shows about the poorest stress-rupture fracture times, while Alloy NR-8 is one of the best. In this one type of alloy composition at least, carbon content plays a very important part in imparting load-carrying ability at 1500°F.

Alloy NR-10 is the Vitallium alloy nominally containing C .20, Cr 28, Co 65, Mo 6. Of the number of cast-to-shape bars available, only one was sound enough to test. At 15,000 p.s.i., at 1500°F., the fracture time was 325.5 hours. This one value has been plotted in Figure 10 and is a good check with the value for Alloy NR-8 (S495). As soon as some additional test bars of Vitallium are available, the stress-rupture tests will be continued at other loads and creep tests started.

Alloy NR-15 is the Timken alloy (nominally Cr 16, Ni 25, Mo 6) and the heat supplied was stated to contain C .10, Ni .115. The stress-rupture properties of this NR-15 alloy were among the lowest tested and lower than obtained on this alloy composition in several other laboratories. It has

been found that the nitrogen content was lower than normal. This heat in two different laboratories analyzed .03 and .07% nitrogen. A replacement heat, NR-49, containing C .08, N₂ .145 has been obtained and stress-rupture tests are in progress. Time-deformation curves for NR-15 stress-rupture tests are shown in Figure 14. The use of some of these alloys in the form of large forgings for turbine rotors will make it impossible to water quench them from the solution heat-treatment temperature. Instead, it will be possible only to air-cool these large forgings. For this reason, stress-rupture properties are being obtained on a few materials as air-cooled from the temperature of the solution treatment. Specimens of NR-15 Timken alloy were tested as air-cooled and, surprisingly, the stress-rupture properties are superior to those of the water-quenched alloy. At 10,000 p.s.i., at 1500°F., the water-quenched alloy fractured in 110.4 hours while the air-cooled alloy fractured in 404 hours and with greater ductility, which may in part be responsible for the greater life. Tests on air-cooled NR-49 are in progress to determine whether similar effects will be obtained in the Timken alloy replacement heat.

Since materials with creep rates of .00001% per hour at 7,000 p.s.i. are desired, it is obvious that most of the alloys shown in Figure 10 would not be satisfactory since many showed stress-rupture properties indicating fractures would result near 1,000 hours at stresses of about 7,000 p.s.i.

Figure 11 shows the stress fracture-time curves for Alloys NR-19 through NR-36. These alloys show much more promising stress-rupture properties than those in Figure 10, in that early failures at 7,000 p.s.i. would not be expected.

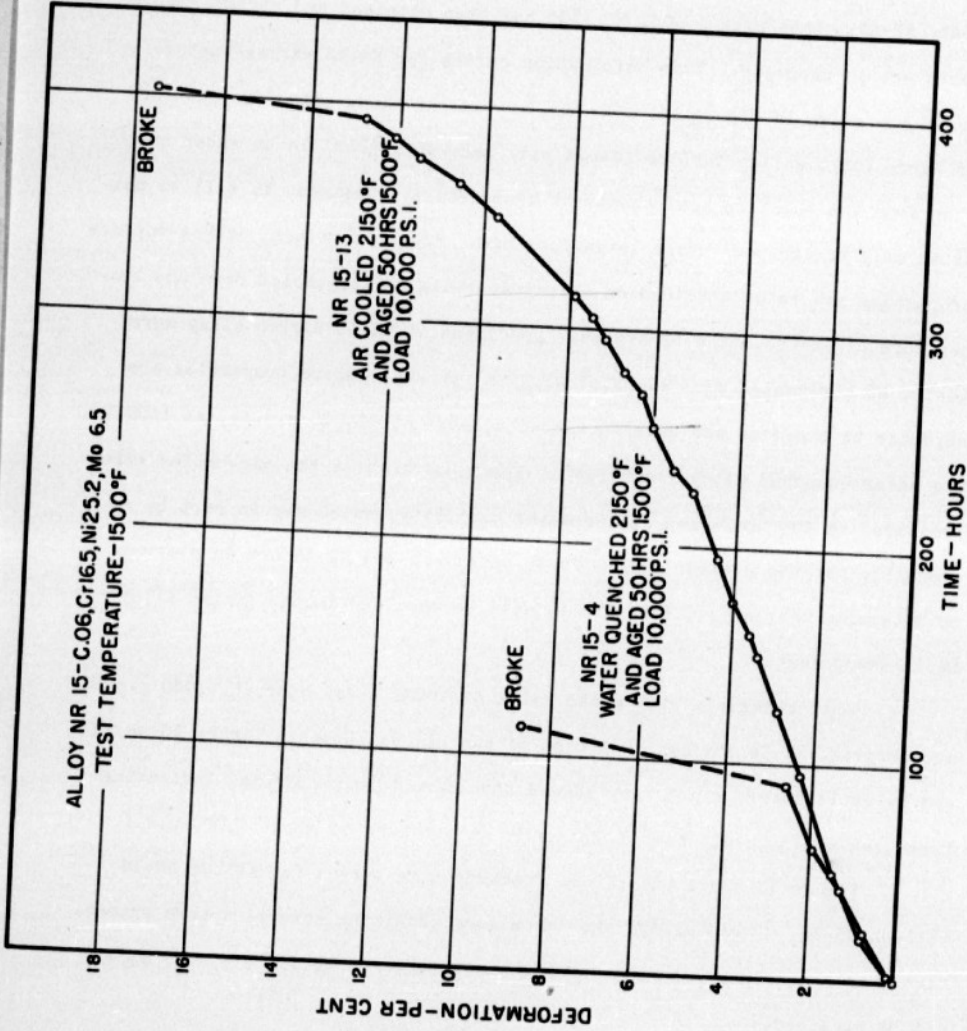


FIG. 14

Among the better alloys are NR-19, NR-20, and NR-21. Their time-deformation curves for stress-rupture tests are shown in Figures 15, 16, and 17. These are Cr-Ni-Co-Fe alloys with carbon contents around 0.35%, and with Mo 3, W 2, Cb 1, with nitrogen contained between .04 and 0.11%. All three of these alloys show 100-hour fracture times at stresses between 17,500 and 19,500 p.s.i. The slopes of their curves in Figure 11 are quite flat and it is regretted that lack of test material prevented extending these tests as long as desired. If material can be obtained, tests with duration of 1000 hours or more will be made.

Alloy NR-22 which has a different Cr-Ni ratio as compared with NR-19, 20, and 21, does not show quite as good stress-rupture properties at 1500°F.

From Cast Alloy NR-24, nominally containing C .10, Cr 25, Ni 20, Co 45, Mo 5, Cb 3, only two sound test specimens have been supplied. Stress-rupture tests on these two specimens at 1500°F. show promising properties with a 100-hour fracture time at about 18,000 p.s.i. The time-deformation curves are shown in Figure 18. When additional test material is available, tests at lower loads and longer fracture times will be run.

Alloy NR-29 is the Nimonic 80 alloy containing C .04, Cr 21, Ni 75, Al .6, Ti 2.45. The first two stress-rupture tests at 30,000 and 20,000 p.s.i. showed very promising fracture times and the rates of deformation were very low for these stresses. However, the slope of the curve in Figure 11 is steeper than for the other materials and the test at 15,000 p.s.i. produced a fracture time considerably lower than for some of the other alloys such as NR-8, 19, 20, 21, 24, and 34. Additional tests at still lower

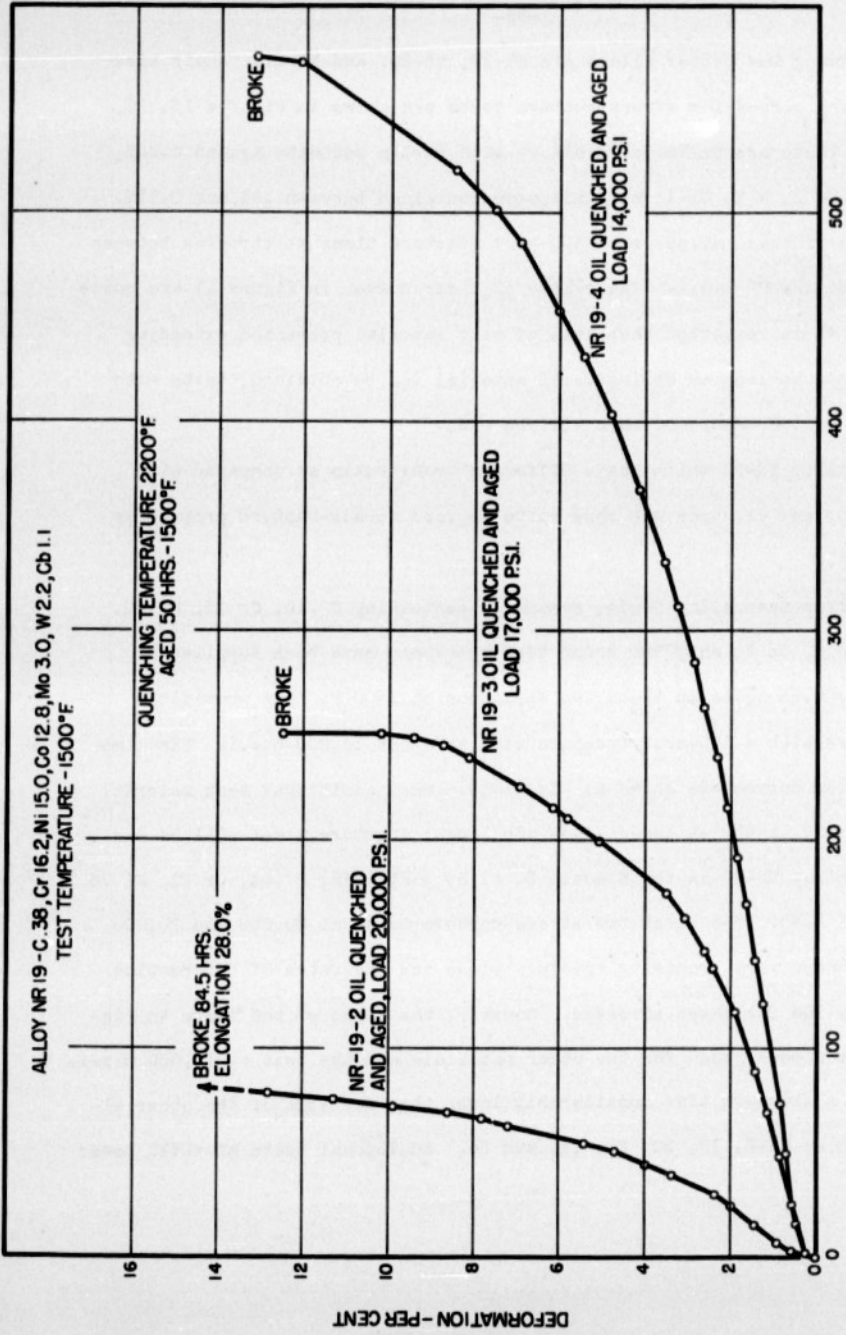


FIG. - 15

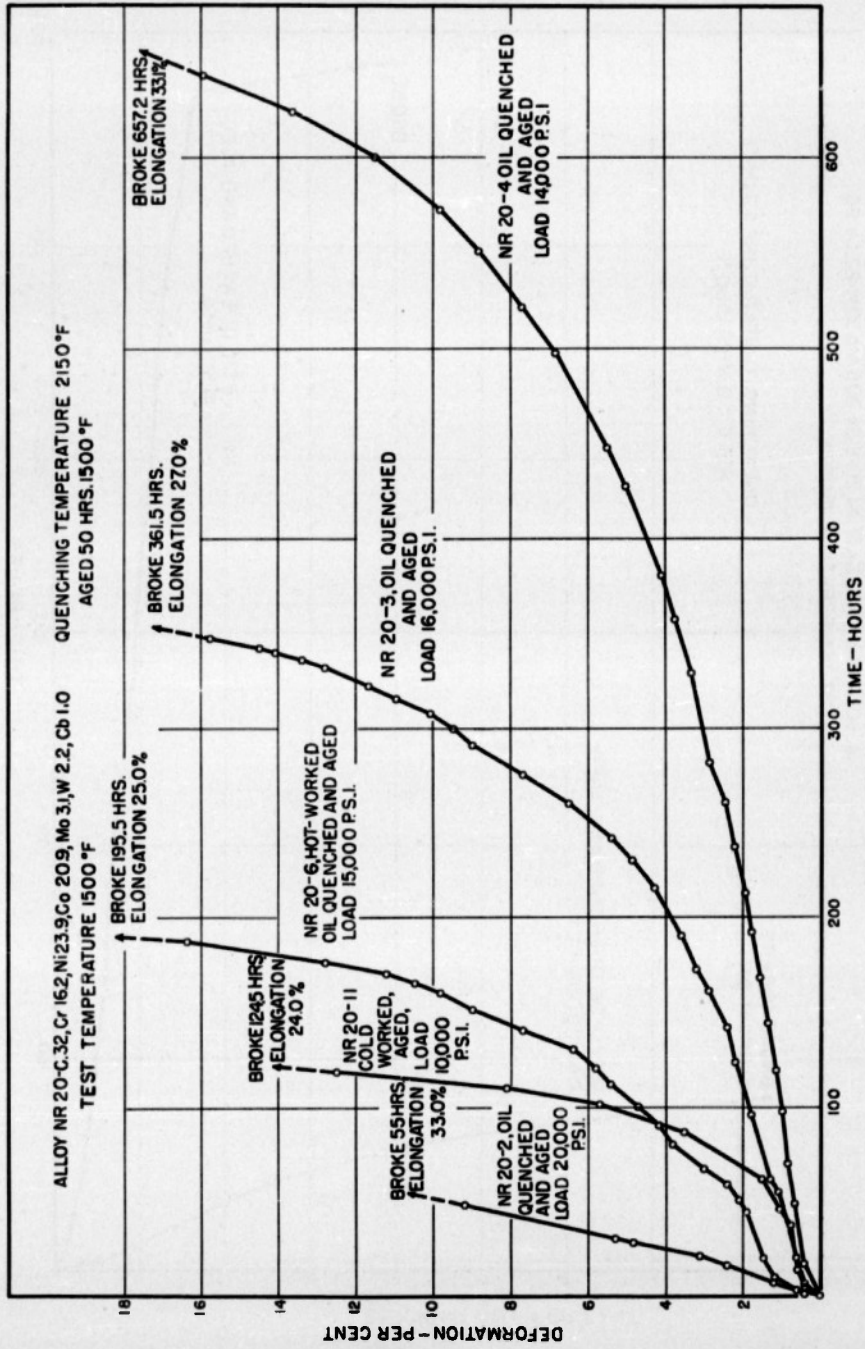


FIG. 16

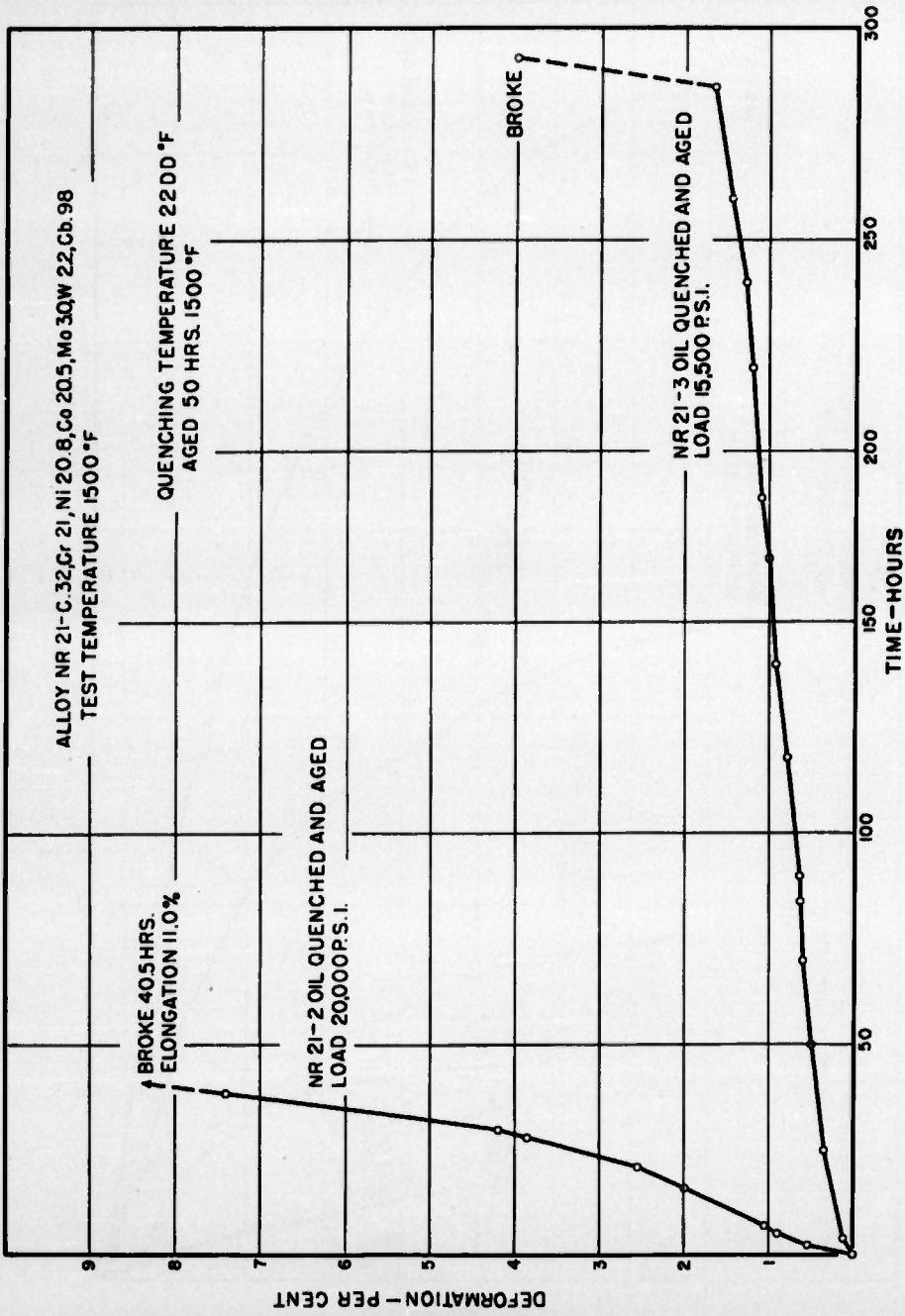


FIG. 17

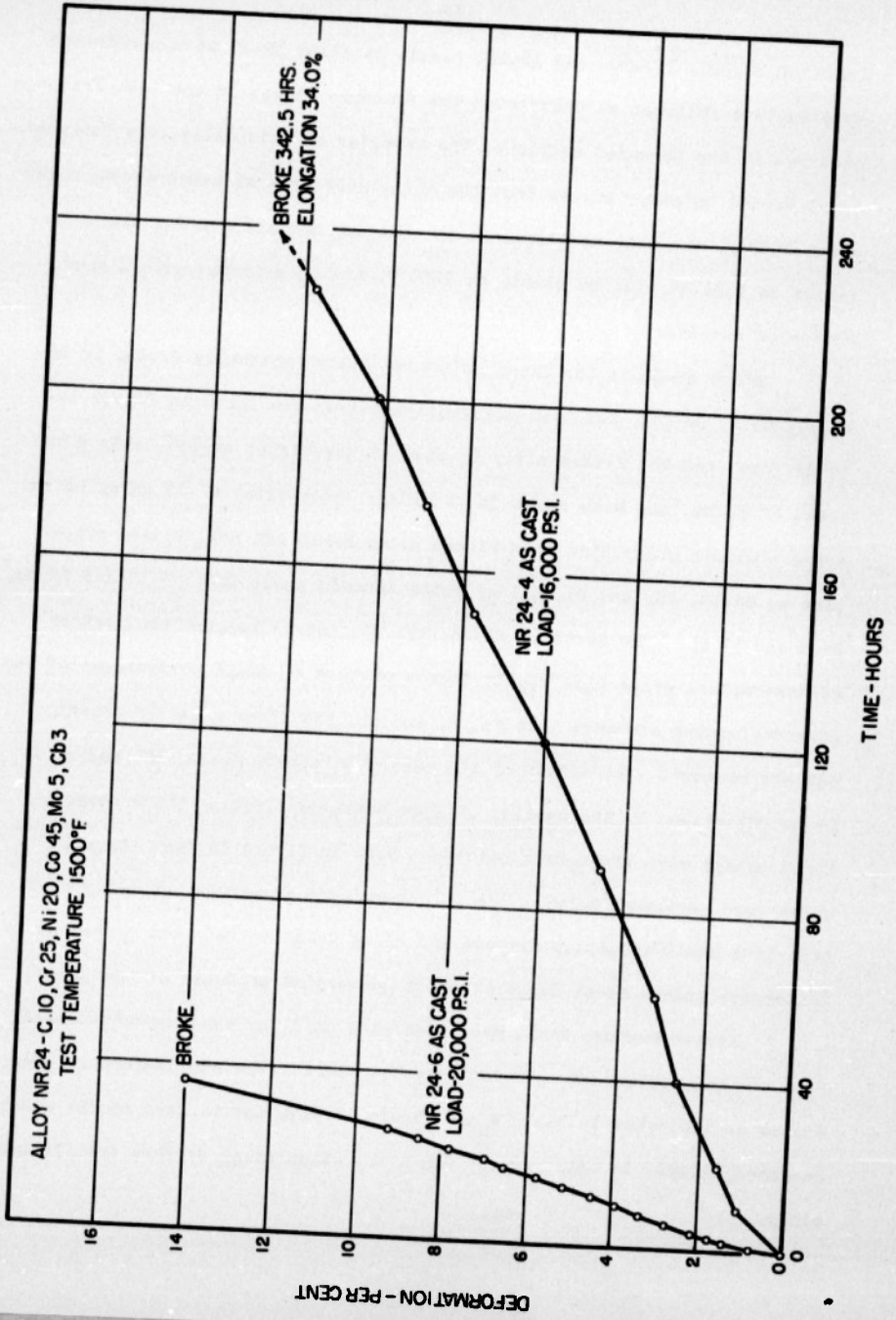


FIG. 18

loads of 10,000, 12,000, and 13,000 p.s.i. on Alloy NR-29 were terminated by premature failures at unexpected low fracture times; in one test fracture occurred in the threaded section. The supplier of this alloy, the International Nickel Company, states that the alloy over-ages at temperatures above about 1475°F. and that developments on changing the alloy aging characteristics so that it will be stable at 1500°F. are in progress with a good chance of success.

Alloy NR-33 is the Gamma Columbian alloy (nominally C .40, Cr 15, Ni 25, Mo 4, Cb 2). The time-deformation curves are shown in Figure 19. It differs from the Timken alloy in that it has higher carbon, only 4 instead of 6% Mo, and with about 2% Cb added. This Alloy NR-33 shows better stress-rupture properties than Timken Alloy NR-15 but not so good properties as NR-19, 20, and 21, all of which contain about 20% cobalt and 3% Mo, 2% W and 1% Cb. The tests on NR-33, 19, 20, and 21 suggest that better stress-rupture properties result from a mixture of small percentages of the carbide-forming elements like Mo, W, and Cb, than from a larger amount of any one element. The effect of the cobalt in Alloys NR-19, 20, and 21 is to be determined by the testing of some heats duplicating their compositions except with the cobalt omitted. Note in Figure 11 that there is quite good agreement between the stress-rupture properties of Alloy NR-9 made in a small induction furnace and Alloy NR-33 melted and processed by Universal-Cyclops Steel Corporation, a commercial producer of the alloy.

Stress-rupture tests have been made on Alloy NR-33 as air-cooled from the temperature of solution heat treatment. The stress-rupture properties as indicated in Table 4 and Figure 11 were not so good as the water-quenched alloy. In this respect Gamma Columbian alloy differs from Timken alloy.

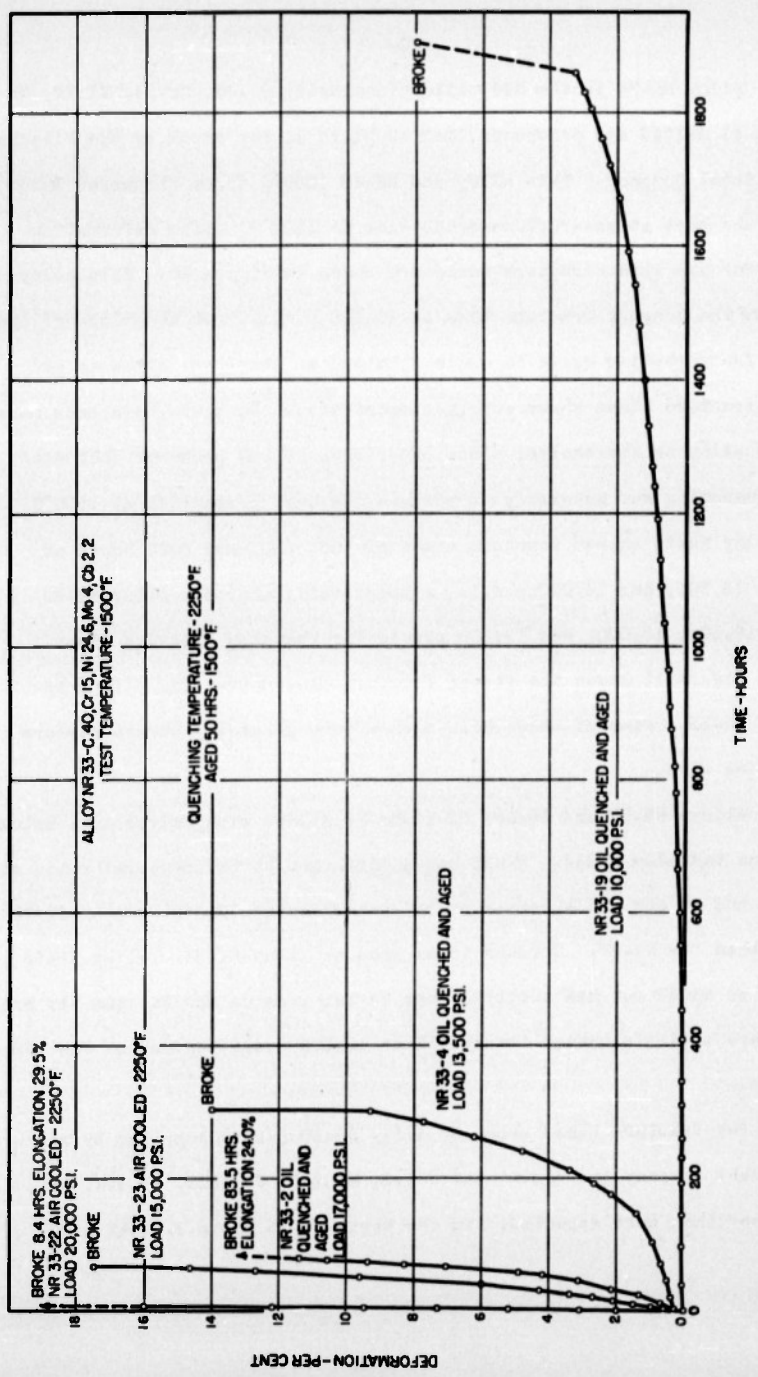


FIG. 19

Alloy NR-34 is the S495 alloy (nominally C .40, Cr 14, Ni 20, Mo 4, W 4, Cb 4) melted and processed, and supplied in bar stock by the Allegheny-Iudlum Steel Company. This alloy and NR-45 (S497) to be discussed later, showed the best stress-rupture properties at 1500°F. Time-deformation curves for the stress-rupture tests are shown in Figure 20. This alloy did not show the longest fracture time at 20,000 p.s.i., but the slope of the stress fracture-time curve is quite flat and at the lower stresses and longer fracture times shows superior properties. No tests have been made on this alloy as air-cooled, since experience of the producer indicated water quenching was necessary to produce the best properties at 1500°F. This Alloy NR-34 showed fracture times of 100, 500, and 1000 hours at 18,000, 15,300, and 14,000 p.s.i., respectively; whereas, Alloy NR-20 showed 18,500, 15,000, and 12,500 p.s.i. for the same fracture times.

Figure 12 shows the stress fracture-time curves for Alloys NR-37 through NR-55. Some of these alloys show very promising stress-rupture properties also.

Alloys NR-37 and 38 are Cr-Ni-Co-Fe alloys with molybdenum, columbium, and tantalum added. NR-38 has a different chromium-nickel ratio and more Mo and Cb and its stress-rupture properties at 1500°F. are a little better than for NR-37. Neither is as good as Alloy NR-34. Alloy NR-43 is similar to NR-37 but has a little more Mo but less Cb and Ta, and its properties are a little better than NR-37 at 15,000 p.s.i. and about the same as NR-38.

The fracture times shown by Alloy NR-40 (4275), supplied by the Crucible Steel Company and containing C 1.0, Mn 4.5, Cr 18.2, Ni 4.4, Mo 3.3, are higher than were expected. In the tests at 15,000 p.s.i. at 1500°F.,

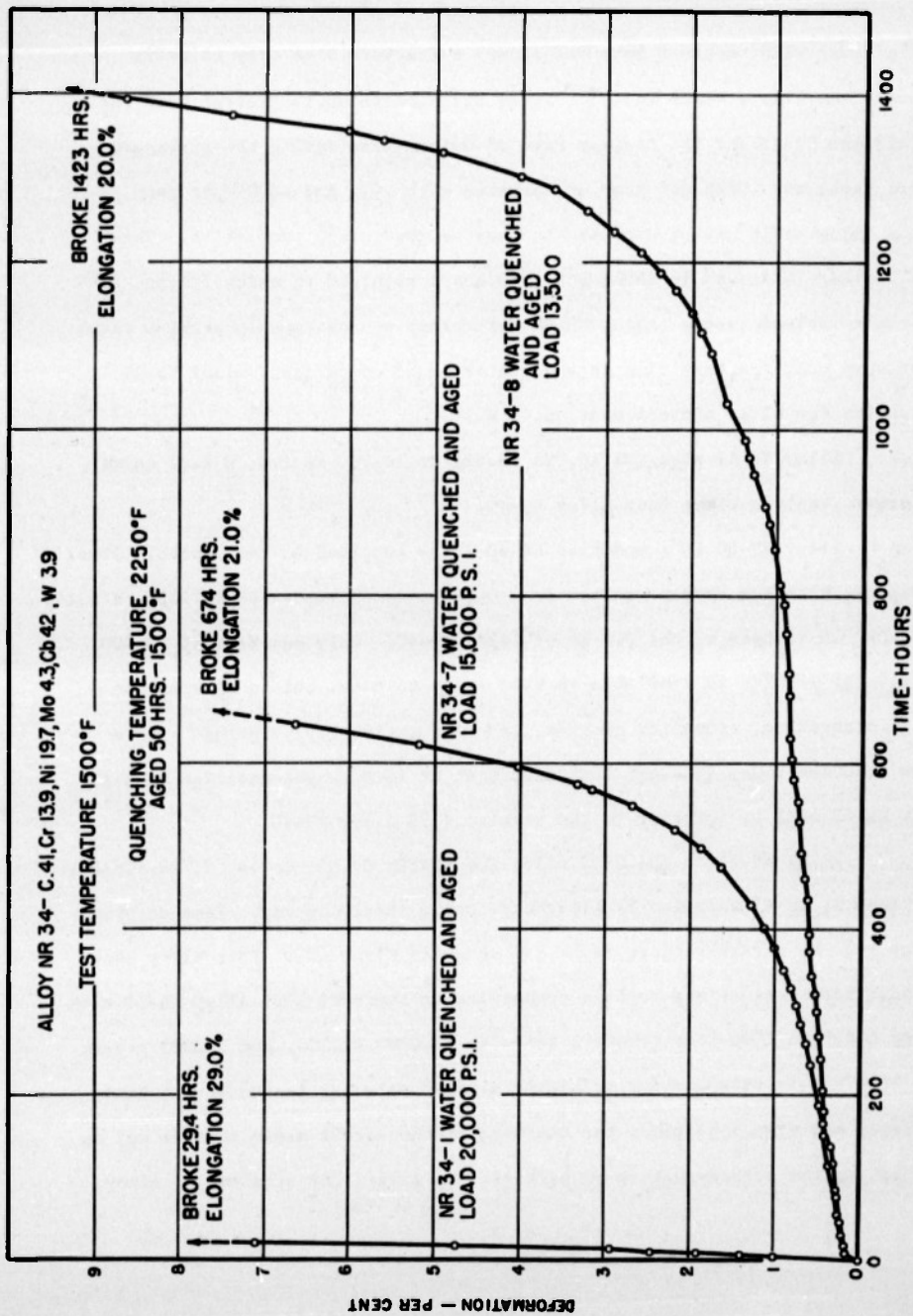


FIG. 20

this lower alloy content material showed a fracture time only slightly lower than Alloys NR-38 and 43. Since its elongation is greater than for NR-38 and NR-43, and the minimum rate of deformation during the stress-rupture tests was .052% per hour as compared with .019 and .009% per hour, this alloy would not be expected to show as good creep properties. This is further indicated in Table 5 by the hours required to reach 1, 2, and 5% for the various tests. Alloy NR-40 deforms at a considerably greater rate, but when only fracture time is the criterion of comparison, Alloy NR-40 with its low alloy content does quite well.

Alloy NR-41 with C 1.16, Mn 12.52, Cr 19.75, Mo 2.0, W 1.87 shows shorter fracture times than Alloy NR-40.

Alloy NR-50 is a modified NR-40 alloy supplied by the Crucible Steel Company, with the carbon reduced from 0.98 to 0.38%, and with Mo 1.35, W 1.34, and Cb 0.6 instead of the 3.3 Mo of Alloy NR-40. Only one test at 20,000 p.s.i. at 1500°F. is available on this alloy to date; but in view of its high elongation, reduction of area, and deformation rate combined with a low fracture time, it seems indicated that at 1500°F. the modified 4275 Alloy NR-50 will be inferior to the regular 4275 Alloy NR-40.

Alloy NR-45 is the S497 alloy (nominally C .40, Cr 14, Ni 20, Co 19, Mo 4, W 4, Cb 4) supplied by Allegheny-Ludlum Steel Company. Time-deformation for the stress-rupture tests are shown in Figure 21. This alloy shows almost identical stress-rupture properties to those of S495 Alloy NR-34 with 100, 500, and 1000-hour fracture times at 18,000, 15,100, and 14,000 p.s.i. at 1500°F. In this particular highly alloyed material tested in the heat-treated and aged condition, the addition of the cobalt seems to have had no effect on the stress-rupture properties. By error, one specimen of Alloy

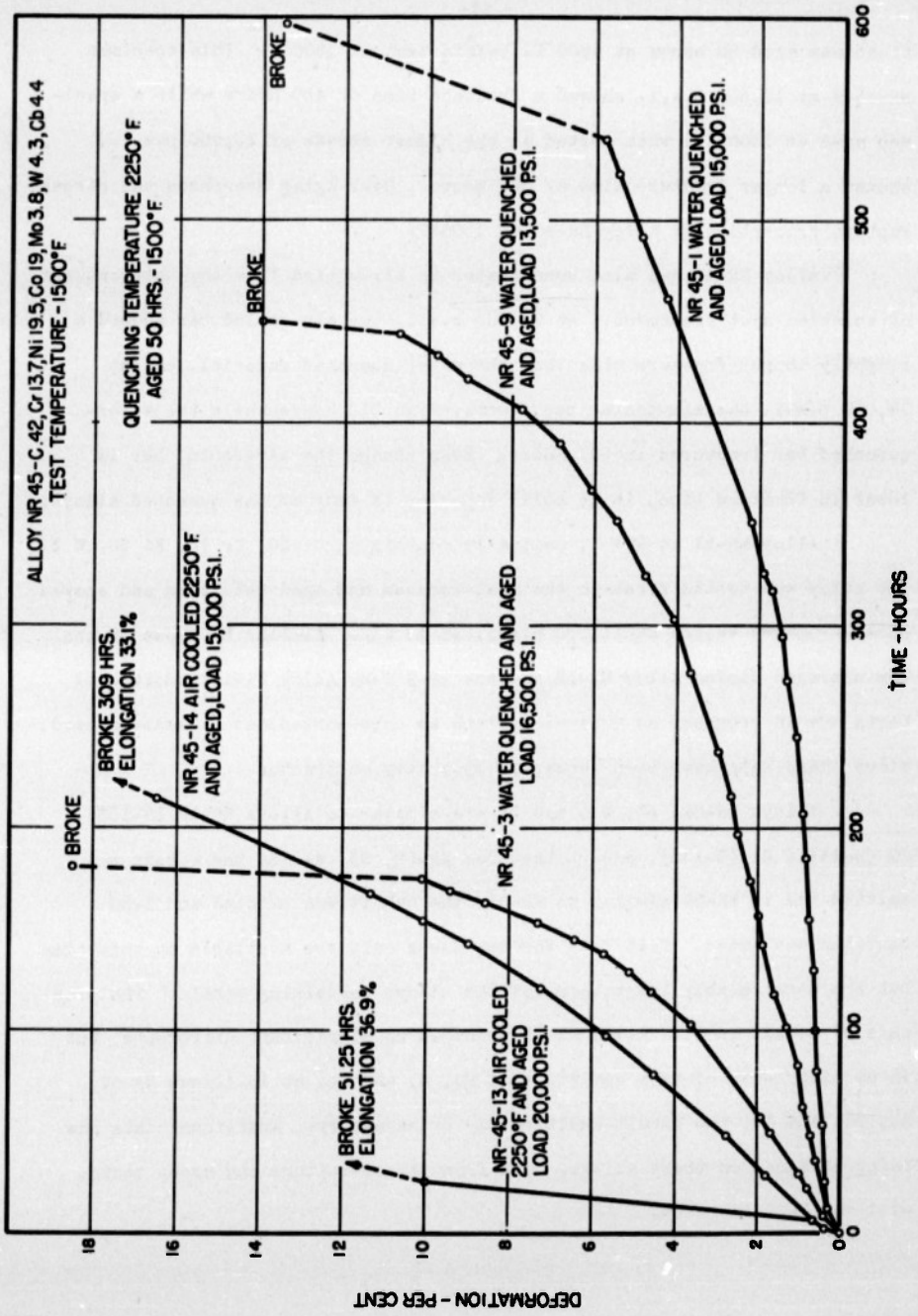


FIG. 21

NR-45 was aged 80 hours at 1600°F. before test at 1800°F. This specimen NR-45-9 at 15,500 p.s.i. showed a fracture time of 450 hours while a specimen aged at 1500°F., when tested at the higher stress of 15,000 p.s.i., showed a longer fracture time of 597 hours. Over-aging decreases the stress-rupture properties of Alloy NR-45 at 1500°F.

Alloy NR-45 has also been tested as air-cooled from the temperatures of solution heat treatment. At 20,000 p.s.i. the air-cooled bar showed a slightly longer fracture time than the water-quenched material, but at 15,000 p.s.i. the air-cooled bar fractured in 310 hours while the water-quenched bar fractured in 597 hours. Even though the air-cooled bar is lower in fracture time, it is still superior to many of the quenched alloys.

Alloy NR-51 is AFV-3, nominally containing C .50, Cr 15, Ni 26, W 3. The alloy was tested first in the heat-treated and aged condition and showed stress-rupture values at 15,000 p.s.i. at 1500°F. similar to those of the low nitrogen Timken Alloy NR-15 and the 19-9 W-Mo Alloy NR-16; additional tests are in progress on this alloy both as cold-worked and as heat-treated, since these data have been requested by a Navy contractor.

Alloys NR-52, 53, 54, and 55 are similar to Alloys NR-19 (N-153), 20 (N-154), 21 (N-155), except that for NR-52, 53, and 54 the cobalt was omitted and in NR-55 similar to NR-21, the cobalt was omitted and 1.0% tantalum was added. Test data for two tests only are available at this time but are considerably lower than for the alloys containing cobalt. The presence of cobalt in S497 Alloy NR-45 produced no significant difference, but in an alloy with minimum additions of Mo, W, and Cb, as in Alloys NR-52, 53, 54, and 55, the cobalt addition may be necessary. Additional data now being obtained on these alloys, both from stress-rupture and creep tests, will settle this point.

Summarizing, in the stress-rupture tests at 1500°F., the best alloys are NR-24 (Cast X-19), NR-34 (S496), and NR-45 (S497) with NR-19 (N-153) and NR-20 (N-154) slightly lower. Of only slightly lower stress-rupture properties are Alloys NR-21 (N-155), NR-38, NR-40 (4275), and NR-43.

Table 4 shows, for all of the alloys tested, the stresses at 1500°F. producing fractures in 10, 100, 500, and 1000 hours. For some of the promising alloys, Figures 22 and 23 show the relation between stress and time to produce 1, 2, and 5% total deformation at 1500°F.

RELATIONS BETWEEN STRESS AND TIME TO PRODUCE 1, 2, AND 5% TOTAL DEFORMATION AT 1500°F

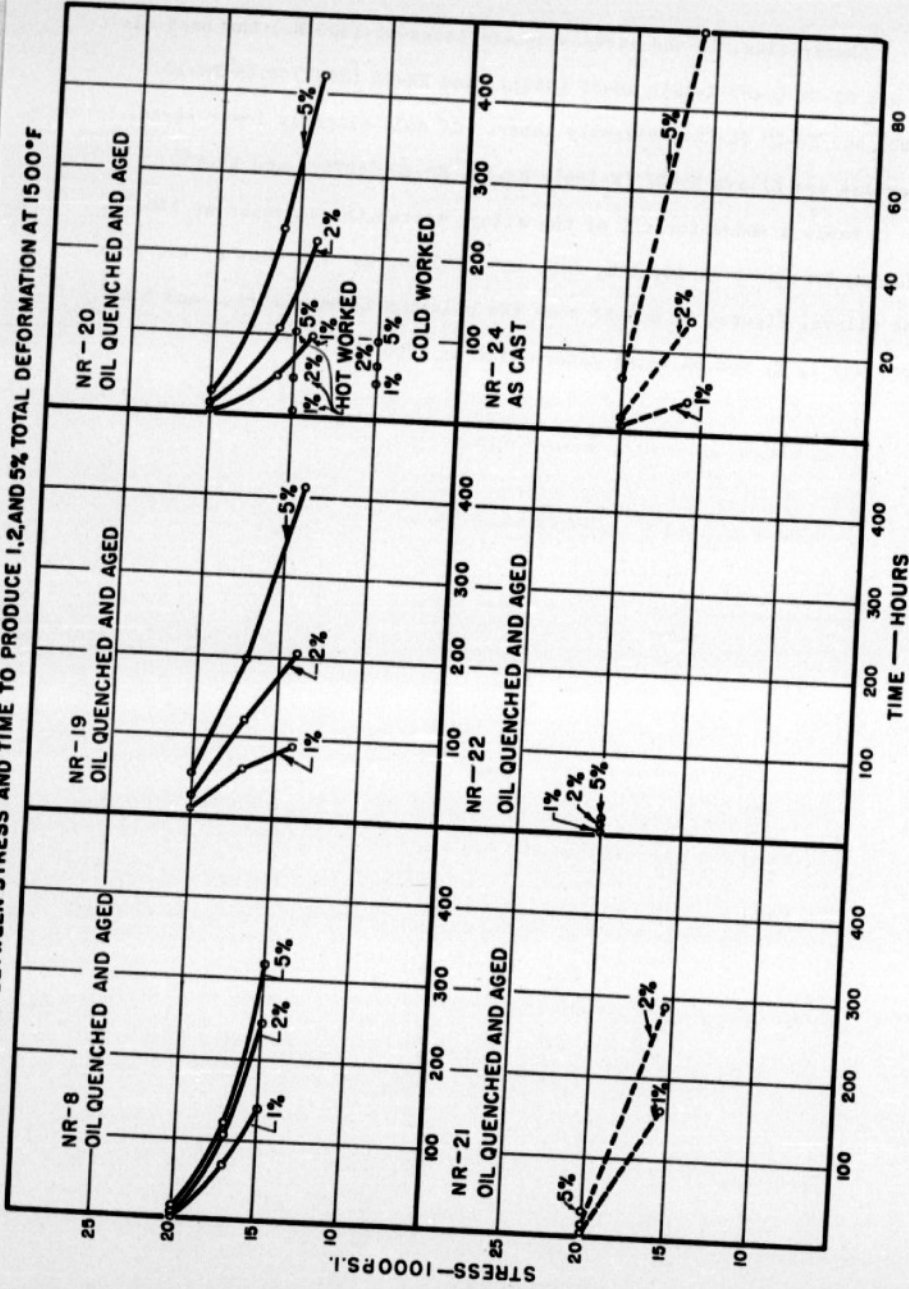


FIG. 22

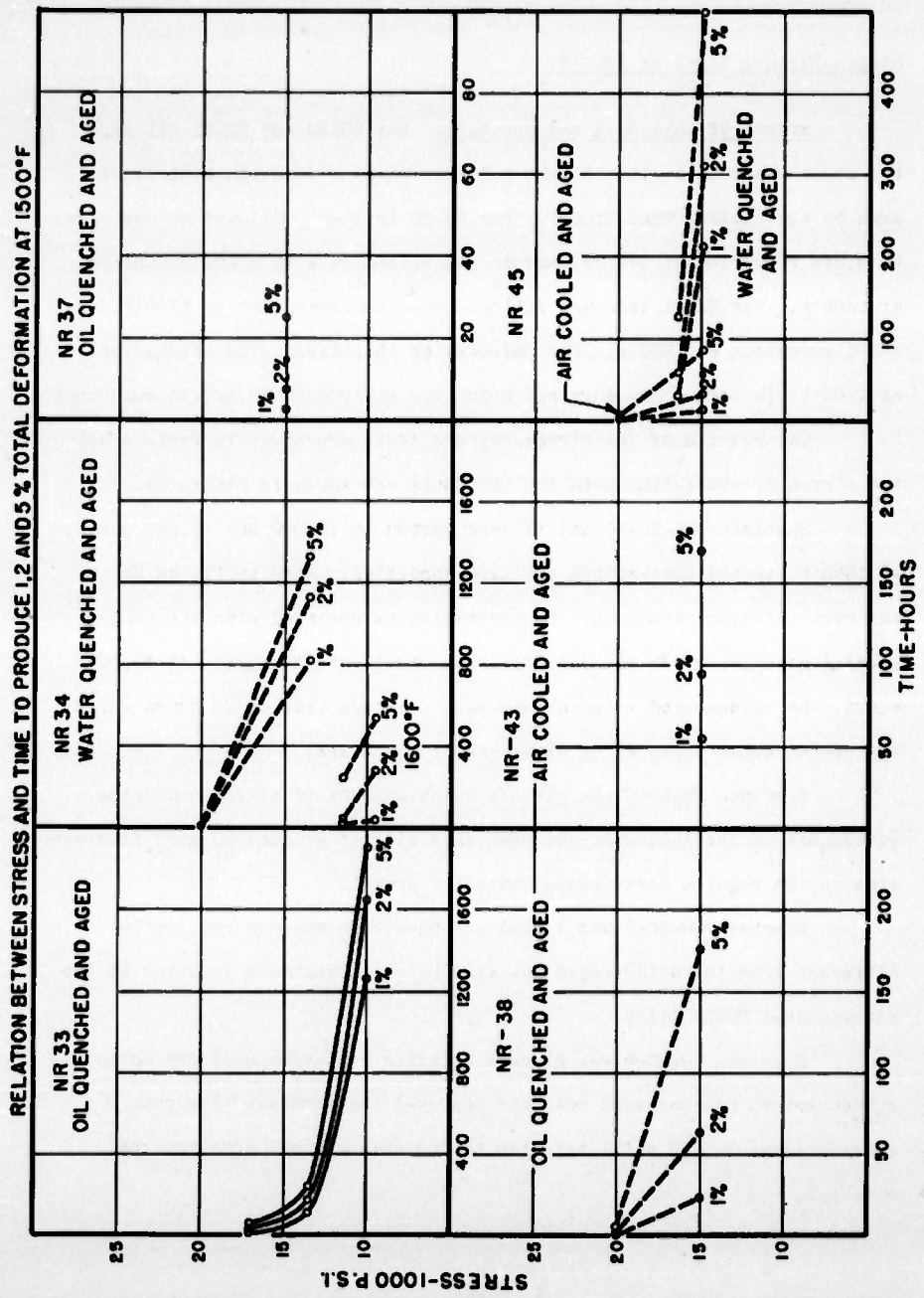


FIG. 23

Stress-Rupture Tests at 1500°F.

Effect of Cold-Work and Hot-Work. For NR-20 and NR-21 alloys, her stock was made available that had been given a solution heat treatment by air-cooling from 2100°F. For NR-20 this was followed in one case by a 22% reduction at 1700°F. and in the second case by a 25% reduction at 1200°F. For NR-21 this was followed by a 26% reduction at 1700°F. or a 26% reduction at 1200°F. For purposes of this discussion, reduction at 1700°F. is termed hot-work and reduction at 1200°F. is termed cold-work.

The results of the stress-rupture tests are shown in Table 4 and the stress fracture-time data for the tests are shown in Figure 24.

Specimens NR-20-10 and 11 were tested at 10,000 and 15,000 p.s.i. at 1500°F. in the cold-worked and aged condition. Note in Figure 24 the much inferior stress-rupture properties as compared with the heat-treated material given the solution heat treatment and aged. At 15,000 p.s.i. the cold-worked material showed a fracture time of 30 hours while the heat-treated NR-20 alloy showed about 450 hours.

Specimen NR-20-5 was given a solution heat treatment and aging subsequent to the cold-work and even this did not produce so good fracture time as the regular heat-treated material showed.

Specimen NR-20-7 was tested as hot-worked and was but little different from the cold-worked and aged material and much inferior to the heat-treated NR-20 alloy.

Specimen NR-20-6 was given a solution heat treatment and aging subsequent to the hot-work and this improved the fracture time considerably but it was still inferior to the unworked and heat-treated material.

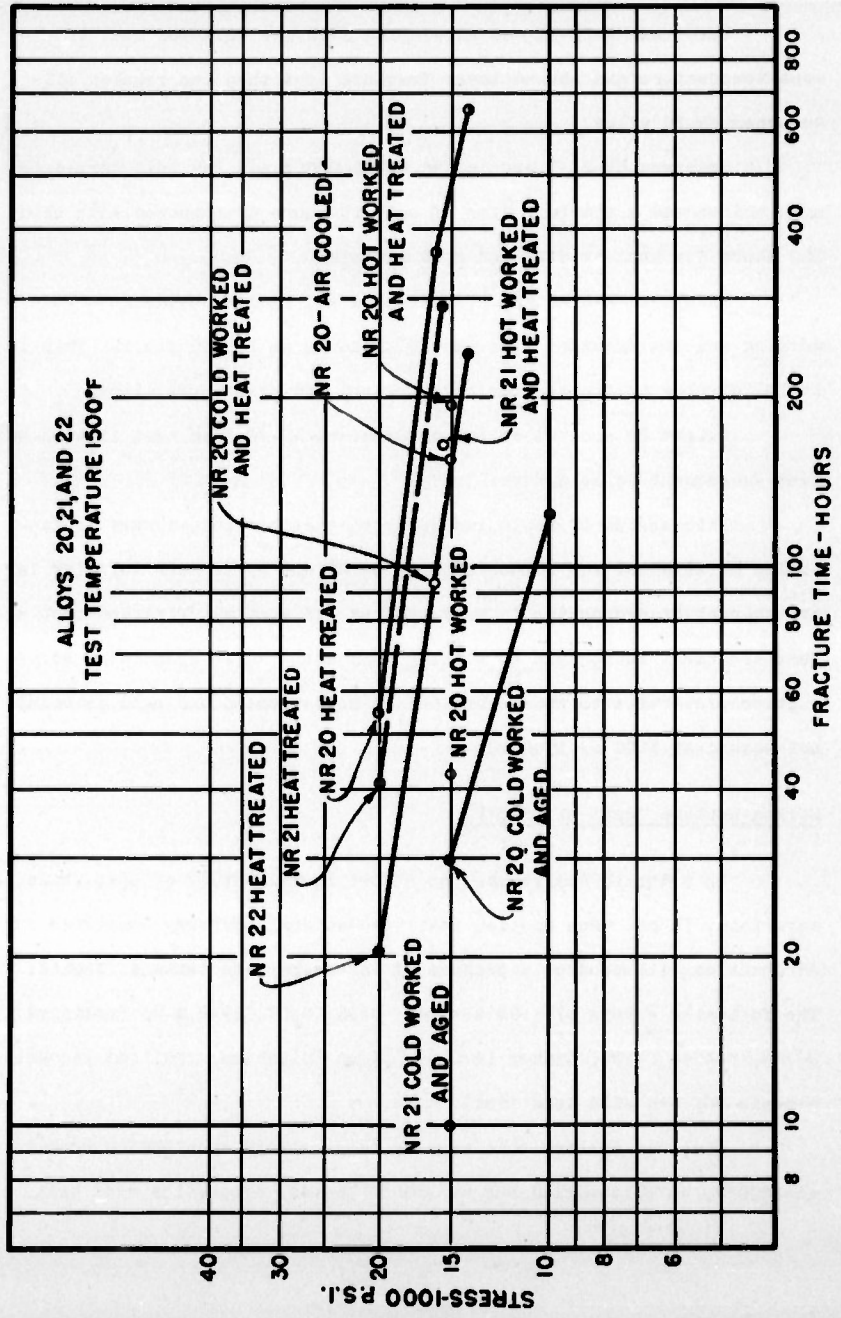


FIG. 24

Specimen NR-20-12 was air-cooled from the solution heat treatment temperature and showed lower fracture time than the regular oil-quenched NR-20 alloy.

Specimen NR-21-7 was tested at 15,000 p.s.i. as cold-worked and aged and showed a fracture time of only 10 hours as compared with about 350 hours for heat-treated and aged material.

Specimen NR-21-6 was heat treated and aged subsequent to hot-working and its fracture time was 161.5 hours at 15,500 p.s.i. This is still inferior to the regular heat-treated and aged NR-21 alloy.

A test is soon to be run on Specimen NR-22-4 as heat treated and aged subsequent to cold-work.

This series of tests indicates that either cold-worked or hot-worked material of the composition of NR-20 and 21 is much inferior in stress-rupture properties to heat-treated and aged material and that even heat treatment subsequent to working does not produce comparable stress-rupture properties to those obtained in heat-treated and aged material not worked at 1200 or 1700°F.

Stress-Rupture Tests at 1350°F.

In order to distribute the effort in this study of heat-resisting materials, it has been decided that the National Advisory Committee for Aeronautics will sponsor a program of stress-rupture tests at 1350°F. The following alloys will be tested: S495, S497, 19-9 W-Mo (modified), N-153, N-154, N-155, Timken 16-25-6, Gamma Columbian, Modified Inconel or Nimonic 80, and 4275 (modified).

Since it appears that many of these alloys show better properties at 1200°F. as cold-worked, but at 1500°F. better properties when heat

treated and aged, the tests at 1350°F. are to be made on both worked and heat-treated materials.

Tests on S495, S497, 19-9 W-Mo, Nimonic 80, and ATV-3 alloy are either already in progress in the NRC-8 program or test specimens are under preparation. No further tests at 1350°F. will be started or planned. All subsequent tests will be run in the N.A.C.A. program and data will be made available in the usual N.A.C.A. reports.

Since the N.A.C.A. stress-rupture data at 1350°F. will be obtained on smaller specimens (0.160-inch diameter and 1.0 to 1.25-inch gage length), the opportunity for comparison with data on a few alloys as determined on the larger 0.505-inch diameter specimens in the NRC-8 program would seem to indicate that the tests already in progress at 1350°F. should be continued. Since the tests on 19-9 W-Mo and ATV-3 alloys in particular have been requested by a Navy contractor and will be available sooner under the NRC-8 program, these will be continued.

Specimen NR-45-20 (S497) at 1350°F. and 32,500 p.s.i. showed a fracture time of 28 hours with an elongation of 26.0% and a reduction of area of 36.3%. Specimen NR-45-21, tested at 25,000 p.s.i. at 1350°F., fractured after 482.0 hours with an elongation of 31.0% and a reduction of area of 41.9%. The data on these two bars indicate fracture times of 100, 500, and 1000 hours at stresses of 29,000, 24,500, and about 23,000 p.s.i. Several additional tests at stresses of about 29,000 and 23,000 p.s.i. at 1350°F. will be needed to confirm the data indicated by the two tests completed to date. These specimens were water-quenched from 2250°F. and aged 50 hours at 1400°F. prior to testing at 1350°F. Figure 25 shows the stress fracture-time data.

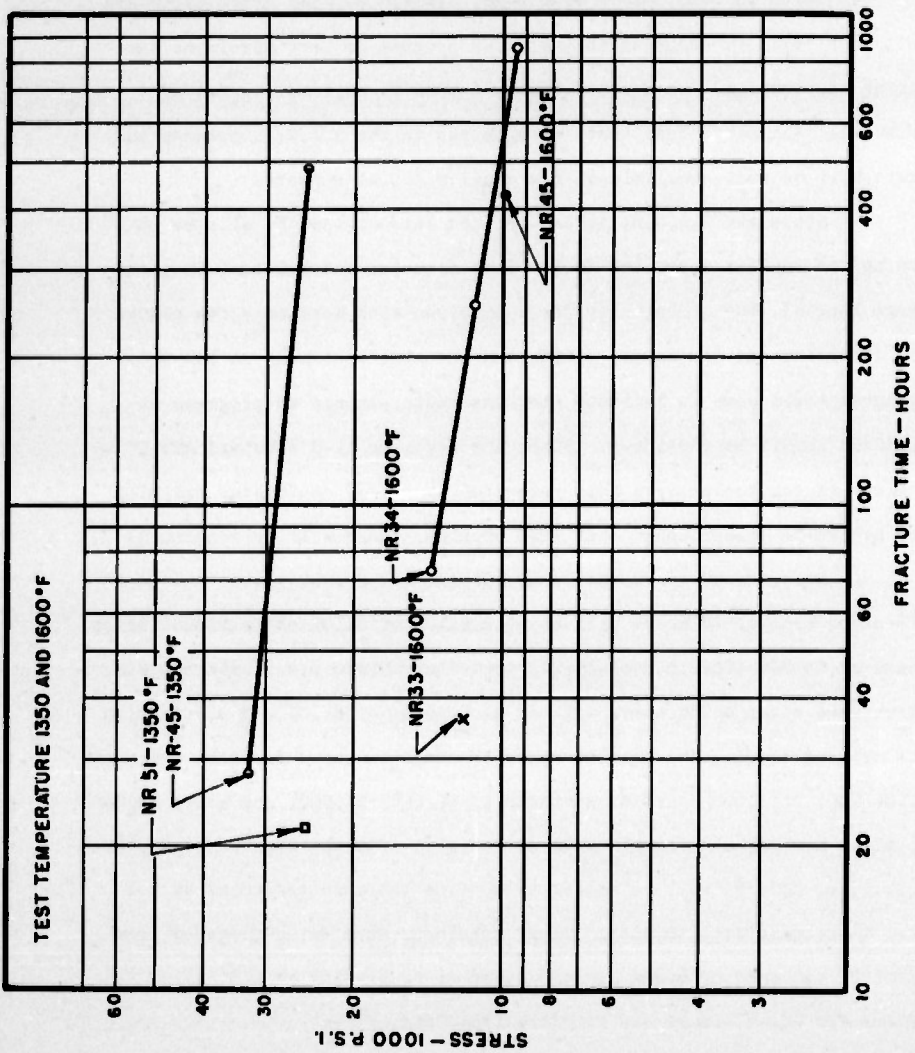


FIG. 25

Specimen NR-51-3 (ATV-3) at 1350°F. and 25,000 p.s.i. showed a fracture time of 21.6 hours with an elongation of 6.8% and a reduction of area of 9.66%. A test is in progress on NR-51-4 at 15,000 p.s.i. These specimens were air-cooled from 2250°F. and aged 50 hours at 1400°F. prior to testing.

Stress-Rupture Tests at 1600°F.

The Navy Department requested that stress-rupture tests be started at 1600°F. on some of the materials indicated best in the tests at 1500°F. Tests are in progress at 1600°F. on Gamma Columbium (NR-33), S495 (NR-34) and S497 (NR-45) alloys. The results obtained to date are shown in Table 4 and Figure 25 on specimens given a solution heat treatment and aged 50 hours at 1600°F.

NR-33-34 at 12,000 p.s.i. at 1600°F. showed a fracture time of 36 hours with an elongation of 28.0% and a reduction of area of 35.0%. A test is in progress on Specimen NR-33-35 at 8500 p.s.i.

Three tests have been completed at 1600°F. on S495 alloy (NR-34). Time-deformation curves for the stress-rupture tests are shown in Figure 26. The results in Figure 25 indicate 100, 500, and 1000-hour fracture times at stresses of 13,200, 10,300, and 9,200 p.s.i. The fracture times for the three tests fell on a straight line in the log-log plot of stress and fracture time indicating surprising stability at this higher temperature.

One test has been completed on S497 (NR-45) at 10,000 p.s.i. with a fracture time of 426 hours which is not quite so long as for S495 (NR-34). The time-deformation curve for this test is shown in Figure 27. Two additional tests are in progress at 9,000 and 14,000 p.s.i. at 1600°

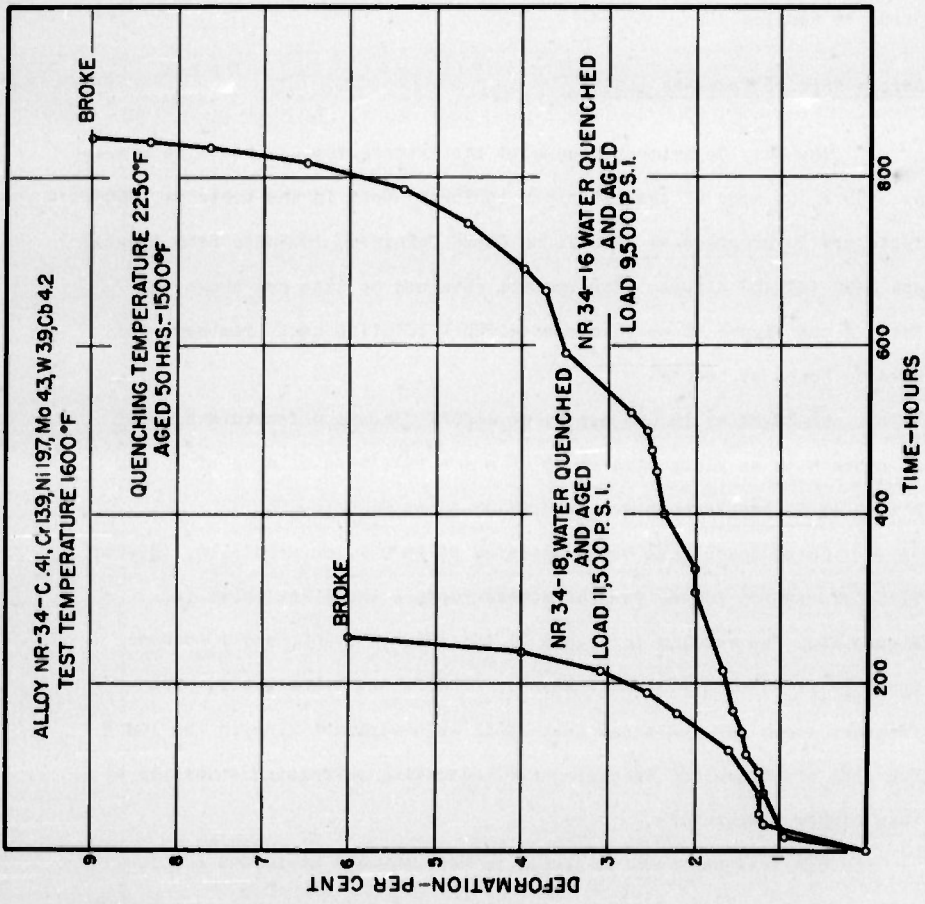


FIG. 26

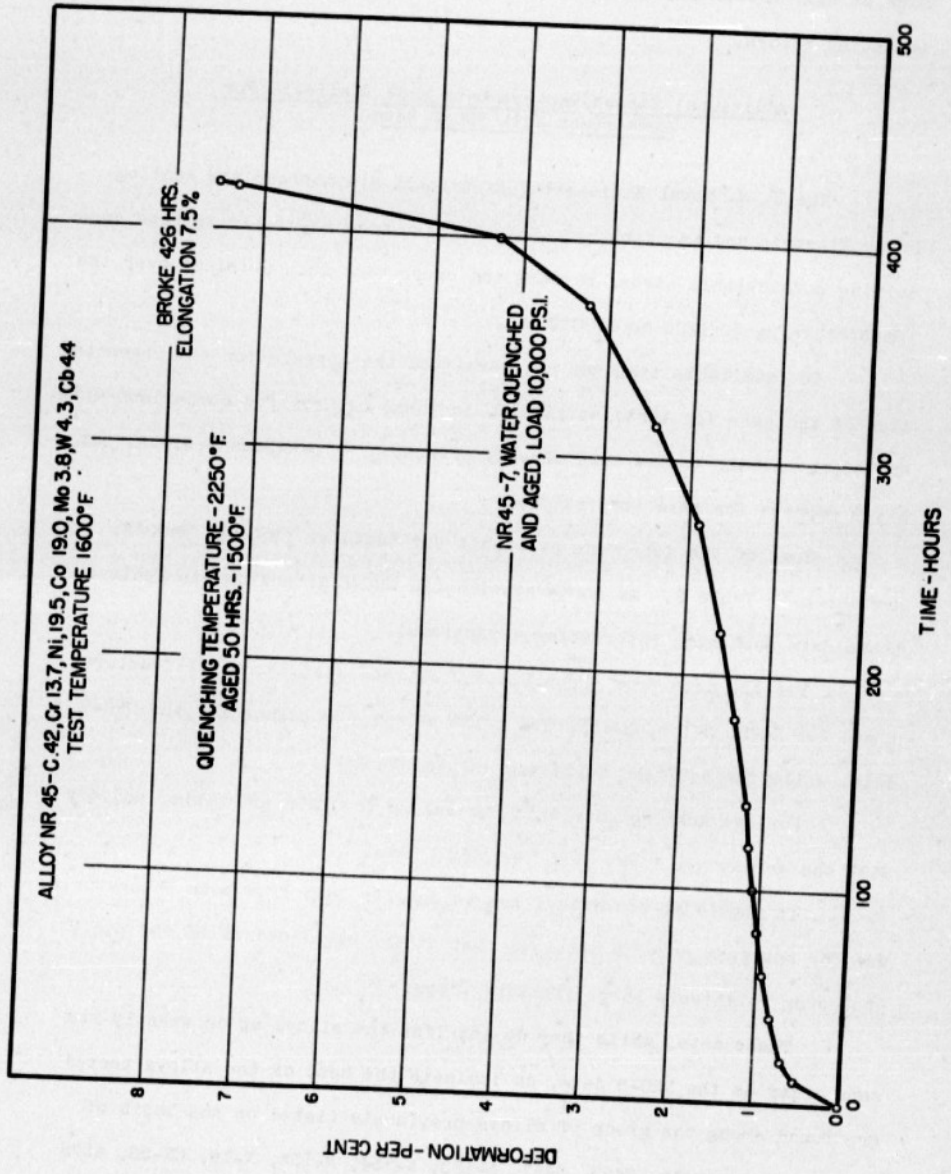


FIG. 27

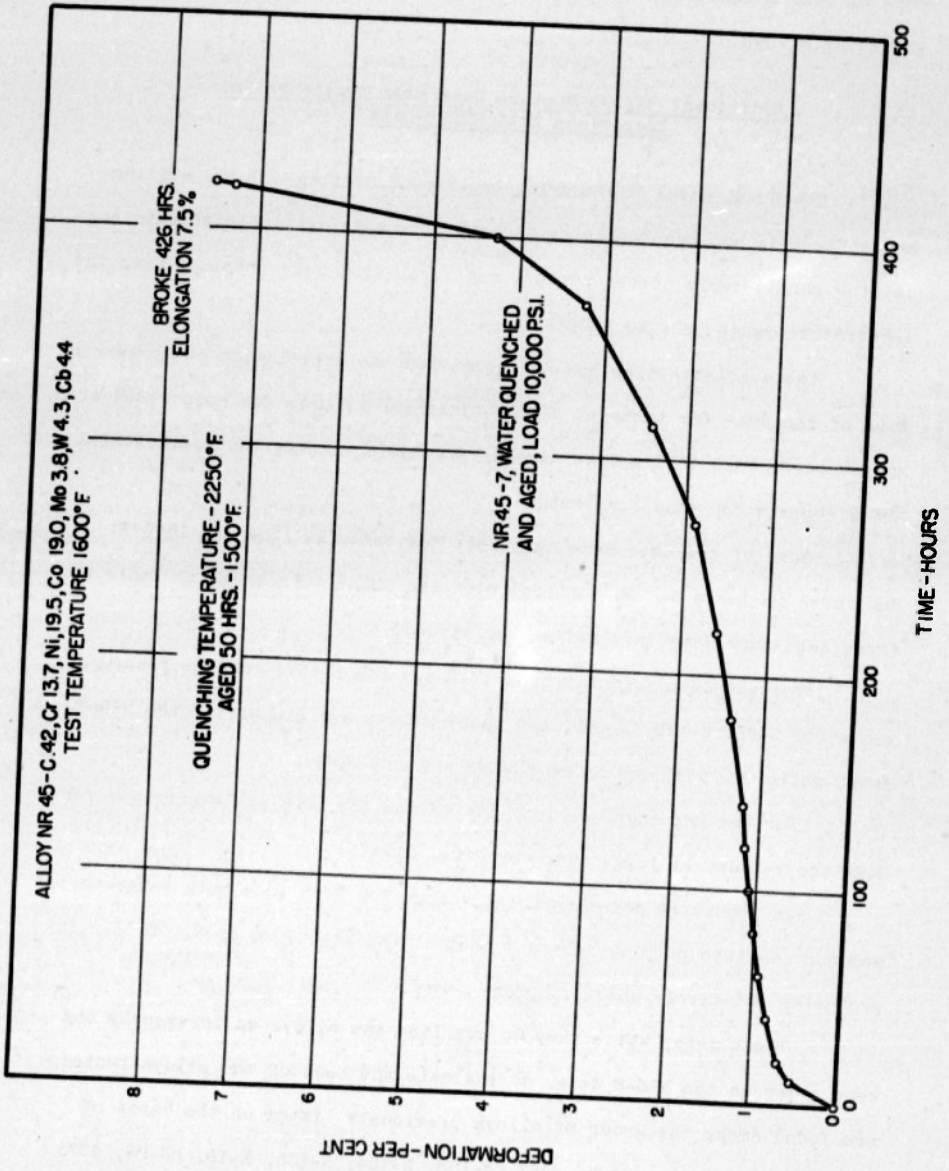


FIG. 27

Lack of test material has prevented tests on several of the other interesting alloys.

Additional Stress-Rupture Data Made Available For
Comparison With NRC-8 Data

The U. S. Naval Engineering Experiment Station and the Westinghouse Electric and Manufacturing Company have made available reports containing considerable stress-rupture and creep test data obtained over the temperature range 1200 to 1500°F.

The available time has not permitted the correlation and presentation of the data for tests at 1500°F. in these reports for comparison with, and supplementary to, the data already presented in previous N.A.C.A. and NRC-8 reports for this temperature.

Some of the data made available for tests at 1350 and 1500°F. are shown in Table 6. As compared with the NRC-8 data shown in Table 4, these data show some interesting variations.

For the data from the U.S.N.E.E.S., the stress-rupture fracture times for S495, N-153, N-155, and N-156 alloys are higher for the NRC-8 data, while for S497 and N-154 the values are lower.

For the Westinghouse data the values for S495 are higher and for S497 the values are lower than for NRC-8 data.

It should be noted that the values for S495 from both laboratories are for one test only, to date, and that at the high load of 20,000 p.s.i. producing relatively short fracture times.

These data, while they do not line the alloys up in exactly the same order as the NRC-8 data, do indicate the best of the alloys tested are found among the group of alloys previously listed on the basis of NRC-8 tests, namely, S495, S497, N-153, N-154, N-155, X-19, NR-38, 4275 (NR-40), and NR-43.

TABLE 6. STRESS-RUPTURE DATA AT 1500°F. ON HEAT-RESISTING ALLOYS

(Data Supplied by U. S. Naval Engineering Experiment Station and Westinghouse Electric and Manufacturing Company.)

Material	Test Temp., °F.	Stress, p.s.i.	Fracture Time, Hours	Elongation, %	Reduction of Area, %
ATV-3 (a)	1200	30,000	157		
"	1350	20,000	60	38.5	37.0
"	1350	10,000	734	21.0	23.0
"	1500	20,000	2.75	22.0	24.5
"	1500	8,000	31.75	29.0	38.8
S497 (a)	1350	40,000	7	27.0	31.2
"	1350	30,000	97.5	23.0	23.8
"	1500	20,000	24	24.0	28.0
"	1500	15,000	217	18.0	27.75
S495 (a)	1500	20,000	68	19.5	31.0
N153 (a)	1500	25,000	9.0	18.0	31.0
"	1500	20,000	82.3	42.5	35.5
"	1500	15,000	517.0	25.0	43.1
N154 (a)	1500	20,000	23.5	27.5	28.0
N155 (a)	1500	20,000	115.0	10.0	13.2
"	1500	15,000	1600	18.0	18.1
N156 (a)	1500	20,000	41.7	7.0	13.3
"	1500	15,000	377.0	9.5	10.0
Gamma Columbian (b)	1500	20,000	7.1	4.3	2.8
"	1500	16,000	38.0	15.4	--
"	1500	12,500	241.0	14.3	--
S497 (b)	1500	20,000	32.0	16.4	--
"	1500	15,000	355.0	5.9	--
"	1500	10,000	Unbroken-1500	2.35	--
S495 (b)	1500	20,000	115	--	37.3

(a) Tested at U. S. Naval Engineering Experiment Station.

(b) Tested at Westinghouse Electric and Manufacturing Company.

For Type Compositions see Table 1

Heat Treatment:

ATV-3 - as received cold rolled.
 S497(a) - 2200°F.-1 hour. Water quenched, aged 1500°F.-4 hours.
 S495(a) - 2250°F.-2 hours. Water quenched, aged 1500°F.-16 hours.
 N153, N154, N155, N156 (a) - 2200°F.-1 hour. Water quenched, aged 1500°F.-4 hours.
 Gamma Columbian (b) - Preheat 1/2 hour - 1550°F., 2250°F.-3/4 hour. Oil quenched, aged 1500°F.-50 hours.
 S495, S497 (b) - 2250°F.-1 hour. Water quenched, aged 1500°F.-16 hours.

Creep Tests

Creep Tests at 1500°F.

Creep tests have been run or are in progress at 1500°F. on twenty of the alloys tested in stress-rupture at 1500°F. The test specimens used had a diameter of 0.505-inch and a gage length of approximately 2 inches. The complete creep test data are shown in Table 7 and a graph showing the log - log relation between stress and creep rate for some of the better alloys is shown in Figure 28. The order of listing of the alloys in the creep test data table is similar to the order used in the stress-rupture test data table. The actual time-deformation curves also are given for the better materials. For all creep tests, Table 7 shows the initial deformation upon application of the load, the creep rates in per cent per hour and the total deformations in per cent at the 500, 1000, 1500, and 2000-hour periods or the duration of the tests. These complete data are presented so that the designing engineers, or any persons using this report, may utilize the data for mathematical treatments and comparisons in any manner in which they see fit. Presentation of the complete data, including time-deformation curves, provides the opportunity for each person to inspect the data critically so as to determine which alloy or alloys best meet the requirement at hand. With the time-deformation curves available, the possible errors involved in considering only creep rates, without at the same time considering the deformations involved or the times and deformations beyond which the minimum creep rate is passed, are largely eliminated.

Alloy NR-2 and Alloy NR-44 (replacement for Alloy NR-3) were tested in creep at 7,000 and 10,000 p.s.i. At 7,000 p.s.i. NR-2 showed

TABLE 7. CREEP TEST DATA ON HEAT-RESISTING ALLOYS

Alloy and Specimen Number	Condi- tion	Temp. Test, °F.	Stress, P.S.I.	Dura- tion, Hrs.	Deformation Upon Application of Load, %	Creep Rate-Per Cent Per Hour at, Hours				Total Deformation - Per Cent at, Hours			
						500	1000	1600	2000	500	1000	1600	2000
NR-2-4	1	1600	10,000	1526	.064	.00053	.00043			0.46	0.63		
Retest NR-2-6	1	1600	7,000	1784	.066	.00062	.00072	.00078		0.423	0.781	1.13	
						.00061	.000643	.00004		0.16	0.163	.163	.19 (e)
Replacement NR-3					.032	.00032(b)							
NR-44-2	1	1600	10,000	760	.038	.00049	.00097			0.23	0.66 (e)		
NR-44-6	1	1600	7,000		.032	.000037	.000065	.000051	In progress	0.116	0.146	0.172	
NR-6-2	2	1600	12,000	910	.055	.00092	.00196 (d)			0.32 (d)			
NR-6-1	2	1600	6,000	2013	.033	.000093	.000064	.000063	.000066	.214	.231	.279	.312
NR-34-9	3	1600	10,000	2280	.062	.00012	.000173	.00019	.0004	.106	.175	.237	.420 (e)
NR-34-4	3	1600	6,000	1999	.041	.000026	.000012	.00001	.000004	.101	.108	.112	.113
NR-34-26	3	1600	8,000		.047				In progress				
NR-34-3	3	1600	6,000	2019	.038	.000012	.000012	.00001	.000002	.073	.079	.063	.066
NR-34-6	6	1600	6,000						In progress				
NR-33-10	2	1600	8,500	283	.044	.000186(f)			In progress	.193 (f)			
NR-33-1	2	1600	7,000	2050	.036	.00003	.00001(g)		.000022	.116	.122(g)		.177
NR-33-20	2	1600	7,000		.031	.000081	.000046	.000031	In progress		.163	.191	.208
NR-13-16	3	1600	7,000	680	.060	.007				1.204	Fractured	580 hours.	
NR-16-14	1	1600	7,000	968	.062	.00192				1.1	"	936 "	
NR-49-6	3	1600	9,000						In progress				
NR-49-6	3	1600	6,000	500	.024	.00021				.173			
NR-49-12	1	1600	7,000						In progress				
NR-49-14	1	1600	6,000						In progress				
NR-19-1	2	1600	10,000	380 (h)	.137	.00028 (h)				0.273 (h)			
NR-19-5	2	1600	10,000		.070	.0003	.00022		(i)	0.389	0.466	(i)	
Retest(i) NR-19-6	2	1600	7,000	1920	.067	.00017	.00019			0.211	0.306		
						.000088	.000063	.000066	.000066	0.069	0.102	0.133	0.162
NR-20-1	2	1600	10,000	1600	.126	.00054	.00073	.00136		0.466	.31	1.46	
NR-20-9	2	1600	7,000		.042	.00008	.0001(j)		In progress	.06	.12(j)		
NR-20-8	7	1600	7,000	786	.049	.00078	.00106(k)			.62	.312(k)		
NR-21-1	2	1600	10,000	2160(l)	.043	.00009	.00009	.00009	.00017	.106	.160	.183	.272
NR-21-12	2	1600	7,000		.037	.00008	.000046			.008	.014		
NR-22-1	2	1600	10,000	2000	.067	.00019	.00019	.00016	.00021	.166	.261	.366	.463
NR-22-7	2	1600	8,500	280		.0001(m)				In progress	.126 (m)		
NR-22-6	2	1600	7,000		.043	.000084	.000063	.000023	.000033	.107	.130	.144	
NR-22-2	7	1600	10,000	696	.045	.0078	.022 (n)				6.6 (n)		
NR-37-4	2	1600	10,000	1777	.029	.000803	.000794	.000966		.609	1.013	1.473	(o)
NR-37-3	2	1600	7,000	1777	.047	.000107	.000107	.000012		.172	.225	.229	(p)
NR-43-3	2	1600	10,000	1601	.062	.00163	.00217	.0069		.913	1.92	3.7	6.0 (q)
NR-43-6	2	1600	8,000						In progress				
NR-43-4	2	1600	7,000	1920	.031	.00012	.000021	.000021	.00024(r)	.079	.066	.109	.206(r)
NR-43-6	6	1600	10,000		.043	.000052	.000064	.000062	.000062	.204	.240	.297	.293
NR-46-4	3	1600	8,000						In progress				
NR-46-11	3	1600	6,000						In progress				
NR-46-3	3	1600	7,000		.053	.000016	.000016			.062	.091	.091	
NR-46-17	3	1600	6,000						In progress				

TABLE 7. (Continued)

Alloy and Specimen Number	Condi- tion	Temp. of Test, °F.	Stress, P.s.i.	Dura- tion, Hrs.	Deformation Upon Application of Load, %	Creep Rate-Per Cent Per Hour at, Hours				Total Deformation - Per Cent at, Hours			
						500	1000	1500	2000	500	1000	1500	2000
NR-46-4	2	1600	5,000		.031					In progress			
NR-51-1	4	1600	7,000	27	.059	.171							
NR-51-2	4	1600	3,000	330	.067	.00442							
NR-51-3	4	1600	1,750	400	.007	.0002							
NR-52-4	2	1600	6,600							In progress			
NR-52-3	2	1600	7,000							In progress			
NR-53-4	2	1600	6,500							In progress			
NR-53-3	2	1600	7,000							In progress			
NR-54-4	2	1600	6,600							In progress			
NR-54-3	2	1600	7,000							In progress			
NR-55-1	2	1600	6,600							In progress			
NR-55-4	2	1600	7,000							In progress			
NR-57-1	3	1600	10,000			.01 (s)							
NR-57-4	3	1600	6,600	2110	.055	.00005	.000027	.000025	.000033	.061	.110	.115	.130
NR-57-2	3	1600	7,000	2640	.067	.00012	.000035	.000035	.000045(t)	.142	.16	.19	.22 (t)
NR-57-3	3	1600	7,000	2315	.025	.000025	.00002	.00001	.000015(u)	.07	.090	.095	.102(u)
NR-58-1	5	1600	7,000	1100	.04	--	.00001			In progress		.115	.121

(s) Discontinued 1754 hours.

(b) At 480 hours, temperature down to 1350°F.

(c) Discontinued at 750 hours.

(d) Discontinued 910 hours.

(a) Discontinued 2280 hours.- 0.535% deformation.

(f) At 255 hours.

(g) Rate and deformation shown at 755 hours, cooled to room temperature with load on, and reheated to 1600°F. with load on, big step in survey.

(h) Overheated to 1630°F.- 21 hours; at 260 hours, test discontinued.

(i) Fuse failure at 1355 hours, furnace down to room temperature, reheated and specimen is showing similar creep rate.

(j) At 500 hours.

(k) At 785 hours.

(l) 0.3% at 2180 hours.

(m) At 290 hours.

(n) Rate and deformation when discontinued at 595 hours.

(o) 1.75% at 1777 hours.

(p) .231% at 1777 hours.

(q) At 1501 hours - test discontinued.

(r) When discontinued at 1920 hours.

(s) At 225 hours.

(t) .000035% per hour at 2540 hours. .255% total deformation.

(u) .000015% per hour at 2315 hours. .105% total deformation.

1. = Air cooled.

2. = Oil quenched.

3. = Water quenched.

4. = Cold-worked and aged.

5. = Cold-worked, oil quenched and aged.

6. = Hot-worked.

7. = Hot-worked, oil quenched and aged.

8. = Aged.

9. = Tested as-cast.

For details of processing, solution heat treatment, and aging, see Table 2.

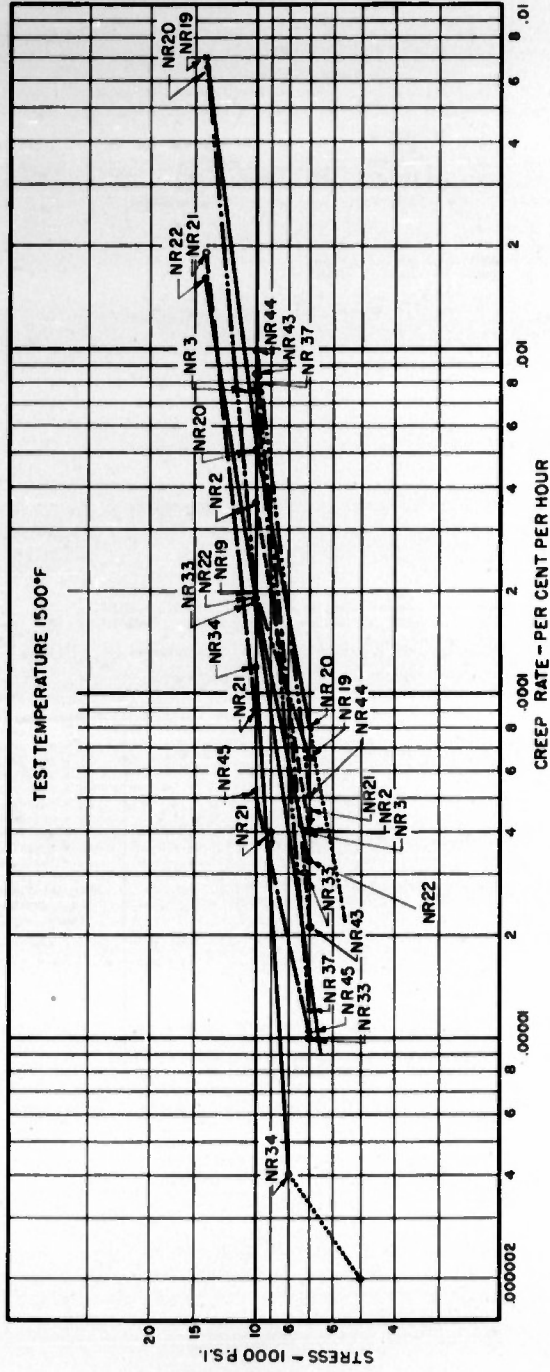


FIG. 28

a minimum rate of .00004% per hour while NR-44 showed .000051% per hour. While these rates are low, the data from these two tests indicate a rate of .00001% per hour would be produced by a stress of 5500 to 6000 p.s.i. To be certain of this, tests should be run at lower loads than 7,000 p.s.i.

These first two alloys illustrate very clearly the difficulties involved in a test program of the scope now in progress. For both of these alloys only two tests were run and to extrapolate even to slightly lower loads from two points is admittedly questionable procedure. Unfortunately, lack of testing equipment for handling more long-time creep tests has restricted the number of tests that could be made on each alloy while there were so many alloys to be studied. When it is realized that only 33 to 40 creep test units are available for this work in addition to the units engaged in stress-rupture testing and that a 2000-hour creep test takes almost three months, the lack of additional data on some of these alloys is not difficult to understand. Every effort is being made to keep every available creep test unit in service and it is necessary that greater attention should be given first to those few alloys that appear most promising. As opportunity provides, additional tests will be run on many of the alloys at other loads than those shown in Table 7.

Alloy NR-8 (S495) at 8,000 p.s.i. showed a minimum creep rate of .000065% per hour. This alloy was a small induction furnace heat. The S495 alloy obtained from Allegheny Ludlum (NR-34) showed a minimum creep rate at 8,000 p.s.i. less than .00001% per hour, indicating the small experimental heat inferior to the production alloy. At 5,000 p.s.i. the rate was definitely less than .00001% per hour and so low that it could not be measured properly. A check test at 8,000 p.s.i. has been started recently but has run too short a time to produce usable data. There seems little doubt that this Alloy NR-34 meets the requirement for a rate not

in excess of .00001% per hour at 7,000 p.s.i. at 1500°F. The time-deformation curves are shown in Figure 29.

Alloy NR-33 (Gamma Columbium) has been tested at 7,000 and 8,500 p.s.i. The time-deformation curves are shown in Figure 30. The test at 8,500 p.s.i. is still in its early stages. The test on Specimen NR-33-1 at 7,000 p.s.i. was interrupted after 785 hours when the temperature by accident fell to room temperature with the load on and then was reheated to 1500°F. with the load on. A big step in the time-deformation curve resulted as is shown in Figure 30 and, subsequently, the rate of deformation was higher. A check test running at 7,000 p.s.i. now in progress over 1500 hours shows a minimum rate of .000031% per hour. It appears that for Alloy NR-33 a stress between 6,000 and 7,000 p.s.i. will produce a rate of deformation of .00001% per hour.

Alloy NR-15 is the Timken 16-25-6 alloy and this alloy fractured at 7,000 p.s.i. It will be recalled that this heat was low in nitrogen content and is not considered representative of Timken alloy. Table 7 indicates that tests are in progress on Alloy NR-49 (replacement for Timken NR-15) at 6,000 and 9,000 p.s.i. at 1500°F. as water-quenched and at 6,000 and 7,000 p.s.i. as air-cooled from the solution heat treatment temperature. Data already made available on Timken alloy by Timken Steel and Tube Company and Allis-Chalmers Manufacturing Company, and reported in O.S.R.D. Report No. 722, Serial M-12, dated July 22, 1942, indicate that a stress between 4,500 and 5,000 p.s.i. at 1500°F. will produce a rate of .00001% per hour.

Alloy NR-19 is being tested at 7,000 and 10,000 p.s.i. The time-deformation curves are shown in Figure 31. The unit in which Specimen NR-19-5 was under test had a fuse failure at 1336 hours and the heating furnace cooled down to room temperature and was then reheated to 1500°F.

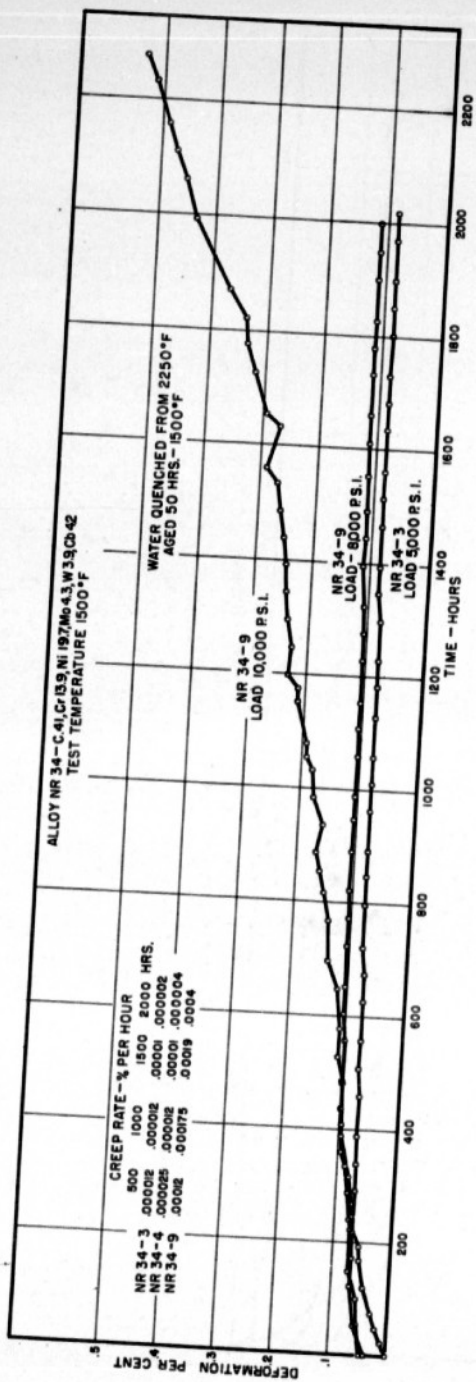


FIG. 29

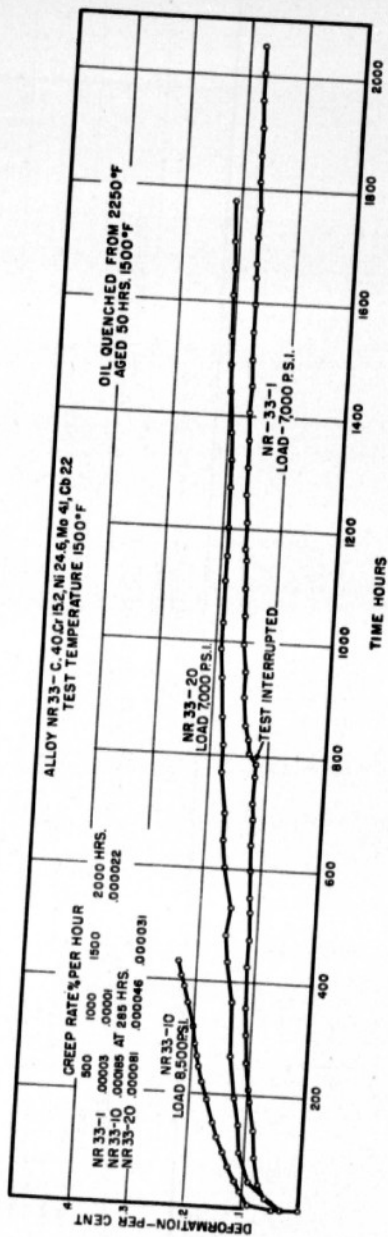


FIG. 30

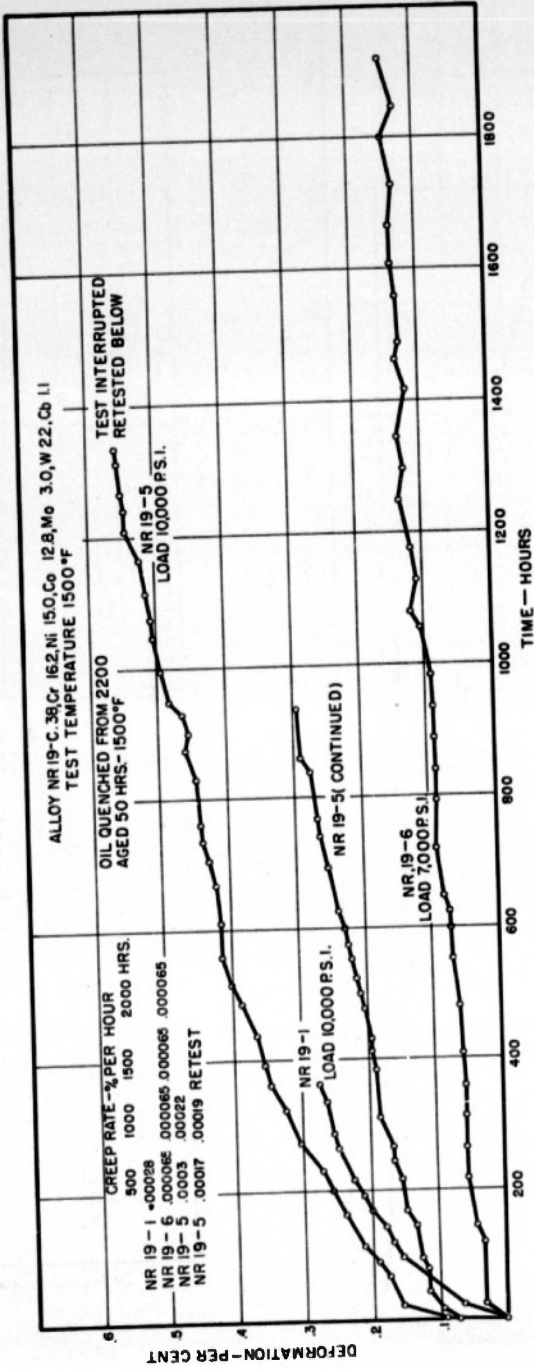


FIG. 31

The creep rate after reheating was very similar to that obtained before the interruption. At 7,000 p.s.i., NR-19-6 showed a creep rate of .000065% per hour. Considering the promising stress-rupture test data for Alloy NR-19, the creep rate was somewhat higher than expected.

Alloy NR-20 is being tested at 7,000 and 10,000 p.s.i. The time-deformation curves are shown in Figure 32. The rate at 800 hours at 7,000 p.s.i. is .0001% per hour. For this alloy as well as NR-19, the creep rate seems high in view of the good stress-rupture properties.

Specimen NR-20-8 was tested at 7,000 p.s.i. at 1500°F. as heat treated and aged subsequent to hot-working at 1700°F. As with the stress-rupture tests previously discussed, the heat-treated material is superior to the hot-worked and heat-treated material.

Alloy NR-21 is being tested at 7,000 and 10,000 p.s.i. The time-deformation curves are shown in Figure 33. Specimen NR-21-1 tested at 10,000 p.s.i. showed a minimum rate of .00009% per hour. The test on Specimen NR-21-12 at 7,000 p.s.i. has progressed 900 hours and the rate is now .000046% per hour. Another test was started on Specimen NR-21-5 but was discontinued owing to overheating after about 200 hours under load. This test had shown a low rate of creep and for this reason it is expected that the rate on NR-21-12 at 7,000 p.s.i. will finally reach a lower rate than the present indicated .000046% per hour, and may go as low as .00001% per hour.

Alloy NR-22 is being tested at 7,000, 8,500 and 10,000 p.s.i. The time-deformation curves are shown in Figure 34. The creep rates of .000033% per hour at 7,000 p.s.i. and .00019% per hour at 10,000 p.s.i. indicate a rate of .00001% per hour would be obtained at a stress of 5500 to 6,000 p.s.i. The test at the intermediate load of 8,500 p.s.i. will assist in the interpretation and extrapolation of the data.

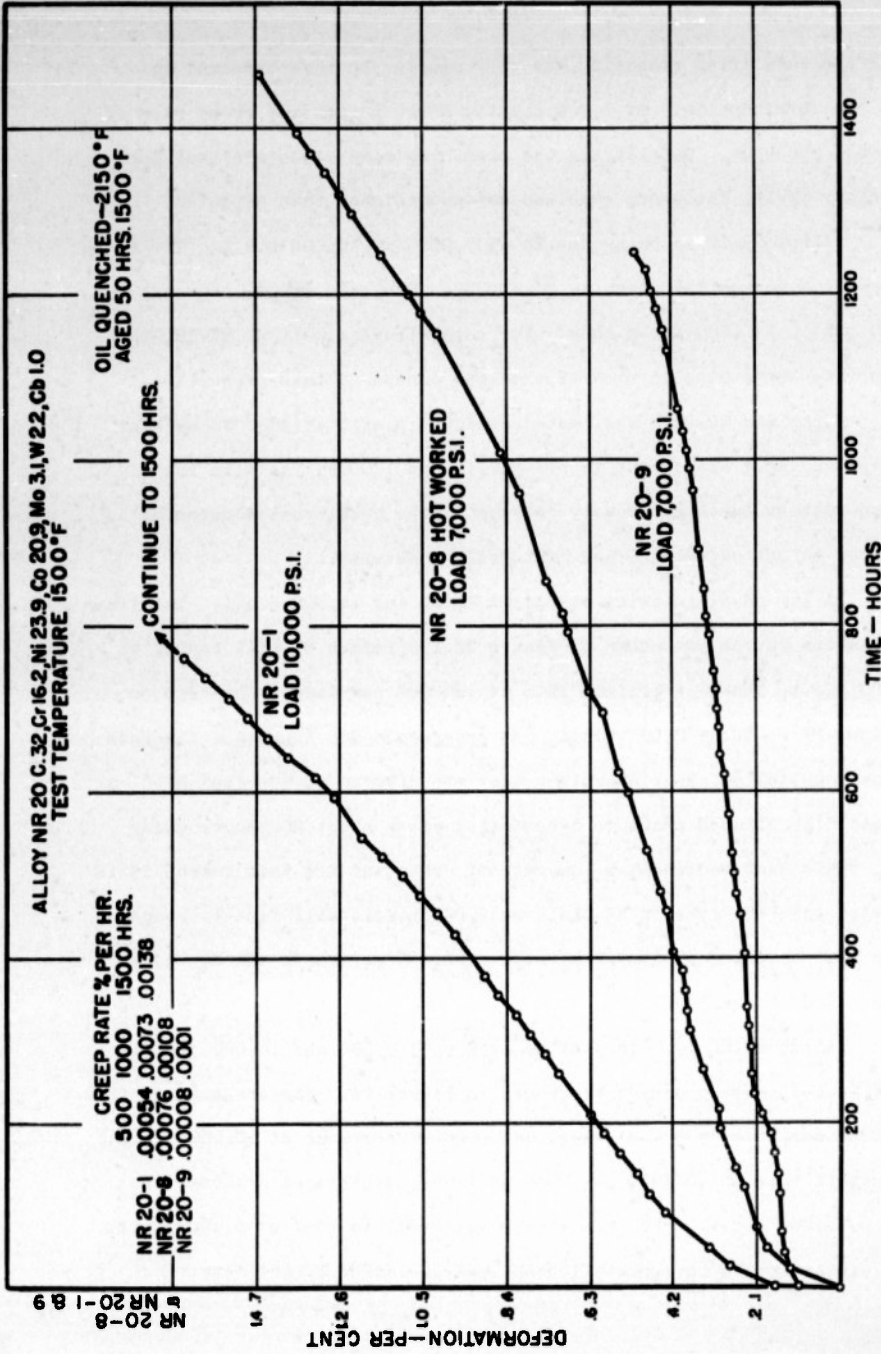


FIG. 32

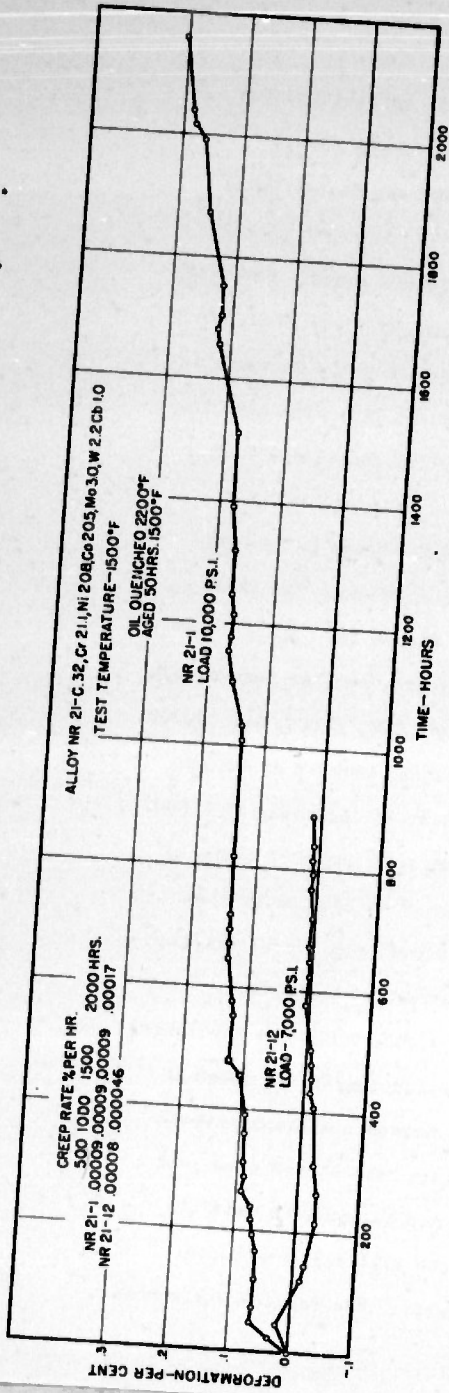


FIG 33

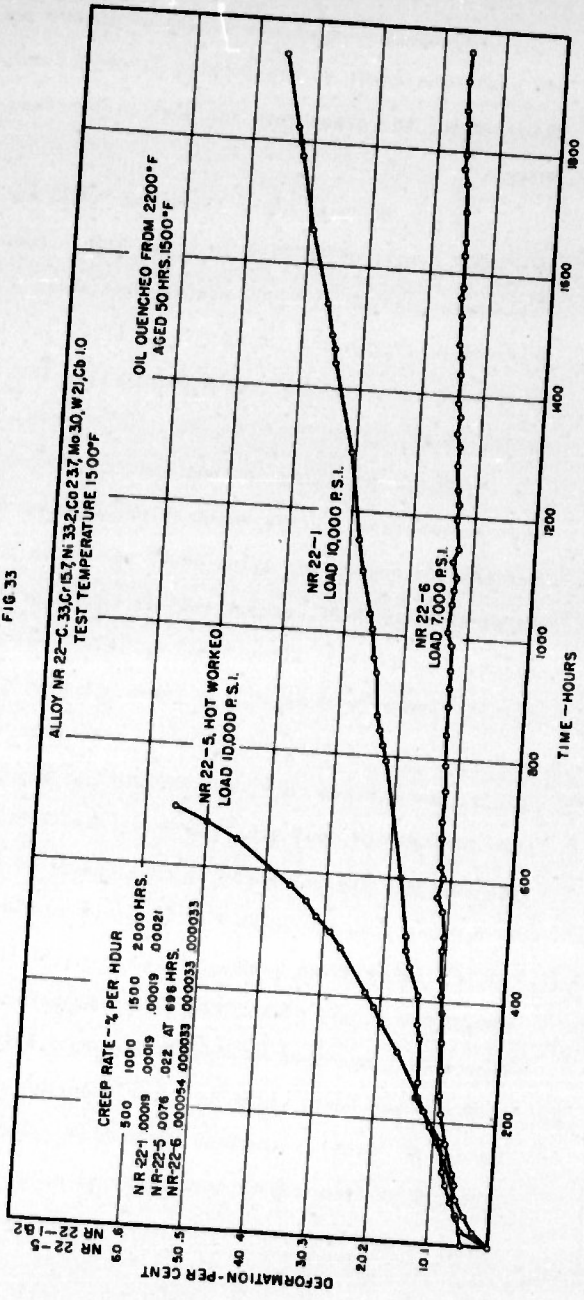


FIG. 34

Specimen NR-22-5 was tested at 10,000 p.s.i. as heat treated and aged subsequent to hot-working (1700°F.) and, as in the case of Alloy NR-20, the creep rate was much higher than for the heat-treated material.

Alloy NR-37 is being tested at 7,000 and 10,000 p.s.i. The rate at 10,000 p.s.i. on NR-37-4 is quite high. Specimen NR-37-3, after about 1000 hours loading at 7,000 p.s.i., has shown a considerable decrease in rate and at 1500 hours is down to .000012% per hour. This will need to be checked by additional tests but if true this alloy, containing C 35, Cr 19, Ni 15, Co 20, Mo 3.66, Cu 1.53, Ta .98, is quite promising.

These promising indications for Alloy NR-37 appear to be somewhat corroborated by the tests in progress on Alloy NR-43. The time-deformation curves for Alloy NR-43 are shown in Figure 35. Alloy NR-43 is similar to NR-37, except that it contains slightly smaller percentages of Mo, Cu, and Ta. Alloy NR-43 is under test at 7,000, 8,000, and 10,000 p.s.i. Probably owing to its lower alloy additions, NR-43-3 at 10,000 p.s.i. shows a considerably faster rate than NR-37-4. However, at 7,000 p.s.i. the minimum rate was .000021% per hour at 1000 and 1500 hours of the test period, but then the rate increased until at 1920 hours when the test was discontinued the rate was up to .00024% per hour. The test at 8,000 p.s.i. on NR-43-6 will assist in appraisal of the alloy.

Alloy NR-45 (S497) is being tested at 7,000, 8,000 (in duplicates) and 10,000 p.s.i. at 1500°F. The time-deformation curves are shown in Figure 36. Specimen NR-45-6 at 10,000 p.s.i. showed a minimum rate of .000062% per hour, which is lower than the creep rate at the same load for NR-34 (S495). Specimen NR-45-5 at 7,000 p.s.i. showed a rate of .000018% per hour up to 1000 hours at which the test was interrupted owing to difficulty with the extensometer strips. The furnace was cooled

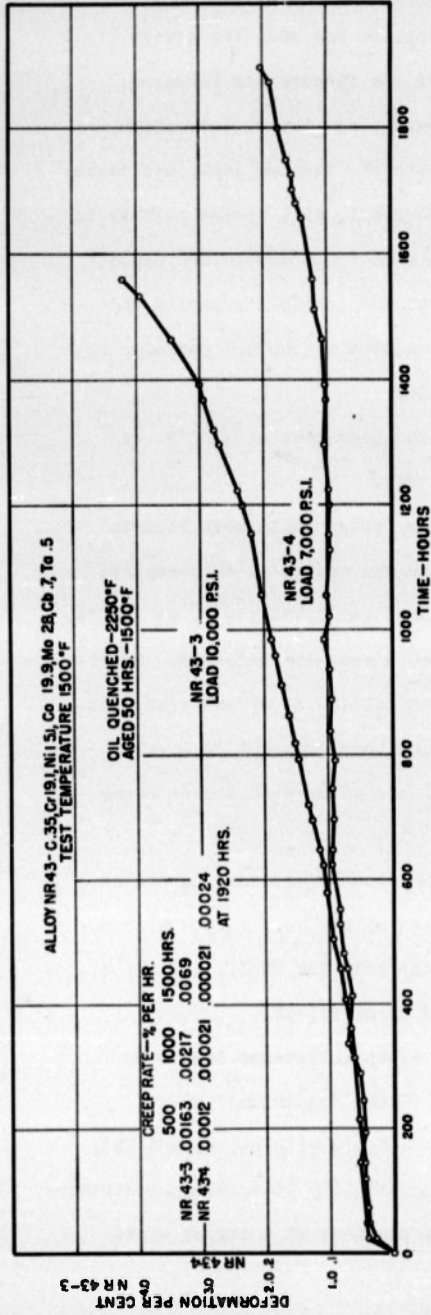


FIG. 35

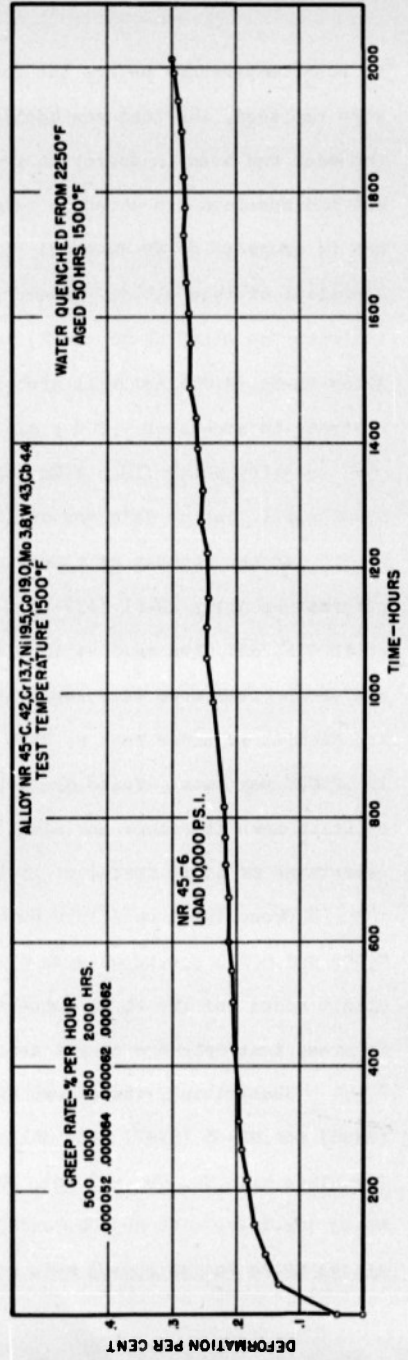


FIG. 36

to room temperature before the load was applied and, when the strips were replaced, the load was applied before the furnace was reheated. The test has been in operation for 800 hours since this interruption and the specimen has shown no measurable creep. The two duplicate tests now in progress on NR-45-4 and 11 at 8,000 p.s.i. will assist greatly in appraisal of this alloy. However, the data at 7,000 and 10,000 p.s.i. indicate the Alloy NR-45 (S497) is equal to, and probably superior to, Alloy NR-34 (S495) and will probably show a rate of .00001% per hour at a stress in excess of 7,000 p.s.i. at 1500°F.

Alloy NR-46 (19-9 W-Mo modified) is under test at 1500°F. at 5,000 p.s.i. but no data are available as yet.

At the request of a Navy contractor, creep tests have been in progress on Alloy NR-51 (ATV-3). The alloy was tested as cold-reduced at 1200°F. and then aged at 1500°F. At 7,000 and 3,500 p.s.i. at 1500°F. the creep rates were very rapid and the tests were discontinued. Specimen NR-51-3 is under test at 1750 p.s.i. and at 400 hours the creep rate is .0002% per hour. Tests are to be made on this material as given a solution heat treatment and aged. This is the alloy with lowest creep resistance of those tested at 1500°F.

Creep tests on Alloys NR-52, 53, 54, and 55 are in progress at 7,000 and 3,500 p.s.i. on each alloy. These alloys were melted with no cobalt added and are to be compared with the data for NR-19, 20, and 21. No creep test data are as yet available on these alloys.

Summarizing, the alloys with best creep resistance are NR-34 (S495) and NR-45 (S497) with Alloy NR-33 (Ganne Columbian), NR-37 (Cr-Ni-Fe with Mo, Cb, and Ta), NR-22 (Cr-Ni-Co-Fe with Mo, W, and Cb), NR-43 (Cr-Ni-Fe with Mo, Cb, and Ta) having slightly lower creep resistance. Alloy NR-34 and 45 show a rate of .00001% per hour at a stress above

7,000 p.s.i. while NR-33, 37, and 43 are close to 7,000 p.s.i. for .00001% per hour.

Creep Tests on Heat-Resisting Alloys for the
U. S. Naval Engineering Experiment Station

The Massachusetts Institute of Technology, one of the NRC-8 cooperating laboratories, is also working in cooperation with U.S.N.E.E.S. on the development and testing of heat-resisting alloys. A series of Cr-Ni-Fe alloys, with varying additions of Co, W, Mo, Cb, and Ta, were prepared and forged and stress-rupture and creep tests have been made at 1500°F.

Two alloys in particular have been outstanding in their tests and these have been assigned numbers NR-57 and 58. Their chemical compositions are shown in Table 1. These alloys contain low carbon and somewhat more chromium and nickel than most of the other alloys tested. They contain 4% of both Mo and W, similar to S495 (NR-34), but instead of containing columbium, additions of tantalum have been made with NR-57, showing 1.9% Ta and NR-58 with 3.67% Ta.

Stress-rupture tests on these two alloys, NR-57 and 58, at 1500°F. and 20,000 p.s.i., while in the heat-treated and aged condition, show fracture times of from 15 to 21 hours. These are in no way outstanding or even so good as many other NR alloys. However, at lower loads at which low creep rates are obtained, the alloys appear very promising. Additional stress-rupture data to bridge the gap between 10,000 and 20,000 p.s.i. at 1500°F. are needed.

Creep tests have been run at 1500°F. on these alloys and their detailed creep test data are shown in Table 7 and their time-deformation curves are shown in Figure 37. At 10,000 p.s.i. and 1500°F., the test on

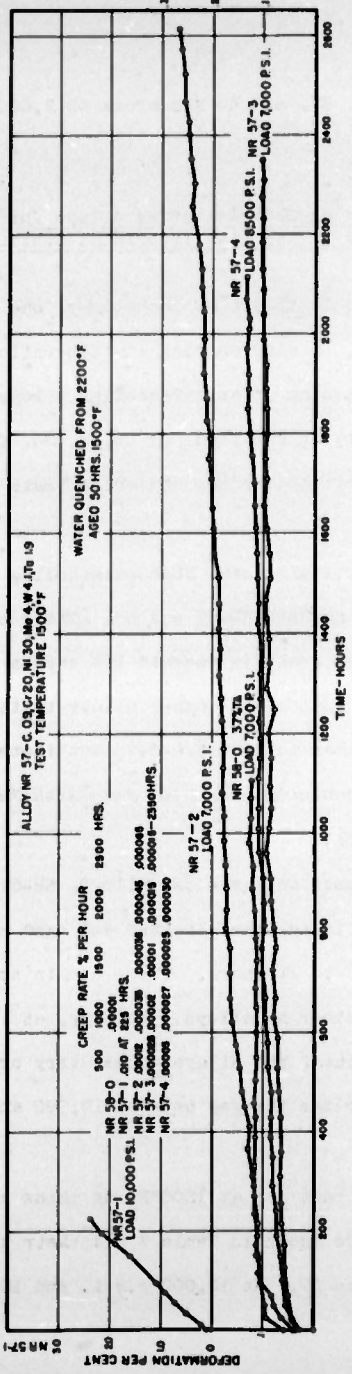


FIG-37

NR-57-1 shows an unusually rapid rate of creep (.01% per hour) for this load for a material which shows such a low rate of creep at slightly lower loads. A test now in progress on NR-57 at 12,000 p.s.i. at 1500°F. indicates that this rapid rate on NR-57-1 at 10,000 p.s.i. was in error owing to some cause unknown at this time. Specimen NR-57-4 at 8,500 p.s.i. showed a minimum rate of about .000025% per hour at about 1500 hours of a total test duration of 2110 hours. Specimens NR-57-2 and NR-57-3 were both tested at 7,000 p.s.i. at 1500°F. NR-57-2 showed a minimum rate of .000035% per hour at about 1000 hours, after which the rate increased slowly until at the termination of the test at 2640 hours the rate was .000065% per hour. Specimen NR-57-3 at the same load of 7,000 p.s.i. showed a minimum rate of .00001% per hour at about 1500 hours with only a slight increase to .000015% per hour at the end of the test at 2315 hours. The cooperating laboratory reports that the difference in creep properties between NR-57-2 and 3 was probably owing to lack of proper control of the solution heat treatment temperature in NR-57-2. It is felt that the data for NR-57-3 are more representative of the particular composition and heat treatment.

Specimen NR-58-1, with the higher tantalum content, shows a rate of .00001% per hour at about 1000 hours of test. This test is continuing.

These two alloys are interesting because they show creep properties about as good as the best of the other NR alloys which contain higher carbon, around 0.35 to 0.40%. One of the difficulties in the use of these heat-resisting alloys will be fabrication and processing. If, by the choice of proper combinations of alloying elements, the desired creep properties can be obtained, better forgeability and processing may be the result. This is an important item and warrants careful consideration.

The indicated properties of these alloys containing tantalum should be checked by the melting and preparation for test of a duplicate heat and this will be done immediately.

Creep Tests

Creep Tests at 1350 and 1600°F.

Creep test specimens of Alloys NR-34 (S495) and NR-45 (S497) have been sent out for creep test at 1600°F. and 5,000 p.s.i. No results are available at this time.

No creep tests are in progress at 1350°F., but as stress-rupture data from the few alloys under test in the NRC program become available and the data on the greater number of alloys in the N.A.C.A. program become available, creep tests will be started on those alloys indicated of interest.

Hardness of Heat Resisting Alloys as Heat-Treated and After Stress-Rupture and Creep Tests at 1500°F.

Test specimens of some of the NR alloys have been tested to determine the changes in hardness resulting from long-time exposure at the test temperature of 1500°F. under stress in the stress-rupture and creep tests. Data for thirteen different alloys are shown in Table 8.

Of the alloys tested, only Alloys NR-15 (Timken 18-25-6), NR-33 (gamma columbium), NR-43, and NR-44 show any appreciable change. Alloy NR-15 dropped from 58.0 to 52.5 Rockwell "A", NR-33 from 57 to 53, NR-43 from 62 to 57, and NR-44 from 66 to 59.5. These are not large reductions in hardness as a result of the rather long times at the temperature of 1500°F.

Isod Impact Resistance of Heat Resisting Alloys After Creep Tests

Two round Isod impact test specimens 0.450 inch diameter ("V" notch) are being cut from the gage length of creep test specimens or stress-rupture test specimens after test and tested in impact at room temperature.

Only six specimens have been tested to date and the results obtained are shown below.

Material	Alloy No.	Hours at 1500°F. in Creep Test	Stress p.s.i.	Isod Impact Resistance Ft. Lbs.
N-154	NR-20-1	1500	10,000	10.5
N-155	NR-21-1	2160	10,000	9.4
Gamma Columbium	NR-33-1	2050	7,000	14.0
S-495	NR-34-9	2280	10,000	4.0
8658-1	NR-43-5	1801	10,000	5.0
8497	NR-45-1	597	15,000	7.2

TABLE 8. ROCKWELL "A" HARDNESS OF HEAT-RESISTING ALLOYS BEFORE AND AFTER STRESS-RUPTURE AND CREEP TESTS AT 1500°F. FOR THE DURATIONS INDICATED

Material	Alloy and Specimen Number	Type of Test	Stress, p.s.i.	Duration, Hours	As Heat Treated and Aged	Rockwell "A" Hardness	
						Threads	After Test Shoulder Gage Length
Ti-6Al-4V	NR-15-16	S-R	7,000	580	58		52.5
19-9 W-Mo	NR-16-2	S-R	13,000	40.5	60	60.5	60
Refractory B	NR-17-1	S-R	20,000	8.3	68	68	67.5
	NR-19-3	S-R	17,000	251.5	59	58	58
N-153	NR-20-3	S-R	16,000	361.5	61	60.5	60
	NR-20-1	Creep	10,000	1500	61		59
N-154	NR-21-1	Creep	10,000	2160	59	59	58
	NR-22-1	Creep	10,000	2000	60	60	59.5
Gamma Columbium	NR-33-19	S-R	10,000	1905	57	57	55.5
	NR-33-1	Creep	7,000	2060	57		53
S495	NR-34-8	S-R	13,500	1423	61	62	60
	NR-34-9	Creep	10,000	2280	61		59
6638-1	NR-43-3	Creep	10,000	1601	62		57
	NR-44-1	S-R	14,000	418	66	60.5	59.5
S497	NR-45-2	S-R	20,000	43.5	62	62.5	62
	NR-45-1	S-R	15,000	597	64		63

Unfortunately, no data are available as yet for these materials tested with the same impact specimen size and shape in the as-heat-treated condition and before test for comparison with the data shown above. All possess some measure of ductility and as in the impact tests shown previously for some of the alloys in the as-heat-treated condition, the Gamma Columbian alloy (NR-33) shows the best residual impact resistance after test of the few alloys tested to date in this manner.

Short-Time High Temperature Tension Test Data

A previous report on "Compilation of Current Data on Selected Alloys Suitable for High Temperature Service in Gas Turbine and Supercharger Parts" by the War Metallurgy Committee to the National Defense Research Committee of the Office of Scientific Research and Development O.S.R.D. Report No. 722, Serial No. M-12 dated July 22, 1942, contained short-time high temperature tension test data on the following alloys:

17 W, 19-9 W-Mo, Timken 16-25-6,

Gamma Columbian, S495, S497.

Additional data on some of the alloys used in other tests mentioned in this report have been made available by the U. S. Naval Engineering Experiment Station and are shown in Table 9. These include modified Inconel (similar in properties to Nimonic 80, NR-29), ATV-3, (NR-51) N-153 (NR-19), N-154 (NR-20), N-155 (NR-21), and N-156 (NR-22). The treatments used were slightly different from those given in this report but the data serve to indicate the range of properties obtainable. Data on S497 are also included for comparison, since Alloy S497 (NR-45) is one of the best, both in the stress-rupture and creep tests.

TABLE 9. SHORT-TIME, HIGH-TEMPERATURE TENSION TEST DATA FOR HEAT-RESISTING ALLOYS
(Data from U. S. Naval Engineering Experiment Station)

Material	C	Cr	NI	Co	Mo	W	Cb	Heat Treatment	Temp. of Test, °F.	Tensile Strength, P.S.I.	Yield Strength, 0.1% Set P.S.I.	Elong. in 2 Ins. %	Reduction of Area, %	Modulus of Elasticity, Millions P.S.I.
Modified Inconel	15.0	74.42							70	171,000	114,200	27.4	46.7	30.0
								At 1,060° F. - 2 hours, water quenched.	1000	145,500	105,500	15.5 (a)	15.9	28.5
								At 1,776° F. - 2 hours, water quenched.	1200	105,000	85,700	3.5	8.1	20.0
								At 1,776° F. - 2 hours, water quenched.	1350	95,200	73,900	3.0 (a)	3.5	18.0
E148	19.48	40.34	22.55						1600	84,000	47,500	4.5 (a)	7.7	16.5
									1700	55,400	36,800	3.0 (a)	7.4	13.5
								At 1,228° F. - 2 hours, water quenched.	70	152,500	97,500	31.0	39.4	31.0
								At 1,228° F. - 2 hours, water quenched.	1100	126,000	85,000	22.0	27.5	25.5
E173	41.14	28.23							1200	128,000	91,200	10.0	15.3	24.0
									1350	101,100	59,700	5.5	10.4	21.5
									1500	71,000	41,280	2.5	4.2	30.0
									1700	25,300		40.5	58.0	--
E174									70	121,700	84,000	21.5	35.6	28.5
									1000	98,450	62,100	21.5	27.8	24.0
									1200	75,200	48,000	25.0	32.2	--
									1500	60,000	30,750	28.0	39.4	--
E185									1500	42,600	15,100	31.0	38.5	13.0
									1700	24,100		38.5	43.5	--
									70	122,000	85,000	25.5	31.5	--
									1500	49,000	27,500	35.5	41.8	--
E186									70	127,800	89,000	25.5	28.2	--
									1500	53,400	27,000	40.0	52.3	--
									70	135,000	70,600	15.0	12.6	--
									1500	56,000	29,000	34.2	25.3	--
E187									70	55,000	30,000	32.0	--	--
									1500	55,000	47,500	26.0	32.4	31.0
									1200	85,000	40,500	32.5	35.5	28.5
									1350	64,400	35,000	35.0	32.0	22.5
E188									1500	49,500	25,800	32.5	29.1	17.5
									1700	25,000	15,000	19.5	18.4	--
									70	122,000	85,000	25.5	31.5	--
									1500	49,000	27,500	35.5	41.8	--

(a) Brackets in punch marks.

High Temperature Fatigue Tests

No test program of fatigue tests at high temperatures has been sponsored by NRC-8. Considerable data at 1200 and 1500°F. have been accumulated at the Research Laboratory of the Westinghouse Electric and Manufacturing Company and data at 1200, 1350, and 1500°F. have been obtained by the U. S. Naval Engineering Experiment Station at Annapolis, Maryland.

The work at Westinghouse has been done in a Westinghouse 120 cycle Electromagnetic Bending Fatigue Machine. A complete description of this type of fatigue test equipment was given in a paper by W. P. Welch and W. A. Wilson⁽¹⁾.

The machine may be classed as a fixed cantilever, constant deflection type, designed primarily for the application of alternating bending stress to the specimen. The operating speed of this machine is 7200 cycles per minute. Heating of the specimen is accomplished by means of a simple bell-type electric furnace. Test specimens are 8.75 inches long with a minimum diameter in the test section of 0.550 inch.

Table 10 shows the compositions of the materials tested by Westinghouse. Table 11 shows the heat treatments and the endurance values obtained. Figure 38 shows the endurance curves for the materials tested at 1200°F. by Westinghouse.

The endurance values in Table 11 at 1200°F. range from 23,000 to about 70,000 p.s.i. for tests of 10^8 cycles with only a slight lowering

(1) W. P. Welch and W. A. Wilson, A New High-Temperature Fatigue Machine, Proc. A.S.T.M. vol. 41, 1941, pp. 733-746.

TABLE 10. CHEMICAL COMPOSITION OF HEAT-RESISTING ALLOYS
(TESTED IN FATIGUE BY WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY)

Material	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ti	Fe	
K42B	.06	.83	.62	19.55	41.10	23.36				2.45	15.20	
Hastelloy B	.12	1.20	.52	.27	60.83		27.10			2.45	9.96	
Nimonic 80	.04			21	74							Al .6
S497	.42	.47	.61	13.68	19.50	19.00	3.84	4.28	4.41			
Timken 16-25-6	.08	1.34	.31	17.95	23.15		6.79					
S495	.49	.36	.81	13.76	19.03		4.43	2.83	4.15			
Hooks 502	.15	.61	1.53	18.35	34.42							
18-8 W-Mo	.11	.94	.79	18.94	8.53		.24	1.78				
17W	.46	.58	.43	13.19	19.16		.52	2.46				
Gamma Columbium	.34	.94	.43	16.23	24.56		4.23		1.84			
25 Cr 20 Ni	.23	1.03	1.80	24.66	19.88							
Timken 25-12	.08	1.34	.31	17.95	23.15		6.79					
Modified Inconel	Low	2.2	.58	15.0	74.82					.74	6.0	Al 1.95
Timken 16-25-6	.10	.82	.26	16.52	24.25		6.35					Ni .11
K42B	.02	.78	.69	19.49	40.35	22.25				2.28		
ATV-3	.41	1.48	1.25	14.68	26.33			5.4				
Timken 16-25-6 (Cast)	.10	.24	.82	16.44	25.34		6.6					
Hastelloy C (Cast)	.11	.65	.65	16.79	55.72	10.0	17.96	3.31				V .20
Hastelloy C (Cast) Plus 10% Co												
Hastelloy Stellite 8B Cast			Not Available									
S497	.42	.47	.61	13.68	19.50	19.00	3.84	4.28	4.41			

(TESTED IN FATIGUE BY U. S. NAVAL ENGINEERING EXPERIMENT STATION)

TABLE 11. ENDURANCE PROPERTIES OF HEAT-RESISTING ALLOYS AT HIGH TEMPERATURES
(Tested by Westinghouse Electric and Manufacturing Company)

Material	Heat Treatment		Endurance Values at 1800°F.		Endurance Values at 1500°F.	
	Solution Treatment	Aging	at 10 ⁶ Cycles	at 2.5 x 10 ⁶ Cycles	at 10 ⁶ Cycles	at 2.5 x 10 ⁶ Cycles
K423	1790°F.-1 hr.-Water quenched	90 hrs.-1290°F.	71,000	70,000		
Hastelloy B	2000°F. -Water quenched	4 hrs.-1200°F.	66,000	64,000		
Inconel 80	1950°F.-4 hrs.-Water quenched	20 hrs.-1300°F.	87,000	86,000		1000°F.
Inconel 80	1950°F.-4 hrs.-Water quenched	50 hrs.-1500°F.			29,000	1000°F.
S497	2000°F.-1 hr.-Water quenched	16 hrs.-1300°F.	50,000	49,000		
S497	2250°F.-1 hr.-Water quenched	16 hrs.-1500°F.				
Tiokon 16-25-6	2000°F. -Water quenched	4 hrs.-1200°F.	46,000			1500°F.-30 min.
Tiokon 16-25-6	2150°F.-4 hr.-Water quenched	50 hrs.-1500°F.				
S496	2000°F.-1 hr.-Water quenched	16 hrs.-1300°F.	42,000	41,000		
S496	2280°F.-1 hr.-Water quenched	16 hrs.-1500°F.				
Rockline 502	2000°F. -Water quenched	4 hrs.-1200°F.	39,000			
17 W	2000°F. -Water quenched	4 hrs.-1200°F.	36,000			
Gamma Columbian	2000°F. -Water quenched	4 hrs.-1200°F.	37,000			
25 Cr - 20 Ni	2250°F.-4 hr.-Oil quenched	50 hrs.-1500°F.	33,000		21,000	1550°F.-30 min.
Tiokon 25-12	2000°F. -Water quenched	4 hrs.-1200°F.	29,000			
Tiokon 25-12	2000°F. -Water quenched	4 hrs.-1300°F.	23,000			

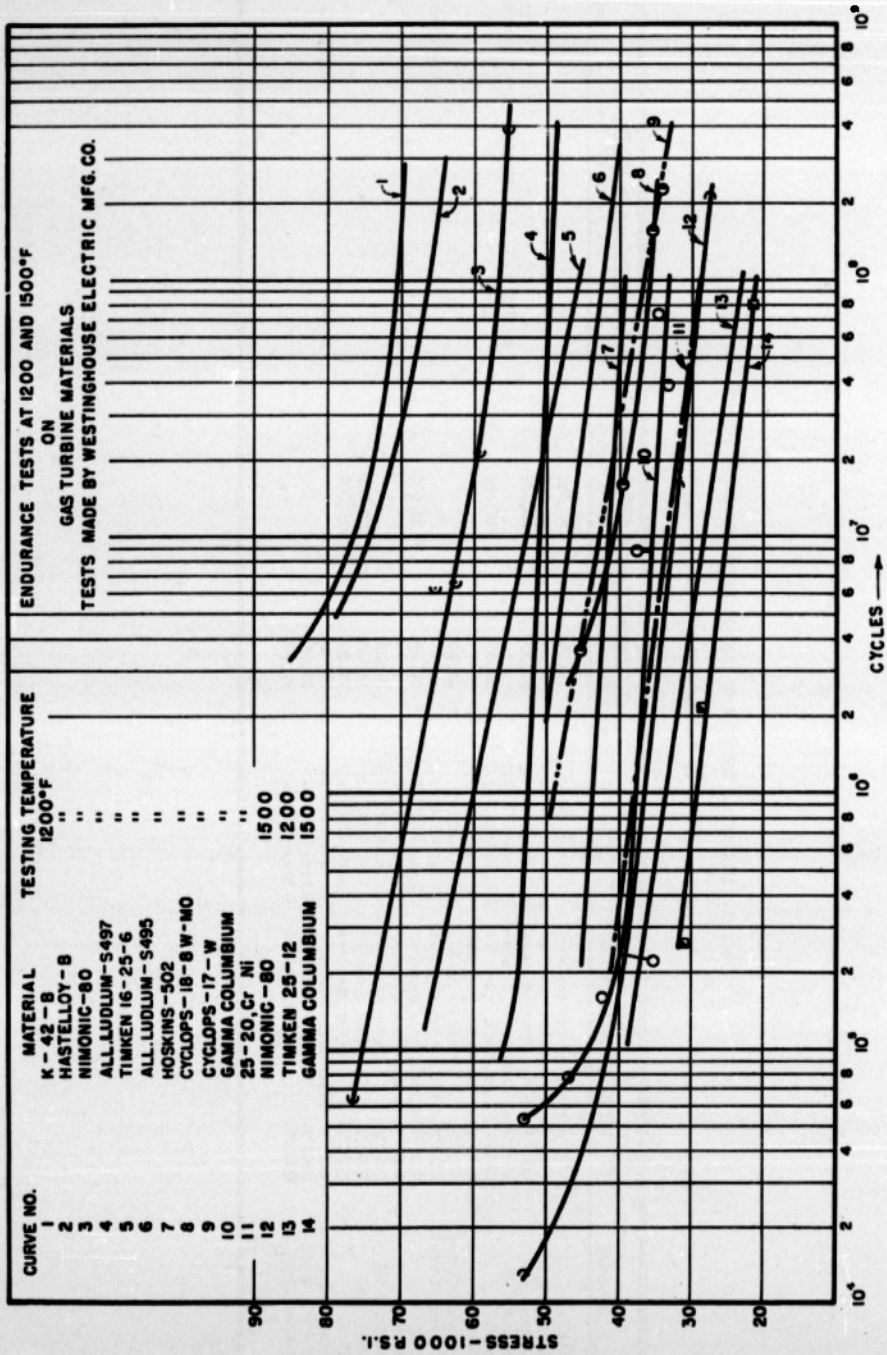


FIG. 38

of the stress as the number of cycles is increased to 2.5×10^8 . It will be noted that some materials show values above 40,000 p.s.i. while about an equal number of those tested show endurance values below 40,000 p.s.i. This is of considerable interest when it is considered that only a few of the materials tested to date at 1200°F. show stresses producing rupture in 1000 hours over 40,000 p.s.i. For instance, the well-known alloys such as Timken 16-25-6, Gamma Columbium, 18-9 W-Mo, and S497 all show fractures in 1000 hours at stresses less than 40,000 p.s.i. This means that in designing parts for a limited service life in which the stresses used are consequently high, it is well to remember that if the part is subjected to fatigue stresses, the endurance limits should be taken into consideration.

There is another disturbing factor indicated by these fatigue tests and the tests run by the U. S. Naval Engineering Experiment Station. Fatigue tests run at room temperature on steels develop an apparent endurance limit or limiting stress range below which a material will not fail even after many million stress reversals. But for fatigue tests made within the range 1200 to 1500°F., there is no apparent tendency for the stress-cycle-to-fracture graphs to level off and the plotted results tend to fall along a straight line. Fractures have been obtained after 2.5×10^8 cycles at 1200°F. Until tests of greater duration are available, it is conservative to assume that at still lower stresses fractures may occur after a considerably greater number of stress reversals.

When these materials are to be used for types of service in which long service life is desired, the lower stresses dictated by the creep rates allowable usually give an ample margin of safety as compared with the

endurance limit and in these cases the creep rate rather than the endurance limit is the limiting factor in design.

The endurance values in Table 12 were obtained at the U. S. Naval Engineering Experiment Station using a rotating cantilever type of test. In this test the range of stress alternates between tension and compression with each cycle. The test machines are motor driven and operate at 1500 r.p.m. Values are shown for tests principally at 1350 and 1500°F. As in the tests by Westinghouse, at these high temperatures there seems no indication of an endurance limit. For the limited comparisons available to date, it appears that at the higher temperatures, the fatigue resistance does not fall off as rapidly as the stress-rupture and creep properties, so that these rather than fatigue are the limiting factors in design.

Additional tests on other alloys are in progress at both laboratories and these will be supplemented in the near future by tests by NRC-8 at 1200, 1350, and 1500°F. on materials indicated of interest by the N.A.C.A. and NRC-8 programs of tests and not already included in the current fatigue test programs.

Corrosion Test in Air-Sulphur Dioxide Mixture

(Experiments at U. S. Naval Engineering Experiment Station)

Samples of five heat-resisting alloys were subjected to corrosion attack at elevated temperatures in contact with a sulfur-containing gas by suspending them in a tubular electrical resistance furnace through which an air-sulphur dioxide mixture was passed at the rate of 150 cc. per minute. This mixture contained 2 to 3 per cent sulphur dioxide by weight and was passed through water before entering the furnace. The

TABLE 12. ENDURANCE PROPERTIES OF HEAT-RESISTING ALLOYS AT HIGH TEMPERATURES
(Tested by U. S. Naval Engineering Experiment Station)

Material	Preheat	Heat Treatment Solution	Aging	Endurance Values at		
				1200° F. 10 ⁷ Cycles 10 ⁶ Cycles	1350° F. 10 ⁷ Cycles 10 ⁶ Cycles	1500° F. 10 ⁷ Cycles 10 ⁶ Cycles
Modified Inconel			2050° F.-2 hrs.-Water quenched 48 hrs.-1350° F.			
Modified Inconel			2050° F.-2 hrs.-Water quenched 48 hrs.-1500° F.			
Modified Inconel (N.T.)			Hot-rolled, 1400° F.-4 hrs. 1300° F.-8 hrs., 1200° F.-12 hrs. 1100° F.-16 hrs.		54,000	<30,000
Timken 16-25-6	1500° F.		2150° F.-Water quenched			
K423			1750° F.-Water quenched		24,000	17,000
AIV-3			2000° F.-3 hrs.-Water quenched 48 hrs.-1425° F.	32,000	25,000	12,500
Timken 16-25-6			2180° F.-45 min.-Air cooled	29,000	43,000	20,000
(Cast)	1550° F.		None - Tested as received		30,000	26,000
Hastelloy C			None - Tested as received		16,000	10,000
(Cast)					17,500*	
Hastelloy C			None - Tested as received			
(Cast)					17,500	15,000
plus 10% Co			None - Tested as received		20,500	13,500
Hastelloy 8B			2200° F.-1 hr.-Water quenched 4 hrs.-1500° F.		26,000	25,000
(Cast)						
S497						

* Estimated

temperature was regulated so that the center of the tube was maintained between 1475 and 1510°F. A water jacket was placed around the protruding outlet end of the tube. Water was circulated through this jacket in order to cool the furnace tube at the outlet end and thus condense the gas. Samples of the five alloys were also placed in the end of the tube surrounded by the water jacket. The temperature for this location was about 70°F. Weight differences for the various alloys after 559 hours exposure in the test are shown in Table 13.

TABLE 13. RESULTS OF CORROSION TESTS IN AIR-SULPHUR DIOXIDE ATMOSPHERE

Material	Change in Weight Per Sq. In., - Grams at Temperature Ranges Indicated			
	70°F. in Condenser	1050- 1075°F.	1325- 1375°F.	1475- 1510°F.
Hastelloy B Ni 68, Mo 25, Al 2.5	-.00615	-.00015	+.0284	*
Nichrome Ni 60, Cr 18	-.0068	-.0802	+.0010	-.0022
Inconel Ni 75, Cr 13, Al 1, Ti .7	-.0104	+.0009	+.0022	-.0016
Timken Alloy Cr 18, Ni 25, Mo 6	-.0007	-.0003	-	+.0023
K 42 B Co 22, Cr 20, Ni 40, Ti 2.5, Al .4	-.0082	-.00045	+.0027	*

* Tungsten supporting rod stuck in hole - weight changes not obtained.

These results show no significant attack except in the case of Hastelloy "B" which for the 1475-1510°F. temperature range exhibited marked growth and exfoliation at the edges.

An experimental unit for simulating the gas jet action of a gas turbine was also used at the U. S. Naval Engineering Experiment Station for testing blade materials. With this apparatus, using gas derived from the combustion of oil as in the case of an actual turbine, it is possible to subject blades of various alloys to gas temperature and velocity conditions simulating an actual installation. The tests to date have been made on Hastelloy "B", Timken 16-25-6, K 42 B, and ATV-3 alloys using gas at 1350°F. impinging on the blades for 996 hours at a velocity of 1380 foot per second. The tests prove the Hastelloy "B", which contains no chromium and high nickel, to be unsuitable for gas turbine parts subjected to 1350°F. temperature gas. The gas causes the material to swell up and exfoliate at the blade edge. The Timken 16-25-6 and the K 42 B alloys withstood the gas attack satisfactorily. The ATV-3 alloy (16 Cr, 25 Ni, 3 W) showed numerous small pits where the gas impinged. Tests are in progress or planned at 1500°F. on several additional materials including Timken alloy, Hastelloy C, Vitallium, Gamma Columbium, S495, and S497.

Research on Chromium-Tungsten Alloys

This project is being conducted in the Research Laboratory of the Climax Molybdenum Company and is for the purpose of finding and developing metallic alloys capable of sustaining sensibly greater loads at temperatures up to 1600°F. than iron-, nickel-, or cobalt-base alloys could be expected to sustain.

At the start, alloys of low melting point were excluded from consideration and iron-, nickel-, and cobalt-base alloys were already being studied in the NRC-8 program. Of the remaining elements, the outstanding metal with respect to melting point is tungsten. Limited data indicated pure tungsten had good strength at 1500°F. but not better than can be obtained by the best of the well-known Cr-Ni-Fe alloys. Tungsten-base alloys seemed more likely to produce the desired properties. After due consideration, the first alloys were prepared alloying chromium with tungsten.

In the first trials, mixed tungsten and chromium powders were melted by resistance fusion in vacuum. Then powdered metal pellets were melted in vacuum inside a cylindrical carbon resistor. A series of alloys so prepared showed a maximum Vickers hardness of 437 for an alloy with chromium 40, tungsten 60.

Further experiments have developed a melting procedure in the induction furnace using zirconia crucibles surrounded by a carbon cylinder. All melting and casting has been done in a vacuum (1 mm. Hg pressure or less). Nonmetallics have been reduced by the use of MgO bonded zirconia crucibles and by deoxidation of the melts with carbon. The chromium and tungsten powders contained over 0.5 per cent oxygen. Porosity was eliminated and finer-grained alloys were obtained by vacuum casting in big-end-up steel molds.

Some qualitative oxidation tests were made in air at 1600°F. on pure tungsten, pure chromium, and three Cr-W alloys. The results are tabulated as follows:

Oxidation Test, 100 Hours at 1600°F.

Tungsten	Badly oxidised after 24 hours
Chromium (0.05% C)	0.00338 g./sq.in. loss in weight
Cr 90, W 10	0.00860 " " " " " "
Cr 80, W 20	0.00892 " " " " " "
Cr 70, W 30	0.0233 " " " gain " "

A series of chromium-tungsten alloys was prepared, machined into stress-rupture test specimens and submitted to the University of Michigan for test. These test specimens have a diameter of 0.160 inch diameter with a 1-1/8 inch gage length. The alloys submitted and the data obtained are shown in Table 14.

All tests were run at 1600°F. and 20,000 p.s.i. except on Heat No. 91 which was at 17,500 p.s.i.

When the tungsten contents are below 20 per cent the stress rupture times are short. Heat No. 176 with 19.04% W showed a fracture time of only 17.0 hours, whereas Heat No. 162 with 23.06% W showed a fracture time of 478.5 hours and Heat No. 166 with 23.67% W showed 555.3 hours. A test on Heat No. 159 with 26.43% W is still in progress at 1150 hours and Heat No. 169 with 23.20% W is still running at 640 hours.

Such fracture times as are shown by these Cr-W alloys with over 20 per cent tungsten are outstanding when compared with the values for Cr-Ni-Fe alloys at 1500°F. The best alloys tested to date at 1500°F. are the S495 and S497 alloys which show a fracture time of 500 hours at about 15,000 p.s.i. The Cr-W alloys containing about 23 per cent W showed about equal fracture times at a temperature 100 degrees higher or at 1600°F. and at the higher stress of 20,000 p.s.i. As far as resistance to fracture is concerned, these alloys show an outstanding improvement in properties.

TABLE 14. STRESS-RUPTURE TEST DATA FOR CHROMIUM-TUNGSTEN ALLOYS

Heat No.	C	W	Cr	Si	Mo	Fe	Temp., °F.	Stress, p.s.i.	Fracture Time, Hrs.	Elong., %	Reduction of Area, %
91	.05	24.4	58.0	0.3		16.2	1600	17,600	643		
158	.05	21.6	59.66		2.36	15.75	Not tested as yet				
159	.09	26.43	55.71		2.06	14.58	1600	20,000	115.0	In progress, unbroken	
162	.05	23.05	59.98			15.36	0.17 A1	20,000	478.5	<1.0	<1.0
166	.02	23.67	60.14			15.30	1600	20,000	555.3	<1.0	Fractured in fillet
167*	.09	22.08	62.17			14.74	Not tested as yet				
168C*	.12	12.01	59.33				Not tested as yet				
168D	.12	12.01	59.33			27.92	1600	20,000	13.0	<2.0	
176	.05	19.94	71.21			7.89	1600	20,000	17.0	Nil	Nil
177A	.05	6.20	77.96			14.71	1600	20,000	6.5	<1.0	Nil
169	.03	23.20	67.70			8.50	1600	20,000	840	In progress, unbroken	

* Heat treated, 164 hours at 1600°F.
All other heats tested as cast

Their only drawback is their lack of ductility. Even in those heats with the lower tungsten contents and with short fracture times, the ductility was practically zero. It was thought that the introduction of iron to replace a portion of the chromium would improve the ductility but this was not the case. These alloys as cast are relatively coarse grained. It is thought possible that centrifugally cast alloys, which would be finer grained, might also be more ductile in the stress-rupture tests.

Equipment is being assembled to produce centrifugal castings in vacuum. When the equipment is available, stress-rupture test specimens with finer grain will be prepared. At the same time preparations are being made to produce in vacuum centrifugally cast Type B 2 supercharger blades from Cr-W alloys which would be tested in a supercharger now installed at the U. S. Naval Engineering Experiment Station at Annapolis, Maryland and which will be run on hot gas formed by the combustion of oil as would be used in a gas turbine.

Research on Tungsten-Rich Alloys

The Vanadium Corporation of America is also investigating tungsten-rich alloys and a number of tungsten-titanium-iron alloys, tungsten-chromium-nickel alloys, tungsten-chromium-nickel-cobalt alloys, and tungsten-chromium-nickel-cobalt-boron alloys have been prepared. The compositions of the alloys prepared and their hardnesses at room temperature and 1500°F. are shown in Table 15.

As shown in Table 15, a wide range of compositions have been covered. The tungsten-titanium alloys prepared at first did not show promising hot-hardness values.

TABLE 16. EXPERIMENTAL HEATS PREPARED BY VANADIUM COPROBATION AND TESTED FOR HARDNESS AT ROOM TEMPERATURE AND AT 1600°F.

Heat No.	C	Si	W	Cr	Ni	Co	Ti	B	V	Fe	Condition	Hardness 70°F.		Brinell at 1600°F.
												Vickers	Rockwell C	
AM-3			18.68				8.72				Quenched and tempered			425
AM-4C			32.35				2.88				Quenched			304
AM-6			16.17				4.87				Quenched			258
AM-6			37.86				2.63				As-cast			73
AM-7K			70.60				1.80				As-cast			114 (a)
AM-8			18.70				7.78				As-cast			313
AM-8			16.70				8.45				As-cast			80
AM-9A			24.24				10.02				As-cast	84		415
AM-10			27.99				2.48				As-cast			247-278
AM-10X			70.87				1.12				As-cast			222
AM-10A			72.00				3.60				As-cast			60
AM-14			54.07				2.10				As-cast			80.98
AM-18EM			37.7				-				Chill cast			106
Binary Fe-S			42.90				1.80				Chill cast			478-625
AM-23	0.55		29.25	24.72			2.00					793-834		478
AM-23			32.00	30.00			2.00					820		358
AM-23 (b)			28.78	28.50			0.92	2.32				738	87	300
AM-23R			26.23	28.98	34.50		0.52	2.18				538	81	330
AM-26	0.26		36.88	29.77	34.88		0.86	2.56				780	89	388
AM-27	0.10		27.20	29.17	4.80	81.11		2.58				860	51	341
AM-28	0.08		29.35	30.45	34.04							800-1000	63+	418
AM-30 (b)			32.00	30.00								800-1000	36	207
AM-30C			28.14	29.94	37.79	33.48						600-650	81	300, 613
AM-31			28.90	30.24								680-770	37	300, 613
AM-32X			22.85	31.17			1.10					580	57	147
AM-32R			20.60	29.85				2.23				580	58	890, 408
AM-34			29.26	30.73	14.77	19.78		2.44				580	51	188
AM-36	0.10		10.82	26.12	33.62	53.10		2.87				580	51	222, 231
AM-37	0.25		11.34	24.41	27.44	28.18		2.66				580	30	207
AM-37R	0.37		11.34	23.79	31.42	29.18		2.43				580	30	130
AM-38E	0.09		29.45	23.18	68.08			4.64				580	60	243
AM-39	0.19		34.08	30.01	19.08	18.78			1.88			580	60	388, 372
AM-40	0.36		31.38	35.98	7.16	20.40						580	60	209
AM-41	0.19		23.09	30.86	17.26	28.54		2.48				580	60	886
AM-42	0.29		16.76	30.35	20.32	20.83		2.40				580	54	278
AM-43	0.40		29.43	30.42	34.00	23.47		2.62				580	54	627
AM-43R			63.69	26.48	20.62	14.72		2.60				580	54	390, 408
AM-45	0.81		27.68	30.35	19.12	17.80		1.22				580	54	300, 313
AM-46	0.37		27.68	30.30	18.87	18.87		1.34				580	54	408, 427
AM-47	0.21	0.14	28.16	30.26	20.89	18.00		0.94				580	54	278
AM-46	0.21	0.14	28.16	30.26	20.89	18.00		0.94				580	54	278

(a) 1000 kg. load

(b) Charged analysis

The tungsten-chromium alloys with additions of some or all of nickel, cobalt, titanium, and boron show the best hot-hardness values at 1500°F. Brinell hardnesses at 1500°F. as high as 475 to 525 were obtained by Heats AN-22 and AN-23 with about W 30, Cr 30, Ti 2. Heats AN-30, AN-30 R, AN-35, AN-45, and AN-47 all show values for Brinell hardness at 1500°F. over 400.

Efforts are now being concentrated on producing cast specimens suitable for stress-rupture testing from those compositions indicated most promising.

Effect of Heat Treatment Variables
on Structure and High Temperature
Properties of Heat Resisting Alloys

Westinghouse Electric and Manufacturing Company under Project NRC-41 is studying the effect of heat treatment variables on the structure and high temperature properties of the three heat-resisting alloys Timken 16-25-6, Gamma Columbian, and S 495 alloys. Bar stock of the latter two alloys is available and the work is in progress. The chemical composition of the two alloys is as follows:

	C	Mn	Si	Cr	Ni	Mo	W	Cb
Gamma Columbian Heat A9707	.35	.68	.52	15.0	25.7	3.88	-	1.88
S 495 Heat 22786	.46	.61	.69	14.0	20.2	3.65	3.74	4.20

Experiments were made to determine the effect of solution heat treatment temperature and time at that temperature on the structure of Gamma Columbian alloy. Table 16 shows the results obtained. Recrystallization starts at 2250°F. and proceeds with increase in temperature and time at temperature. During recrystallization there is a complex mixture

TABLE 16. EFFECT OF SOLUTION TEMPERATURE AND TIME AT TEMPERATURE
ON GRAIN SIZE OF GAMMA COLUMBIUM, HEAT #A9707

Solution Treatment		ASTM Grain Size No.		
Temp., °F.	Time, Hrs.	Fine	Coarse	Mean
2150	2	100% #6+	-	#8+
2250	3/4	50% #8	50% #7	#7.5
2250	4	40% #8	60% #6	#7
2300	4	20% #3-5	80% #1	#2
2370	2	5% #7	95% #2-4	#4
2370	4	-	100% #2	#2
2395	3/4	10% #7	90% #3-5	#5

of grain sizes, which is indicated in Table 16 by the percentage of the area which is relatively fine-grained and of that which is coarse-grained. A uniformly coarsened grain size was obtained after 4 hours heating at 2370°F. and stress-rupture tests will be made on specimens so treated. Because oxidation of specimens heated in air is severe above 2250°F., a protective atmosphere was used in the heat treatments.

Data on the response of Gamma Columbium to aging after solution treatment have been obtained. The hardness tests were made on transverse sections. The data are shown in Table 17. It may be seen that there is no significant hardening on aging after quenching from 2150 or 2250°F. A small and typical reaction to aging is obtained after quenching from 2370 and 2395°F., the hardness increasing about 30 points, diamond pyramid hardness. Maximum hardness is reached in a few hours but the effect of longer aging times is also needed to determine the stability of the alloy for long-time service.

Several stress-rupture tests have been made on Gamma Columbium alloy given several heat treatments and the data are shown in Table 18. The rupture time at 20,000 p.s.i. at 1500°F. increases moderately with the solution temperature as aged either at 1500 or 1700°F., while the ductility decreases. A definite effect of aging temperature is indicated since the rupture times are lower after aging at 1700°F. than at 1500°F. This effect seems to be due to the lower hardness resulting from the higher aging temperature. The increased life associated with an increase in solution temperature may be due to either or both of grain coarsening or of greater increase in hardness on aging owing to the reprecipitation during aging of the material taken into solution which inhibited the grain growth at the lower temperatures. Sufficient test data are not available to evaluate the relative effects of grain size and hardness resulting from

TABLE 17. HARDNESS OBSERVATIONS ON GAMMA COLUMBIUM, HEAT #A9707,
AS QUENCHED IN OIL AND AGED

Solution Treatment		Aging Temp., °F.	Hardness-DPH		Time to Reach Max. Hardness, Hrs.
Temp., °F.	Time, Hrs.		As Quenched	Aged to Max. DPH	
2150	4	1500	195	200	12
2150	4	1600	203	205	32
2150	4	1700	-	203	86
2150	4	1900	197	209	16
2250	0.75	1500	203	220	20
2250	0.75	1600	239?	218	64
2250	0.75	1700	-	212	50
2250	0.75	1900	202	214	16
2250	4	1500	241?	240	4
2250	4	1600	214	208	2-128
2250	4	1700	-	218	50
2250	4	1900	201	213	16
2370	2	1500	179	218	8
2370	2	1600	189	222	1.8
2370	2	1700	188	210	1.5
2370	4	1500	179	224	4
2370	4	1600	193	226	2.5
2370	4	1700	190	217	3
2395	0.75	1500	195	234	3
2395	0.75	1600	201	228	1.5
2395	0.75	1700	197	212	1.5

TABLE 16. RUPTURE TEST OBSERVATIONS ON GAMMA COBALTUM AS QUENCHED IN OIL AND AGED 50 HOURS
TEST TEMPERATURE - 1500°F.

Spec. No.	Solution Treatment		Aging Temp., °F.	Hardness-DPH		Nominal Stress, p.s.i.	Rupture Time, Hrs.	Elongation, %	Red. in Area, %
	Temp., °F.	Time, Hrs.		Quenched	Aged				
B102	2150	4	1500	199	207	20,000	4.8	42	42
B113	2150	4	1700	202	193	20,000	3.9	57	52
B106	2250	0.75	1500	207	200	20,000	6.6	24	30
B107	2250	0.75	1500	199	210	16,000	32.7	21	30
B110	2250	4	1500	202	214	20,000	7.3	23	28
B104	2250	4	1700	201	196	20,000	5.0	31	42
B115	2300	4	1500	176	207	20,000	16	5.3	10.7
B116	2300	4	1700	186	194	20,000	7.0	29	27

aging on the rupture properties.

Specimens of Gamma Columbium are being heat treated at 2350°F. for 4 hours and will be tested in stress-rupture for comparison with the tests already run.

This work at Westinghouse has been started only recently and soon similar experiments will be in progress on all three alloys, Timken 16-26-8, Gamma Columbium, and S496.

FUTURE WORK

Stress-rupture and creep properties will continue to be obtained and amplified on the promising alloys now available and other alloys soon to be obtained. Stress-rupture tests with cyclic stress or cyclic temperature or combinations of the two variables are to be made on a few alloys. Similar tests are to be made on the Cr-W and W-Cr-Ni-Ce alloys. Those alloys of all types indicated promising are to be processed into supercharger blades for insertion and testing in the supercharger installed at the U. S. Naval Engineering Experiment Station.

Promising alloys indicated by the tests at 1500°F. are to be tested in stress-rupture and creep at both 1350 and 1600°F. Stress-rupture tests at 1350°F. on all but a few alloys will be conducted by the National Advisory Committee for Aeronautics. Creep tests at 1350°F. will be included in this NRC test program.

Fatigue test data on all promising alloys will be obtained by arranging for the necessary tests with Westinghouse Electric and Manufacturing Company whenever test data in addition to those already supplied by Westinghouse and the Navy are needed.

General Electric Company is already engaged in determining damping capacity of heat resisting alloys at temperatures up to 1500°F. Their method is so new and the results are of such apparent interest that it appears desirable to obtain an independent corroboration of the General Electric results. Somewhat similar equipment is now being assembled at Battelle Memorial Institute and damping capacity at 1200, 1350, and 1600°F. will be determined on promising alloys.

Short-time tension test properties at 1200 and 1350°F. will be determined and made available by the N.A.C.A. Tests at 1600 and 1600°F. will be made by NRC-8.

Determinations of coefficient of expansion on N.A.C.A. materials tested at 1200 and 1350°F. and NRC materials tested at 1500 and 1600°F. will be made.

Density determinations will be made on all promising N.A.C.A. and NRC materials not included in this report.

The best alloys at 1200, 1350, 1500, and 1600°F. will be tested for impact resistance in both the notched and unnotched conditions at both room temperature and at the various elevated temperatures at which load-carrying ability is promising.

Unnotched bars are to be tested in impact at 1500°F. in two conditions; (1) after exposure of 150 hours at 1500°F. to combustion products of fuel containing tetraethyl lead and (2) to combustion products of bunker "C" fuel oil burned under gas turbine combustion conditions. Some tests may be made later at 1200°F.

The effects of stress-concentration on the stress-rupture properties at 1500°F. of N-155, S495, and Vitallium alloys will be determined. Tests are to be made with various types of notches in the gage length of the stress-rupture specimens.

The following oxidation and corrosion tests are planned.

In their equipment at West Lynn, Massachusetts, General Electric is to run stress-rupture tests on 17 W, Stoddy 72 alloy (.10 C, 6 Cr, 52 Ni, 17 Mo, 6 W, 4 Co), Vitallium (.20 C, 28 Cr, 65 Co, 6 Me), 61 alloy (.40 C, 25 Cr, 60 Co, 4 W), N-153, N-155, S495, Hastelloy B (Ni-base with 25-30 Mo), and X-40 (composition not yet available). These alloys are to be run in air at a constant temperature of 1500°F. and with a cyclic temperature of 600-1500°F. while the specimens are exposed to an atmosphere resulting from the combustion of gasoline containing tetraethyl lead.

The U. S. Steel Corporation is running some oxidation tests on some of the HRC-8 alloys by heating in air at 1500°F.

There is a possibility that some tests may be made in an atmosphere resulting from the combustion of bunker "C" fuel oil in compressed air. These may be either without lead or leaded for stress-rupture testing. The possibility of running such tests at the U. S. Naval Engineering Experiment Station will be investigated.

Progressive oxidation tests should be run at 1500°F. on all promising alloys for comparison with Timken alloy. The effects of surface finish, weld beads (cleaned and uncleaned), metal contact with other composition alloys, flat contacts, wedge contacts, and protective coatings (Cr and Si) are to be investigated.

The following alloys are to be studied; Timken alloy, S495, N-155, Vitallium, 61 alloy, and possibly Hastelloy B.

This is a research job. First the conditions which produce the spongy progressive oxidation will need to be determined, and then corrective measures will be studied.

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** Gas Turbines*

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