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U. S. NAVAL TECHNICAL MISSION TO JAPAN
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24 November 1945

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From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Metallurgy, High Temperature Alloys for Gas Turbines, Rocket Nozzles and Lines.

Reference: (a) "Intelligence Targets Japan" (DNI) of 4 Sept. 1945, Fascicle X-1, Target X-13.

1. Article 1, covering the high temperature alloy section of Target X-13 of Fascicle X-1 of reference (a), is submitted herewith.

2. This report has been prepared by Lieut. J.H. Norwood, USNR, assisted by Capt. Milton S. Zaslow, AUS, as interpreter and translator.

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JAPANESE METALLURGY - ARTICLE 1
HIGH TEMPERATURE ALLOYS FOR GAS TURBINES, ROCKET NOZZLES AND LINES

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE X-1, TARGET X-13, ARTICLE 1

NOVEMBER 1945

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

MISCELLANEOUS TARGETS

JAPANESE METALLURGY - ARTICLE 2
HIGH TEMPERATURE ALLOYS FOR GAS TURBINES, ROCKET NOZZLES, AND LINES

This report covers the agencies developing high temperature metals in JAPAN and shows the state of that development in November 1945. The Japanese were severely handicapped by shortages of nickel and cobalt and were forced to rely mainly on the Cr-Mn steels as heat-resisting materials with a consequent sacrifice in some properties.

TABLE OF CONTENTS

REFERENCES

Location of Target:

Navy Technical Bureau (Air), TOKYO.

First Naval Technical Arsenal, YOKOSUKA.

Navy Technical Department (Ships), TOKYO.

Tohoku Imperial University, SENDAI.

Japanese Personnel Assisting in Gathering Documents:

Rear Adm. Yoshio KUBOTA, IJN, Head, Materials Dept., Navy Technical Dept. (Air).

Rear Adm. I. UBUSUKI, IJN, Head, First Naval Technical Arsenal, YOKOSUKA.

Japanese Personnel Interviewed:

Comdr. Karima KOTA, IJN, Special Steels Section, Navy Technical Dept. (Air); 12 years technical experience; capable engineer.

Lt. Comdr. Y. SATO, IJN, First Naval Technical Arsenal, YOKCSUKA; 13 years technical research experience; very capable.

Dr. Kotaro HONDA, Head of Metals Research Institute, Tohoku Imperial University, SENDAI; Japan's most outstanding metallurgist.

Dr. T. HIRONE, Dr. HONDA'S Assistant at Tohoku Imperial University; very capable research man.

LIST OF ENCLOSURES

(A) Abstract of Researches at Tohoku Imperial University on "Mn-Cr Steels as Heat-Resisting Material".

INTRODUCTION

The content of this report enumerates the high temperature alloys developed in JAPAN for gas turbines, rockets, etc. The best of these materials were incorporated into Navy Specifications. Some of these alloys came into being as a result of the acute shortage of nickel and cobalt which are used in the more conventional types. Much of the research in high temperature alloys had as its purpose the development of a satisfactory alloy containing no nickel and no cobalt.

THE REPORT

Part I. Alloys Developed
IJN Research on High Temperature Alloys

1. Naval interest in high temperature alloys was stimulated by Captain I. TANAGESHIMA who returned from Switzerland in 1940 with a Brown-Boveri turbo-supercharger. At his urging the First Naval Technical Air Arsenal at YOKOSUKA was assigned the problem of developing high temperature alloys and coordinating civilian research in the field. Civilian agencies designated as collaborators were:

a. TOHOKU Imperial University at SENDAI.
b. The Imperial University at NAGOYA.
c. SUMITOMO Steel Company, Ltd.
d. DAIDO Steel Manufacturing Company, Ltd.
e. NIPPON Specialty Steel Company.
f. HITACHI Manufacturing Company.

2. The combined efforts of these agencies, integrated at YOKOSUKA, resulted in the development of the alloys shown in Table I.

TABLE I.
CHEMICAL COMPOSITION OF HEAT RESISTING STEELS

NO.	CLASS SPEC. C	SERIES	C	Si	Mn	Cr	Ni	W	Mo	Ti	V	N2
1	Ni-Cr-W (i-306)	LOW CARBON	.10	.60	.60	17-20	7-10	1.0-1.4	.3-.7	-		-
2	Mn-Cr-W (i-307)	LOW CARBON	.10-.20	.80-1.20	15-17	10-12		1.8-2.2	.5	.4		
3	Mn-Cr-V (i-309)	LOW CARBON	.20-.25	.80-1.20	15-17	10-12					.5-1.0	
4	Mn-Cr-V-N2 (i-311)	LOW CARBON	.10-.20	.80-1.20	13-15 15	10-12					.6-1.0	.10 .20
5	Si-Cr-W (i-342)	LOW CARBON	.15-.22	1.50 -2.5	14.60 13	10-13		.70-1.3				
6	Si-Cr-W (i-322)	HIGH CARBON	.35-.45	1.560 -2.5	.600	10-13		.70-1.3				
7	Ni-Cr-W (i-301)	HIGH CARBON	.35-.45	2.060 -3.0	.6	14-16	13-15	2.0-3.0				
8	Mn-Cr-W (i-308)	HIGH CARBON	.30-.40	1.80-1.72	15-17	12-14		1.8-2.2	.5	.4		
9	Mn-Cr-V (i-310)	HIGH CARBON	.30-.40	.80-1.12	15-17	12-14					1.0-1.5	

3. The physical properties of the alloys in Table I. at room temperature are shown in Table II.

TABLE II.
PHYSICAL PROPERTIES AT ROOM TEMPERATURE

NO.	Y.P.	T.S.	El %	Rd %	Imp.	HB
1	92.5	92.5	57	71.2	840	286
2		100	50	64	466	284-399
3		121	42.7	57	285	352-458
4		128	28.5	42.7	140	383-486
5	92.5	121	25.6	50	140	352-458
6	100	128	21.3	42.7	140	352-458
7		100	25.6	42.7	280	342
8		107	42.7	57	140	313-428
9		128	28.5	42.7	140	383-486

Y.P. - Yield Point (1000lb/sq. in.).
T.S. - Tensile Strength (1000lb/sq. in.).
El. - Elongation in percent (14mmDia).
Rd. - Reduction of area in percent.
Imp. - Impact value (Charpy) (lb-ft/sq. in.).
HB - Brinell Hardness Number.

4. The physical properties at elevated temperature of the alloys in Table I. are shown in Table III.

TABLE III.
PHYSICAL PROPERTIES AT ELEVATED TEMPERATURES

	500°C			550°C			600°C			650°C			700°C
NO.	P.S.	C.L.	F.L.	P.S.	C.L.	F.L.	P.S.	C.L.	F.L.	P.S.	C.L.	F.L.	C.L.
1	21.3	25.6		19.9	21.3		18.5	17.1	38.4	17.1	14.2	34.2	11.4
2	21.3	25.6		19.9	21.3		18.5	18.5	39.9	17.1	15.6	35.6	11.4
3	44.2	34.2		42.8	28.5	52.8	39.9	25.6	49.9	37.0	21.3		17.1
4	49.9	28.4		47.1	39.9		45.6	34.2		44.2	28.5		22.7
5	49.9	27.0		42.8	17.1		28.5	4.27					
6	57	28.5		49.9	18.5		35.6	5.7					
7	47.1			39.9	28.5		35.6	22.7		28.5	18.5		14.2
8	27			25.6	25.6		21.8	21.3	44.2	22.7	15.6		12.8
9	43.5			47.1	35.6		45.6	31.3		44.2	25.6		19.9

P.S. - Proof Stress, in thousands of pounds per square inch where permanent set equals 0.2 percent of original gauge length.
C.L. - Creep Limit, the load at which a specimen creeps at a rate of 50 X 10-4 percent per hour.
F.L. - Fatigue Limit, the maximum load at which a specimen does not break in 10 cycles in a rotary bending fatigue tester of the "one type".

5. Heat treatment of these alloys is shown in Table IV.

TABLE IV.
HEAT TREATMENT

NO.	Annealing Temperature °C	Quenching Temperature °C	Tempering Temperature °C
1	about 1000	about 1000 air cool	
2	about 1000	about 1000 air cool	750-850 air cool
3	-----	-----	as forged about 800-3hr A.C.
4	-----	-----	as forged about 750-3hr A.C.
5	about 750 slow cool	1020-1080 oil quench	700-800 air cool
6	about 750 slow cool	980-1050 oil quench	700-800 air cool
7	about 1000	about 1000 air cool	-----
8	about 1000	about 1000 air cool	750-800 air cool
9	-----	-----	as forged about 800-3hr A.C.

A.C. - Air Cooled.

6. The steps in the manufacture of these steels are as follows:

a. Melting in high frequency induction furnace of 1-ton capacity using a high grade magnesia liner.
b. Casting into round or square ingots and trimming on turning lathe or abrasive planer.
c. Forging with a 3 to 5-ton steam hammer or hydraulic forging press of 1000 to 1500 tons capacity.
d. Stamp-forging of parts in a 20 to 30-ton-meter counter-blow hammer or a 2 to 3-ton drop hammer.

7. The low carbon series was used for gas turbine installations having welded blades and the high carbon series for installations using the mechanical locking method to join blades and rotor. Steels No. 1 and 2 were used for the rotors and blades of exhaust gas turbines. No. 2 and 3 were used for jet turbine rotor blades and for rockets. No. 5 was used for gas turbine rotors alone. No. 6 and 7 were used for inlet and outlet valves and rotors and blades of gas turbines. No. 8 was used in gas turbine parts and No. 9 in jet turbine and rockets parts.

8. Steel No. 1 was considered the best alloy, but steel No. 3 and No. 7 were principally used since sufficient nickel could not be obtained to make steel No. 1 in quantity. Steel No. 4 (containing a small amount of N_2) was considered as having promise but was not developed sufficiently to permit use in practice.

9. Welding of blades to rotors in the low carbon series was accomplished by the atomic-hydrogen process using d.c. current. The chemical composition of the electrode core wire and its physical properties are shown in Table V.

TABLE V.
CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES
OF ELECTRODE CORE-WIRE

	Chemical Composition							Physical Properties	
NO.	C	Si	Mn	Cr	W	Ni	Cb	T.S. 18°C	T.S. 600°C
1	.06	--	--	18		8	0.4	92.3	71
2*	.15	.80 1.20	.16 .18	.10 .12	1.8 2.2	--	--	100	85

T.S. - Tensile Strength in thousands of pounds per square inch.
*Substitute for No.1.

The flux for these electrodes has the following chemical composition and is applied by dipping:

CaF	62% by weight
CaO	28% by weight
$MnCO_3$	2% by weight
$MgCO_3$	1% by weight
TiO_2	5% by weight
Fe_3O_4	5% by weight
Na_2SiO_3	17% by weight (binder)
Total —	120% of dry weight (binder and moisture included)

The all-weld metal from specimens welded with these electrodes had the physical properties shown in Table VI. below.

TABLE VI.
PHYSICAL PROPERTIES OF ALL-WELD METAL (600°C)

Electrode No.	Elongation %	Creep Limit (1000 psi)
1	25	18.5
2	20	25.6

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Part II. Further Research to Conserve Nickel

1. In view of the highly critical nickel situation much of the research was designed to develop alloys containing no nickel as substitutes for the more common nickel-bearing type. To this end research men at Tohoku Imperial University developed the alloy shown in Table VII. to replace stainless steel in the exhaust and combustion chambers of gas turbines.

TABLE VII.
STAINLESS STEEL SUBSTITUTES (Mn-Cr-Alloy)

Chemical Composition						Heat-Treat	Physical Properties	
C	Si	Mn	P	S	Cr	Anneal	T.S. (1000 psi)	Elongation %
.20	1.2	15	.03	.03	12	1000°C	85	30

2. At Tohoku Imperial University, T. MURAKAMI and T. KOINUMARU conducted an extensive series of researches on the Mn-Cr steels as heat-resisting materials. An abstract of their work is contained as Enclosure (A). The results of this work were never translated into any practical alloy.

ENCLOSURE (A)

INVESTIGATIONS OF Mn-Cr STEELS AS HEAT-RESISTING MATERIAL AT TOHOKU IMPERIAL UNIVERSITY

Abstract

The tensile, hardness, and impact values, oxidation-resistance and the creep limit measurements, as well as the microscopic pattern were obtained for steels with the compositions shown in Table I(A) through III(A). The following is a summary of the results obtained.

1. Effects of Mo and W on several properties of Cr-16% Mn-8% steels and Cr-15% Mn-16% steels.

Several properties of steel (16Cr-8Mn and 15Cr-16Mn) with Mo and/or W added were studied and the following conclusions were drawn:

a. On addition of Mo or W, the hardness as quenched is increased, the effect for 16-8 Cr-Mn steels being more marked.

b. On addition of Mo or W, tensile strength and elastic limit at high temperatures increase. For 16-8 Cr-Mn steels the increase is small, though for 15-16 Cr-Mn steels, the effect of Mo is remarkable. The toughness is, however, insufficient, the elongation and the reduction of area being very low.

c. Effect of addition of Mo or W on the creep limit is small and the creep limit at 700°C is low. Steels containing alpha-phase on addition of Mo into 15-16 Cr-Mn steels show low values of creep limit.

d. The oxidation-resistance at high temperatures increases on addition of Mo or W. 15-16 Cr-Mn steels with high Mn content show less oxidation-resistivity than 16-8 Cr-Mn steels. The creep limit is higher in steels consisting of a single gamma-phase than in those consisting of duplex (alpa and gamma) structure. Oxidation-resistance is large in those having a high content of Cr. For heat-resisting materials, therefore, it is necessary to select those consisting of a single stable gamma-phase on addition of proper element into high Cr steel. (Table I(A) gives chemical analysis of the steels studied.)

2. Effect of C, Mo, W, Cu, Al, Si and N on several properties of Cr-10% Mn-18% steels.

Several properties of steels (10Cr-18Mn) with C, Mo, W, Cu, Al, Si, and N added which consist of a single stable gamma-phase were studied and the following conclusions were drawn: (The chemical analyses of steels studied is shown in Table II(A).

a. As carbon content increases, the strength increases and the ductility decreases, the impact value being markedly lowered. The creep limit increases, the oxidation-resistance being decreased. Hence, the carbon content is optimum at one-tenth percent or below.

b. On addition of W, the strength and the impact value at high temperature increase, though the strength at room temperature is lower. The tendency to get ductility by heating at high temperature is almost nil, the creep limit and the oxidation-resistivity being increased. Hence, the addition of less than three percent of W is very benificial.

ENCLOSURE (A), continued

c. On addition of Mo, the strengths at room and high temperature are increased. Until about one and five tenths percent of added Mo, brittleness under extended heating is not observed, the creep limit and the oxidation-resistance being increased. Hence, it is useful to add a maximum of one percent of Mo.

d. Addition of Cu does not increase the strength at high temperature or the ductility. No remarkable influence is observed in the creep limit, the impact value, or oxidation-resistance.

e. Addition of Al increases the strength at high temperature and decreases the impact value. On heating at high temperature, brittleness increases, the creep limit being lowered, but the oxidation-resistance is markedly increased. The amount of Al added should be kept to less than two percent.

f. Addition of Si to less than three percent increases the strength and toughness, though the tendency to become brittle on heating at high temperature increases. The oxidation-resistance is markedly increased and the creep limit decreases. The amount of addition should be kept less than two percent.

g. On addition of nitrogen, the austenite structure becomes stable and the grain size is refined, grain growth being retarded. Consequently, the strength at high temperature and the creep limit are raised. Impact resistance at high temperature does not decrease and no tendency to increase brittleness on long heating at high temperature is observable. The addition of nitrogen into high Mn-Cr steels (as above described) is very beneficial.

3. <u>Effect of Mo, Ni, W on Several Properties of High Mn-Cr-Si Steels</u>.

Effects of Mo, Ni and W on several properties of 16%-Mn, 12%-Cr, 2%-Si steels and 18%-Mn, 10%-Cr, 3.5%-Si Steels were studied. (Chemical analysis of steels studied is shown in Table III(A). The results are summarized as follows:

a. Addition of Mo increases the hardness as quenched and the oxidation-resistance, but decreases the impact value and the creep limit.

b. Addition of Ni increases the strength at high temperature and the impact value, and decreases brittleness under heating. Oxidation-resistance increases without decreasing the creep limit.

c. Addition of W increases the strength at high temperature and the hardness as quenched, decreasing the impact value. Oxidation-resistance increases without decreasing the creep limit. Addition of Ni to high Mn-Cr steels containing more than two percent of Si as used in the present experiment is very effective; addition of Mo or W, however, damages the several properties. It is necessary to decrease the Si content or to increase the Mn content to get a homogeneous austenitic structure.

ENCLOSURE (A), continued

TABLE I(A).
Cr-Mn STEELS WITH Mo-W ADDED

Specimens No.	C%	Cr%	Mn%	W%	Mo%	Si%	P%	S%
A-1	0.10	16.02	8.81	-	-	0.20	-	-
A-2	0.15	17.29	7.67	-	-	0.29	-	-
A-3	0.11	17.79	7.32	1.85	-	0.42	-	-
A-4	0.17	16.72	6.63	-	2.32	0.50	-	-
A-5	0.18	15.64	7.93	1.84	1.15	0.29	-	-
A-6	0.27	19.89	14.28	-	-	0.14	-	-
A-7	0.05	15.08	15.70	-	-	0.42	0.010	0.012
A-8	0.16	14.89	16.10	1.74	-	0.30	0.011	0.009
A-9	0.32	14.48	17.08	-	2.33	0.29	0.013	0.011
A-10	0.37	16.06	18.71	-	-	0.47	0.010	0.012

TABLE II(A).
10Cr-8Mn STEEL WITH C, Mo, W, Cu, Al, Si, N_2 ADDED

Specimens No.	C%	Cr%	Mn%	Si%	P%	S%	N_2%	Other elements
C-0	0.09	9.78	18.67	0.29	0.009	0.002	-	Cu 0.10
C-1	0.29	10.16	18.45	0.22	0.004	0.036	-	-
C-2	0.56	9.92	19.06	0.42	0.005	0.018	-	-
C-3	0.75	10.07	18.58	0.74	0.009	0.037	-	-
C-4	1.04	10.49	18.99	0.24	0.003	0.024	-	-
W-1	0.06	11.33	20.53	0.45	0.014	0.020	-	W 0.94
W-2	0.10	11.52	19.89	0.24	0.019	0.014	-	1.71
W-3	0.09	11.55	20.51	0.30	0.009	0.020	-	2.80
W-4	0.08	11.32	19.03	0.26	0.007	0.019	-	3.73
Cu-1	0.07	11.07	19.78	0.47	0.028	0.017	-	Cu 0.66
Cu-2	0.05	10.85	19.47	0.24	0.023	0.009	-	1.20
Cu 3	0.04	10.90	19.69	0.42	0.028	0.015	-	2.25
Al-1	0.03	10.62	18.25	0.19	0.008	0.012	-	Al 1.15
Al-2	0.06	10.23	17.91	0.19	0.019	0.011	-	2.69
Al-3	0.40	10.29	18.20	0.41	0.017	0.013	-	3.48
Al-4	0.12	10.41	17.71	0.22	0.022	0.011	-	5.16
Mo-1	0.05	10.40	16.71	0.43	0.028	0.011	-	Mo 0.57
Mo-2	0.05	10.48	16.98	0.57	0.040	0.011	-	0.91
Mo-3	0.07	10.77	17.44	0.58	0.031	0.013	-	1.58
Mo-4	0.08	10.32	16.98	0.37	0.029	0.011	-	2.10
Si-1	0.15	10.38	12.05	1.04	0.006	0.003	-	-
Si-2	0.09	10.44	12.06	2.17	0.007	0.005	-	-
Si-3	0.08	10.58	12.85	3.32	0.004	0.003	-	-
Si-4	0.07	10.46	12.66	4.19	0.009	0.009	-	-
Si-1	0.07	10.61	17.25	0.62	0.024	0.010	-	-
Si-2	0.06	10.53	16.78	1.60	0.028	0.011	-	-
Si-3	0.06	10.46	16.26	2.82	0.022	0.015	-	-
Si-4	0.06	10.37	16.97	3.66	0.019	0.011	-	-
N-1	0.07	12.54	16.86	0.24	-	-	0.206	-
N-2	0.04	11.57	17.15	0.23	-	-	0.178	-

ENCLOSURE (A), continued

TABLE III(A).
HIGH Mn-Cr-Si STEELS WITH Mo, Ni, W ADDED

Specimens No.	C%	Cr%	Mn%	Si%	Ti%	Mo%	W%	Ni%	P%	S%
CMS 1	0.06	11.90	18.48	2.21	0.48	-	-	-	0.013	0.052
CMS 2	0.10	12.05	16.84	2.38	0.40	1.05	-	-	-	-
CMS 3	0.05	12.10	17.16	2.13	0.40	2.05	-	-	-	-
CMS 4	0.42	11.05	15.95	3.08	0.35	-	-	1.88	-	-
CMS 5	0.07	11.45	16.99	3.07	0.36	-	-	3.81	-	-
CMS 6	0.06	9.84	18.91	3.83	0.49	-	-	-	0.013	0.066
CMS 7	0.07	9.90	18.93	3.45	0.43	1.07	-	-	-	-
CMS 8	0.08	9.[illegible]3	18.96	3.41	0.46	1.99	-	-	-	-
CMS 9	0.09	9.34	18.59	4.50	0.36	-	-	1.88	-	-
CMS 10	0.07	9.40	19.57	4.80	0.39	-	-	3.73	-	-
CMS 11	0.02	10.08	17.91	3.35	0.44	-	1.03	-	-	-
CMS 12	0.07	9.74	16.46	4.05	0.05	-	2.50	-	-	-
CMS 13	0.04	9.93	18.13	3.20	0.52	-	3.02	2.07	-	-