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

Subject: Target Report - Japanese Steel Manufacturing Methods.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, dealing with Target O-15 of Fascicle O-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Lt. Comdr. L.E. Pleva, USNR, assisted by Lt.(jg) K. Lamott, USNR, interpreter and translator.

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30644

JAPANESE STEEL MANUFACTURING METHODS

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE O-1, TARGET O-15

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ORDNANCE TARGETS

JAPANESE STEEL MANUFACTURING METHODS

This report deals mainly with the Japanese methods of manufacturing steel utilized in the production of common and armor piercing Navy projectiles. Japanese steel manufacturing processes were similar to those used in the United States and England, but from chemical analysis charts obtained through Japanese personnel, the pre-war steels appeared to be refined to a greater degree, the phosphorus and sulphur content being quite low. During the war, when nickel became a critical alloying element, substitute steels with little or no nickel were used. The phosphorus and sulphur content increased, indicating that the Japanese encountered difficulties in obtaining good grades of pig iron. Most of the pig iron used in the manufacture of acid open hearth steel was imported from Manchuria.

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REFERENCES

Location of Target:

Kure Naval Arsenal, KURE.

Navy Yard, YOKOSUKA.

Nippon Special Steel Company, TOKYO. This company is the second largest producer of steel in Japan, and produced steel for both Army and Navy use.

Japanese Personnel who Assisted in Gathering Documents:

Capt. Seiichi TAKEBAYASHI, in charge of steel making department at Kure Naval Arsenal.

Capt. OHIRA, with Administration Section of Materials, Navy Technical Department.

Japanese Personnel Interviewed:

Capt. YAJIMA, commissioned a Lieutenant (jg) in 1926; worked on loading equipment at KURE from 1927 to 1930; inspector of gun barrels from 1930 to 1933; head of projectile factory from 1933 to 1938; in New York inspecting machine tools from 1938 to 1941; in charge of projectile design at KURE from 1941 to 1943; in projectile design section of Navy Technical Department from 1943 to end of war.

Capt. Seiichi TAKEBAYASHI, in charge of melting department at Kure Naval Arsenal through September 1942; head of steel research laboratory through November 1943; in charge of steel making department at KURE to end of war.

Capt. OHIRA, worked at Kure Arsenal from 1926 to June 1943; studied at Berlin Technical College in Germany, mainly in shell production, from 1936 through 1937; in charge of heat treating department of armor piercing shells at KURE from 1930 through May 1943; connected with administrative section of materials in the Navy Technical Department from June 1943 through the end of war. Speciality is electric steel production and heat treatment.

Comdr. M. KONO, worked in melting shop at Kure Naval Arsenal; was manager of melting shop at KURE from 1939 to the end of the war. Speciality is acid open hearth steel manufacture.

LIST OF ENCLOSURES

(A) List of Pertinent Documents Forwarded Through ATIS to WDC.

(B) Nickel, Molybdenum, and Tungsten Saved Special Steels.

INTRODUCTION

The object of this investigation was to obtain data on steel making methods, types of temperature control devices, and slag viscosimeters used by the Japanese. The information was gathered from interrogations of key military and technical Japanese personnel familiar with steel making methods. Data was also gathered from visits to the Yokosuka Navy Yard and the Kure Naval Arsenal.

THE REPORT

All Japanese armor-piercing Navy shells, from 8cm through 36cm, were fabricated from steel manufactured in the basic electric furnace. Common Navy projectiles of all sizes were manufactured from both basic electric and acid open hearth steel.

A. Basic Electric Furnace Steel

1. The sizes of electric (Heroult) type furnaces used in steel manufacture were 30, 15, 10, 8, 6, 3, 1.5, and 1.0 ton capacities. Several of the larger type furnaces were of American make (Bridgeport steel).

2. The steel produced in the larger types of furnaces was generally cast into ingots. Steel produced in furnace capacities of eight tons down to three tons was usually poured directly into shell molds. This process was adapted for shells of 20cm and larger. The one and one-half and one ton capacity furnaces were used mainly for experimental purposes.

3. The raw materials used in production of electric (charge based on SL4 steel) furnace steel were as follows:

Washed steel scrap (low in P & S)	50%
Steel turnings	15-20%
Crop ends (electric steel only)	20-35%

Electrode scrap, small amounts of pig iron, and ferro alloys of known composition were also added in the charge to approach the following calculations: C: 0.5 - 0.6%; Ni: 2.5 - 3.0%; Cr: 0.9 - 1.1%. The washed steel was composed of about 40% Japanese pig iron and 60% scrap melted in a basic open hearth furnace and poured into molds. The approximate analysis of the pig and scrap was as follows:

	Percentage		
	C	P	S
Pig iron	3.5	0.10	0.05
Scrap	0.3	0.05	0.10

4. Slag forming materials (based on the six ton Heroult furnace) were used in the following quantities:

Fluorspar	25kg
Burnt calcite	100-200kg

Both the charge and the slag forming materials were added to the furnace before current was applied. After the charge had become molten, iron ore was added as the oxidizing agent. The iron ore was imported from Manchuria, and was purer than that available in Japan. This oxidation process was continued for a period of one to two hours, during which time test bars were obtained and checked for carbon content. When the carbon content was lowered to about 0.4%, the furnace was tilted and the slag removed.

5. A second batch of slag forming materials in the following quantities was then introduced to the melt:

Fluorspar	20-30kg
Calcium oxide	200kg
Coke	50kg
Aluminum	1.5kg

The aluminum was first melted and a piece of shell steel was immersed in the melt. The aluminum clung to the shell steel and was, therefore, distributed to a greater degree throughout the molten steel. The aluminum served a three-fold purpose: (1) it was a good deoxidizer; (2) it was a good grain refiner; (3) it eliminated some percentage of loss in steel due to piping when the steel solidified in molds. The molten steel was sampled after about forty minutes of the deoxidizing period and also about every half hour thereafter. Ladle samples for "sand tests" were also obtained periodically. These tests were accomplished by pouring some melt into a cavity (formed in a sand block) about one inch in diameter and four inches long. The degree of deoxidation was determined by the depth of cavity (piping) formed when the sample solidified.

6. Total time for the manufacture of basic electric steel was from three to four hours. The temperature range during the melting period was from about 1530°C to 1650°C. Before tapping the melt, the temperature was reduced to about 1580°C.

7. The furnaces were not equipped with recording pyrometers. Temperatures were controlled by the use of optical pyrometers, and also by tungsten-graphite thermocouples; the latter, however, were only used for special tests. Another means employed for checking temperatures was to insert alloy rods of various melting temperatures into the melt periodically. However, recording pyrometers were used for checking temperatures in heat treating furnaces.

8. Slag viscosimeters were not employed in electric steel manufacture. The color of the slag played an important part in steel manufacture. The first slag removed in the electric process was a blackish color. During the deoxidizing period, the operator kept the slag in a slightly carbide condition (white slag) until the melt was tapped. This was accomplished by adding sufficient calcium oxide to the melt to offset the action of silicon oxide tending to combine with the impurities (P & S) in the molten steel. Those impurities were most stable in the form of calcium phosphate and sulphate. Slag viscosimeters were not employed in the production of acid open hearth steel.

9. The chart below lists the chemical and physical properties of steel used in armor-piercing Navy projectiles. Type SL3 was used for projectiles of 20cm and larger; Type SL4 was used for projectiles from 8cm to 20cm. Type SL6 was developed, when nickel became quite critical, as a substitute for the SL4 type. The Japanese did not think it feasible to lower the nickel content in shells 20cm or larger, and therefore did not develop a substitute steel.

Type	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	Y.P. kg/mm^2	T.S. kg/mm^2	Elong. %	R.A. %
SL3	.55/.65	<.8	<.3	<.03	<.03	2.5/3.0	2.0/2.6	<.25		35/70	70/100	>10	>20
SL4	.45/.55	<.4	<.3	<.03	<.03	3.4/4.0	.6/1.0		.4/.8	40/70	70/100	> 8	>10
SL6	.43/.53	<.4	.8/1.2	<.03	<.03	.8/1.2	1.8/2.2		.24/.4	35/70	70/100	>10	>20

The phosphorus and sulphur content in these steels is lower than in similar S.A.E. steels. This would indicate that refining is carried to a greater extent.

10. The designing, forging, machining, and heat treatment of common and armor-piercing projectiles is covered in NavTechJap Report, "Japanese Projectiles - General Types", Index No. O-19.

B. Acid Open Hearth Process

1. Acid open hearth steel was the only other type used extensively in common projectile manufacture. Basic open hearth steel was also used during the last year of the war, but only to a limited extent. The capacities of open hearth furnaces vary from twenty to seventy tons.

2. The charge for the acid open hearth furnace consisted of the following:

	Percent of Charge	Percentage		
		C	P	S
Pig Iron	30-35%	4.3	.025	.035
Washed Metal	20%	.3	.035	.050
Scrap	45-50%	.3	.025	.030

The pig iron used in the charge was obtained from PEN-CH'I-HU, Manchuria. Pig iron from this source was much purer form than that manufactured in Japan (it was lower in P and S content). The washed metal was of the same composition as that used in the electric furnace. Iron ore and limestone were added as the oxidizing agents. The silica sand on the bed of the acid open hearth furnace was the main flux forming material in the acid open hearth process.

3. Iron ore was added to the melt when the carbon content was lowered to about 1%. Limestone was added when the carbon content was lowered to about 0.7%. When it was reduced to about 0.5% the necessary ferro alloys were added to the melt. The melt was tapped approximately thirty minutes after the ferro alloys were added. Total time for the acid open hearth process was between seven and eight hours. Melting temperatures ranged between 1620°C and 1650°C, and tapping temperatures were between 1520°C and 1550°C. A Herty (American manufacture) slag viscosimeter was used extensively for controlling the viscosity of the slag during the steel making process in the acid open hearth process.

4. The types of steels used in the manufacture of common projectiles, with their chemical and physical properties, are listed in the following chart:

Type	C	Si	Mn	P	S	Ni	Cr	Y.P. kg/mm^2	T.S. kg/mm^2	Elong. %	Shock Value ft-lbs
FS$_3$a	.41/.45	.05/.3	.3/.7	<.045	<.04	1.2/1.7	.25	>55	80/100	>10	
FS$_3$b	.53/.58	.05/.3	.3/1.4	<.035	<.03	0/.3	.7/1.0	>55	80/100	>12	
FS$_3$c	.40/.45	.3	.5	<.045	<.04	<1.7	1.0	>55	80/100	>12	
No.1	.45	<.3	.5	<.045	<.04	<1.7	1.0	>50	75/100	>12	10
No.2	.45	<.3	.5	<.045	<.04	<1.7	1.0	>50	75/100	>12	15
No.3	.45	<.3	.5	<.045	<.04	.8/1.7	.5/1.0	>55	80/100	>10	10

The FS_3 types of steels were used before the war. Type FS_3a was used for projectiles from 36cm to 40cm in diameter. Type FS_3b was used for projectiles 15cm to 36cm in diameter, and FS_3c was used for projectiles below 15cm. During the early part of the war, Type No. 1 was used for projectiles below 15cm, Type No. 2 for projectiles of 15cm to 36cm, and Type No. 3 for projectiles 36cm to 40cm in diameter. The only difference between Types No. 1 and No. 2 was that the latter type was to have a shock value of greater than fifteen foot pounds after heat treatment.

5. To economize further on the nickel content of projectile steel, the following types were used during 1943 and 1944:

Type	C	Si	Mn	P	S	Ni	Cr	Y.P. kg/mm^2	T.S. kg/mm^2	Elong. %	Remarks
Sdg 1	.45/.55	.05/.40	.45/.80	< .05	< .05			>35	>65	>12	annealed
Sdg 2	.4/.5	.05/.40	.7/1.2	.045	.045			>50	>70	>10	annealed
Sdg 3	.4/.5	.05/.40	.3/.7	<.040	<.040	.6/1.7	.5/1.0	>55	80/100	>10	annealed
MC	.53/.58	.05/.3	.8/1.4	<.040	<.040	.3	.7/1.0	>50	75/100	>12	annealed

Type Sdg 1 steel was used for projectiles less than 15cm, Type Sdg 2 for projectiles from 15cm to 36cm, and Type Sdg 3 for projectiles from 36cm to 40cm. During the last year of the war, Type MC was also used in production of all sizes of common projectiles.

6. In the manufacture of Type I steel cartridge cases, steel of the following analysis was used:

C	0.08%
Si	0.1%
P	<0.025%
S	<0.025%
Mn	0.3-0.8%

The bases of Type II and Type III cartridge cases were forged from the Sdg 1 steel. The cylindrical portion of Type II and III cases was made from a mild structural steel 1mm in thickness. The complete manufacturing process and heat treatment of cartridge cases is covered in NavTechJap Report, "Japanese Navy Ammunition Cases for 5cm and Larger Caliber Guns", Index No. 0-14.

C. <u>Basic Open Hearth Process</u>

1. In the basic open hearth process, the charge usually consisted of 30% pig iron and 70% scrap. However, the amount of pig varied from 20% to 50%. The slag forming materials consisted of fluorspar, iron ore or mill scale, and limestone, which were added to the molten steel in that order.

2. Very little basic open hearth steel was used in projectile manufacture; it was used only to a limited extent in the last year of the war. The majority of basic open hearth steel was used in the construction of merchant ships.

D. Armor Plate and High Frequency Steel

1. All light armor for airplane construction was produced in the basic electric furnace. The charge consisted of the following raw materials:

Armor scrap and crop ends	30%
Mild steel turnings	10%
Miscellaneous scrap	60%

The same fluxing materials were used as in the manufacture of electric projectile steel. Both carburized and homogeneous armor was used in airplane construction. Homogeneous armor plate was below 8mm in thickness. The carburized armor plate used was 8mm and 16mm in thickness. A detailed report of the manufacturing processes, types of armor used, and the heat treatment methods employed is to be found in NavTechJap Report, "Japanese Light Armor, Article 1", Index No. 0-36-1.

2. All Japanese heavy armor was produced in the acid open hearth furnace. The percentage of raw materials in the charge was as follows:

Pig Iron	30-35%
Washed metal	40%
Miscellaneous scrap	25-30%

The flux used was the same as that employed in the open hearth process for projectile steel. A complete report on manufacturing methods, types of armor used, and heat treatment employed is to be found in NavTechJap Report, "Japanese Heavy Armor", Index No. 0-16.

3. High frequency electric steel was used mainly in the production of machine tools. It was, however, also used in casting various airplane engine parts. The high frequency electric furnaces employed were of 1000 and 500 kilogram capacity. The raw materials used in the charge consisted of alloy scrap and washed metal.

4. Enclosure (A) contains a list of documents concerning research work carried on in various phases of iron and steel manufacture. Some of these documents are recent publications and are possibly of value.

ENCLOSURE (A)

LIST OF PERTINENT DOCUMENTS FORWARDED THROUGH ATIS TO WDC

NavTechJap No.	Title	ATIS No.
ND50-3700	Reports of results of experiments.	3644
ND50-3701	Research on special steels.	3645
ND50-3702	Research on heat-resisting materials for steel manufacture.	3646
ND50-3703	Special steels research information.	3647
ND50-3704	Research into special steels	3648
ND50-3705	Research into heat-resisting materials for steel manufacture.	3649
ND50-3706	Research on special steels	3650
ND50-3707	Research on heat-resisting materials for steel manufacture.	3651
ND50-3708	Research on special steels.	3652
ND50-3709	Research on special steels.	3653
ND50-3710	Research on special steels.	3654
ND50-3711	Research on special steels.	3655
ND50-3712	Research on special steels.	3656
ND50-3713	Research on special steels.	3657
ND50-3714	Research on heat-resisting materials for steel manufacture.	3658
ND50-3715	Experiments on Zirconium steel.	3659
ND50-3716	Research on special steels.	3660
ND50-3717	Research on special steels.	3661
ND50-3718	Research on special steels.	3662
ND50-3719	Research on special steels.	3663
ND50-3720	Research on special steels.	3664
ND50-3721	Research on special steels.	3665
ND50-3722	Research on special steels.	3666
ND50-3723	Research on special steels.	3667
ND50-3724	Research on special steels.	3668
ND50-3725	Inspection of qualities of non-nickel steel.	3669

ENCLOSURE (A), continued

NavTechJap No.	Title	ATIS No.
ND50-3726	Research on measurement of melting steel.	3670
ND50-3727	Research on measurement of melting temperature.	3671
ND50-3728	Research on steel defects (piping).	3672
ND50-3729	Various topics on medium and small calibre forged steel shell materials.	3673
ND50-3730	Research on copper-nickel-chrome steel.	3674
ND50-3731	Reference materials on the mechanical qualities of steel.	3675
ND50-3732	Steel shell cases.	3676
ND50-3733	Construction of iron ore reducers in rotary furnaces.	3677
ND50-3734	Manufacture of sponge iron by rotary furnaces.	3678
ND50-3735	Defects in special type steel.	3679
ND50-3736	Nitrogen break-up in heating of steel.	3680
ND50-3737	Forging temperature for steel and steel alloys.	3681
ND50-3738	Low phosphorus content in nickel iron.	3682
ND50-3739	Manufacture of ferrous nickel.	3683
ND50-3740	Experiments with cast iron.	3684
ND50-3741	Influence of nickel and chrome on heat-resisting qualities of cast iron.	3685
ND50-3742	Cuprose steel experiments.	3686
ND50-3743	Tests with coarse nickel.	3687
ND50-3744	On nitrides of steel.	3688
ND50-3745	Tests on special steels for general purpose bombs which economize on molybdenum.	3689
ND50-3746	Research on scrap.	4150
ND50-3747	Influence of small amounts of nickel on CM steel (chrome-manganese-molybdenum), used as a substitute for nickel in explosive resistant metals.	4151

ENCLOSURE (A), continued

NavTechJap No.	Title	ATIS No.
ND50-3748	Research on manufacture of high quality steels.	4152
ND50-3749	Mass effects on special steels.	4153
ND50-3750	Tool steel (MOB) tests.	4154
ND50-3751	Stainless clad steel.	4155
ND50-3752	Metallic cutting.	4156
ND50-3753	Magnetic tests for steel.	4157
ND50-3754	Changes in fatigue characteristics in tempering steel materials.	4158

ENCLOSURE (B)

NICKEL, MOLYBDENUM, AND TUNGSTEN SAVED SPECIAL STEELS

ENCLOSURE (B), continued

TABLE I

NICKEL SAVED SPECIAL STEEL

Use	Name	Specification No.	Chemical Composition (%)										Heat Treat		
			C	Si	Mn	P	S	Ni	Cr	Mo	W	Ti	Normalizing T. (°C)	Annealing T. (°C)	Quenc I (°C)
Case Hardening Steel	Cr-Mo Steel	I 107	0.17 ~ 0.23	<0.35	0.7 ~ 1.0	<0.03	<0.03		1.0~ 1.5	0.2~ 0.4			850~ 920	850 F.C.	850~920 in oil or air
	Cr-Ni-Mo Steel	I 108	0.14~ 0.2	<0.4	<0.6	<0.03	<0.03	1.8~ 2.0	1.8~ 2.3	0.2~ 0.4			850~ 920	850 F.C.	850~920 in oil or air
Structural Special Steel	Low Cr-Mn-Mo Steel	I 224 KO	0.3 ~ 0.37	<0.35	0.5 ~ 0.8	<0.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water
		I 224 OTSU	0.3 ~ 0.37	<0.35	0.5~ 0.8	<0.03	<0.03		1.0~	0.15~			830~	850	830~880 or water
		I 224 HEI	0.3 ~ 0.37	<0.35	0.5~ 0.8	<0.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water
		I 224 TEI	0.3 ~ 0.37	<0.35	0.5~ 0.8	<0.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water
	High Cr-Mn-Mo Steel	I 225 KO	0.24 ~ 0.34	<0.4	0.6 ~ 1.0	<0.03	<0.03		2.3~ 2.7	0.2~ 0.4			850~ 920	700 A.C.	850~920 in oil or water
		I 225 OTSU	0.24 ~ 0.34	<0.4	0.6~ 1.0	<0.03	<0.03		2.3~ 2.7	0.2~ 0.4			850~ 920	700 A.C.	850~920 in oil or water
	Low Cr-Ni-Mo Steel	I 226 KO	0.26 ~ 0.34	<0.4	<0.8	<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C	820~900 in oil
		I 226 OTSU	0.26 ~ 0.34	<0.4	<0.8	<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C.	820~900 in oil
		I 226 HEI	0.26 ~ 0.34	<0.4	<0.8	<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C.	820~900 in oil
	High Cr-Ni-Mo Steel	I 227	0.25 ~ 0.35	<0.4	0.8~ 1.5	<0.03	<0.03	1.5 ~ 2.0	2.5 ~ 3.5	0.2~ 0.4			850~ 910	700 A.C.	850~910 in air or oil
	Cr-Ni-Mn-Mo Steel	I 228	0.15 ~ 0.22	<0.4	0.8 ~ 1.2	<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.3~ 0.6			850~ 920	650 A.C.	850~920 in air or oil
Heat Resisting Steel	Mn-Cr-W Steel	I 307	0.1 ~ 0.2	0.8~ 1.2	15 ~ 17	<0.03	<0.03		10~ 12	<0.5	1.8~ 2.2	<0.4		1000	1000 in air
	Mn-Cr-V Steel	I 309	0.2 ~ 0.25	0.8~ 1.2	15 ~ 17	<0.03	<0.03		10~ 12	V 0.5~ 1.0				800 3H A.C.	
	Mn-Cr-V-W Steel	I 311	0.1~ 0.2	0.8~ 1.2	13 ~ 15	<0.03	<0.03		10~ 12	V 0.6~ 1.0		N2 0.1~ 0.2		750 3H A.C.	
	Si-Cr-W Steel	I 342	0.15 ~ 0.22	1.5~ 2.5	<0.6	<0.03	<0.03		10~ 12		0.7~ 1.3			750 F.C.	1020 ~ 1080 in oil
	Si-Cr-W Steel	I 332	0.35 ~ 0.43	1.5~ 2.5	<0.6	<0.03	<0.03		10~ 13		0.7~ 1.3			750 F.C.	980 ~ 1050 in oil
	Mn-Cr-W Steel	I 308	0.3 ~ 0.4	0.8~ 1.2	15 ~ 17	<0.03	<0.03		12~ 14	<0.5	1.8~ 2.2	<0.4		1000	1000 in air
	Mn-Cr-V Steel	I 310	0.3 ~ 0.4	0.8~ 1.2	15 ~ 17	<0.03	<0.03		12~ 14	V 1.0~ 1.5				800 3H A.C.	
Stainless Steel Plate	18-Cr Stainless Steel Plate	RO 404	<0.12	< 0.6	<0.6	<0.03	<0.03	17~ 21						750~ 900	
	Mn-Cr Stainless Steel Plate	RO 407	0.1 ~ 0.2	0.8~ 1.2	15 ~ 17	<0.03	<0.03	10~ 12						1000	

F. C. = Furnace Cool A. C. = Air Cool

TABLE I

NICKEL SAVED SPECIAL STEEL

hemical Composition (%)							Heat Treatment					Physical Properties						
P	S	Ni	Cr	Mo	W	Ti	Normalizing T. (°C)	Annealing T. (°C)	Quenching T. I (°C)	Quenching T. II (°C)	Tempering T. (°C)	Yield Point (kg/mm²)	Tensile Strength (kg/mm²)	Elongation (%)	Reduction of Area (%)	Impact Value Charpy (kg/cm²)	Brinell Hardness	Effective Diameter (mm)
.03	<0.03		1.0~ 1.5	0.2~ 0.4			850~ 920	850 F.C.	850~920 in oil or air	800~850 in water or oil		>80	>100	>15	>40	>16		
.03	<0.03	1.8~ 2.0	1.8~ 2.3	0.2~ 0.4			850~ 920	850 F.C.	850~920 in oil or air	780~850 in oil		>90	>110	>12	>40	>7		
.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water		600~ 700	>70	>90	>18	>50	>9	262~ 321	>60
[illegible]	[illegible]		1.0~ [illegible]	0.15~ [illegible]			830~ [illegible]	850 [illegible]	830~880 [illegible] or water		500~ [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water		450~ 550	>95	>115	>12	>40	>5	331~ 401	>50
0.03	<0.03		1.0~ 1.5	0.15~ 0.25			830~ 880	850 F.C.	830~880 in oil or water		350~ 450	>115	>135	>7	>20	>3	375~ 429	>30
<0.03	<0.03		2.3~ 2.7	0.2~ 0.4			850~ 920	700 A.C.	850~920 in oil or water		550~ 650	>80	>100	>15	>40	>7	285~ 363	>120
<0.03	<0.03		2.3~ 2.7	0.2~ 0.4			850~ 920	700 A.C.	850~920 in oil or water		500~ 600	>100	>120	>10	>40	>4	331~ 401	>100
<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C	820~900 in oil		550~ 670	>80	>100	>17	>40	>8	285~ 363	>150
<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C.	820~900 in oil		530~ 630	>95	>115	>15	>40	>6	331~ 401	>150
<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.2~ 0.4			820~ 900	650 A.C.	820~900 in oil		450~ 550	>115	>130	>10	>30	>4	363~ 429	>100
<0.03	<0.03	1.5~ 2.0	2.5~ 3.5	0.2~ 0.4			850~ 910	700 A.C.	850~910 in air or oil		200		>160	>7	>25	>5	444~ 534	>150
<0.03	<0.03	1.8~ 2.3	1.8~ 2.3	0.3~ 0.6			850~ 920	650 A.C.	850~920 in air or oil		200	>100	>120	>13	>40	>8	341~ 415	>150
<0.03	<0.03		10~ 12	<0.5	1.8~ 2.2	<0.4		1000	1000 in air		750~ 850		>70	>35	>45	>10	200~ 280	
<0.03	<0.03		10~ 12	V 0.5~ 1.0				800 3H A.C.					>85	>30	>40	>6	248~ 321	
<0.03	<0.03		10~ 12	V 0.6~ 1.0		H2 0.1~ 0.2		750 3H A.C.					>90	>20	>30	>3	269~ 341	
<0.03	<0.03		10~ 12		0.7~ 1.3			750 F.C.	1020~ 1080 in oil		700~ 800 A.C.	>65	>85	>18	>35	>3	248~ 321	
<0.03	<0.03		10~ 13		0.7~ 1.3			750 F.C.	980~ 1050 in oil		700~ 800 A.C.	>70	>90	>15	>30	>3	269~ 321	
<0.03	<0.03		12~ 14	<0.5	1.8~ 2.2	<0.4		1000	1000 in air		750~ 850 A.C.		>75	>30	>40	>3	220~ 300	
<0.03	<0.03		12~ 14	V 1.0~ 1.5				800 3H A.C.					>90	>20	>30	>3	269~ 341	
<0.03	<0.03	17~ 21						750~ 900					>60	>23				
<0.03	<0.03	10~ 12						1000					>70	>30				

F. C. = Furnace Cool   A. C. = Air Cool

TABLE II

MOLYBDENUM SAVED SPECIAL STEEL

Use	Name	Specification No.	Chemical Composition (%)										Heat Treatment					Physical Properties						
			C	Si	Mn	P	S	Ni	Cr	Mo	W	Al	Normalizing T. (°C)	Annealing T. (°C)	Quenching T. I (°C)	Quenching T. II (°C)	Tempering T. (°C)	Yield Point (kg/mm²)	Tensile Strength (kg/mm²)	Elongation (%)	Reduction of Area (%)	Impact Value Charpy (kgm/cm²)	Brinell Hardness	Effective Diameter (mm)
Case Hardening Steel	Cr-W Steel	I 137	0.17 ~ 0.23	<0.35	0.7~ 1.0	<0.03	<0.03		1.0~ 1.5		0.4~ 0.8		850~ 920	700 A.C.	850~920 in water or oil	800~870 in water or oil	100~ 200	>80	>100	>15	>40	>6		
	Cr-Ni-W Steel	I 138	0.14~ 0.2	<0.4	<0.6	<0.03	<0.03	1.8 2.3	1.8~ 2.3		0.4~ 0.8		850~ 920	700 A.C.	800 880 in oil or air	780~850 in oil	100~ 200	>90	>110	>12	>40	>7		
	Cr-Al Nitriding Steel	I 131	0.35~ 0.45	<0.5	<0.6	<0.03	<0.03		1.4~ 1.7			0.6~ 1.0	880~ 980	750 A.C.	880~980 in oil		700	>70	>85	>15	>50	>10		
Structural Special Steel	75kg Si-Mn-Cr Steel	I 232 KO	0.25~ 0.35	0.7~ 1.0	0.7~ 1.0	<0.03	<0.03		0.7~ 1.0				850~ 900	850 F.C.	850~900 in water or oil		550~ 650	>60	>75	>20	>50	>10	212~ 277	<50
		I 232 OTSU	0.25~ 0.35	0.7~ 1.0	0.7~ 1.0	<0.03	<0.03		0.7~ 1.0				850~ 900	850 F.C.	850~900 in water or oil		450~ 550	>75	>95	>13	>40	>6	269~ 341	<30
		I 232 HEI	0.25~ 0.35	0.7~ 1.0	0.7~ 1.0	<0.03	<0.03		0.7~ 1.0				850~ 900	850 F.C.	850~900 in water or oil		250~ 450	>90	>115	>8	>35	>4	331~ 388	<30
	90kg Si-Mn-Cr Steel	I 234 KO	0.33~ 0.4	0.3~ 0.8	0.8~ 1.2	<0.03	<0.03		0.8~ 1.2				850~ 900	850 F.C.	850~900 in water or oil		600~ 680	>70	>90	>18	>50	>7	262~ 321	<60
		I 234 OTSU	0.33~ 0.4	0.3~ 0.8	0.8~ 1.2	<0.03	<0.03		0.8~ 1.2				850~ 900	850 F.C.	850~900 in water or oil		570~ 650	>80	>100	>15	>45	>5	286~ 341	<50
		I 234 HEI	0.33~ 0.4	0.3~ 0.8	0.8~ 1.2	<0.03	<0.03		0.8~ 1.2				850~ 900	850 F.C.	850~900 in water or oil		450~ 600	>95	>115	>12	>40	>4	331~ 401	<40
		I 234 TEI	0.33~ 0.4	0.3~ 0.8	0.8~ 1.2	<0.03	<0.03		0.8~ 1.2				850~ 900	850 F.C.	850~900 in water or oil		350~ 500	>115	>135	>7	>20	>3	375~ 429	<30
	Cr-Ni-W Steel	I 237	0.25~ 0.35	<0.4	0.8~ 1.5	<0.03	<0.03	1.5~ 2.0	2.5~ 3.5		0.4~ 0.8		850~ 910	700 A.C.	850~910 in air or oil		200		>160	>7	>25	>5	444~ 534	<150
	Cr-Ni-Mn-W Steel	I 238	0.15~ 0.22	<0.4	0.8~ 1.2	<0.03	<0.03	1.8~ 2.3	1.8~ 2.3		0.7~ 1.1		850~ 920	650 A.C.	850~920 in air or oil		200	>100	>120	>13	>40	>6	341~ 415	<100

F. C. = Furnace Cool A. C. = Air Cool.

TABLE III

TUNGSTEN SAVED SPECIAL STEEL

Use	Name	Specification No.	Chemical Composition (%) C	Si	Mn	P	S	Ni	Cr	W	V	Co	Heat Treatment Normalizing T. (°C)	Annealing T. (°C)	Quenching T. I (°C)	Quenching T. II (°C)	Tempering T. (°C)	Physical Properties Yield Point (kg/mm²)	Tensile Strength (kg/mm²)	Elongation (%)	Reduction of Area (%)	Impact Value Charpy (kgm/cm²)	Brinell Hardness	Effective Diameter (mm)
Case Hardening	Cr Steel	I 147	0.17~0.23	<0.35	0.7~1.0	<0.03	<0.03		1.0~1.5				850~920	700 A.C.	850~920 in water or oil	800~870 in water or oil	100~200	>80	>100	>15	>40	>6		
	Cr-Ni Steel	I 148	0.14~0.2	<0.4	<0.6	<0.03	<0.03	1.8~2.3	1.8~2.3				850~920	700 A.C.	850~920 in oil or air	780~850 in oil	100~200	>90	>110	>12	>40	>7		
Structural Steel	High Cr-Ni Steel	I 247	0.25~0.35	<0.4	0.8~1.5	<0.03	<0.03	1.5~2.0	2.5~3.5				850~910	700 A.C.	850~910 in oil or air		200		>160	>7	>25	>5	444~534	<150
	Cr-Ni-Mn Steel	I 248	0.15~0.22	<0.4	0.8~1.2	<0.03	<0.03	1.8~2.3	1.8~2.3				850~920	650 A.C.	850~920 in oil or air		200	>100	>120	>13	>40	>6	341~415	<100
High Speed Steel*	High Speed Steel	I 821	0.65~0.9	<0.35	<0.5	<0.035	<0.035		3.5~4.5	9~12	1.3~1.8			850 880	1240~1290		550~580						<248	>62
		822	0.65~0.9	<0.35	<0.5	<0.035	<0.035		3.5~4.5	10~13	1.3~1.6	3.4~4.0		850 880	1240~1290		560~590						<269	>63

*Forging Ratio = 9 F. C. = Furnace Cool. A. C. = Air Cool.