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U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

January 1946

RESTRICTED

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

Subject: Target Report - Japanese Heavy Armor.

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

1. Subject report, covering manufacturing and testing of Japanese heavy armor plate as outlined by Target O-16 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. M.M. Herman, USNR, assisted by Lt. (jg) R. Boggess, USNR, interpreter and translator, Comdr. N. Hancock, RN, and Lt. Comdr. J. J. Glancy, USNR.

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RESTRICTED O-16

JAPANESE HEAVY ARMOR

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE O-1, TARGET O-16

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ORDNANCE TARGETS

JAPANESE HEAVY ARMOR

Japanese armor for large combat vessels was patterned originally after German (Krupp) and later after English (Vickers) armor. During the war the Japanese suffered from a serious shortage of nickel and short supplies of other alloying elements to a lesser degree. Consequently, a large part of their wartime research concerned itself with trying to maintain ballistic quality with low nickel analyses of their own devising.

Face-hardened armor of about 30% chill was used for nearly all vertical protection heavier than 11". YAMATO class battleships bore 25" face-hardened turret plates. For the last ten years, Japanese face-hardened plate has been non-cemented.

Cruisers had relatively thin armor in contrast to the heavy battleships. Turret-face plates of most of the 8" cruisers were less than 2" thick.

All Japanese production armor steel was made in the acid open hearth furnace. Average sulphur and phosphorous contents each ran below 0.02%. There was a tendency toward fairly high carbon content which was never below 0.30% and usually about 0.45 to 0.50%. Tensile strengths averaged slightly above those of American armor produced during the war, but the ductility was lower, particularly the reduction of area.

Ballistic tests were conducted on a basis somewhat similar to U. S. Navy tests.

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REFERENCES

Location of Target:

Imperial Japanese Navy Proving Ground, KAMEGAKUBI, Kurahashishima, in the Japan Inland Sea near KURE.

Ordnance and Steel Making Sections, Kure Naval Arsenal, Kure Navy Yard.

Japanese Personnel Who Assisted in Gathering Data:

M. KANERO, Civilian Engineer, Kamegakubi Proving Ground and Kure Naval Arsenal. (Many years experience in ballistic testing of armor and A.P. projectiles.)

Kazuo HORIKAWA, Ex-Technical Lt. Commander, Kure Naval Experimental Laboratory. (About 10 years at KURE, a research metallurgist.

Kazuo NAKAMAE, Ex-Technical Commander, Chief Metallurgist Kure Naval Arsenal, directly in charge of armor production. (Many years experience in heat treatment of alloy steels.)

Pertinent Reports of Other Intelligence Agencies:

U. S. Army Technical Intelligence - Ordnance Report No. 7, Part I and Part II. "Metallurgical Development of Japanese Ordnance".

INTRODUCTION

The Japanese claim that almost all blueprints and data on this subject which were not destroyed by air raids were subsequently burned or otherwise disposed of before the occupation. In most cases, there was little evidence to discount this claim. Fortunately, exploration in the rubble and burned buildings at Kure Naval Arsenal and Meguro Research Laboratories revealed a number of documents which supplemented and, what is more important, permitted spot confirmations of the statements made by the persons interviewed so that it is now possible to give general credence to the information obtained from them.

The purpose of this report is to provide the available data on the manufacturing and testing of heavy armor plate for Japanese cruisers, aircraft carriers, and battleships. Samples of the various types of armor produced have been shipped to the United States where tests using American standards may be performed.

Heavy armor for Japanese combat vessels was produced at two plants: Kure Naval Arsenal and MURORAN, Hokkaido. The Kure plant made all types and gauges of armor in large quantities; the Muroran plant turned out only 30% of the Kure tonnage, in gauges less than 8" only, and no face-hardened plate. The processes used at MURORAN were identical to those employed at KURE except for minor differences necessitated by local conditions such as fuel quality, etc.

Experimental and developmental work on heavy armor was carried on at several locations, principally at Meguro Second Naval Research Institute and Sendai Metals Research Institute, where reduced scale studies and fundamental research were conducted, and Kure Experimental Laboratory (in combination with the arsenal and proving ground) where pilot heats and full scale tests were performed together with basic research on production obstacles. (See Enclosure (C).

It is of interest to note that for many years the Yawata Works in northern KYUSHU has produced no heavy armor plate but only thin plating, not classed as heavy armor.

THE REPORT

A. TYPES OF HEAVY ARMOR PLATE

1. Homogeneous

a. NVNC (New Vickers, non-cemented)
b. MNC (Molybdenum alloy, non-cemented)
c. CNC (Copper alloy, non-cemented)
d. CNC_1 and CNC_2, variations of the CNC type (see table of compositions below)

2. Face-Hardened

a. VC (Vickers cemented)
b. VH (Vickers hardened - non cemented)

3. Others

A number of different analyses had been tried, but those noted above were the only ones sufficiently successful for production. Others included face-hardened versions of the molybdenum and copper alloy steels (MH, MH_1, CH_1) and variations of the homogeneous types (MNC_1, CNC_3), none of which were placed in service. The development of these steels is discussed in part C of this report.

4. General

The thinnest armor produced for combat vessels was about one inch thick. For thinner plate, where some fragment protection was desired, a high manganese medium carbon steel was used, called Ducol (symbol DS). Some Ducol was made up to a two inch thickness. For structural members not directly exposed to fragments damage, H.T. steel(high tensile) was used, a plain carbon (0.2%) steel with 0.5 to 0.6% nickel added.

B. ANALYSES

Type	C	Si	Mn	P	S	Ni	Cr	Cu	Mo
NVNC, VC and VH	.43 / .53	under .35	.30 / .45	under .035	under .045	3.7 / 4.2	1.8 / 2.2	under .25	--
MNC	.30 / .38	under .35	.30 / .45	under .035	under .045	3.3 / 3.8	1.8 / 2.3	under .25	.25 / .40
CNC	.38 / .46	under .35	.30 / .45	under .035	under .045	2.5 / 3.0	0.8 / 1.3	0.9 / 1.3	--
CNC_1	.38 / .46	under .35	.30 / .45	under .035	under .045	1.8 / 2.3	1.5 / 2.0	0.6 / 1.0	.10 / .20
CNC_2	.38 / .46	under .35	.30 / .45	under .035	under .045	1.3 / 1.8	1.5 / 2.0	0.6 / 1.0	.10 / .20
DS*	.23 .24	about 0.35	about 1.40	under .035	under .045	Trace	none	about .20	none

*While Ducol Steel is not considered "armor", it is included here for comparison purposes. The data for DS are average values as opposed to specification values for the other steels. The heat treatment operations described hereinafter do not apply to DS. Analysis is made from a ladle sample just prior to casting.

C. = DEVELOPMENT OF JAPANESE ARMOR (dates are approximate)

1900: Two 150mm (5-3/4") Krupp cemented (KC) armor plates were produced, the first real armor made in Japan.

1905: The armor suit for the BB IKOMA, about 2000 tons of KC, and patterned after the above experimental plates, was completed. (Note: Tonnages expressed herein are metric tons of 2200 lbs. unless otherwise noted).

1910: The Vickers Armstrong Co. supplied Japan with a quantity of VC plate.

1915: Patterned after the above, an experimental 200mm (8") VC plate (No.1) was made in Japan.

1925: An experimental NVNC plate with 4% nickel was made in Japan.

1926: An experimental 450mm (18") VC plate was made in Japan, the thickest plate possible at that time. Subsequently, plates as heavy as 26" were made.

1928: Tapered plates were first attempted, the object being "to decrease and properly distribute the weight."

1931: CNC experimental plates were made and ballistically tested in 1.4", 1.7", 2.5", 3.9", and 8.5" gauges, to conserve the nickel supply. The gauges up to and including 3.9" had ballistic qualities equivalent to the NVNC armor but the 8.5" plate was inferior. For this reason, and also to provide some margin of safety, the CNC analysis was adopted for armor under 75mm (3") in thickness.

1937: VH armor was investigated as a substitute for VC. After extensive ballistic tests, it was adopted for production for the following economic reasons:

1. To eliminate fuel consumption used in carburizing.
2. To eliminate carburizing materials.
3. To increase shop capacity.
4. To decrease the time cycle for production.
5. To permit plates which had certain types of defects, such as flaking, to be re-rolled into thinner homogeneous NVNC plates when necessary.
6. To prevent (or lessen the susceptibility of) surface cracking after face-hardening.

As noted above, the NVNC and VH plates have the same analysis, both containing about .50% carbon. Hence it is possible to change a plate from VH to NVNC at any time during or even after the processing. VH plate was not adopted in lieu of VC for ballistic reasons. Tests indicated only a slight superiority for VH in heavier gauges (13" to 17") and no advantage or even an occasional inferior result for thinner gauges such as 6"(see NavTechJap Document No. ND50-3173 0.1-0.5-"Reports on Armor Ballistic Tests".) The Japanese claim that the differences observed between plates of the two types were no greater than could be expected of two different plates of the same type. However, it is noteworthy that the Imperial Japanese Navy did not use face-hardened armor of any type thinner than about eleven inches for combat vessels, i.e., only battleships had face-hardened armor, the cruisers and carriers bearing only homogeneous armor, according to information available. Face-hardened plates considerably thinner than eleven inches were produced but only for experimental purposes or projectile tests. The thinnest such plate found was a ten year old 100mm

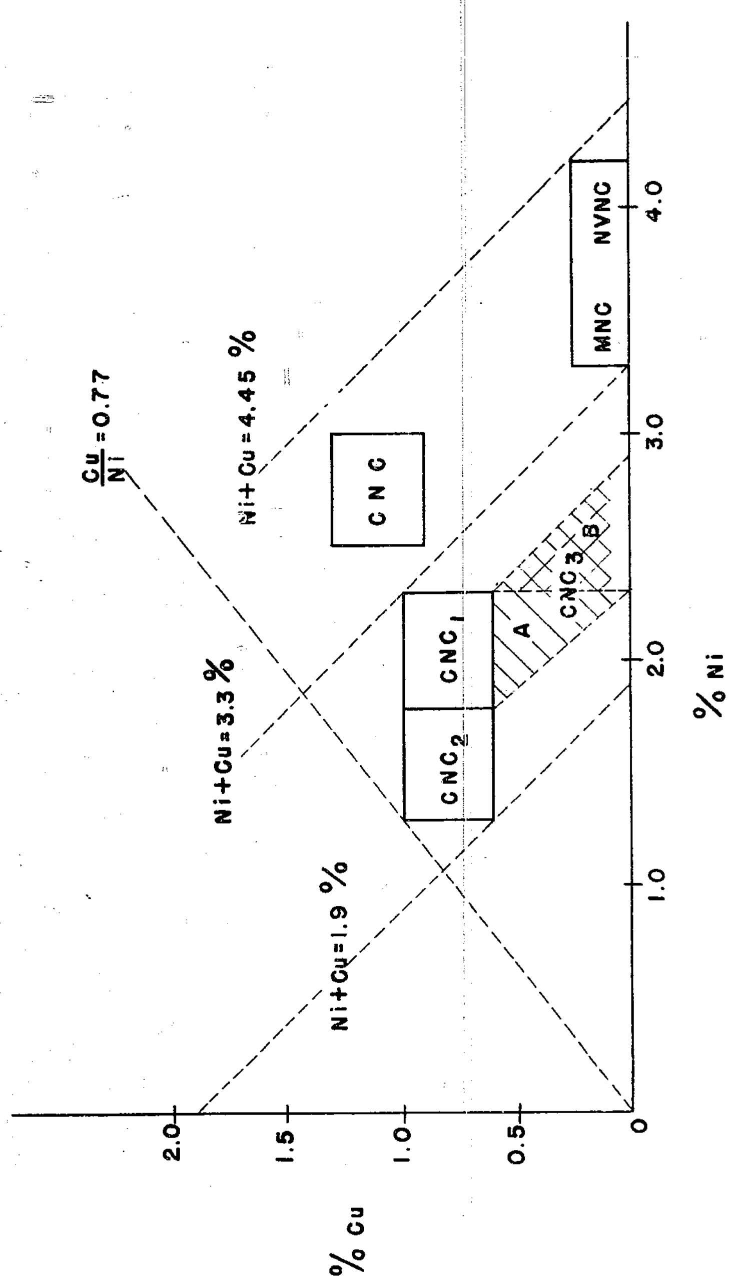

Figure 1
RELATIONSHIP OF COPPER AND NICKEL IN JAPANESE HOMOGENEOUS ARMOR STEELS

(4") VC plate in the Kure plant, awaiting scrapping. The thinnest such VH plate found was a relatively new 183mm (7") plate at Kamegakubi Proving Ground used for projectile testing.

1940: MNC homogeneous armor was produced. The Japanese claim that this armor had superior ballistic resistance for shock or high obliquity impacts. It was used interchangeably with NVNC armor but was preferred for horizontal protection. It was found to be less susceptible to a grain fracture under severe impact conditions than NVNC armor.

1942: In order to further conserve nickel, the CNC analysis was again investigated. As previously noted, this type of steel was deficient in heavier gauges. The analysis was modified (see analysis table) to reduce nickel and still maintain the ballistic quality with the following results:

1. No copper analysis was satisfactory over 4".
2. CNC_1 plates of 1.4", 2", and 3.9" gauges were ballistically equivalent to CNC plates.
3. CNC_2 plates of 1.4" and 2" gauges were ballistically equivalent, but 3.9" plates were inferior to CNC.
4. From these data, the CNC_1 analysis was adopted for gauges from 1.5" to 3.9", and the CNC_2 for gauges from 1" to 1.5". For plates 4" and heavier, the MNC or NVNC analysis was continued.

1943: Further tests were conducted on copper bearing armor intended for use as deck armor through analysis termed "CNC_3". These analyses were characterized by somewhat lower copper content because the Japanese were faced with a shortage of copper, as well as nickel. They had available certain grades of low copper and nickel-bearing scrap which they were forced to use in greater percentages in the material balances.

For these CNC_3 steels, the percentage of Ni + Cu was held to about 2.4 - 2.9%, and the maximum copper content was 0.8%, usually less. Since the CNC_3 steels covered a range which overlapped the CNC, and CNC_2 in some respects, no further distinction is made in this report. In some Japanese literature, CNC_3 is called PL $_{10}$, after its specification number. See NavTechJap Document No. ND50-3422, "Plans for the Manufacture of Experimental Armor Plate (CNC Analysis)".

D. MELTING AND INGOT PRACTICE

1. Except for few experimental heats, all armor steel was made in the acid open hearth (see Enclosure (A) and NavTechJap Report, "Japanese Steel Manufacturing Methods" Index No. 0-15). For heavy plates it was sometimes necessary to use the heats of three furnaces to fill up one mold. The largest furnaces had capacities of 70 tons, with a charge of approximately 65-70% scrap. Single heat ingots were, of course, preferred to multiple heat ingots because sounder steel was thereby obtained and less was wasted in the cropping.

2. The large ingots used for the armor of YAMATO class battleships (VH plates) had the following details:

a. Top pouring mold, big end up.
b. Rectangular section with rounded corners and a slight taper.
c. Approximate Dimensions (data in inches):

	Height	Width	Thickness
Hot Top	52	107	75
Body	143	115/112½	75

d. Weight: 175 tons.

The smaller ingots were similarly shaped and roughly proportional.

3. Including the hot top, 30% of the top and 10% of the bottom of each ingot were cropped. Consequently the largest production plates were nominally about 100 tons, finished. In practice, the 40% total cropping was occasionally reduced to 30% for single-heat large plates.

E. NUMBERING OF PLATES AT KURE

1. Each acid open hearth heat was numbered chronologically. The ingot was assigned the same number as the heat. If two heats were requi[illegible] to fill one ingot, then both numbers were used:

e.g. 52713
52714.

Likewise, the ingot had a triple number if three heats were used.

2. The plates were assigned the same number or numbers as the ingot and, in addition, one or more fractions signifying the following:

a. The first fraction indicated the number of ingots poured from the heat and the order of pouring of the individual ingot:

Thus, 57362-½:

Two ingots were poured from the heat; this plate was made from the first ingot.

b. The second fraction indicated that the ingot was divided into two or more plates:

Thus, 57363 1/1 1/2:

One ingot was poured from one heat and was then divided into two plates. This plate came from the bottom half (1 = bottom) of the ingot.

c. In rare cases, three fractions appeared. The last fraction indicates that, after the division of the ingot and assignment of numbers were complete, it was decided to sub-section one of the plates. Since the original fractions could not be changed, another fraction was added.

3. The approximate dates of the acid open hearth heats can be determined as follows:

Date	Approximate Heat No.
January, 1920	37,000
January, 1925	39,500
January, 1930	42,000
January, 1935	47,500
January, 1940	53,500
January, 1941	54,500
January, 1942	56,500

Date	Approximate Heat No.
January, 1943	58,500
January, 1944	61,000
January, 1945	62,500

Armor production stopped in January 1945, due partly to the termination of large combat shipbuilding at most shipyards and to bomb damage at the yards still in operation. The plant at KURE continued to operate until July 1945 when it was rendered inoperative by bomb damage. However, production capacity by this time had been turned to torpedoes, common projectiles, etc. The last heat was about No. 63,400.

4. Further information from numbering can not be obtained since all types of acid open hearth heats for all purposes were included in this system.

F. ROLLING AND FORGING

1.

Thickness of Plate (Finished)	Operations Performed
Under 8.7"	Rolling only.
Over 8.7"	Rough forging approximately half of reduction, rolling for remainder.

2. Typical example for 16.5" VH plate. The slab weighed approximately 100 tons after cropping and was approximately 75" x 112" x 85" (the latter figure being the ingot length and the forging direction).

a. Heat in a producer-gas fired furnace(as for all below) in 32 hrs. to 1200°C., hold 10 to 15 hrs.
b. Press from 75" to 61". Then second press to 53".
c. Heat in 25 hrs. to 1200°C., hold 8 to 10 hrs.
d. Press to 43.5".
e. Heat in 20 hrs. to 1200°C., hold 8 hrs.
f. Roll to 33.5" (161" wide).
g. Reroll to 23.5" (161" wide).
h. Relief heat in 28 hrs. to 650°C., hold 32 hrs., air cool. Then reheat in 28 hrs. to 650°C., hold 30 hrs., air cool.
i. Scale and scarf.
j. Heat in 25 hrs. to 1200°C., hold 8 hrs.
k. Roll to 16.5" (161" wide and, in this case, 256" long). If this plate were to have been a VC instead of VH, an extra half inch of thickness would have been allowed.
l. Relief heat in 20 hrs. to 650°C., hold 20 hrs., air cool.

3. The heaviest forging was accomplished by a Japanese-made 50,000 ton hydraulic press, the largest in the Empire. Rolling was accomplished in one of two 9000 hp mills. One unit, manufactured by Davy Bros., England, had 48" diameter rolls, 11'10" long. The other unit, copied from the Davy unit by the Japanese, had 48" rolls, 20'7" long. Both were driven by reciprocating steam engines.

4. Maximum Dimensions for Japanese Armor

Thickness	660mm (26")
Width	4,500mm (14'9")
Length	11,000mm (36')
Weight	220,000 lbs.

G. CARBURIZATION

1. VH plates are non-cemented. However, the older type VC plates were carburized at this point in the following manner:

a. Two plates are arranged face to face with the carburizing mixture sandwiched between them, the upper plate supported by angle bars a few inches from the edges. The support method also served to confine the gases.

b. The mixture consisted of three layers from top to bottom as follows:
3/8" to 1/2" of bone ash, 2¼" to 2½" of charcoal, and 3/8" to 1/2" of bone ash, the total being approximately 3".

c. The furnace was fired with produced gas and the plates were held at 930° for two to seven days, depending upon the quality of the compound and the thickness of the plates.

2. The plates were not hot worked in any manner after carburizing.

3. The maximum carbon content of the face usually reached 1.30% and occasionally even higher. The question of austenite retention as a result of the high face carbon content did not seem to concern the Japanese, nor did they appear to be aware of any deficiencies which could result from it.

4. The carbon gradient near the surface of VC plates is shown in Fig. 2. Attention is invited to the range of the depth of cementation, 1/2" to 1". The average was roughly 5/8".

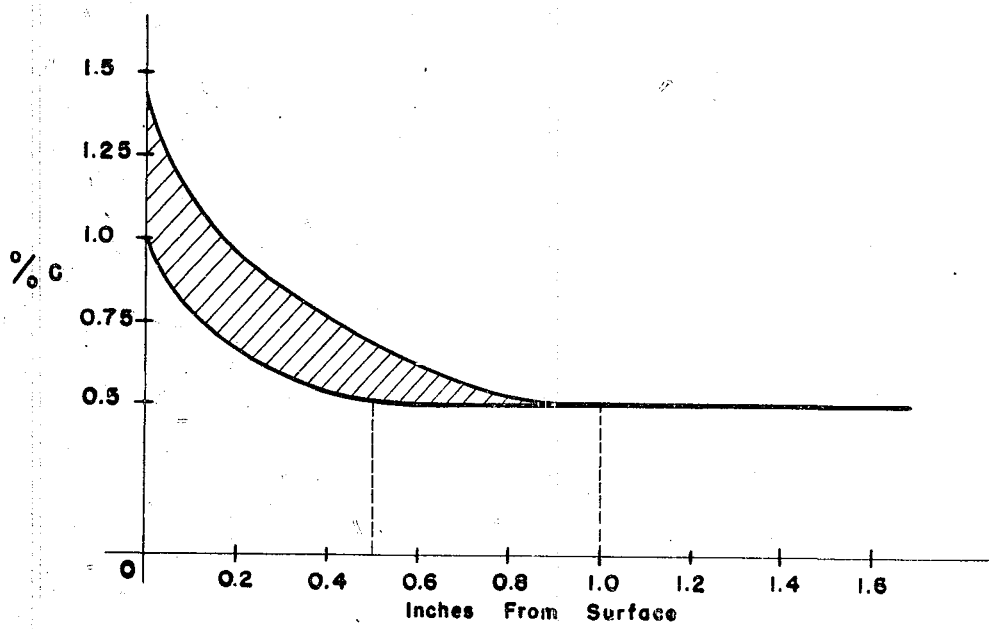

Figure 2
CARBURIZATION RANGE FOR VC PLATES

H. HEAT TREATMENT

1. Heat treatment for all types of armor (except face-hardening) was similar insofar as the sequence of operations and the temperatures were concerned; a few operations were eliminated for the thinner gauges and, of course, the heating and holding times varied accordingly. The usual practice for heating and holding is given in the following typical examples:

Operation	Temperature (°C)	Gauge (in)	Time (hours)	
			Heating	Holding
Quench Heating	840 to 860	1 10 16½	5 10 22	4 8 20
Temper	640 to 670	1 10 16½	6 12 18-20	5 10 16-18

Quenching was done in rape-seed oil for 12 to 14 minutes per inch of thickness. All tempers were followed by water-spray cooling. The quenching in oil of the heavier plates resulted, of course, in the formation of bainite in the middle of the plate. An appended Japanese discussion of this condition, Enclosure (C), states that lower bainite was not particularly objectionable, but upper bainite was the principal underlying cause of brittle fracture under impact conditions for the finished plate. The Japanese translated this deficiency (Shirome) as "temper brittleness", but the two deficiencies, while possibly related, undoubtedly spring from different causes. It could not be definitely determined without placing classified information in jeopardy, whether the confusion arose from the Japanese interpretation of the English expression "temper brittleness" or a difference of opinion on the cause of this phenomenon.

2. All heating was done in producer-gas fired furnaces with a mobile car-type bed. The following sequences were followed: (X means done)

Operation	Armor Plate Thickness (in)		
	Under 2	2 to 8	over 8
a. Oil quenched	X	X	X
b. Tempered		X	X
c. Retempered			X
d. Oil quenched		X	X
e. Rectified and tempered (see note)		X	X
f. Tempered	X	X	X
g. Tempered	X	X	X
h. Tempered			(X over 15.8" only)

Note: Plates thinner than 2" were straightened cold. The rectifying of heavier armor and the temper following it were carried out at 690°C to 700°C, which is somewhat higher than the temperature of the other tempering operations. This arose from some early tests on brittle fractures under impact conditions in which it was found that a short-time temper at a little higher temperature reduced (but did not eliminate) difficulties encountered on this subject. The relatively short period at the higher temperature did not destroy the desired hardness or strength of the plate, according to the Japanese interviewed. Details on this matter are contained in the appended Japanese discussion of "Shirome", Enclosure (C), part B.

3. The heat treatment of homogeneous plate was complete at this point.

I. FACE HARDENING

1. The face was heated in a Siemens-type reverberatory furnace, with recuperator equipment, fired with producer-gas. The heat-treated plate was placed face up on a bed of wet sand of roughly the same thickness as the plate. The edges of the sand and the plate were insulated with fire-brick. The whole assembly was supported on two layers of 3" to 4" steel plates.

2. Two Pt-Pt/Rd thermocouples were used. One was secured to the face of the plate; the other was inserted into a hole through the back of the plate and extended through 70% of the plate's thickness.

3. The furnace was brought to 1100°-1150°C. The above assembly, on a car, was then charged into the furnace, and further heating was applied as rapidly as the furnace construction permitted. The plate was removed when the interior thermocouple registered about 730°C. at which time the face had reached at least 850°C. The plate was immediately water-sprayed, front and back.

4. The hardness pattern obtained is illustrated roughly by Fig. 3.

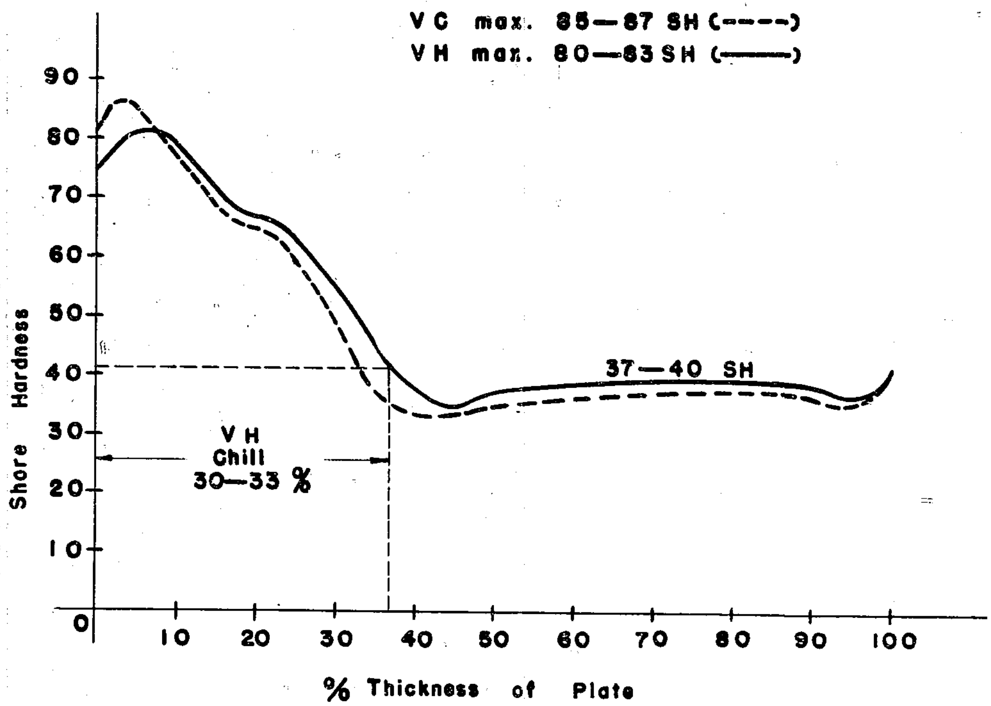

Figure 3

HARDNESS PATTERN FOR VH AND VC PRODUCTION PLATES

Indentation hardness data were not obtained in the armor industry; the available data were in Shore. The desired depth of chill, as determined by the 42 SHN point, was 30 to 33% for production armor. Some experimental plates were made with chills up to 40%, as discussed in Enclosure (C), part C.

5. Plates intended for face-hardening were charged with a concave curve so that the quench would result in a more or less flat plate. However, when necessary, the face-hardened plates were rectified at a low temperature (about 150°C). There appeared to be no other stress relief after hardening. Before the war, however, heavy plates were weathered for six months before being sent to the shipyards in order to determine whether the plates would crack under average conditions (KURE has a climate similar to Washington, D. C.)

PHYSICAL TESTS

1. After the plate had been fully heat-treated, the test samples were obtained. There was no attempt, in the case of VH plates, to obtain these data prior to face-hardening. Further details on physical tests are given in Enclosure (B).

2. Blow-Bend Fracture Test. A specimen, approximately 6 to 8" wide in the rolling direction and 15 to 25" long in the transverse direction was flame cut from two diagonally opposite corners of each plate. A groove was cut about one inch deep on one side normal to the face. The specimen was broken by a hydraulic press with the load applied normal to the face. The fracture was required to have a "deep grayish fibrous structure". The chill depth, in the case of face hardened plates, was also determined by this means. (The Shore data given in Fig. 3 were obtained only for development purposes). No drill or core tests were made.

3. Tensile Test. From one of the broken fracture specimens from each end of the plate, two tensile bars were machined. One of these bars was longitudinal, the other transverse. Thus, four tensile tests were made for each plate. No normal specimens were obtained. The standard bar had a 50mm gauge length and 14mm diameter. The specimens were usually obtained from a layer about 1" from the back surface. The following table was translated from the specifications:

TENSILE SPECIFICATION

Gauge (in)	Type	Min. Yield pt (psi)	Tensile strength (psi)	Min. Elong, 25mm (%)
3"	CNC	85,000	120,000±7,000	19
	NVNC	70,000	120,000±7,000	18
3"-7"	NVNC, VH	64,000	113,000±9,000	19
3"-7"	MNC	70,000	120,000±7,000	20
7"	NVNC, VH	57,000	106,000±10,000	20
7"	MNC	57,000	106,000±10,000	21

Note: Minimum R.A. for all types is 40%.

There is no distinction in these requirements between longitudinal and transverse specimens.

4. Izod Impact Test. A standard impact specimen (10mm x 10mm section, V-notch 2mm deep with 0.25mm bottom radius) was taken adjacent to each tensile specimen. The required minimum averages of the four specimens and the minimum value for any one specimen are tabulated as follows: (The

test was conducted at ambient temperature)

Gauge	Type	Foot pounds	
		Ave.	Min.
under 3"	CNC, NVNC	30	25
3" to 7"	NVNC, VH, VC	33	28
3" to 7"	MNC	35	30
over 7"	NVNC, VH, VC	35	30
over 7"	MNC	40	35

The Izod test was the standard impact test used. Experimental tests were conducted at low temperatures down to 40°C. For average production armor, the Japanese observed no appreciable drop in the impact value at -40°C. Furthermore, the Japanese claim that ballistic quality is independent of Izod impact value as long as it was at least 30 ft/lb. However, the ballistic quality was below average if the impact value fell below 30 ft/lb.

5. Charpy Shock Test. An extra-large Charpy specimen was taken from each end of plates over 8" thick in order to observe the appearance of the impact fracture. The absorption value was of secondary importance in this test. The specimen was 25mm x 25mm x 150mm with a 45° V-notch 3mm deep having 0.05mm bottom radius. The data obtained from this test were for information only and were not required by the specifications. The specimen was broken in a special, large machine. Good steel was expected to absorb about 650 ft/lb. The fracture was expected to show a "deep grayish fibrous structure". A grainy fracture was taken as an indication of Shirome mentioned previously. Like the Izod, the specimen was broken at ambient temperature.

K. BALLISTIC TESTS

1. Projectile.

a. Acceptance ballistic test plates were tested against the appropriate caliber of the Type 91 armor piercing projectiles, which are described in detail in NavTechJap Report, "Japanese Projectiles - General Types", Index No. O-19. The calibers produced were as follows:

Gun	Bourrelet Diameter (in)	Weight complete lbs.
40cm Type 94	18.07	3210
40cm/45 cal	16.11	2245
36cm/45 cal	13.96	1482
20cm/50 cal	7.96	277
15.5cm/50 cal	6.07	123

The 18" projectile was, of course, a 46cm, but was referred to as a 40cm (Type 94) for security purposes. It was nevertheless a Type 91 design. The YAMATO class battleships had 18" main batteries. Consequently armor for these ships was tested against this projectile. Enclosure (B), the specifications for armor plate, omits any reference to this projectile, again for security purposes. Special instruction sheets were issued on 18" test velocities, but none was found, and Japanese personnel interviewed experienced sudden attacks of poor memory when questioned on this point.

b. The 14", 16", and 18" projectiles, Type 91, had armor piercing caps, but the 6" and 8" projectiles had no true caps. All calibers were equipped with "cap-heads". The cap-head looked like a relatively small slice of the forward end of a cap, with a flat rear face. For the major caliber projectiles it fitted flush against the forward face of the cap which also was flat. For the medium caliber projectiles, the cap-head fitted flush against the nose of the projectile, which was flat. The cap-head was weakly secured to the cap or body, as the case may be, merely by the windshield threads which screwed over both parts holding them together. The windshield was weakened adjacent to the cap-head interface, so that when the projectile struck water, the windshield and cap-head would break away leaving a flat forward end on the projectile. This was purported to permit "an undisturbed underwater trajectory" for tactical usage in the case of short near-misses. For low obliquity direct attack, the cap-head probably operated as part of the cap. See NavTechJap Document No. ND50-3178, "Defense Against Projectiles (effect of cap and ogive on penetration formulae)". For high obliquity, the Japanese claim that the cap-head is wiped clear of the impact area and takes very little part in the penetration mechanism. There appeared to be some advantage to the sharp flat shoulder of the cap or body for medium calibers in biting the plate at high obliquity. The projectiles were about 4.3 calibers long and had boat-tails.

2. The standard penetration formula used by the Japanese was the DeMarre equation, expressed in the following form:

$$V_d = 1530 \frac{D^{0.75} T^{0.70}}{P^{0.50}}$$

where V_d is the DeMarre critical velocity (m/s)
- D is the projectile diameter, decimeters
- T is the plate thickness, decimeters
- P is the projectile weight, kilograms

A discussion of the formula is contained in NavTechJap Document No. ND50-3174, "Japanese Discussion of DeMarre's Formula".

a. This formula may be converted to English units by changing the coefficient from 1530 to about 1020, in which case Vd is in ft/sec, D and T are in inches, and P is in pounds.

b. The formula does not correct for obliquity. It is claimed to predict the performance of the very old type 3rd Year Japanese AP projectile (having a cap similar to the U.S. Navy 12" Mk.15 projectile) against homogeneous armor at normal obliquity. It does not apply, therefore, to the modern Japanese Type 91 projectile even at normal obliquity, which appears to require somewhat higher velocities for penetration under these conditions. In order to use the formula for oblique impact with modern projectiles a "Figure of Merit", referred to as F.M. was applied. The F.M. values for most service conditions had been established by the Japanese but most available charts giving these data were claimed to been destroyed (see paragraph c below). The F.M. varies from 1.1 to 1.4 at normal obliquity to somewhat more than 2.5 for the high obliquities. A number of documents (NavTechJap Document Nos. ND50-3173.1-.5) have been obtained containing test reports under various conditions which, if pieced together, might provide a fair picture of the F.M. values. The F.M. values for Limit Velocity are based on criteria similar to that used by the U.S. Navy, i.e., a major portion of the projectile penetrating with zero remaining velocity.

c. The following data on the limit F.M. values of the 20cm (8") projectile, Type 91, against homogeneous armor (NVNC and MNC) for all obliquities were found in NavTechJap Document No. ND50-3178 -

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"Defense Against Projectiles (effect of cap and ogive on penetration formulae)". Apparently, the F.M. had a negligible variation with e/d at constant obliquity -(θ):

θ	F.M.	θ	F.M.
0°	1.30	50°	1.72
10	1.30	55	1.92
20	1.32	60	2.17
30	1.37	65	2.49
40	1.48	70	2.91

3. The Butt. The ballistic tests of heavy armor were conducted at Kamegakubi Proving Ground. The butts at the proving ground consisted of the following parts: (See Fig. 4).

a. Two vertical parallel 16" plates extended about 10 feet above grade, about 11 feet apart. These plates were the main target supports for normal impacts.

b. The gun-side half of these two plates each rested on heavy bed plates about five feet wide which extended out in front of the butt at ground level.

c. A roof plate, about 8" thick, straddled the upright plates. The roof plate was bolted to the bed plates by four heavy connecting shafts.

d. The uprights were braced against impact shock by heavy gun forging cylinders locked into the uprights' after edges and sunk into the ground at a 20° angle.

For oblique impacts, a prefabricated wedge assembly was placed in front of the butt (i.e., between the uprights and the target plate) which gave the correct angle in a vertical plane. The target plate was leaned back against the wedge. Fig. 4 shows a wedge for a 20° impact angle in front of the butt. If the projectile penetrated the plate, the round would pass between the upright plates and hit the ground behind the butt.

The plates were prevented from kicking out at the bottom by heavy timbers braced between the bottom edge of the plate and a sill plate about 20 feet in front of the butt. The test plates had no securing holes in them (except for some of the thinner gauges). They were handled by means of flame cut recesses at the corners and were secured to the butt by heavy wire cables.

4. The velocity was measured for each impact by means of two sets of boulenge chronographs. Two pairs of screens were used with base-lines of about 50 feet. The muzzle-to-butt distance was about 480 feet. No galvanometric or electronic equipment was used at the armor test range. At certain experimental laboratories located at MEGURO and other places, an Aberdeen-type synchronous chronograph and, in rare cases, a solenoid-galvanometric oscillograph were used. No evidence was found indicating the use of electronic equipment for this purpose. The Japanese claimed that the boulenge units gave excellent accuracy, but examination of the equipment and the methods of handling lead to doubt on this point. The tolerance for desired versus obtained velocity on acceptance tests was 2.5 m/s or about 8 f/s.

5. The obliquity was measured by a special quadrant similar to that used by the U.S. Navy except that it was equipped with a telescopic sight (the ocular at 90° to the eye-piece, using a prism reflector). A vernier gave readings to one minute, but the smallest angle read for practical purposes

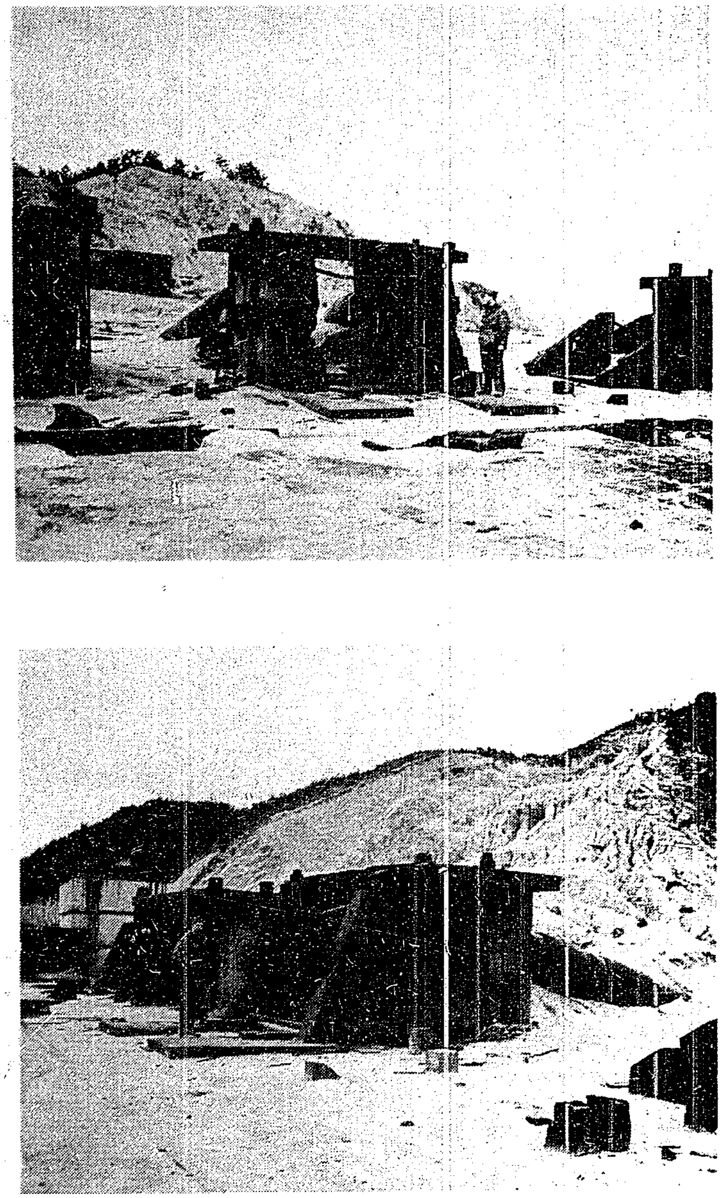

Figure 4

TYPICAL BUTT AT ARMOR TEST RANGE
KAMEGAKUBI PROVING GROUNDS

was 5 minutes. Special care was taken on acceptance tests to set the plate at exactly the nominal angle to avoid having to correct the specification velocity.

6. The detailed requirements for the ballistic test, together with the velocities (except for YAMATO class heavy plates as noted above), are given in Enclosure (B). The following comments are made on these specifications:

a. No distinction is made, so far as ballistic test is concerned, between face-hardened and homogeneous armor. The only distinction is whether the armor is intended for vertical or horizontal protection. In practice, this does to some extent separate the two classes of armor since most vertical armor heavier than 275mm (11") is face-hardened, and face-hardened armor was normally not used for horizontal protection. No projectile-breaking quality was required.

b. There is no system set up for minor corrections of obliquity. It is understood that for the rare cases when this is necessary, the F.M. is altered according to the chart mentioned above.

c. Attention is particularly invited to that part of Enclosure (B) which states in effect that a plate tested at 20° obliquity fails if the projectile penetrates beyond the forward bourrelet.

d. The second letter of modification at the end of the specifications states that no failures occurred during acceptance tests. This statement was confirmed by independent sources. It refers, of course, to the war ship-building period. While this indicates that the specifications were too mild, attention is invited to the fact that the projectiles were tested at the same obliquities at 12% to 18% above the armor specification velocities, under which conditions they were expected to penetrate in effective bursting condition.

SPECIAL TYPES OF ARMOR

1. Cast Steel Armor. The Japanese did not exploit the field of cast steel from the viewpoint of high ballistic (or fragment) protection. They did, of course, use cast steel for a number of exposed parts aboard ships, but the steel was neither well alloyed nor did it receive any special heat treatment. The steel castings used were made largely by private concerns with little experience in treatment for ballistic resistance. Some exposed equipment which would have been protected by cast steel armor on American combat vessels, was enclosed by rolled plating, pressed to shape and riveted together. No evidence of extensive experimental studies of cast steel armor was found.

2. Aluminum Armor. No evidence was found that the Imperial Japanese Navy made use of aluminum or other light metals for armor.

3. Body Armor of Flak-Suits. The details on this subject may be found in NavTechJap Document No. ND50-3149.1,.2,.3, "Bullet Proof Jacket Tests" and Technical Intelligence Ordnance Report No. 7, Part I and Part II, "Metallurgical Development of Japanese Ordnance". Body armor was not used by the Imperial Japanese Navy except for the marines. The Japanese police used it to some extent. The Naval Air Arsenal had also experimented with it. The analysis most recently adopted was approximately:

C 0.33	P .... under 0.007
Mn 2.2	Ni .... Trace
Si .... under 0.19	Cr 0.99
S .... under 0.009	Mn 0.80

The plates were made from 1 to 2mm thick. They were oil quenched from 850° C and tempered at 200° C which resulted in hardnesses from 450 to 500 BHN. The suit gave protection over the chest and abdomen but not around the back, and consisted of six shaped plates sown into the vest. It was usually ballistically tested with a 6.5mm lead ball bullet. The suits were considerably lighter than those used by U.S. forces, weighing less than 10 pounds.

ENCLOSURE (A)

SUMMARY OF THE STEEL MAKING DEPARTMENT
NAVAL ARSENAL, KURE, JAPAN

1. The steel making department at the Naval Arsenal, KURE, Japan, consisted of three open hearth shops as listed below:

FURNACES AVAILABLE

1st Open Hearth Shop	2nd Open Hearth Shop	3rd Open Hearth Shop
20 ton BOH	50 ton AOH	70 ton AOH
35 ton AOH	30 ton AOH	70 ton AOH
50 ton AOH	35 ton BOH	*50 ton BOH
50 ton AOH	20 ton BOH	*50 ton BOH
30 ton AOH		
7 ton AOH		

2. In addition to the above mentioned open hearth furnaces, the following electric furnaces were available:

Two	30 ton Heroult type	(basic lining)
Four	6 ton Heroult type	(basic lining)
One	3 ton Heroult type	(basic lining)
Two	1100 pound high frequency furnace	

In the basic open hearth furnaces, about 40% pig was used in the charges while only 35% pig was used in the charges of the acid open hearth furnaces. Approximately 5% pig was used in the charges of the Heroult electric furnaces. Pig iron sources were reported to be as follows: (1) HONKEIKO (Manchuria), (2) KENJUKO (Korea), (3) KAMAISHI (Honshu, Iwate Prefecture).

The time required for heats averaged from 6 to 10 hours for all furnaces. The following table gives the average monthly steel production of each shop at the naval arsenal during 1943 and 1944.

Average Production Per Month (tons)

1st Open Hearth Shop	2nd Open Hearth Shop	3rd Open Hearth Shop	Electric Furnaces
4,500	4,000	5,000	4,500

The average monthly steel production at KURE during 1943 and 1944 was 18,000 tons.

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*50 tons when used as a basic open hearth furnace and 70 tons when used as an acid open hearth.

ENCLOSURE (B)

SPECIFICATIONS FOR THE INSPECTION AND TESTING OF ARMOR PLATE

(Translation of NavTechJap Document No. ND50-3179, ATIS No. 3584)

* * * * *

Gungokuhi
(Military-Very Secret)

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TABLE OF CONTENTS

ENCLOSURE (B), continued

CHAPTER I - GENERAL

Basic specifications are established for the structural tests and inspection of each type of armor and its accessory steel materials.

These tests and inspections are performed by the Navy Yard Inspector or the Naval Ordnance Inspectorate (in the case of ballistic tests, by the Naval Ordnance Inspectorate), hereafter referred to as "Inspector".

The inspector, in all tests and inspections except ballistic tests, will reject all products not recognized as satisfactory by the specifications established by the basic regulations.

The nomenclature and code designations of the various types of armor plate are established as follows:

A. Face-Hardened Armor Plate.

1. Vickers type carburized armor plate (VC)
2. Non-cemented face-hardened armor plate (VH)

B. Homogeneous Armor Plate.

1. Vickers type homogeneous armor plate (NVNC)
2. Copper alloy homogeneous armor plate (CNC)
3. Molybdenum alloy homogeneous armor plate (MNC)

CHAPTER II - ARMOR PLATE

Section 1 - Structural Tests

Carefully selected materials must be used in the manufacture of armor plate; and the various processes of smelting, casting, forging, rolling, carburizing, heating, etc., should be fully coordinated.

The ingots are produced from an acid open hearth furnace. Cracking, webbing, internal stresses (TN: Sesshutsu), "ghosts", etc., to a degree which would affect adversely the impenetrability of the finished armor plate, must not be permitted.

Surface cracks, wrinkles, etc., on the armor plate after carburizing and face-hardening to a degree which would affect adversely the impenetrability of the finished armor plate must not be permitted.

Section 2 - Composition (analysis) Tests

Composition tests for the various types of armor plate are to be conducted as follows: (quantities of carbon and sulphur, however, depend respectively on combustion and weight laws).

A. Chemical Analysis. Test is made on a sample dipped from the ladle at the time of casting the ingot. Standard composition percentages are as follows:

Type of Plate	Composition								
	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
VC, VH, NVNC	0.43/0.53	0.35 or less	0.30/0.45	0.035 or less	0.045 or less	3.70/4.70	1.80/2.20	--	0.25 or less
CNC	0.38/0.46	0.35 or less	0.30/0.45	0.035 or less	0.045 or less	2.50/3.00	0.80/1.30	--	0.90/1.30
MNC	0.30/0.38	0.35 or less	0.30/0.45	0.035 or less	0.045 or less	3.30/3.80	1.80/2.30	0.25/0.40	0.25 or less

ENCLOSURE (B), continued

(Note: The max. Ni for VC, VH, NVNC was never approached in practice. Later tables show this value to be 4.2% instead of 4.7%).

B. Carbon-gradient analysis. For cemented armor plate, after the carburizing process has been completed and hardening, tempering and other heat treatments have been applied, so far as will permit boring of the surface, a chemical analysis of the following six depths is to be performed to determine the adequacy of the carburization process: 5mm, 10mm, 15mm, 25mm, 35mm, 50mm. (Note: The carbon content at the specified depths is not given, and is apparently left to the discretion of the inspector).

Section 3 - Tests for Strength of Materials and Fracture Tests.

After the heat treatment on each type of armor plate is completed, a test fragment should be broken off and be tested for strength of materials, and the cross-section examined.

The tests for strength of materials are to be performed as follows:

A. Type of Test

1. Tensile Test
2. Impact Test

B. Test Fragments. In the case of armor plate under four meters in length, the test fragment should be cut from the top of the ingot. If the plate is over four meters, the fragment should be cut both longitudinally and transversely from portions at both the top and bottom of the ingot, with its center at a point 25mm from the under surface of the plate. In the case of a cylindrical plate, the fragment should be cut so that its center is at a tangent to the circumference of the inside (bore) of the plate. In the case of a skewed plate, it must be cut lengthwise or transversely from the portion near the substantial body (Jittai: this implies that sample should come from as close to the central or important part of the plate as practicable).

The shape and measurements of the test fragments are as shown in Table #1, Essential Ordnance Materials Tests Regulations, in the case of tensile test fragments, and Table #11 in the above, in the case of impact test fragments.

(Note: For information, these measurements are summarized as follows: Tensile specimen has 50mm gauge length and 14mm diameter. Izod impact specimen has 10mm x 10mm section with V-notch 2mm deep having 0.25mm bottom radius.)

Standard Specifications

(See table on next page)

The fracture tests are to be performed as follows:

After the plate has been subjected to the final heat treatment, a test fragment is cut from the edge. This is again cut (broken) and the effectiveness of the heat treatment of the plate and the fracture is determined by examination of the cross-section. The cross-section should be photographed for reference.

ENCLOSURE (B), continued

Plate		Yield Pt. (kg/mm^2)	Tens. St. (kg/mm^2)	Elong. (%)	Izod, Impact Value (ft-lbs)
Gauge	Type				
75mm or less	CNC	60 or over	85(±6%)	19 or over	(Ave. 30 or over (Min. 25 or over
75mm or less	NVNC	50 or over	85(±6%)	18 or over	(Ave. 30 or over (Min. 25 or over
75-180 mm	NVNC VC,VH	45 or over	80(±8%)	19 or over	(Ave. 33 or over (Min. 28 or over
75-180 mm	MNC	50 or over	85(±6%)	20 or over	(Ave. 35 or over (Min. 30 or over
180mm or over	NVNC VC,VH	40 or over	75(±10%)	20 or over	(Ave. 35 or over (Min. 30 or over
180mm or over	MNC	40 or over	75(±10%)	21 or over	(Ave. 40 or over (Min. 35 or over

Note: R.A. for all types is 40% or over.

Section 4 - Tolerance on Measurements and Weights

Tolerances on measurements and weights are determined as follows:

A. Measurement tolerance. Transverse and longitudinal: as shown in the table or as indicated by the pattern measurements.

Thickness: the mean value of the thickness of the four corners, the ends, and the center of the plate is as follows:

Less than 100mm thick .... plus 0, minus 2mm
100 to 250mm thick .... plus 0, minus 4mm
250mm or more .... plus 2mm, minus 4mm

Locally, however:

Less than 100mm thick .... plus 2mm, minus 3mm
100 to 250mm thick .... plus 3mm, minus 6mm
250 to 400mm thick .... plus 3mm, minus 10mm
400mm thick or over .... plus 3mm, minus 14mm

For Wedge (probably means tapered) plate, finished width in addition to above is as follows:

Average thickness less than 100mm

Width less than 2000mm .... minus 2mm
Width 2000mm or more .... minus 3mm

Average thickness 100mm or more

Width less than 2000mm .... minus 3mm
Width 2000mm or more .... minus 5mm

B. Weight tolerance

Plus zero
Minus: Less than 100mm .... $20kg/m^2$
100mm or more .... $25kg/m^2$

ENCLOSURE (B), continued

Tolerance on plate curvature is as follows (the length of the curved plate is measured according to its surface):

A. Face-hardened plate

Less than 250mm thick, length 3 m. plus 10mm, minus 5mm
250mm to 400mm thick, length 3 m. plus 20mm, minus 10mm
400mm or over thick, length 3 m. plus 30mm, minus 15mm

Less than 250mm thick, length 1 m. plus 7mm, minus 5mm
250mm to 400mm thick, length 1 m. plus 14mm, minus 10mm
400mm or over thick, length 1 m. plus 21mm, minus 15mm

B. Homogeneous plate

Less than 250mm thick, length 3 m. plus 5mm, minus 5mm
250mm to 400mm thick, length 3 m. plus 10mm, minus 10mm

Locally, however:

Less than 250mm thick, length 1 m. plus 3mm, minus 3mm
250mm or more thick, length 1 m. plus 7mm, minus 7mm

After the plate is finished, it is assembled at the plant and its measurements and the tightness of the joints must be tested. Tolerance on assembly measurements is as follows:

A. Flat Plate

	Surrounding Plate and Joint Construction	
	Using Liner	Not Using Liner
Longitudinal	Plus 3mm Minus 5mm	Plus or Minus 3mm
Transverse	Plus 3mm Minus 5mm	Plus or Minus 3mm

When fitting, however, it is necessary to make corrections using the end plate.

B. In the case of barbette plate, for example, which is finished and assembled, tolerance in diameter (radius) from the center of the barbette to the inner surface of the walls is minus 6mm.

Tolerance on measurements of the gun ports, sight ports and observation ports, etc., is as follows:

Longitudinal and transverse .... plus or minus 3mm

Section 5 - Firing Tests

Firing (ballistic) tests are carried out on armor for ships under construction, usually on the total armor suit for each ship.

Ballistic plates are selected from each group of plates, and are designated by the Chief of the Naval Technical Department. "Group of plates", however, means a group of uniform thickness, for each type of armor plate, of the armor for one ship. Selection is as follows:

A. One plate is taken from the principal group used for horizontal protection. When there are many such groups, one plate is taken from each

ENCLOSURE (B), continued

of several groups.

B. One plate is taken from the principal group used for side protection. When there are many such groups, one plate is taken from each of several groups.

The selection of the plates for ballistic test is customarily made after the tests for strength of materials have been completed on all the groups of plates from which the selection is to be made. When circumstances require, however, the selection should be made when part of the groups from which the choice is to be made are completed. (Note: During the war, selection was made after at least 60% was completed).

The plates for the ballistic test are fixed securely to the armor plate framework to obtain the specified obliquity. The target surface is the top surface and no backing or underplates are attached.

The mean thickness of the plates for the ballistic test is determined from measurements of their thickness at the four edges.

Three projectiles or less are fired at each plate in the test. Before the test, however, one or two practice shells may be fired, to "warm up". (Note: These warming rounds were not fired at the plate, of course).

The different projectiles used in the ballistic tests are established as follows. The projectiles, however, have sand filler equivalent to the normal weight of the service projectile (filler). (Note: Minor changes in this table were affected in a letter from the Minister of the Navy which letter is appended).

A. Vertical Protection.

Thickness of Plate	Type of Shell
400mm or over	As directed by Chief of Naval Technical Dept. (Note: The Chief directed the 46cm Type 94 which, due to security, was not mentioned herein)
325mm to 400mm	40cm Type 91 AP(NavTechDept. Chart No. 17137)
250mm to 325mm	36cm Type 91 AP(NavTechDept. Chart No. 13107)
150mm to 250mm	As directed by Chief of Naval Technical Dept. (Note: No requirement for this as practically no vertical armor of this gauge was made).
100mm to 150mm	20cm Type 91 AP(NavTechDept. Chart No. 12775)
35mm to 100mm	15.5cm Type 91 AP(NavTechDept. Chart No. 17138)

B. Horizontal Protection.

Thickness of Plate	Type of Shell
200mm or over	As directed by Chief of Naval Technical Dept. (46cm AP Type 94, see note above).
150mm to 200mm	40cm Type 91 AP
85mm to 150mm	36cm Type 91 AP
55mm to 85mm	20cm Type 91 AP
35mm to 55mm	15.5cm Type 91 AP

Standard impact angles (obliquities) have been established, where impact angle means the angle of intersection of the trajectory and the normal to the plate surface at the point of impact:

ENCLOSURE (B), continued

<u>Type of Plate</u>	<u>Impact Angle or Obliquity</u>
Vertical protection	20°(Except when plate thickness is less than 75mm; angle is the same as below).
Horizontal protection	55°(Except when plate thickness is less than 50mm; angle is 65°).

(Note: When the 46cm projectile was used on vertical armor, the obliquity was changed from 20 to 30°).

Standard impact points are as follows:

First round ..... Corner of plate corresponding to bottom of ingot.
Second round .... Corner of plate corresponding to top of ingot.
Third round .... Wherever suitable.

In the case of vertical protection armor plate, however, it is customary to select a point three or more calibers away from the edge of the plate, and to keep the distance between impact points at least three calibers of the projectile used, in consideration of the exfoliation on the front and back of the plate. Furthermore, in the case of horizontal protection armor, the point should be approximately four calibers from the edge of the plate, and the distance between impact points should be determined with consideration of the exfoliation on the front and back of the plate. (Note: The plate is leaned backwards on the butt, hence the line of fire for oblique impacts is transverse to the rolling direction).

The standard impact velocities have been established as follows. In the case of the second round (when firing space is limited to two rounds), or the third round (when there is space available for three rounds), suitable changes in velocity may be made in order to ascertain the maximum resistance of the plate, provided the results of the first round, or of the first and second rounds, have passed according to the specifications below.

A. Standard impact velocities, for plate used for <u>side protection</u>, (m/s):

(Note: When thickness of plate is less than 75mm, the standard impact velocity is the same as for plates used for horizontal protection.)

Plate Thickness	Projectile			
	40cm.	36cm.	20cm.	15.5cm.
400mm and over	As directed			
400mm	395			
475mm	375			
350mm	355			
325mm	335	385		
300mm		360		
275mm		335		
250mm		310		
225mm			As directed by the Chief of Navy Technical Dept.	
200mm				
175mm				
150mm			355	
125mm			305	
100mm			260	315
75mm				265

ENCLOSURE (B), continued

B. Standard impact velocities for plates used for horizontal protection, in meters per second.

Plate Thickness	Projectile			
	40cm.	36cm.	20cm.	15.5cm.
200mm and over.	As directed			
200mm	400			
175mm	360			
150mm	315	365		
125mm		315		
100mm		265	405	
75mm			320	415
50mm				230
50mm*				330
35mm*				250

(*when impact angle is 65°)

C. When actual mean thickness differs from the foregoing plate thickness, the impact velocity is interpolated lineally.

Plates are considered satisfactory upon being ballistically tested at the above velocities with the following results:

A. In the case of an impact angle of 20° (also applied to 30° tests vs. 46cm) if the projectile penetrates no deeper into the plate than the shoulder of the projectile (meaning forward bourrelet, not thread-shoulder).

B. In the case of an impact angle of 55° or more, if the plate is not penetrated, but a fragment of the projectile may penetrate the back of the plate.

C. If the plate is not cracked or broken. The results of the second and third rounds fired at velocities other than those given above aid in determining the effectiveness of the plate.

When the results of the above ballistic tests are uncertain, another plate should be selected from the same group and the test repeated. If the results of this test satisfy the conditions given above, the group of plates is satisfactory.

If the results of the repeated ballistic test are also uncertain, the measures to be taken are dependent upon the decision of the Chief of the Navy Technical Department.

* * * * *

(The following letter was found attached to NavTechJap Document No. ND50-3179, "Specifications for the Inspection and Testing of Armor Plate")

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ENCLOSURE (B), continued

19 March 1943
Navy Technical Dept.
Comdr. INADA

Administrative Equipment Order.

For the time being, standard impact velocities and types of projectiles to be used in acceptance ballistic tests on armor plate used for horizontal protection, from 50mm to 75mm in thickness, are established as follows, despite the provisions in Armor Plate Manufacturing Test and Inspection Regulations:

Dated in 1943
Minister of the Navy
Kintaro SHIMADA

Plate Thickness	Type of Proj. Used	Standard Impact Vel.		Notes
		20cm.	15.5cm.	
75mm	20cm. Type 91 A.P. Proj. for 60 to 75mm.	320		When actual plate thickness differs from that shown in the left column, proportionate calculations must be made.
60mm	20cm. Type 91 A.P. Proj. for 60 to 75mm.	230	290	
50mm	15.5cm. Type 91 A.P. Proj. for 50 to 60mm.		230	

Remarks:

1. In the present regulations, the limit for 20cm and 15.5cm tests vs. armor plate for horizontal protection is 55mm (Note: Apparently exterpolation of 20cm data had been permitted to 55mm, while the minumum thickness at 55° for the 15.5cm projectile was also 55mm) but the standard impact velocity for a 20cm projectile is actually regulated only down to 75mm. Accordingly, there is some lack of precision for impact velocity against armor plate of around 60mm. Since a considerable quantity of 56mm armor plate has been manufactured recently, it is essential that the aforementioned confusion be clarified.

2. Since there is a scarcity of materials for 56mm armor plate which could definitely resist 20cm projectiles, the cross-over from one caliber to the other will immediately become 60mm, and impact velocities are respectively established for both calibers at this point. A plan for revision of the regulations after sufficient experimental data have been obtained is scheduled to be submitted.

* * * * *

(The following is a summary of a letter found attached to NavTechJap Document No. ND50-3179, "Specifications for the Inspection and Testing of Armor Plate".)

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Administrative Equipment Order, by Minister of the Navy dated 11 November 1942 to the effect that the regulations governing the test and inspection of armor are not applicable to plate re-rolled from material intended for ships

ENCLOSURE (B), continued

on which construction has been suspended, based on the following facts:

1. No plates have failed the specifications (presumably referring to ballistic tests).
2. The results of the physical tests did not change for the worse as a result of re-rolling plates.
3. When re-rolled armor from the ships of the "8-to-8" fleet, on which construction was suspended, was used, acceptance ballistic tests were omitted.

* * * * *

CHAPTER III - ARMOR PLATE ACCESSORY STEEL MATERIALS

Armor plate accessory steel materials (bolts, washers, cleats, etc. used in plate fitting) are all forged from ingots manufactured in acid open hearth furnaces or in electric furnaces. After forging they are annealed or given a heat treatment. They must be without cracks, flaws, etc. Bolts and cleats are subjected to hardening and tempering processes.

Although bolts should be finished according to the plans, the top and sides require only enough finishing to permit a wrench to grip the head. The same applies to the slender part of the shaft.

Screws must all be checked with a die gauge and must be interchangeable, to permit use with any plate.

The outside edge of washers must be thoroughly finished, and the outside must fit the inside of the screw head properly. If necessary, the inner surface should be finished to fit the curve of the under-plate (rihan).

The bolts manufactured are to be extracted in lots of 200; then of the fraction remaining two are selected, and after being forged and given the heat treatment, they are treated.

The washers manufactured are taken in lots of 200 and of the fraction two are selected, which are then tested.

Cleats manufactured are taken in lots of five, and of the fraction one is selected and tested.

Test specifications are as follows:

A. Tensile strength and bending test. Bolts and washers must conform respectively to the specifications set forth in Class 5 and Class 6, Forged Steel Articles, Navy Shipbuilding, Aircraft Mfg. and Ordnance Mfg Essential Materials Tests and Inspections. Cleats must conform to the same specifications as those given herein for NVNC in Section 3. It matters not if the tensile strength of the bolts exceeds the upper limit of the specifications given above, provided their expansion meets the following specifications:

$$60 + \text{Expansion } (\%) \times 1.5 > 90$$

B. Impact Test. As for bolts, the D No. 1 Test Fragment, Navy Shipbuilding, Aircraft Mfg., Ordnance Mfg., Essential Materials Tests and Inspections, must meet the following specifications:

Impact value - 20 ft/lbs or more

ENCLOSURE (B), continued

CHAPTER IV - COORDINATION OF RESULTS AND REPORTS

When the firing test is completed, the inspector must compile a report on the results of the firing test in duplicate, and the OinC of the Navy Yard must submit it to the Chief of the Navy Technical Department.

ENCLOSURE (C)

ARMOR RESEARCH AND DEVELOPMENT PROGRAMS

Part I - INTRODUCTION

The first organized research committee was set up in 1934 and became known as the Japanese Society for Promotion of Scientific Research. Special Committee No. 10 of the society investigated or supported research on armor steel. However, for reasons beyond the scope of this article it was not very successful and, in November 1944 the society was dissolved in favor of the Army-Navy Technical Liaison Committee. The latter was the first attempt to consolidate the talent and effort of the Army and Navy; until that time, the two military forces conducted independent research with practically no liaison connections. This committee made ample use of civilian facilities and talent, but apparently had no civilian representation. It appeared to have had a certain amount of authority in the financial, personnel, and material allocations for scientific research. It did not control such organizations as the Naval Technical Research Institute, etc., but was aware of their activities and hence could act as coordinator.

One of the programs directly sponsored by the Army-Navy Technical Liaison Committee was the study of Induction Hardening of Armor, discussed in Part VI.

The Kure Naval Arsenal Experimental Steelmaking Laboratory was operated under the jurisdiction of the Navy Technical Dept. at TOKYO (via the Navy Headquarters of Kure Arsenal). Consequently, the various programs attached to that laboratory were only remotely connected to the Liaison Committee. The laboratory was completed in 1938. Prior to the bombings of June and July, 1945, it was equipped to perform chemical, gas, spectrum, cathode-ray, and X-ray analysis, photography and metallography, heat treatment, physical and mechanical testing. The laboratory was concerned with the improvement of steel in armor and projectiles. The laboratory did very little armor work, except as noted below, after January 1945, when heavy armor production was terminated. From interviews with Japanese navy officers attached to the laboratory it was determined that the following experiments had been conducted on armor:

A. The study of shirome, brittle fracture, in armor. This experiment was completed after the production of heavy armor had ceased.

B. The optimum depth of chill required for 330mm (13") face-hardened armor for defense against the 40cm (16") Type 91 armor piercing projectile at normal obliquity.

C. Investigation of zirconium in armor steels.

D. Substitute analysis to conserve nickel and other scarce alloying elements.

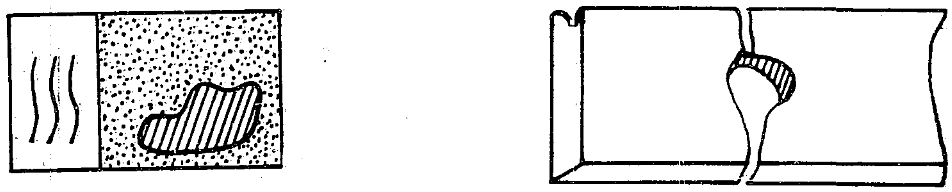
The above programs are discussed in Parts II to V below.

Part II - SHIROME, GRANULAR FRACTURE OF ARMOR

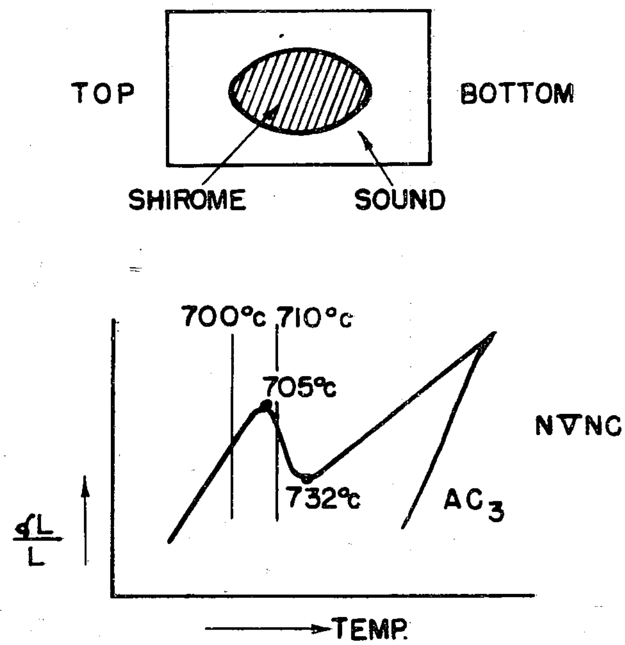
A. The information contained in this discussion was taken directly from interviews with and data obtained from Kazuo HORIKAWA, a Japanese technical naval officer of the Steelmaking Department at KURE, who performed the experiments. He also supplied the illustrations accompanying the discussion. No comment has been made on the technical accuracy of the results and conclusions contained herein.

B. In 1936, the Japanese manufactured two face-hardened VH plates, 330mm (13") and 420mm (16.5") thick respectively. On ballistic test, each of

ENCLOSURE (C), continued



a



b

Figure 1(C)
SHIROME

ENCLOSURE (C), continued

the plates broke apart into two sections with but one impact each. The fractures of the plates displayed a whitish granular structure which was termed shirome. (See Fig. 1(C), part a). A metallurgical investigation was conducted to determine the cause of the embrittlement in the armor. This investigation covered the period of years from 1936 to 1945.

C. Fracture specimens were taken from various parts of the plates mentioned above. The tests indicated that the center portions of both plates were brittle while the corners were fibered. It was therefore concluded that insufficient tempering was the cause of shirome. In order to prevent reoccurrance of this deficiency, the tempering temperature after the straightening operation was raised from 650° to 710°C. (See Fig. 1(C), part b).

D. From the results of the experiment mentioned above, it was concluded that a large type Charpy specimen (25mm x 25mm x 150mm instead of a standard Izod specimen (10mm x 10mm x 75mm) was necessary to distinguish brittle armor from fibered armor. Therefore, this large type Charpy specimen was adopted. (See Fig. 2(C)) Despite the adoption of the 710° tempering temperature, the records showed that approximately 5% of the armor produced demonstrated shirome. In 1941, severe shirome appeared in experimental basic open hearth armor, and the investigation was commenced anew as follows:

1. Segregation Test. To determine whether shirome had volume (i. e., existed in three dimensions or was manifested only on surfaces), a quantitative spectro-analysis was conducted and it was decided that shirome had no volume, only surface. (See Fig. 2(C)).

2. Fracture Test. From a series of fracture tests in which the hammer had different striking velocities, it was found that shirome was not a manifestation of cracks or flakes which would exist in the steel originally, but rather was a phenomen that appears on steel surfaces when the steel is broken at high velocities. (See Fig. 3 (C)).

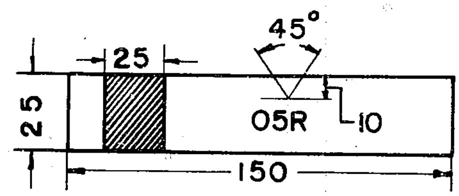
3. Hydrogen Gas Test. It had been noted that (a) basic open hearth steel was more sensitive to shirome than acid open hearth steel, and (b) the sensitivity to shirome was different for individual heats even when made in the same furnace. For these reasons, the effect of hydrogen gas in steel was investigated by impregnating armor test specimens with hydrogen. However, not a single test piece showed shirome when fractured. Therefore it was concluded that hydrogen gas contained in armor steel was not the main cause of shirome.

4. Heat Treatment Test. Specimens of armor steel containing shirome (or known to exhibit shirome when fractured) were tempered at the production temperature, 650°C., for different lengths of time. In all cases, shirome was still present. However, when the test pieces were heated above the AC_3 point, quenched in oil, and tempered, shirome disappeared. When broken, the specimens showed a grayish fibrous fracture.

E. In paragraph D-4 above, it was found that shirome could be eliminated provided the test specimens were small. In other words, it appeared to the Japanese that shirome was obtained during the quenching operation and that if it could be so produced and eliminated at will, this point could be clarified. There appeared to be a positive correlation between shirome and the cooling rate. It was found that, even if a steel was very

ENCLOSURE (C), continued

Large Type Charpy Impact Test Piece



Segregation Test

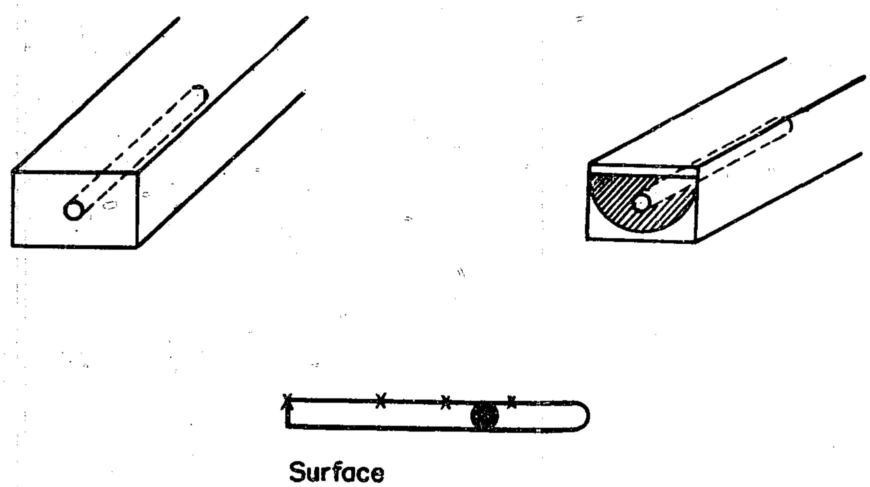


Figure 2(C)
IMPACT AND SEGREGATION TEST

ENCLOSURE (C), continued

sensitive to shirome in production, if this material was quenched in the laboratory, shirome disappeared. The primary difference between production and laboratory conditions was the cooling rate. For instance, one experiment showed that the middle center section of a 16.5" plate, upon quenching, took two hours to cool from 850° to 200°C. (See Fig. 3(C)). In order to create shirome in the laboratory, three special furnaces were built. Cooling rates corresponding to the middle center sections of 420mm (16.5"), 280mm (11"), and 100mm (4") production plates could be duplicated in these furnaces (see Fig 4(C)). Test specimens were prepared from sound NVNC armor. By cooling a series of these specimens in the above mentioned furnaces and tempering for two hours, "production conditions were duplicated." (See Fig. 5(C)) shirome appeared in the fractures. It was observed that the slower the cooling rate the greater was the area of shirome in the fracture.

F. In order to ascertain whether the shirome produced in the laboratory was identical to that which appeared in the production plates, the following tests were conducted:

1. A tempering test of the armor, the same as outlined in paragraph D-4, with the result that shirome could not be eliminated by tempering (see Fig. 5(C)).

2. Heating the armor above the AC_3 point and quenching and tempering with the result that the shirome disappeared, in the same manner as noted in paragraph D-4.

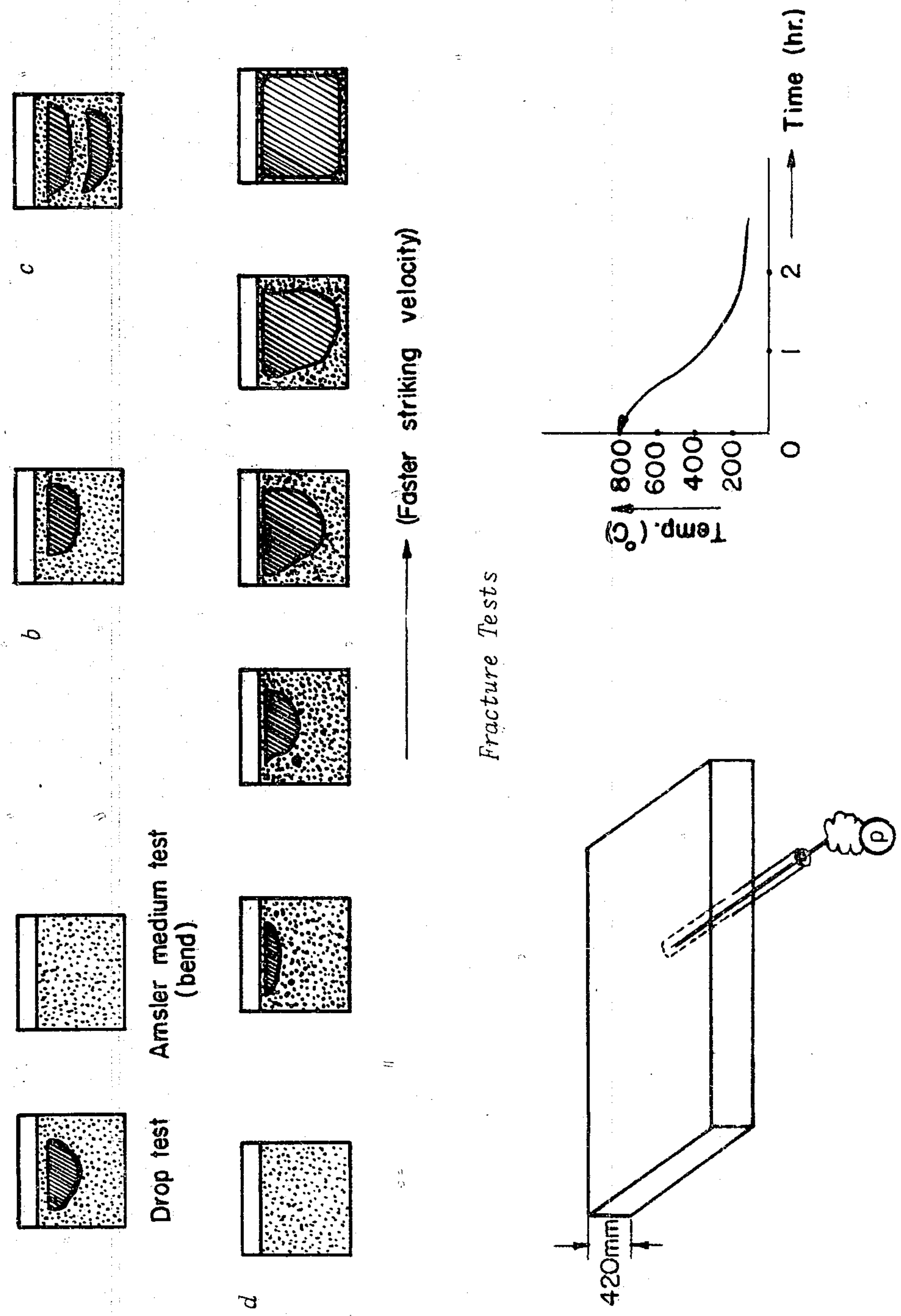
3. The 710°C. tempering temperature was tried with the result that shirome did not disappear. (See Fig. 6(C)).

4. MNC, CNC, CNC_1. and CNC_2 steels were very sensitive to shirome, CNC_1 moderately sensitive, and NVNC and MNC slightly sensitive. These results confirmed the observations made on production plates.

5. A metallographic examination showed no difference between the microstructures of production and laboratory steels exhibiting shirome. (See Fig. 7(C)).

G. Since there is a clear relation between shirome and the quenching cooling rate, according to the Japanese, there must exist relationship between shirome and transformation. For this reason, an investigation of the transformation products of armor was carried out in an attempt to determine the exact cause of shirome. Specimens were placed in the furnaces described in paragraph E above, and at various times during cooling were removed and quenched rapidly to room temperature. Microscopic examinations indicated that the maximum quenching cooling rate which still produced shirome was not fast enough to prevent the formation of an intermediate transformation product (Bainite). (See Fig. 8(C)). From this experiment, it was concluded that there exists a relationship between shirome and intermediate transformations. The isothermal transformation tests were made for all kinds of armor and the S-curves were drawn. From these S-curves it was noted that pearlitic transformation under the worst production quenching conditions was out of the question. That the cause of shirome was a Bainite structure now became evident to the Japanese. In order to determine whether "upper" or "lower" Bainite was the true cause of shirome, test pieces were heated above the AC_3 temperature and transformed isothermally in a molten metal. It was found from these tests that "upper" Bainite was the true cause of shirome. Furthermore, microscopic studies of plates with shirome showed them to have a tempered Bainite structure.

ENCLOSURE (C), continued

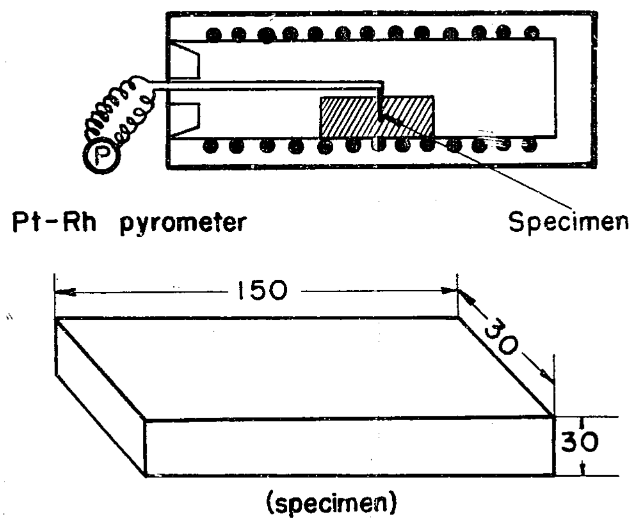


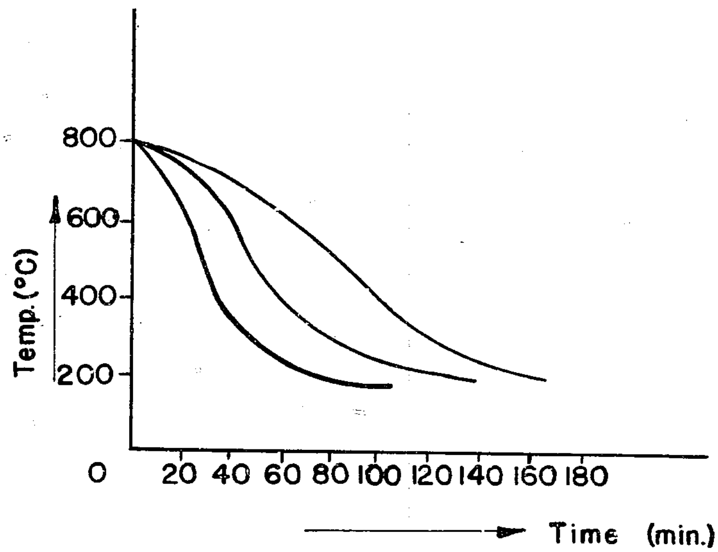
Cooling Velocity of Armor Plates in the Quenching Operation

Figure 3(C)

FRACTURE TESTS AND COOLING VELOCITY

ENCLOSURE (C), continued

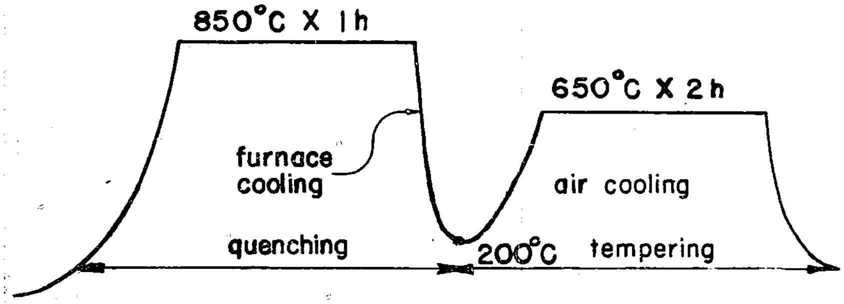




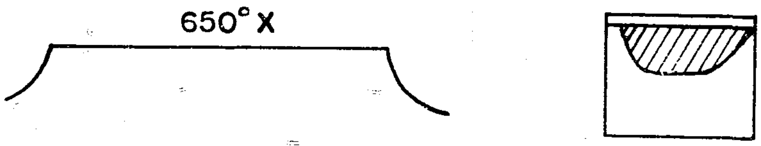
Electric Furnaces Having Various Cooling Velocities

Figure 4(C)
ELECTRIC FURNACE

ENCLOSURE (C), continued



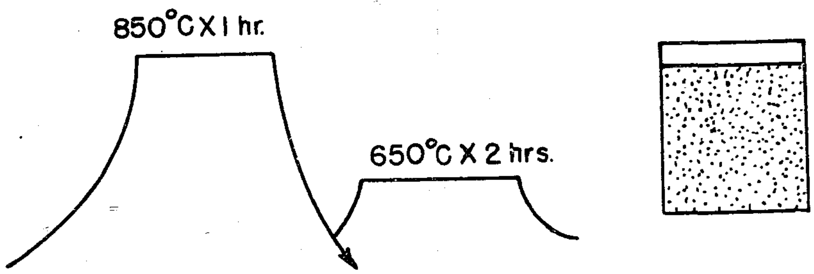
Generation of "Shirome"



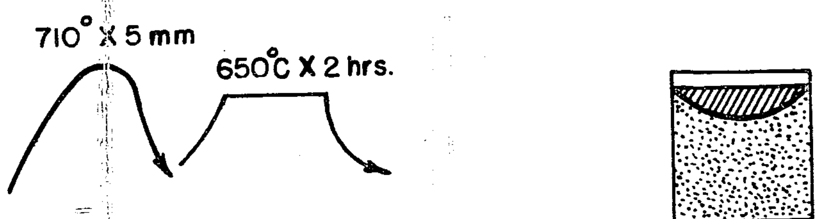
Tempering Test

Figure 5(C)
SHIRONE HEAT CURVES

ENCLOSURE (C), continued



Quenching Test



New Heat-Treatment Test

Figure 6(C)
SHIROME HEAT CURVES

ENCLOSURE (C), continued

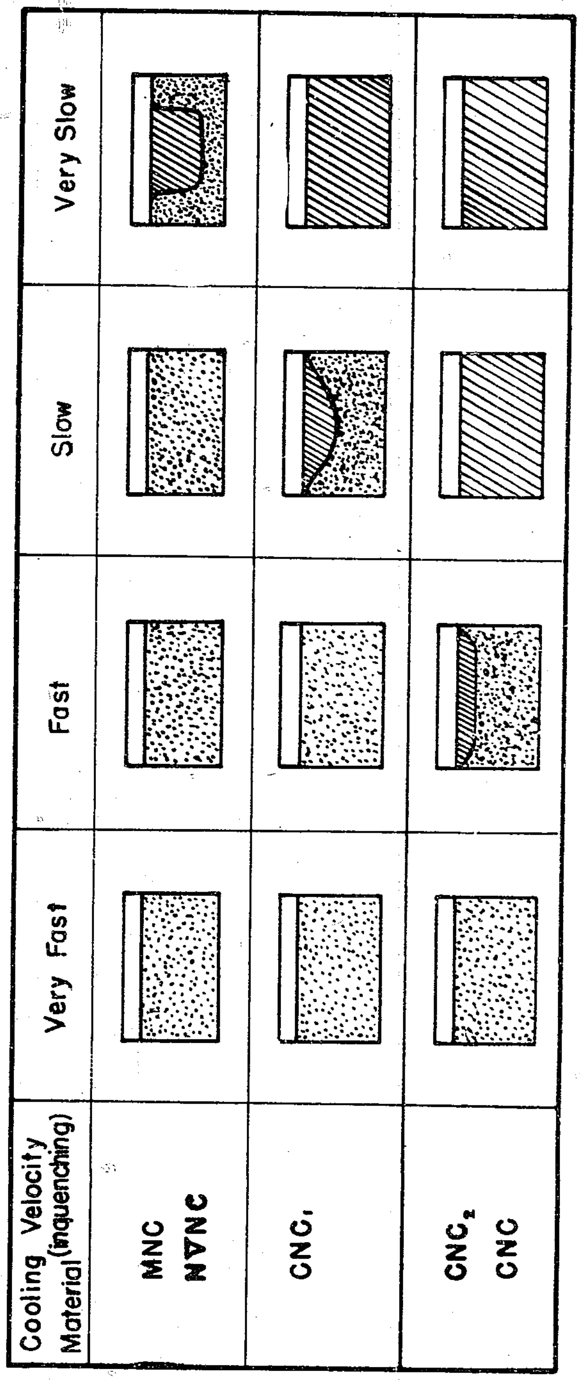
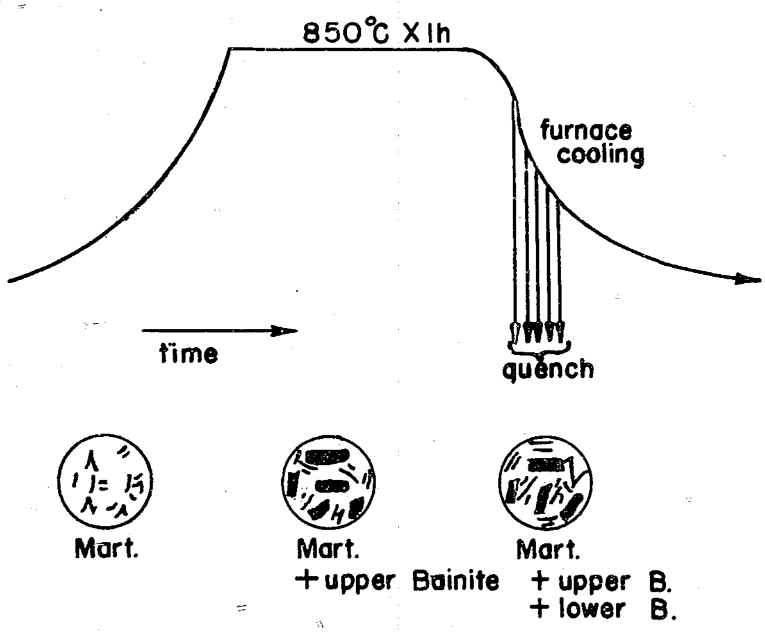
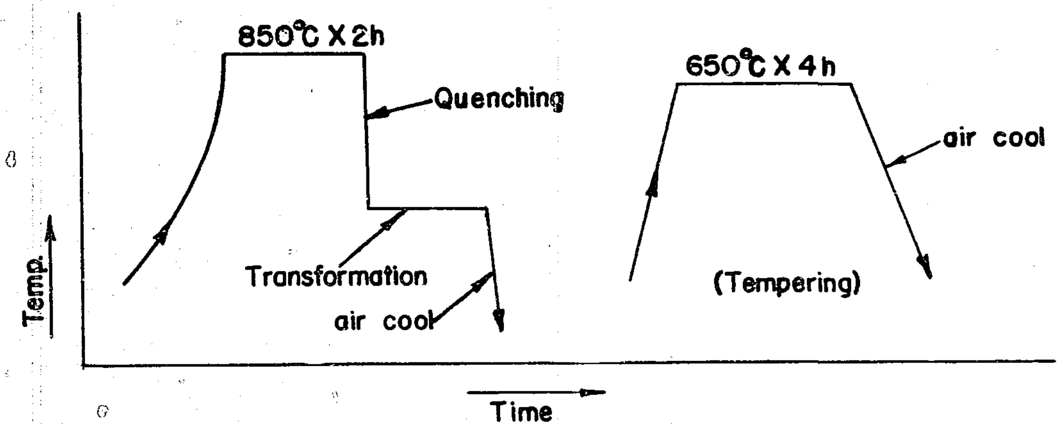


Figure 7(C)
SENSIBILITY TEST

ENCLOSURE (C), continued



Structural Change During the Quenching Operation of Armor Plates



Isothermal Transformation Test

Figure 8(C)
STRUCTURAL CHANGES AND HEAT CURVES

ENCLOSURE (C), continued

H. Conclusions:

1. Shirome is not small cracks or flaws that would exist originally in the steel.

2. Shirome is a deficiency which appears only when the material is broken at high velocities.

3. There are many causes of brittle fracture in steel such as high breaking velocity, low testing temperature, insufficient tempering, excessive hydrogen, sulphur, or phosphorous, non-metallic segregation, etc.; however, the principal cause of shirome in armor steels appears to be the presence of "upper" Bainite.

I. Prevention of Shirome:

1. If the same quenching equipment and cooling rates are used, the analysis of the steel must be enriched by increasing the hardening elements such as nickel or chromium to prevent the formation of intermediate transformation products (particularly "upper" Bainite) during the quenching process; or else, a material must be selected whose tempered Bainite structure is sufficiently tough to prevent the generation of shirome.

2. However, if the basic analysis is unchanged, the quenching cooling rate must be increased. To a lesser degree, the following changes will improve the condition:
(a) Temper the center part of the plate sufficiently,
(b) Reduce such impurities as hydrogen, phosphorous, sulphur and non-metallic inclusions,
(c) Decrease segregation, and "increase the uniformity and fineness of the carbide precipitation".

J. This study was confined to research of shirome in armor plate, but since shirome is a so-called "quench brittleness" deficiency in alloy steels in general, the results of this study may be applied to the manufacturing of all alloy steels.

Part III - OPTIMUM DEPTH OF CHILL

A. This program, under the supervision of the Experimental Laboratory, was conducted by the Steelmaking Department of Kure Naval Arsenal and Kamegakubi Proving Ground.

B. Five 330mm (13") VH armor plates were produced. These plates were face-hardened to obtain nominal chill depths of 20, 25, 30, 35, and 40% respectively. The method of obtaining the desired depth of chill is discussed in Part IX of the basic report.

C. The plates were tested with 40cm (16.1") armor piercing projectiles Type 91 at normal (0°) obliquity. The plate with 40% chill depth gave the best ballistic results.

D. The program was not further pursued to find the upper limit or optimum chill depth, nor were the test conditions varied as to scale, e/d or obliquity, apparently because the heavy armor production had been terminated.

ENCLOSURE (C), continued

Part IV - INVESTIGATION OF ZIRCONIUM IN ARMOR STEELS

A. Zirconium was, to a certain extent, available to the Japanese. One unconfirmed source placed the production rate at 300 tons of FeSiZr, containing 4% Zr, per month. Consequently, an investigation of the properties of armor containing this element was conducted at the Experimental Laboratory of Kure Arsenal.

B. Three heats of steel with analysis of CNC, CNC_1, and CNC_2, respectively, were prepared. Each of these heats was divided into two parts. On part was inoculated with sufficient FeSiZr to give 0.05% Zr, the other to give 0.20% Zr.

C. 25mm (1") plates were produced from these six ingots and were ballistically tested with a 47mm A.P. projectile at 0° obliquity (see Enclosure (D)). Little difference in ballistic performance of the high and low Zr plates could be found under these test conditions and the plates demonstrated no improvement over standard CNC, CNC_1, and CNC_2 armor. The program was not further pursued.

Part V - SUBSTITUTE STEELS

The Japanese spent a great deal of their research effort on developing analysis, and the heat treatments for them, which would maintain the ballistic quality while at the same time containing lesser quantities of scarce alloying elements. The elements in order of their decreasing scarcity were nickel, chromium, molybdenum, copper, and zirconium. There was no apparent attempt to use vanadium in heavy armor. There appeared to be ample supplies of the common steel elements such as manganese, silicon, and other de-oxidizers. The progress of this program, which extended over a period of years, is covered in detail in the basic report. It is of interest to note that none of the substitute steels (the CNC series) approached the over-all ballistic quality of the standard Vickers analysis.

Part VI - INDUCTION HARDENING OF ARMOR

Face-hardening by induction methods had barely reached the experimental stage by the end of the war. The only experimental unit in operation for this purpose was a small one sponsored by Osaka Arsenal and produced by the Shibaura Electric Company. The unit is described in detail in Technical Intelligence Ordnance Report No. 7, Part I and Part II, "Metallurgical Development of Japanese Ordnance" and in NavTechJap Report, "Japanese Methods of High Frequency Induction Heating and Melting", Index No. X-37 (N). It was capable of hardening a plate 3" thick, 24" wide, and of any reasonable length. The plate was moved through the equipment at the rate of approximately 1mm per second, depending on the thickness and pattern desired. The bed was sloped to drain the quench water which was applied continuously across the plate as it emerged from the coils unit. The Japanese experienced difficulty with the unit due to the fact that the edges of the plate heated faster than the middle. They were experimenting with cooling the edges with water under pressure during the heating cycle. No samples of naval armor steel which had been treated by this process were found.

ENCLOSURE (D)

47mm TEST RANGE AND HIGH SPEED CAMERA

I. DESCRIPTION OF RANGE

A. The range was located at Kamegakubi Proving Ground. A 47mm gun. single-shot and percussion fired, was located in an armored housing about 40 feet from the armor butt. The butt was mounted on a concrete pedestal. Target supports of the butt were interchangeable to give various obliquities, including 0°, 15°, 30°, 45°, and 60°. The target plates were approximately 18" x 24" and were rigidly bolted to the supports. Obliquity was achieved in the vertical plane, i.e., the plates leaned backwards. Figure 1(D) is a general photographic view of the range; Figure 3(D) is a sketch of the plan with details of the butt support, and Figure 2(D) shows the gun.

B. The striking velocities were obtained by a short baseline (about 11 feet) boulenge frame set-up located just in front of the butt. The circuit was piped to a main velocity building about half a mile away. Residual velocities were determined by a high speed camera which took in a small field perpendicular to the line of fire including the plate and a few feet behind it. (See II below).

C. The projectile generally used was a small scale prototype of the old 40cm A.P. Mark 5 projectile, minus the cap. The 47mm projectile was a solid monoblock shot with an ogive having about two calibers radius and sharply pointed. It was heat-treated to resist appreciable deformation for most impacts against armor less than 1¼". When the projectile penetrated the target, it was caught in a sand bunker behind the butt.

D. The range was used principally for testing new types of armor under development, and probably was used also for reduced-scale tests for penetration, and limit velocity (V_L) was calculated from the striking velocity (V_S) and the residual velocity (V_R) by the following formula:

$$V_S^2 = V_L^2 + V_R^2 (1 + \alpha)$$

Where α is a function of obliquity (about 1.4 at 0° and about 0.1 at 60°, exact data not found).

II. DESCRIPTION OF CAMERA

A. The camera itself was not found, but a document on its design has been forwarded to the Washington Document Center (NavTechJap Document No. ND50-3436). It ran off 10,000 frames per second for about 150 frames on a 35mm film about 3 feet long. The film was curled around the inside surface of a rotating drum. The drum was brought to speed before the shot was fired and the rotational velocity was checked by a tachometer at the moment of firing. No synchronous clocks were used. The shutter was opened by means of a break-screen in the line of fire, about 20 feet in front of the target, which operated a relay at the camera.

B. The optical system is beyond the scope of this report (see NavTechJap Document No. ND50-3436) but the method of directing the image on the moving film was briefly as follows: a drum, about half the diameter of the film drum, was mounted inside and concentric to the latter. The edge of the center drum was beveled at 45°. The beveled edge was not smooth but

ENCLOSURE (D), continued

was faceted with a large number of plane mirrors adjacent to each other. The image was transmitted through one optical system in a line perpendicular to the plane of the revolving drums, and was reflected 90° by each mirror in succession on to the moving film. The mirror drum was, of course, carefully synchronized by gears to the film drum.

C. The high film speed (i.e., short exposure time) and the use of a telescopic lens severely restricted the light, and the pictures were limited to silhouettes. Since this situation could not be avoided the silhouettes were sharpened and the depth was flattened by the use of intense searchlight beams on the opposite side of the target from the camera. The searchlights were contained in the wood-slat boxes shown in Figure 1(D). The butt supports were constructed so that they did not seriously obstruct the view behind the plate.

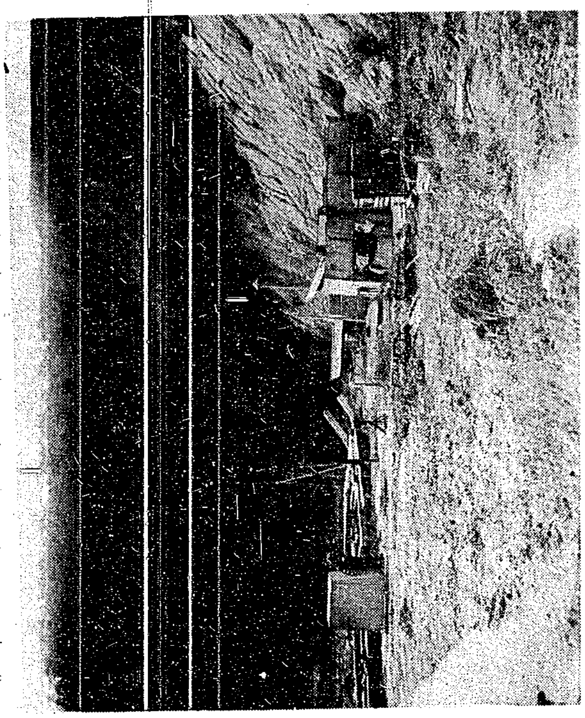


Figure 1(D)
GENERAL VIEW OF RANGE

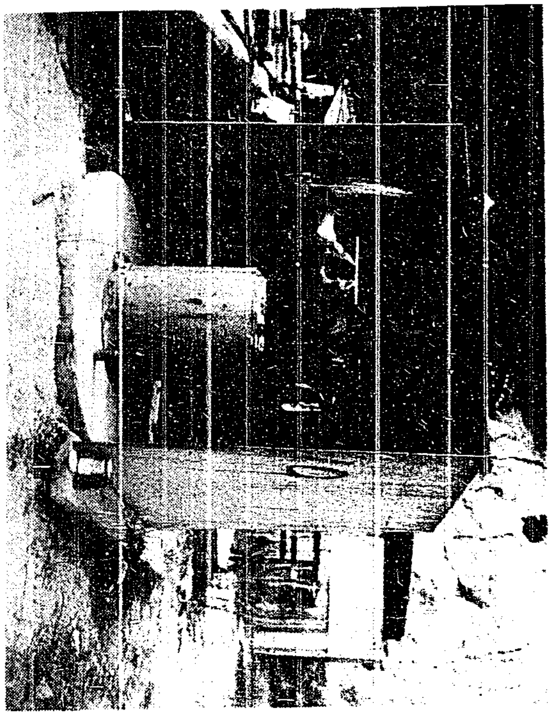


Figure 2(D)
CLOSE-UP OF 47mm GUN

ENCLOSURE (D), continued

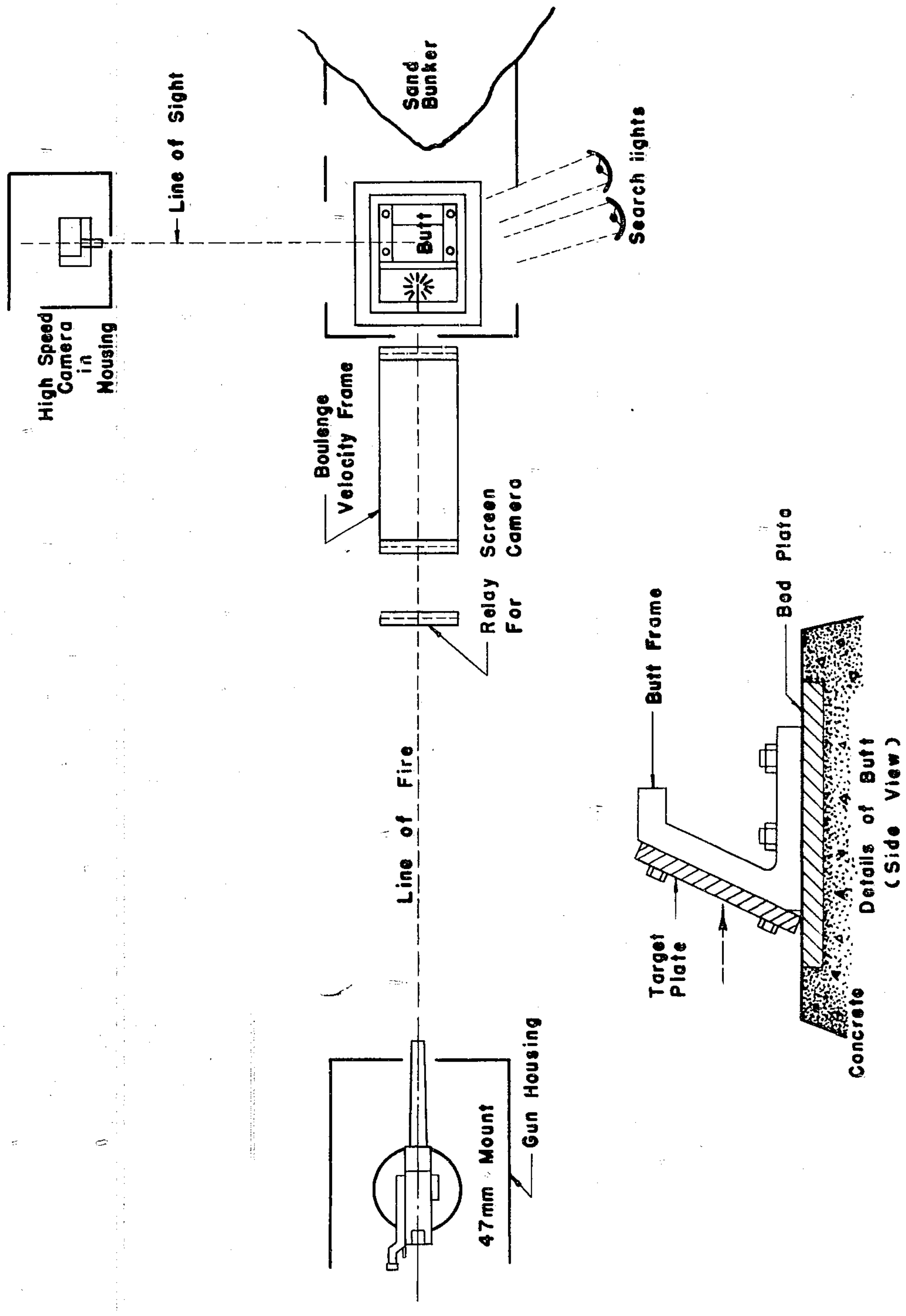


Figure 3(D)
SKETCH OF RANGE AND BUTT

ENCLOSURE (E)

LIST OF JAPANESE ARMOR SHIPPED TO THE UNITED STATES

I. METALLURGICAL SPECIMENS OF ARMOR FROM SHOPS AT KURE NAVY YARD

NavTechJap No.	Gauge	Size	Remarks
JE50-3150	13½"	2' x 3'	
JE50-3151	2¼"	4' x 4'	CNC_1
JE50-3152	1½"	4' x 4'	CNC_1
JE50-3153	1¼"	4' x 4'	CNC_1
JE50-3154	4 "	5' x 6'	VC No. 46299½
JE50-3155	12-3/4"	2' x 3'	VH
JE50-3156	16 "	2' x 3'	VH

(Note: Certain of the above specimens may be tested ballistically at Naval Proving Ground, Dahlgren.)

II. INVENTORY OF USEFUL PLATES AT KAMEGAKUBI PROVING GROUND

A. VH Plates

NavTechJap No.	Gauge	Japanese No.		Approx. Dimensions	Remarks
JE50-3133	7"	46711 46712	1/1	12' x 18'	No impacts.
JE50-3124	12.8"	54677	1/1	10' x 18'	3 impacts, ½ of plate OK.
JE50-3109	15"	55648 55649	1/1	12' x 22'	1 impact, 3/4 of plate OK.
JE50-3110	15"	55026 55027	1/1	12' x 18'	2 impacts, 5/8 of plate OK.
JE50-3113	15"	55775 55776	1/1	12' x 18'	No impacts.
JE50-3127X	16.1"	55368 55369	1/1	12' x 18'	3 large impacts, good for metallurgical specimens only.
JE50-3130X	16.1"	55632 55633	1/1	12' x 22'	4 large impacts, good for metallurgical specimens only.

B. MNG Plates

NavTechJap No.	Gauge	Japanese No.		Approx. Dimensions	Remarks
JE50-3101	5.9"	53418 53419 53420	1/1 ?/?	12' x 20'	5 impacts, ½ of plate OK
JE50-3122	5.9"	54407 54408 54409	1/1 3/3	13' x 18'	No impacts.

ENCLOSURE (E), continued

NavTechJap No.	Gauge	Japanese No.	Approx. Dimensions	Remarks
JE50-3134	5.8"	5636? 2/2	12' x 22'	1 impact, almost all of plate OK.
JE50-3128	6.8"	56219 1/1	12' x 18'	4 impacts, 2/3 of plate OK.
JE50-3125	7.8"	56462 1/1	10' x 18'	2 impacts, 2/3 of plate OK.
JE50-3112	7.8"	57249 2/2	12' x 18'	1 impact in center, 1/3 of plate OK.
JE50-3136X	9.8"	55142 55143 2/2	12' x 22'	3 large impacts, metallurgical specimens only.
C. Special Experimental CH_1				
JE50-3106X	$3\frac{1}{4}$"	57612 2/2 2/2	10' x 18' plate, designated CH_1	No impacts. This plate is a face hardened CNC_1 not very successful. A 37" x 37" specimen should be cut out for shipment to NPG Dahlgren, attention A and P Laboratory.
D. NVNC Plates				
JE50-3111	2.75"	55289 1/2	13' x 18'	No impacts.
JE50-3120	3.1"	55289 1/2 (?)	12' x 18'	No impacts.
JE50-3119	3.8"	55112 1/3	12' x 18'	No impacts.
JE50-3123	5.8"	52531 1/1	13' x 18'	No impacts.
JE50-3108	12.0"	54581 54582 54583 ?/?	11' x 32'	One end has a few shaped charge holes, 2/3 of plate OK.
E. CNC_1 Plates				
JE50-3104	2.6"	58784 1/2	10' x 20'	No impacts.
JE50-3115	3.0"	17732 2/2 (?)	10' x 17'	2 impacts, ½ of plate OK. (See note below).
JE50-3116	3.0"	17732 2/2 (?)	10' x 17'	1 impact, over ½ of plate OK. (See note below).
JE50-3132	3.0"	46165 ?/?	11' x 18'	2 impacts, 3/4 of plate OK.
JE50-3114	3.2"	58700 1/1 2/2	12' x 22'	No impacts.

Note: Plates 3115 and 3116 were special experimental basic open hearth plates made about 1940. All others acid open hearth steel.

F. Unidentified plates. (Note: Nature can doubtless be determined by metallurgical examination. Paint markings were illegible on these plates).

ENCLOSURE (E), continued

NavTechJap No.	Gauge	Japanese No.	Approx. Dimensions	Remarks
JE50-3131	1-1/2"	?	12' x 23'	No impacts.
JE50-3126	1-3/8"	58751 1/2 1/2 1/2	12' x 18'	No impacts.
JE50-3121	1-7/8"	?	9' x 17'	No impacts.
JE50-3102	2-3/4"	58354 1/2	5' x 9'	No impacts.
JE50-3103	2-3/4"	?	5' x 9'	No impacts.
JE50-3105	2-5/8"	?	10' x 20'	No impacts, probably CNC_1.
JE50-3107	3"	?7016 ?/?	12' x 20'	No impacts.
JE50-3117	3-7/8"	?	7' x 12'	2 impacts, 1/2 of plate OK.
JE50-3135	6"	?	12' x 22'	3 impacts, 3/8 of plate OK.
JE50-3137	9"	?	12' x 22'	1 large impact: 1/2 of plate OK.
JE50-3118	9-3/4"	56244 1/1	13' x 21'	4 impacts, 3/8 of plate OK, probably homogeneous.
JE50-3129	12"	54670 1/1	11' x 22'	No impacts.

ENCLOSURE (F)

JAPANESE DOCUMENTS FORWARDED THROUGH
ATIS TO THE WASHINGTON DOCUMENT CENTER

NavTechJap No.	ATIS No.	Title
ND-50-3436	3691	High Speed Camera for Use in Photographing Penetration Ballistics.
ND-50-3149.1 thru .3	3692	Bullet Proof Jacket Tests
ND-50-3170	3576	A Collection of Documents on Heavy Armor and Passive Defense.
ND-50-3171	3577	A Collection of Documents on Heavy Armor as Applied to Ship Construction Problems.
ND-50-3173.1 thru .5	3578	Reports on Armor Ballistic Tests, Vols. 1 to 5, incl.
ND-50-3174	3579	DeMarre's Formula, Japanese Discussion of.
ND-50-3175.1 thru .2	3580	Vol. 1 - Effectiveness of Projectiles against Armor Plate. Vol. 2 - Tests of Homogeneous Armor vs. A.P. Projectiles. (Trajectory during and after penetration).
ND-50-3176	3581	Honeycomb Type Armor, Ballistic Tests. (Gratings, reduced scale).
ND-50-3177	3582	Warship Defense. (Gunnery lessons vs. American and British armoring).
ND-50-3178	3583	Defense Against Projectiles. (Effect of cap and ogive on penetration formulae).
ND-50-3179	3584	Specifications for the Inspection and Testing of Armor Plate.
ND-50-3422	3585	Plans for the Manufacture of Experimental Armor Plate (CNC analysis).