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

Subject: Target Report - Japanese Light Armor, Article 1.

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

1. Subject report, dealing with Targets O-36 and O-37 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. J. J. Glancy, USNR, assisted by Lt. Comdr. M. R. Herman, USNR, and Lieut. R. R. Boggess, USNR, interpreter and translator.

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JAPANESE LIGHT ARMOR
ARTICLE 1

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE O-1, TARGETS O-36, AND O-37

FEBRUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ORDNANCE TARGETS

JAPANESE LIGHT ARMOR - ARTICLE 1

This report covers light armor used by the Japanese during World War II. Various data on steel armor are given, such as the types used, heat treatment, hardness, chemical composition, and ballistic requirements.

The Japanese used principally silicon-manganese-chromium electric-furnace steel of 0.2 to 0.4% carbon for aircraft armor. This armor was either homogeneous or carburized and was heat treated by quenching and tempering to a specific hardness. Ballistic tests conducted on the experimental and production armor are given.

Armor and structural steel in tanks, landing barges, and gun shields are discussed briefly.

The Japanese used safety glass and sponge rubber for protection of pilots and fuel cells, respectively, but there was no indication that materials such as aluminum alloy, magnesium alloy, nylon, silk, glass cloth, or leather were used as protection for personnel or equipment against the effects of minor caliber gunfire.

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LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

REFERENCES

Location of Target:

First Naval Technical Arsenal, YOKOSUKA, and branch, KANAGAWA.
Naval Aeronautical Ordnance Department, Navy Ministry, TOKYO.
Naval Arsenal, JAPAN Steel Making Department, KURE.
Steel Experimental Laboratory, Proving Ground, KAMEGAKUBI.
Tohoku Imperial University, SENDAI.
Naval Technical Research Institute, Meguro, TOKYO.
Nippon Special Steel Co., Omori, TOKYO.

Japanese Personnel Interviewed:

Kazuo NAKAMAE, former Technical Commander in the Steel-Making Department, Kure Naval Arsenal; heavy armor production metallurgist, 15 years experience in the manufacture of armor.

Kazuo HORIKAWA, former Lieutenant Commander in Steel-Making Experimental Laboratory, Kure Arsenal; heavy armor research metallurgist, four years experience with armor.

Mitsuo KANERO, Civilian engineer in Experimental Ordnance Section, Kure Naval Arsenal; seven years experience in ballistic testing of armor, projectiles, and guns.

Koi KAWAMURA, former Engineer Captain in Naval Aeronautical Ordnance Department, TOKYO: PhD in engineering; 10 years experience with aircraft ordnance.

Todao SATO, former Technical Lieutenant Comdr. at First Naval Technical Arsenal, YOKOSUKA: research metallurgist in ferrous and non-ferrous metals used in aircraft; eight years experience.

Sotoji UNISHI, engineer at Kanagawa Branch of First Naval Technical Arsenal; six years experience in tests of aircraft machine guns and ballistic tests of aircraft armor.

Masaichi SATO, chief production engineer at Nippon Special Steel Co.; 30 years experience in steel manufacturing, six years experience in light armor manufacture.

T. OYAMA, engineer at Naval Technical Research Institute, Meguro, TOKYO; eight years experience in experimental testing of naval materials.

Keisuke UDO, former Major at Army Air Force Technical Laboratory, TACHIKAWA; graduate in metallurgy, Tohoku Imperial University SENDAI; not much experience in aircraft armor.

T. MURAKAMI, Professor of Metallurgy at Tohoku Imperial University, SENDAI; 30 years experience in metallurgical engineering.

K. HONDA, President of Tohoku Imperial University, SENDAI; world famous metallurgist; 40-50 years experience in metallurgy.

I. OHIRA, former Navy Technical Captain, Ordnance Section, Navy Ministry, TOKYO.

Reports of Other Intelligence Agencies:

Technical Intelligence Co. No. 5250, Ordnance Report No. 7.

INTRODUCTION

During World War II light armor was used in tanks and aircraft by the Japanese Army and Navy. This armor was alloy steel less than two inches in thickness. Some of the details of manufacture, together with the ballistic properties, are given in this report. Most of the data describe 3mm to 16mm aircraft armor as manufactured by the Navy. Japanese tank armor and the structural type steel used for landing craft and gunshields are described briefly.

The questioning of Japanese naval aircraft ordnance personnel revealed that they did not consider aircraft armor to be effective. For example, they believed that for a given weight of armor carried in an airplane, the speed and maneuverability lost would have been of more value than the protection gained. Such views appear to have inhibited the development of Japanese aircraft armor. Nevertheless, a certain amount of aircraft armor was used. During 1943 the Japanese Navy used from 5mm to 7mm homogeneous armor as pilot-seat armor in the Zero fighter, in the Betty bomber, and in torpedo bombers. During the remainder of the war, however, 12mm carburized armor was used for rear protection to the pilot in such planes as the Zero fighter, Francis 11, Jill 12 and Judy.

THE REPORT

PART I - AIRCRAFT ARMOR

A. GENERAL

Although the Japanese Navy experimented with various aircraft armor steels as early as 1939, production was not undertaken until 1943. Prior to that time, the Japanese Army used aircraft armor steel, and throughout the war, used more and heavier aircraft armor than the Navy.

Information available shows that the armor steel used by the Japanese was of two types, homogeneous and carburized. It varied in thickness from 3mm to 20mm, but very little armor over 13mm in thickness was actually used. The following table lists the principal manufacturers in order of the quantity of light armor produced for Japanese Army and Navy aircraft.

Manufacturer	Location	Production*
Nippon Iron Mfg. Co.	Yawata, KYUSHU	11,000 lbs.
Daido Steel Mfg. Co.	NAGOYA	11,000 lbs.
Nippon Special Steel Co.	Omori, TOKYO	22,000 lbs.
Nippon Steel Mfg. Co.	Muroran, HOKKAIDO	33,000 lbs. (only armor for Navy)
Nippon Electric Steel Co.	YOKOHAMA	(only armor for Army)

*Monthly Average for Navy (1944-45)

These manufacturers of aircraft armor used a Heroult type basic electric furnace for production armor and occasionaly a high-frequency induction furnace for experimental armor. The Heroult type furnace varied in capacities from 5 to 15 tons. Table I shows the chemical composition and specifications for production armor manufactured by the Japanese Navy.

Table I
SPECIFICATIONS AND COMPOSITION OF NAVY ARMOR

Spec.	Chemical Composition (o/o)							Thickness (mm)
	C	Mn	Si	P-S	Ni	Cr	Mo	
Ro 601*	0.35-0.40	0.8-1.0	< 0.35	< 0.030	2.5-3.5	1.5-2.0	0.4-0.6	3,4,5,6,7,
Ro 631**	0.18-0.25	0.8-1.2	0.6-1.0	< 0.030	---	1.0-1.5	---	8,12
Ro 632***	0.23-0.30	0.8-1.2	0.6-1.0	< 0.030	---	1.0-1.5	---	16

*For Homo. armor up to 1943 and for 7mm Homo. only during 1944-45.
**For carburized armor only.
***For carburized armor only.

During the early part of the war, armor for the Japanese Army was made of nickel-chromium-molybdenum, manganese-chromium-molybdenum, and chromium-molybdenum steels with 0.35% to 0.50% carbon.

Table II lists the specifications for analyses of armor used by the Japanese Army during 1944 and 1945.

Table II
SPECIFICATIONS AND COMPOSITION OF ARMY ARMOR

Spec.	Chemical Composition (o/o)					Thickness (mm)
	C	Mn	Si	P-S	Cr	
2-704*	0.35-0.45	0.8-1.8	0.8-1.8	<0.030	0.8-1.8	3 to 20
2-707**	0.25-0.35	0.9-1.2	0.9-1.1	<0.030	1.0-2.0	7 to 20

*For homogeneous armor.
**For carburized armor.

B. MANUFACTURING PROCEDURE

1. Aircraft Armor

As stated previously, basic electric furnace steel was used for aircraft armor. Ingots produced by different manufacturers were various sizes and usually weighed from 660 to 2,200 pounds. Ingots were cropped approximately 20% from the top and 10% from the bottom. All plates were cross rolled. (See Enclosure (C) for details of rolling performed at the Daido Steel Mfg. Co.) All manufacturers except the Daido Steel Mfg. Co. carburized the armor in the final thickness.

2. Homogeneous Armor

The steels listed in Tables I and II were used by the Japanese Navy and Army for homogeneous armor. Plates were heat treated by normalizing at 850°C - 900°C, holding for one hour, quenching cold in oil or a press, and tempering at 100°C - 200°C for two hours.

The quenching press was used for plates under 7mm in thickness to prevent warping. The plates of the press were cooled by air or circulating water The desired hardness for 3mm to 7mm Naval aircraft armor was from 500 Brinell to 560 Brinell while the 3mm to 16mm armor for Army aircraft ranged in hardness from 500 BHN to 630 BHN.

3. Carburized Armor

The carburizing of armor (see analysis in Tables I and II) was conducted in the final gauge except at the Daido Steel Mfg. Co. where armor was carburized in a slab 30mm in thickness, as described in Enclosure (E). The carburizing process was quite similar at all manufacturing plants. The usual commercial carburizing compounds of a mixture of barium carbonate and charcoal were used. The plates were pack carburized two at a time, face to face, in a cast steel or rolled steel box. This box was placed in a car type furnace; a carburizing temperature of 950°C was used. Carburizing time was varied according to the depth of case desired and the carburizing compound used. The aim depth of case was 20% of the nominal thickness. After carburizing, except at the Daido Steel Mfg. Co. where plates had to be rolled first to the desired thickness, the plates were heat treated as follows: normalized at $800 - 850^{\circ}C$, annealed at $700^{\circ}C$ for one hour, cooled in air, hardened at $800 - 850^{\circ}C$ for one hour, quenched in oil tempered at $100 - 200^{\circ}C$ for two hours. The resultant hardness of the armor was the prime factor and heat treatments were adjusted, at times, to give a face hardness greater than 550 BHN and a back hardness greater than 400 BHN.

C. INSPECTION OF ARMOR

In general, both the Army and Navy had inspectors or representatives with each of the companies. These inspectors were not always detailed to inspect light armor but, in a general manner, they guided the production of armor. Inspection was performed primarily by the company with Navy and Army light armor inspectors being summoned periodically. Apparently no hard and fast rules were set up for government inspection but the manufacturer was expected to abide by the fundamental specifications for analysis, hardness, and dimensional tolerances. The following inspection was carried out by each company to insure a satisfactory product:

(1) Analysis check taken from the ladle

(2) Dimensional check of each plate after completion with an allowance of plus 10% and minus 0% of the desired thickness

(3) General-appearance check of each plate after completion

(4) Hardness measurements on the face and back of each plate after completion

(5) Periodic tensile and shock tests, usually upon request of the government inspector. If a plate did not meet the hardness requirements shown in Table III, it was reheated or scrapped.

Table III
SPECIFIED MECHANICAL PROPERTIES

Spec.	For Core Only				Carburized Face Brinell Hardness
	Tensile Strength (psi)	Elongation (o/o)	Charpy (ft/lbs)	Brinell Hardness	
Navy Ro 601	> 250,000	>6	--	>500 >560	---
Navy Ro 631	> 199,000	>8	>50	>400	>550
Navy Ro 632	> 213,000	>5	>36	>400	>550
Army 2-704	-------	-	--	>500 630	---
Army 2-707	-------	-	--	>400	>550

After a group of plates, consisting of all plates from one heat of steel, had been completed, a government inspector generally was called to check hardness and dimensions, and to select a ballistic-test sample. This practice was altered in the later stages of the war and ballistic-test samples were not selected; only inspections for hardness were performed. The reduction in standard was accepted to speed up production of aircraft.

D. BALLISTIC TESTING OF AIRCRAFT ARMOR

1. Navy Tests

The approximate conditions of test for acceptance of Naval aircraft armor are listed in Table IV. Acceptance ballistic testing was conducted by the Navy on one plate from each group. A group of plates consisted of all plates processed in the same manner and from a single heat of steel. Ballistic tests were conducted by the inspector at the plant of the manufacturer or at the branch of the First Naval Technical Arsenal of KANAGAWA. Towards the end of the war, all armor was supplied without the ballistic test.

Table IV
TEST CONDITIONS FOR JAPANESE NAVY AIRCRAFT ARMOR

Spec.	Thickness (in.)	Projectile (AP)	Obliquity (°)	Striking Vel. (ft/sec)	Remarks
Ro 601	0.197-5mm(1) 0.236 0.276	7.7mm(2) 7.7mm 7.7mm	0 0 0	2362 2558 2624	Firing Range was 50 meters from gun to plate
Ro 631	0.315 0.472 0.472	13mm(3) 13mm 20mm(4)	0 0 0	1640 2132 1476	Impacts had to be at least three calibers apart as measured from the edge of impacts
Ro 632	0.632 0.632	13mm 20mm	0 0	2378 1886	

(1) Navy armor of less than 5mm thickness was not given a ballistic test. This armor was found to have no practical application in service.

(2) An 11.4 gram projectile consisting of a 5.75 gram A.P. core with a 2.85 gram lead nose cap and a 2.80 gram copper jacket.

(3) A 51.8 gram projectile consisting of a 31.8 gram A.P. core with a 2.9 gram lead nose cap and a 17.2 gram copper jacket.

(4) A 116 gram A.P. projectile inert loaded to 131.3 grams for armor tests.

Complete descriptions of the projectiles referred to in notes may be found in a Japanese document entitled "Various Types of Machine-Gun Ammunition", which has been forwarded to the Washington Document Center, under NavTechJap Document No. ND50-3111, ATIS No. 4364.

In addition to the conditions of test listed in Table IV, for naval aircraft armor from 5mm to 16mm in thickness, no further velocity compensations were made for slight variations in plate thickness. At least three projectiles were fired to test a plate. Velocities were measured by a "Boulenge" chronograph or an oscillograph. As a rule, when two projectiles were listed for testing a particular thickness of armor, both were fired. If a plate passed the test with one projectile and failed with the other, the group of armor represented by the test plate would be rejected and scrapped.

A plate failed the ballistic test under the conditions set forth in Table IV when: (1) a depth of penetration was greater than 5mm, providing the striking velocity of the projectile was equal to or less than that listed; and (2) cracking or breaking of the plate was excessive, as judged by the inspector; and (3) unless one impact was obtained with specified projectile having a striking velocity greater than that listed. Approximately 10% of the armor tested failed to meet these ballistic requirements. A greater number of failures occurred in the thinner gauges than in the heavier thicknesses. It may be noted that the ballistic requirements for the Ro 601 type armor were severe. These data were reported by the Japanese from memory and may not be accurate.

2. Army Tests

Table V lists the conditions of test for army aircraft armor.

Table V

Spec.	Thickness (in.)	Projectile* (AP)	Obliquity (°)	Striking Velocity (ft/sec)
2-704 Homogeneous	.079	7.7mm	0	1312
	.118	"	0	1476
	.158	"	0	1640
	.197	"	0	1960
	.236	"	0	2296
	.276	"	0	2362
2-704 2-707 Homogeneous and Carburized	.315	13mm	0	1935
	.355	"	0	1984
	.394	"	0	2034
	.433	"	0	2083
	.472	"	0	2132
	.550	"	0	2230
	.591	"	0	2280
	.632	"	0	2329

*Projectiles apparently identical with those described in Table IV.

The Japanese Army ballistic acceptance procedure differed from the Navy method only in interpertation of a failing impact. A plate failed the ballistic test under the conditions of test listed in Table V when either of the following occured:

a. A through hole in the plate, providing the striking velocity of the projectile was equal to or less than that listed.

b. Excessive cracking or breaking of the plate as defined by the inspector.

The Japanese Army considered acceptance testing of 10mm, to 16mm, carburized armor with 20mm A. P. projectiles, but never put it into effect.

E. WELDING OF AIRCRAFT ARMOR

In fabricating and installing aircraft armor, the Japanese employed no welding nor did they investigate the possibility or study the effects of welding of aircraft armor.

F. DEVELOPMENT OF ARMOR

In general the Japanese were thorough in their investigation of experimental armor. Enclosure (A) is a report on a typical investigation. Records indicate that the Japanese conducted complete metallurgical investigations, in addition to ballistic tests, on all experimental armor.

The Japanese Navy and Army conducted the following experiments during the war in an attempt to improve the quality of aircraft armor:

1. Determination of the optimum depth of carburization for armor versus the 13mm A.P. Projectile. This experiment showed a 30% case to be the most effective against the 13mm A.P. projectile, however, a 20% depth of case was adopted for production armor because of manufacturing difficulties associated with making a heavier case.

2. Development of substitutional steels without nickel and molybdenum for use in armor.

3. Determination of the optimum heat treatment for each type armor.

4. Experimentation with composite armor produced by casting one steel into a mold, removing a partition, and quickly casting the second steel: This experiment was conducted in order to make armor with a face of greater depth and a higher and more uniform hardness pattern. In addition, composite armor was carburized. The results of the investigation showed that a good bond could be obtained between the two steels and that carburized composite armor offered greater penetration resistance to 13mm A.P. and 25mm A.P. projectiles than did ordinary cemented armor. However, composite armor of this type apparently never was used in service. Complete details of one such experiment may be found in the Japanese document entitled "Manufacture and Ballistic Test of Composite Armor" which has been forwarded to the Washington Document Center, under NavTechJap Document No. ND50-3157, (See Enclosure (E)).

5. Development of an aircraft armor for protection against high explosive projectiles. On the basis of this experiment the Japanese decided upon the use of: (1) a carbon steel of approximately S.A.E. 1040 composition, and (2) a silicon-manganese-chromium steel. A straight quench and temper to produce a hardness of 250 to 400 BHN was used. Table VI lists the average limits obtained with this armor under high explosive projectile fire.

Table VI
STRIKING VELOCITY
(ft/sec)*

Thickness of Armor (in.)	Average Plate Limit Versus:		
	20mm HE	30mm HE	40mm HE
.632	----	----	2427
.550	----	----	2165
.472	----	2296	1902
.394	2788	2066	1640
.315	2296	1837	1378
.236	1804	1640	----

*All projectiles were fuzed with a nose detonating fuze of the air column type (no firing pin).

A limit was an estimate of the minimum striking velocity of a projectile required to cause:

a. A depression in the plate of 15mm depth or

b. Excessive cracking of the plate, as decided by the firing official.

6. Ballistic tests of various combinations of spaced aircraft armor.

This experiment was conducted in an attempt to determine if two or more thin sections of armor separated by air were equivalent in protection afforded to one solid section of armor of equal weight. Some combinations of armor spaced approximately 15mm apart were found to afford approximately 20% more protection than an equal weight of solid armor.

PART II - TANK ARMOR

The Japanese Army used both homogeneous and carburized armor for tanks. The analysis of the homogeneous armor was C:0.25-0.35; Mn:0.60; P:0.030; S:.030; Si:0.35; Ni:2.0-4.0; Cr:0.8-1.8; and Mo:0.20-0.50 with 0.7 to 1.5% tungsten sometimes substituted for the molybdenum. The armor was quenched and tempered to a hardness of approximately 320 BHN. Table VII lists the conditions of test for acceptance.

Table VII

HOMOGENEOUS TANK ARMOR PENETRATION TESTS

Projectile	Thickness of Armor (inches)	Obliquity	Striking Velocity (ft/sec)
7.7mm Ball	.079 .118 .158 .197	0° 0° 0° 0°	1210 1570 1890 2230
7.7mm A P	.236 .314 .394 .473 .550	30° 0° 0° 0° 0°	2230 1640 2000 2220 2580
20mm A P	.630 .787	30° 0°	1470 1150
37mm A P	.983 1.18 1.38 1.57	30° 0° 0° 0°	1310 1180 1380 1570
47mm A P	1.97	0°	1570
37mm A P	.236 to .787	0°	1080
47mm A P	.983 to 1.57	0°	1150

In general, carburized armor for tanks was a nickel-chrome-molybdenum steel of the same composition as the homogeneous armor. However, a nickel-chromium-molybdenum steel with approximately 0.48% carbon also was used for face-hardened armor. Table VIII gives the ballistic requirements for the above armors.

Table VIII

BALLISTIC REQUIREMENTS FOR TEST ARMOR

Type of Armor	Thickness (inches)	Projectile	Obliquity (°)	Striking Velocity (ft/sec)
Ni-Cr-Mo 0.24-0.28C Face Hardened	.236	7.7mm A P	0	2156
	.314	"	0	2320
	.394	"	0	2490
	.473	"	0	2650
	.787	20mm A P	0	1800
	.983	37mm A P	0	1640
	1.18	"	0	1830
	1.38	"	0	2000
	1.57	"	0	2150
Shock Test	.236-.787	37mm A P	0	1080
	.983-1.38	47mm A P	0	1310
Ni-Cr-Mo 0.48C Face Hardened	.158	7.7mm A P	0	1640
	.197	"	0	1960
	.236	"	0	2296
	.314	"	0	2450
	.394	"	0	2610
	.473	"	0	2710

PART III. LANDING BARGE AND GUNSHIELD ARMOR

During the war, the Japanese Navy used very little steel in landing barges and gunshields which could properly be called armor. Instead of armor steel, they used mild steel and a basic open hearth semi-kilned structural type steel having a tensile strength of 80,000 to 90,000 PSI. The average analysis of the structural type steel, called "Ducol" by the Japanese, was C:0.24, Mn:1.4, Si: 0.35, S:0.035, P:0.035, Ni:trace and Cu:0.20. The high manganese content gave increased strength to the steel and the copper addition supplied corrosion resistance. Nevertheless, this steel could not be classified as armor nor did the Japanese consider it armor, as it was not subjected to ballistic acceptance tests. "Ducol" and mild steel were used for gunshields on mounts up to the 12.7mm anti-aircraft type. The side, back, and top of these gunshields usually were constructed of one or two thicknesses of 3.2mm plate. The front side of the gun shield was made of 8mm or 12mm plate.

Prior to the war, the Japanese Navy experimented with and used many types of armor in gunshields. A document entitled "Firing Tests of Non-Nickel Shields", which has been forwarded to the Washington Document Center under NavTechJap Document No. ND50-3166 (see Enclosure (E)), lists various steels for gunshields and gives their respective ballistic performance as well as a good description of experimental ballistic testing methods employed by the Japanese Navy. Table IX , lists the steels investigated in the experiment and gives the mechanical properties.

Table X lists the ballistic results obtained on these types of steel.

An austenitic manganese steel with a small amount of nickel and chromium was used as armor by the Japanese Navy. This armor generally was less than 1½ inches in thickness and since it was non-magnetic, it was used for protection when the operation of nearby instruments would be hampered by ferromagnetic armor.

Table IX
STEELS TESTED

Type of Armor	Chemical Analysis (%)							Mechanical Properties				
	C	Mn	Si	Ni	Cr	Mo	Cu	Direction	T.S. (psi)	Elong. (o/o)	Izod Value (ft. lbs.)	BHN
25mm BK	0.38	1.31	0.17	0.27	1.35	0.26	0.28	L T	120,000 119,000	24.1 21.7	51.2-56.4 41.0-40.8	254 253
18mm BK	0.35	1.30	0.13	0.25	1.36	0.26	0.27	L T	134,000 134,000	20.8 19.9	37.3-39.6 35.6-38.3	282 282
12mm BK	0.34	1.30	0.14	0.27	1.37	0.24	0.27	L T	135,000 136,000	21.5 19.9	32.7-38.7 25.2-28.3	287 289
NC	0.28	0.73	0.21	4.12	0.95	0.54	0.14		130,000	24.0	63.5-60.5	265
NVNC	0.43-0.53	0.30-0.45	0.05-0.25	3.7-4.2	1.8-2.2				> 100,000	>18	>30	
CNC	0.38-0.46	0.30-0.45	0.05-0.25	2.5-3.0	0.80-1.30		0.90-1.30		110,000 125,000	>19	>30	
DS	0.27	1.20	0.085				0.044		85,000 93,000	>20	Charpy 5.5-9.9	180-200

Table X
BALLISTIC RESULTS WITH TEST STEELS

Type of Armor	Thickness (mm)	Hardness (BHN)	Projectile	Obliquity (°)	Limit* Velocity (ft/sec)
BK	25	254	20mm A P	0	1700
BK	25	254	"	30	1820
BK	18	282	"	0	1350
BK	18	282	"	30	1748
NC	25	265	"	0	1680
NVNC	25		"	0	1638
DA	25		"	0	1472
CNC	18	250	"	0	1305
DS	20		"	0	1250
DA	20		"	30	1712
BK	12	288	13mm A P	0	1530
BK	12	288	"	30	1810
DS	12		"	0	1270
DA	12		"	30	1630

*Limit velocity was estimated from firing data and then corrected by Demarre formula for variations in gauge. (For further details see NavTechJap Report "Japanese Heavy Armor", Index No. O-16.)

PART IV. OTHER TYPES OF LIGHT PROTECTIVE MATERIALS

For protection against the effects of gun fire, the Japanese apparently used, in addition to steel, only bullet-resistant glass and sponge rubber. Bullet-resisting glass was used for aircraft windshields. It was manufactured in various thickness up to three inches and consisted of several laminations of heat-treated glass separated by layers of polyvinyl formaldehyde resin. This glass was designed to provide protection against 7.7mm and 13mm ammunition. Details of experiments performed by the Japanese with bullet-proof glass may be found in pamplets forwarded to the Washington Document Center under NavTech Jap Document Nos. ND50-3147 and ND50-3189 (see Enclosure (E)). Natural rubber between layers of vulcanized rubber was used for self-sealing protection of fuel cells in aircraft.

The Japanese used no materials such as nylon, silk, leather, or glass cloth for the protection of personnel or equipment against the effects of gunfire. With the exception of a few experimental ballistic tests on very thin aluminum plate, there was nothing to indicate that the Japanese were investigating aluminum or magnesium alloys for use as armor.

PART V. DISCUSSION

Enclosure (D) lists Japanese light armor samples shipped to the Naval Proving Ground, Dahlgren, Virginia. Pertinent documents recovered in JAPAN are listed in enclosure (E) and have been forwarded to the Washington Document Center. Experiments performed at the Tohoku Imperial University, SENDAI, are listed as NavTechJap Documents No. ND50-3146, ND50-3162, and ND50-3164. Enclosure (B) is a discussion of the static torsion test performed at the University.

Date available indicate that Japanese light armor steel (homogeneous and carburized) used in aircraft, landing barges, and gunshields was inferior to U.S. Navy armor steel for protection against the effects of gunfire.

While their homogeneous armor appeared to the Japanese to possess the correct hardness for supplying protection, this armor, at a hardness of 500 to 630 BHN, offered poor penetration resistance to overmatching projectiles which were used against it. In addition, the shock properties of the armor no doubt were very poor. However, Japanese data indicated the hardness of the armor to be optimum.

A recent report entitled "Experimental Mn-Va Steel Torsion Test" which has been forwarded to the Washington Document Center as NavTechJap Document No. ND50-3162 (see Enclosure (E)), shows that the calculated thickness of armor required to stop a projectile at a specified velocity was less at lower tempering-temperatures than at higher ones. In other words, it was evident to the Japanese that as the hardness of armor increased, the thickness required to afford a given amount of protection decreased.

The carburized armor manufactured by the Japanese generally was of good quality. However, it was noted that no improvement in the quality of this armor was effected during the war. This may be attributed to the substitution of other alloying elements for nickel and molybdenum.

There appeared to be some reluctance on the part of the Japanese Navy to use aircraft armor. The Army believed aircraft armor necessary and did more development work on it.

ENCLOSURE (A)

EXPERIMENTS WITH SPECIAL ARMOR PLATE, FOR USE IN PLANES, MANUFACTURED BY THE DAIDO STEEL CO. LTD.

(Translation)

Report No. 03104 Material Report 0330

Period of Experiment:

10 April 1942 - 20 December 1942

Experiment No:

No. 103 Material Test 17

Type of Notification Bulletin:

Air Headquarters Top Secret Bulletin #11115 on 20 Dec., 1940 (See Addendum)

Persons Compiling Report:

Navy Senior Technician Hideo YAMAGUCHI

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Purpose:

To test the special armor plate for use in planes manufactured by the Daido Steel Co., Ltd. and to determine the value of using protective armor plate on planes.

ENCLOSURE (A)

ENCLOSURE (A), continued

INTRODUCTION

A. OUTLINE OF RESULTS

1. Firing Test

a. The bullet resistance power of BK3 is slightly superior to BK8, but it is difficult to say that it is perfected when judged from the standard necessary for armor plate.

b. Both BK3 and BK8 generally are brittle. Compared to the "Ro 601" used at present, they have a great tendency to begin to crack and peel. This is especially true of BK8.

2. Test for Composition of Materials

a. BK3 is made up of chrome, manganese, molybdenum steel (carbon content 0.3). BK8 is made up of silicon, manganese, chrome steel (carbon content 0.37).

b. The degree of hardness of BK3 and BK8 (inner degree of hardness of cemented plates) is 530 Hv and 600 Hv respectively.

c. Even though the cemented thickness averages 15%, the degree of hardness of cemented parts of both steels is very low and no effect of cementation is noticed in 2, 4mm plates of BK3.

d. There are many non-metallic foreign inclusions in both types of armor plate and there is marked bending and breaking.

e. The degree of crystallization of BK3 is G6, of BK8 is G7.

3. Opinions of OinC of Navy Air Department

a. Among the materials tested, BK3 is a non-nickel steel plate and so it is not quite suitable, but if its flexibility were improved, there would be nothing to prevent its use.

b. Since BK8 is very brittle, it is thought that it has few useful characteristics.

4. Opinions of OinC of Navy Technical Dept. (Air)

(TN: none given)

B. PERSONS IN CHARGE OF EXPERIMENTS AND ASSISTANTS

1. Material Supply Dept:

Fsunahiko YOTEI, Navy Senior Technician
Hideo YAMAGUCHI, Navy Senior Technician
Keishi MATSUBARA, Navy Lieut. (Technical)
Masao SEMBA, Navy Technician

2. Equipment Department:

Heishiro NISHIDA, Navy Capt.
Masa KUGIMIYA, Navy Lieut.
Akio YANAKA, Navy Lieut. (Technical)
Yukishige MATSUMOTO, Navy Technician

ENCLOSURE (A), continued

CHAPTER I. PURPOSE

To test special armor plate, for use in planes, manufactured by the Daido Steel Co. Ltd, and to determine the value of using protective armor plate on planes.

CHAPTER II. RESULTS AND OPINIONS

A. RESULTS

1. Firing Tests

a. The critical angle in oblique-firing tests and bullet-resistive powers in direct-firing tests are shown in Table I(A). The bullet-resistive power of BK_3 is slightly superior to BK_8, but it is difficult to say that it is perfected when judged from the standard necessary for armor plate.

b. Both BK_3 and BK_8, generally, are brittle, and compared to "Ro 601" used at present, they have a great tendency to begin to crack and peel. This is especially true of BK_8.

2. Test for Composition of Materials

a. BK_3 is made up of chrome, manganese, molybdenum steel (carbon content 0.37) (See Tables II(A) and III(A).

b. The degrees of hardness of BK_3 and BK_8 (inner degrees of hardness of cemented plates) are 530 Hv and 600 Hv respectively. The results of the tempering tests are the same.

c. Even though the cemented thickness averages 15%, the degrees of hardness of cemented parts of both steels is very low and no effect of cementation is noticed in 2 and 4mm plates of BK_3.

d. There are many non-metallic foreign inclusions in both types of armor plate and there is marked bending and breaking.

e. The degree of crystallization of BK_3 is G6 (Gakushinho method of testing) and of BK_8 is G7.

B. OPINIONS

1. Since the same constituent elements have been used in both the cemented and non-cemented plates, they are considered unsatisfactory. It is thought that one must choose constituent elements (particularly carbon content) which are most suitable to each type of plate respectively.

2. The bullet-resistive strength of non-cemented BK_3 is roughly the same as "Ro 601" now being used, but it is less flexible. Cemented BK_3 plate is on the whole, as good, but on testing its constituent elements, inner hardness, thickness of cementation, etc, it was found that these characteristics (flexibility, most of all) had to be increased.

3. Non-cemented BK_8 plate does not come up to the bullet-resistive strength of the presently used "Ro 601" and is extremely brittle. BK_8 cemented plate also is brittle. It is necessary again to check on the constituent elements, inner hardness, etc. and follow a method whereby the carbon content is reduced to 0.25-0.30.

ENCLOSURE (A), continued

4. The characteristics of BK_3 are not satisfactory, but since it is a non-nickel plate, there is a good chance that it can be used at the present time. (However, it is thought that further research concerning the improvement of its flexibility is necessary.)

If no further steps are taken to improve BK_8, it is thought that it has little practical value.

5. Because there are foreign objects in the plates and there is bending and breaking, further improvements are necessary.

CHAPTER III. DEVELOPMENT OF TESTS AND RESULTS

A. TEST MATERIALS

The tested materials were two kinds of special steel plates, BK_3 and BK_8, to be used as armor plate and manufactured experimentally by the Daido Steel Co., Ltd. Table IV(A) lists the measurements and number of samples provided by the Company. The records of the plates are given in Tables II(A) and III(A).

B. FIRING TESTS

1. Vickers type 7.7mm fixed MG, Model 3 Modification 1; 13mm fixed MG used on test planes.

2. Direct-Firing Test: Ordinary bullets and armor piercing shells, 7.7mm, were fired at a range of 25 meters. Details of results of the test for bullet-resistive strength under direct fire are shown in Table V(A) and Figure 1(A).

The bullet-resistive strength of BK_3 non-cemented plates toward ordinary bullets surpassed the present standard used for bullet-resistive strength, but against armor-piercing shells, did not come up to the present standard. The bullet-resistive strength of BK_8 non-cemented plates toward both ordinary and armor piercing shells does not satisfy the present standard used for bullet-resistive strength.

The cemented plates, except for BK_8 4mm plate, come up to the standards now used, but the bullet-resistive strength of the 2 and 4mm plates is the same as the non-cemented plates. An increase in resistive strength due to cementation is seen for the first time in the 6mm plates. This is noted in the article about the material test. The cementation thickness in the 2 and 4mm plates is very thin and it is thought that there is very little increase in surface hardness by cementation. Also, when comparing the resistive strength of BK_3 and BK_8, the strength of BK_3 slightly surpasses that of the latter. Generally speaking, it is difficult to say that the resistive strength of either is good.

Both BK_3 and BK_8 generally are brittle. Compared to "Ro 601" used at present, they have a great tendency to begin to crack and peel. This is especially true of BK_8. This insufficient flexibility is thought to be due to the composition of the materials. Moreover, the thin plates, especially 2 and 4mm, are generally brittle. When one observes these cracks, it is obvious that they are in the direction of the rolling process of the plate.

3. Oblique-Firing Test

a. Using the same plates as in the direct-firing tests, the firing angle was changed by various degrees. The results which tested the critical angle of oblique firing are given in Table VI(A) and Figure 2(A). The balanced firing angle of the 7.7mm armor piercing shell fired at 100 meters range toward the various plates is given in Table VII(A).

By increasing the firing angle toward both BK_3 and BK_8, their resistive strength increase is almost the same. Under conditions of a firing range of 100 meters and at an identical firing angle, both cemented and non-cemented plates fall within these limits: plates 2 and 4mm thick, 50^o-60^o; plates 6mm thick, 25^o-35^o. Also, because of the firing angle toward both BK_3 and BK_8, there was the same tendency to split and peel as when firing directly. They were somewhat brittle, especially BK_8.

b. Firing test by 13mm MG: Results of the investigation of conditions of damaged armor plate from a 13mm MG armor piercing shell with the normal service charge used in aircraft, are shown in Table VIII(A). As the thickness of the plate increased, the diameter of the hole increased. There were no other particular changes.

Figure 3(A) and Figure 4(A) show conditions of the plates following firing.

4. Materials Tested

a. Appearance and measurements: There was a thin oxidized layer over the outside layer of the plates provided for the test. The materials were bent very little, and there were no noticeable defects, such as folds, resulting from the rolling process. All the 2 and 4mm plates had variations and were not good. The results of investigating the differences in thickness of the plates are given in Table IX(A). Except for BK_3, 2mm plates (cemented) and 6mm plates (cemented) all were good. (Table IX(A) is on page 29.)

b. Range of hardness of samples provided: The measurement of hardness of material provided is given in Table X(A). The average hardness of BK_3 is 50-52 H_{RC}. and of BK_8 is 53-55 H_{RC}. Although BK_8 is slightly harder, each plate's hardness range is about the same. The surface hardness of cemented plates is generally low. Particularly in the care of the 2 and 4mm plates, the cemented surfaces are nearly as hard as the rear surface. The effect of cementation is very slight.

c. Range of cross-sectional hardness: The results of the investigation of cross-sectional hardness for each cemented plate are shown by curves in Figure 5(A). The thickness of cementation is shown in Table XI(A). The hardness of the cemented portions generally are low, and BK_3 2 and 4mm plates, especially, show no effect from cementation. BK_8 2 and 4mm plates show few results from cementation. The hardness of the inner part of BK_3 is about 530 Hv and of BK_8 is about 600 Hv (C-4-2, however, is slightly lower). The hardness of BK_8 is high.

d. Non-metallic foreign inclusions: On investigating the foreign inclusions according to the method set forth by the Gakujitsu Shinkokai (Scientific Advancement Society), exceedingly many were found in all plates, especially many traces of oxidized substances. BK_8, as compared to BK_3, had many more non-metallic foreign inclusions. This condition is shown in Table XII(A) and Figure 6(A).

ENCLOSURE (A), continued

e. Microscopic formations: On investigating for miscroscopic formations of each plate which had been provided, all were found to have similar Martinsite formation. There were no other particular differences (see Figure 7(A)). The plates and their formations, which had been annealed at 900°C for 1 hour, are shown in Figure 8(A). Bending and breaking of each plate was severe and examples of this are shown in Figure 9(A).

f. Degree of crystallization: The results of measuring the degree of crystallization have been obtained by the cemented method set up by the Gakujitsu Shinkokai and are shown in Table XIII(A). The crystallization of BK_3 is G6 and of BK_8 is G7. BK_8's crystals are smaller than those of BK_3 and are almost uniform in size. Figure 10(A) shows this condition.

g. Hardness, tempering relationship: Selecting a plate to be tested from among the non-cemented plates, they obtained a plot showing the hardening and tempered hardness of BK_3 to be about 5 H_{RC} lower than that of BK_8.

6 April 1943.

ENCLOSURE (A), continued

ADDENDUM

REFERENCES FOR TESTS

Air Hq. Top Secret Bulletin No. 11115. 20 December 1940

From: OinC, Naval Air Headquarters, Administration Dept.
To : OinC, Naval Air Technical Depot, Administration Dept.

Subject: References concerning tests of special steel plates for the use of aircraft manufactured by the Daido Steel Co., Ltd.

We will send samples of the above plate to you and request that upon testing it, you send us your results and opinions by the end of March, 1941.

The expenses involved will be paid by the Military budget from the Ship Building Ordnance and Repair Fund, Ordnance Fund, and Air Technical Experiment Fund.

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METHOD OF PROCEDURE

Air Technical Depot Top Secret Order No. 148.

The procedure to be carried out in the experiments with special steel plate for aircraft manufactured by the Daido Steel Co., Ltd. referred to in Air Headquarters Top Secret Bulletin No. 11115, 1940, is as follows:

The OinC of the Material Department is to be in charge of these experiments.

10 January 1941

C. O. Naval Air Tech. Depot - Misao WADA

1. Purpose

Test these plates and determine their practical value as armor plate for airplanes.

2. Nature of Research

a. Firing tests.
b. Tests of uniform characteristics of materials.
c. Physical and mechanical characteristics.

3. Date and Place

a. Date: 10 January 1941 to end of March 1941.
b. Place: Material Supply Dept., No. 4 Laboratory, Equipment Dept. No.1.

4. Method of Procedure

a. Test materials

(1) BK_3 (thickness 2 and 4mm), 2 plates each, total 4 plates.
(2) BK_8 (thickness 2, 4, and 6mm), 2 plates each, total 6 plates.

ENCLOSURE (A), continued

b. Firing tests: Fire 7.7mm ordinary and armor piercing shells. At a firing range of 25 meters, measure the initial velocity. In addition to measuring the bullet-resistive strength at direct fire, measure the acute angle under conditions of oblique firing if there is room left on the steel plate.

Follow, generally, the "Special Steel Plate Testing Regulations" given in Air Headquarters Top Secret Bulletin No. 4379, 1940, in carrying out these experiments.

c. Test for uniform characteristics of materials

(1) Examine outer appearance
(2) Investigate range of hardness
(3) Investigate differences in plate thickness
(4) Make a reduction test (TN: for constituent elements)
(5) Other tests thought necessary

d. Determine physical and mechanical characteristics

(1) Heating procedure for plates tested will be decided upon specially (TN: In another bulletin?)
(2) Items to be measured

(a) Measure unusual points
(b) Test qualities caused by heat process
(c) Test for microscopic formations

e. Test for other things thought necessary

5. Work Schedule

Make all tests and compile reports from 10 January 1941 to end of March 1941.

6. Report

Submit a report as soon as possible after the tests are made.

7. Persons in Charge of Tests

Material Supply Dept:

Koi KAWAMURA, Navy Comdr. (Engineer)
Kazuma KOTO, Navy Lt. Comdr. (Ordnance)
Mitsugu IKOMA, Navy Ensign (Ordnance)

Equipment Dept:

Chosu SHINOZAKI, Navy Comdr. (Ordnance)
Tsao KUBO, Navy Lt. (Ordnance)

ENCLOSURE (A), continued

Table I(A)
RESULTS OF FIRING TESTS

Projectile	Plate	Thickness (mm)	Direct Firing		Oblique Firing	
			Impact Speed (m/sec)	Range (m)	Impact Speed (m/sec)	Angle (°) (Range - 100 m)
7.7mm Ball	BK_3	2.07	475	532		
		2.55	497	479		
		3.98	636	174		
		4.23	617	216		
		6.03	>722	> 31		
		6.28	>729	> 12		
	BK_8	2.25	425	658		
		2.17	345	923		
		4.06	539	385		
		3.87	545	373		
		6.24	678	93		
		6.04	> 729	> 22		
7.7mm A.P.	BK_3	2.05	345	923	680	60
		2.50	344	936	680	58
		4.00	380	796	680	54
		4.23	405	715	680	50
		6.04	560	340	680	14
		6.15	630	187	680	18
	BK_8	2.25	333	995		
		2.17	> 337			
		4.01	372	820	680	47
		3.94	355	888	680	55
		6.22	532	401	680	29
		6.02	583	290	680	20

Note: Treatment - Carburized

ENCLOSURE (A), continued

Table II(A)

TABLE OF RECORDS OF SAMPLE STEEL PLATES, DAIDO STEEL COMPANY, (Ltd.)

18 March 1942

Type	Smelting Number	Cemented*	Number of Plates**			Chemical Elements (%)								
			2mm Thick	4mm Thick	6mm Thick	Materials	C	Si	Mn	P	S	Cu	Cr	Mo
BK_3	T 115269	Yes	2	2	2	Mn-Cr-Mo	0.31	0.36	1.17	0.019	0.030	0.22	1.49	0.36
		No	2	2	2									
BK_8	T 36503	Yes	2	2	2	Si-Mn-Cr	0.37	7.00	1.02	0.022	0.031	0.22	1.00	
		No	2	2	2									
Total Number Plates			8	8	8									

**All 450mm square

*Method of Cementation: Sheeting bars of BK_3 10mm thick and BK_8 20mm thick are cemented 8 hours at 900°C and then rolled to various thicknesses.

ENCLOSURE (A), continued

Table III(A)
CHARACTERISTICS OF MATERIALS

Kind of Plate	Thickness (mm)	Test No.	Plate No.	Annealing			Tempering Hardness (H_{RC})	Cemented
				Normalizing Temp.	Hardening Temp. (in oil)	Tempering Temp. (6 hrs)		
BK_3	2	T 115269	2-1 2-2		870° 870°	180° 180°	50.8 50.3	No No
			C-2-1	900°C AC*	870°	200°	front 54.3 back 49.8	Yes
			C-2-2	900° AC	870°	200°	front 53.0 back 49.0	Yes
	4	T 115269	4-1 4-2		870° 870°	150° 150°	50.8 49.8	No No
			C-4-1	900° AC	870°	200°	front 53.0 back 45.5	Yes
			C-4-2	900° AC	870°	200°	front 55.0 face 49.0	Yes
	6	T 115269	6-1 6-2		870° 870°	120° 120°	50.8 50.3	No No
			C-6-1	900° AC	870°	200°	front 55.5 face 47.5	Yes
			C-6-2	900° AC	870°	200°	front 56.0 face 51.0	Yes
BK_8	2	T 36503	2-1 2-2		860° 860°	180° 180°	53.5 54.3	No No
			C-2-1	900° AC	860°	200°	front 53.3 face 52.5	Yes
			C-2-2	900° AC	860°	200°	front 54.3 face 52.7	Yes
	4	T 36503	4-1 4-2		860° 860°	150° 150°	50.8 49.8	No No
			C-4-1	900° AC	860°	200°	front 55.8 face 52.0	Yes
			C-4-2	900° AC	860°	200°	front 54.5 face 50.8	Yes
	6	T 36503	6-1 6-2		860° 860°	120° 120°	53.0 53.5	No No
			C-6-1	900° AC	860°	200°	front 56.0 face 49.8	Yes
			C-6-2	900° AC	860°	200°	front 57.3 face 52.0	Yes

*AC - air cooled

ENCLOSURE (A), continued

Table IV(A)
THICKNESS AND NO. OF PLATES

Type	Cemented			Non-Cemented			Total
	2mm	4mm	6mm	2mm	4mm	6mm	
BK_3	2	2	2	2	2	2	12
BK_8	2	2	2	2	2	2	12

Table IX(A)
VARIATION IN THICKNESS OF TEST PLATES

Type	Treatment	Variation in Thickness (mm)		
		2mm Plate	4mm Plate	6mm Plate
BK_3		1.95-2.19	3.70-4.10	5.90-6.20
	Carburized	2.40-2.95	4.00-4.27	6.00-6.90
BK_8		2.15-2.30	4.00-4.14	6.07-6.30
	Carburized	2.10-2.27	3.80-4.10	5.88-6.10

ENCLOSURE (A), continued

Table V(A)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Date: 15 May 1942
Place: Firing Range, Branch Depot, Air Technical Depot
Machine Gun: Vickers Type 7.7mm, Fixed MG (Air) Type 3 Mod 1

Type	Target		Type Shell*	Firing Speed (m/sec)	Corre-spond-ing Range (m)	Pene-trate	Diam-eter of Hole (mm)	Depth of Inden-tation (mm)	Penetration Condition
	No.	Thick-ness (mm)							
BK_3	2-1	2.19	Common	384	782	No		3	2 cracks - 70, 70mm
		2.19		448	598	No		4	2 cracks - 80, 40mm
		2.13		424	662	No			3 cracks - 60, 75, 35mm
		2.00		464	560	Yes			3 cracks - 60, 40, 40mm
		2.03	A.P.	337	974	No			
		2.03		334	990	Head	5x5		Projectiles head only
		2.03		385	780	Yes	8x8		
		2.00		335	986	No			
		1.94		375	825	Yes	10x20		
		2.16		379	798	No			
		2.19		333	995	Yes	8x8		4 cracks: 20, 25, 20, 20mm
	2-2	2.01	Common	414	689	No			1 crack: 130mm
		2.02		443	612	No			1 crack: 110mm
		2.01		485	507	No			1 crack: 90mm
		2.02		524	420	Yes	8x8		
		2.04	A.P.	342	946	No		0.5	
		2.03		343	942	Part	4x4		1 crack: 70mm
		2.00		352	900	Part			Penetrated armour, stopped, caused crack 75mm long
	C-2-1 **	2.50	Common	528	410	Yes	30x20		2 cracks - 40, 40mm
		2.45		395	746	No		2	
		2.49		459	572	No		5	2 cracks - 70, 30mm
		2.48		472	541	Yes	20x55		
		2.50	A.P.	344	936	Head	10x4		Head only penetrated
		2.45		391	758	Yes	15x6		
		2.54		387	772	Yes	8x8		Projectile core only
	C-2-2 **	2.97	Common	557	346	Yes	25x17		
		2.51		490	497	No			1 crack 30mm
		2.48		483	514	No			1 crack 50mm

*Reduced charge

**Includes blister plate

ENCLOSURE (A), continued

Table V(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Type	Target		Type Shell*	Firing Speed (m/sec)	Corresponding Range (m)	Penetrate	Diameter of Hole (mm)	Depth of Indentation (mm)	Penetration Condition
	No.	Thickness (mm)							
BK_8	2-1	2.26	Ordinary	331	1006	No			2 cracks - 60, 100mm
		2.29		431	642	Yes	40x18		2 cracks - 20, 20mm
		2.32		445	606	Yes	30x27		
		2.25		474	536	Yes	30x25		1 crack - 25mm
		2.28		416	684	Yes	30x25		
		2.29		403	722	Yes	35x18		
		2.27		418	678	No			
		2.28	A.P.	333	995	Head	5x5		3 cracks - 40, 50, 60mm
		2.30		346	930	Yes	20x30		
		2.25		343	944	Yes	25x25		
	2-2	2.23	Common	456	580	No			
		2.21		419	675	No			
		2.20	A.P.	343	942	Yes			The steel plate was torn away
	C-2-1 **	2.11	Common	424	662	Yes	20x20		1 crack - 40mm
		2.10		416	684	Yes	20x20		1 crack - 20mm
		2.11		399	732	Yes	15x15		
		2.11		366	844	Yes	30x25		
		2.12		330	1012	No			
		2.11		329	1016	No			1 crack - 60mm Plate torn away (55x70mm)
		2.18	A.P.	337	974	Yes	15x15		
		2.13		350	910	Yes	15x15		
		2.26		380	796	Yes	20x20		
	C-2-2 **	2.17	Common	342	946	Yes			
		2.23		341	951	No	20x55		
		2.20	A.P.	343	944	Yes	20x25		

*Reduced charge

**Includes blister plate

ENCLOSURE (A), continued

Table V(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Type	Target		Type Shell*	Firing Speed (m/sec)	Corresponding Range	Penetrate	Diameter of Hole (mm)	Depth of Indentation (mm)	Penetration Condition
	No.	Thickness (mm)							
BK3	4-1	4.05	Common	609	234	No		3	2 cracks - 35, 25mm
		4.05		606	242	No		2	2 cracks - 40, 40mm
		4.03		671	104	Yes	15x35		Back (30x50mm) falling off
		4.03		672	102	No			2 cracks - 70, 30mm
		4.06	A.P.	409	704	Head	8x4		Only head penetrated
		4.06		461	567	Yes	10x10		Slight falling off
		4.08		342	946	No			
		4.08		439	622	Yes	10x13		Back (15x25mm) falling off
		4.09		406	712	Yes	6x6		
	4-2	3.91	Common	608	238	No		4.7	1 crack - 100mm
		3.92		561	338	No		3	1 crack - 90mm
		3.92		654	136	Yes	12x13		(20x40mm) falling off
		3.91	A.P.	467	552	Head	6x7		
		3.93		335	986	No		4.6	Back slightly cracked
		3.93		333	995	Yes	6x7		(8x15mm) falling off
		3.91		357	880	No		2	1 crack - 15mm
		3.91		414	690	Yes	7x7		(14x13mm) falling off
		3.92		419	676	Yes	6x6		
		3.91		333	994	No		0.8	Slight swelling
		3.95		334	990	No		1	
		3.91		354	892	No		2	1 crack - 10mm
	C-4-1 **	4.20	Common	662	120	Yes	8x9		2 cracks - 30, 20mm back falling off
		4.27		561	338	No			
		4.15		612	229	No		7	3 cracks - 20, 25, 20mm back falling off
		4.25		621	210	Yes	27x35		2 cracks - 30, 25mm
		4.22	A.P.	336	980	No			Shell adhered to plate
		4.24		398	736	Part.	6x6		Partial penetration with partial adherence
	C-4-2 **	4.22	Common	616	240	No		3.7	Vertical crack 90mm Horiz. crack 10mm
		4.20		669	108	Yes	22x14		(37x18mm) falling off
		4.24		675	94	Yes	17x12		Back falling off vertical crack 70mm
		4.24		625	200	Yes	20x10		(27x15) falling off vert. crack 70mm
		4.22	A.P.	333	995	No		1.4	Slight swelling
		4.22		411	698	Part.			Partial penetration with partial adheronces

*Reduced charge

**Includes blister plate

ENCLOSURE (A), continued

Table V(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENT ON PROJECTILE RESISTANCE

Type	Target		Type Shell*	Firing Speed (m/sec)	Corre-sponding Range (m)	Pene-trate	Diameter of Hole (mm)	Depth of Indentation (mm)	Penetration Condition
	No.	Thickness (mm)							
BK_8	4-1	4.10	Common	514	442	No		0.8	Slight swelling at back
		4.09		513	444	No		1.3	1 crack - 150mm
		4.00		526	414	Yes	24x21		Back (35x40mm) falling off; 2 cracks - 100, 60mm
		4.03		527	412	Yes	25x20		Back (30x25) falling off, one part flew off
		4.02	A.P.	368	836	No		0.7	Scratch-like scar
		4.09		339	963	No		0.1	Scratch-like scar
		4.06		402	724	Yes	12x16		Back (27x31mm) falling off
		4.13		338	966	No		0.7	Slight swelling at back
		4.14		348	918	Yes	10x8		
	4-2	4.08	Common	627	1985	Yes	32x20		
		4.10		580	296	Yes	30x20		4 parts flew off
		4.05		536	392	No			7 parts flew off
		4.00	A.P.	411	698	Yes	17x12		(20x25mm) falling off
		4.07		387	772	No		0.5	Slight swelling
	C-4-1 **	3.82	Common	333	995	No			
		3.90		422	666	No		1	90mm Vert. crack front 60mm crack above 110mm L.R. crack on back
		3.83		463	562	No		0.6	230mm crack from left to right
		3.82		535	395	No		1.4	Split into 2 parts
		3.86		621	210	Yes	26x30		Back (36x41) falling off
		3.82		480	520	Yes	21x27		Back (32x56) falling off
		3.95	A.P.	456	578	Yes	17x21		
		3.91		408	707	Yes	15x24		Back (23x27mm) falling off
		3.91		387	772	Yes	19x23		Back (20x30mm) falling off
		3.89		337	974	Yes	13x12		Back (23x30mm) falling off
		3.96		327	1016	No		0.2	Scratch-like scar
	C-4-2 ##	3.97	Common	379	798	Yes	20x20		
		3.97		355	888	No			
		3.93		399	733	Yes	20x20		(25x30mm) falling off
		3.97	A.P.	380	796	Yes	17x19		(25x27mm) falling off
		3.97		381	792	Yes	19x23		(25x32mm) falling off
		3.93		373	820	No		1.7	3 cracks - 60, 66, 30mm

**Reduced charge

##Includes blister plate

ENCLOSURE (A), continued

Table V(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Type	Target No.	Target Thickness (mm)	Type Shell	Firing Speed (m/sec)	Corresponding Range (m)	Penetrate	Diameter of Hole (mm)	Depth of Indentation (mm)	Penetration Condition
BK_3	6-1	5.96	Common #	714	42	No		3	
		5.94		722	31	No			
		5.94	A.P. *	537	392	No			
		5.94		566	326	Yes			
		5.95		555	350	No			
	6-2	6.12	Common #	712	44	No			Caused a slight swelling in rear
		6.09		702	58	No			Caused a slight swelling in rear
		6.09	A.P. *	505	462	No			
		6.06		541	382	No			
		6.20		679	90	Yes	11x11		
		6.12		607	236	No		1	
		5.88		534	398	Part.	7x7		Rear peeled off (27x25)mm
		6.20		634	180	Yes	10x10		Rear peeled off (30x20)mm
		6.05		575	308	Yes	15x15		Rear peeled off (26x20)mm
	C-6-1 **	6.07	Common #	706	52	No		0.5	
		5.98		709	48	No		0.5	
		6.19	A.P. *	584	288	No		3	Caused a round crack-Dia. 30mm
		6.09		599	256	No	front 5x5		Center of shell penetrated slightly, caused swelling in rear
		6.09		635	177	Yes	6x7		Rear peeled off (4x6)mm
		6.15		632	284	Yes	7x6		Rear peeled off (10x6)mm
		6.18		599	256	No		2	
	C-6-2 **	6.91	Common #	714	42	No			
		6.16		729	22	No			
		6.11	A.P. *	594	267	No			
		6.25		643	160	Head	6x6		Projectile head only

*Reduced charge
#Ordinary charge

**Includes blister plate

ENCLOSURE (A), continued

Table V(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Type	Target No.	Target Thickness (mm)	Type Shell	Firing Speed (m/sec)	Corresponding Range (m)	Penetrate	Diameter of Hole (mm)	Depth of Indentation (mm)	Penetration Conditions
BK_8	6-1	6.17	Common *	630	188	No			Plate broke into triangular form (40x100mm) 5 cracks - 150, 120, 90, 75, 200mm
		6.32		680	90	Yes	16x16		Plate was cut in half
		6.20	A.P. *	523	422	No		0.2	Caused 2 x-shaped cracks in back 120, 110mm
		6.19		520	430	No		0.5	Rear peeled off (25x35mm) 1 crack across 150mm
		6.17		557	346	Yes	10x13		Rear peeled off(30x32mm)
		6.22		535	396	Yes	10x12		Rear peeled off (40x30mm) 1 crack across 90mm
	6-2	6.28	Common #	711	46	Yes	15x5		Broke into many pieces
		6.27		720	34	Yes			
		6.17	Common *	689	76	No			
		6.25	A.P. *	497	480	Yes			
		6.25		565	330	No			
		6.29		498	478	No			
	C-6-1 **	5.94	Common #	726	26	No		1	Caused a round crack (75x50mm), 3 cracks on back H-shaped 80, 50, 10mm
		5.98		729	22	No		1	
		5.98	A.P. *	685	82	Yes	20x19		Back pealed slightly
		5.90		595	246	Yes	25x20		Caused slight crack in back; back peeled off (43x35mm)
		5.93		536	392	No		0.4	Caused 2 cracks, 25, 15mm
		5.90		533	400	No		0.7	Caused a scratch
		5.94		561	337	No		0.5	Caused a scratch
	C-6-2 **	6.16	Common #	720	34	No	25x30		Peeled off (45x45mm)
		6.08		720	34	No			
		6.08	A.P. *	526	414	No			
		6.15		531	404	No			
		6.06		570	318	No			
		6.10		654	136	Yes			
		6.07		631	185	Yes			
		6.07		603	246	Yes			

*Reduced charge
#Ordinary charge

**Includes blister plate

ENCLOSURE (A), continued

Table VI(A)
DAIDO STEEL PLATE - RESULTS OF EXPERIMENTS ON PROJECTILE RESISTANCE

Date: 8 June 1942
Place: Firing Range of Air Tech. Br. Depot
Machine Gun: Vickers, 7.7mm fixed M.G. Type 3, Mod 1

Type	Target No.	Target Thickness (mm)	Type Shell	Angle of Incidence (degrees)	Firing Speed (m/sec)	Corresponding Range (mm)	Penetrate	Size of Hole (mm)	Depth of Indentation (mm)	Penetration Condition
BK_3	2-2	2.03	A.P. *	25	342	946	Head	4x6		Head only penetrated - caused cracks of 30 and 20mm
		2.04		25	354	892	Part.			Penetrated the armor, stopped caused cracks of 65 & 25mm
		2.02	A.P. #	50	421	670	No		9	1 crack - 130mm
		2.02		50	443	612	Yes	6x15		1 crack - 30mm
		2.02		60	637	173	No		7	Caused a swelling & a crack 40mm
		2.00		60	709	48	Yes	30x70		Caused a crack 7.8mm
	C-2-2 ##	2.58	A.P. *	25	433	636	Yes	6x7		Caused 2 cracks, 15, 15mm
		2.50		25	338	970	Yes			
		2.58		25	334	990	Head			
		2.51		50	474	535	No		0.6	Caused only a swelling
		2.52		50	541	382	No		1.4	Caused a crack 30mm
		2.50		50	540	384	Yes	15x52		Crack 60mm and a peeling off
		2.90		50	536	392	No		2	
BK_8	2-2	2.23	A.P. *	25	335	986	Head	25x10		
		2.25		35	342	950	Head			
		2.27		40	341	954	No			
		2.23		50	335	986	Yea			Plate scattered into several pcs.
		2.22		55	371	825	Head			
		2.19		65	343	942	No			
	C-2-2 ##	2.15	A.P. *	45	343	942	Yes			2 cracks - 50 and 45mm
		2.17		50	340	960	Yes	35x35		2 cracks - 25 and 20mm
		2.16		50	343	942	No			1 crack - 9mm
		2.17		55	378	802	Yes	12x7		2 cracks - 80 and 40mm

*Reduced charge
#Ordinary charge
##Cemented plate

ENCLOSURE (A), continued

Table VI(A)(Continued)
DAIDO STEEL PLATE - RESULTS OF PROJECTILE RESISTANCE TEST (OBLIQUE FIRING)

Type	Target No.	Target Thickness Where Hit (mm)	Type Shell*	Firing Angle (°)	Impact Velocity (m/sec)	Range (meters)	Type of Penetration	Size of Hole (mm)	Depth of Indentation (mm)	State of Penetration
BK_3	4-2	3.92	A.P. *	25	334	990	No		1.4	
		3.92		25	331	1006	No		1.6	Scratched
		3.96		25	416	684	Part			Projectile stopped in hole
		3.90		45	520	430	No		1.2	a bulge
		3.93		45	561	337	Yes	7x12		(13x12mm) peeled off
		3.93		45	546	370	No		2.	Bulge
	C-4-2 ##	4.24	A.P. *	20	546	370	Yes	12x12		(20x27mm) peeled off
		4.24		20	530	466	Yes	15x9		Little peeled off
		4.18		25	512	447	Yes	7x13		Little peeled off
		4.21		25	457	576	Head	7x6		Little peeled off - very near partial penetration
		4.18		25	465	556	Yes	7x13		(10x16mm) peeled off
		4.20		25	457	576	Head	7x6		Little peeled off - very near partial penetration
		4.17		45	644	158	Yes	7x12		Crack 20mm - little peeled on near surface
		4.14		45	583	290	No		2	Little bulge
		4.07		45	597	260	No		5	3 horizontal cracks 50, 50, 30mm
		4.18		45	624	202	Yes	7x19		
BK_8	4-2	4.01	A.P. *	25	483	514	Yes	15x23	0.6	(25x35mm) peeled off 3-30mm cracks
		4.08		25	411	698	No		1	120mm horizontal crack
		4.04		25	426	656	No			
		4.03		25	447	601	Yes	14x20		(25x30mm) peeled off- 80, 60, 60, 50mm cracks
		4.09		45	568	322	No		1	On rear surface 120mm horizontal crack
		4.04		45	588	280	No		1	Little bulge
		4.08		45	640	166	No		1.7	90mm crack
		4.07		45	700	60	Yes	23x30		(35x40mm) peeled off - 100mm horizontal & vertical crack
		4.01	A.P. #	45	667	110	Yes	19x20		(30x35) peeled off - 50mm crack 50x25mm torn off
	C-4-2 ##	3.96	A.P. #	20	571	316	Yes	18x19		23x35mm peeled off
		3.95		20	512	446	Yes	15x22		30x20mm peeled off
		3.94		25	333	995	No		1.5	
		4.01		25	334	990	No		0.5	Just a scratch
		3.93		25	398	736	Yes	20x14	0.6	(34x14mm) peeled off - 27mm crack
		3.98		30	438	624	Yes			
		3.96		30	332	1000	No		1.5	2 cracks - 50, 15mm
		3.98		30	344	936	No		0.6	(45x27mm) peeled off
		4.00		45	640	166	Yes	22x23		(20x18mm) peeled off 30mm crack
		3.93		45	577	302	Yes	15x14		(27x18mm) - peeled off
		3.91		45	557	346	Yes	17x20		Horizontal 120mm crack
		3.88		45	513	444	No		1.2	
		4.09		45	528	410	Yes	40x60		(65x70mm) peeled off

*Reduced charge
#Ordinary charge
##Cemented plate

ENCLOSURE (A), continued

Type	Target No.	Target Thickness Where Hit (mm)	Type Shell	Firing Angle (°)	Impact Velocity (m/sec)	Range (meters)	Type of Penetration	Size of Hole (mm)	Depth of Indentation (mm)	State of Penetration
BK_3	6-1	5.97	A.P. *	5	644	158	Head	7x7		
		5.97		5	636	174	No		3	Back surface cracked
		5.97		5	649	146	Yes	13x16		20x26mm peeled off
		5.93		10	632	184	No		3	
		5.94	A.P. #	20	712	44	Yes	10x16		
		5.94		25	678	92	No		2	
		5.92		30	706	52	No			
		5.92		40	706	52	No			
	C-6-2 ##	6.20	A.P. *	20	644	158	No			
		6.23		20	683	85	Yes	8x10		
		6.17		20	673	100	No		3	
		6.23	A.P. #	30	714	42	Yes	9x15		Rear surface peeled off
		6.10		35	704	55	No			
		6.28		40	671	104	No			Scratch
		6.26		50	678	94	No			Scratch
BK_8	6-2	6.24	A.P. *	10	631	185	Yes	12x15		25x25mm peeled off
		6.24		10	643	160	Yes	12x15		25x25mm peeled off
		6.21		15	642	162	Yes	12x15		25x25mm peeled off
		6.21		15	652	140	Yes	12x15		30x35mm peeled off
		6.28		15	632	184	Yes	11x11		25x25mm peeled off
		6.13		20	605	244	No			3 cracks - 360, 320, 180mm small pieces flew off
		6.13		20	618	214	No			Flew off in several pieces
		6.21	A.P. #	25	722	31	Yes	15x7		30x35mm peeled off
		6.21		30	714	42	Yes	15x20		30x30mm peeled off
		6.26		35	705	54	No			
	C-6-2 ##	6.09	A.P. *	5	646	154	Yes	27x27		
		6.09		10	644	158	No			
		6.09		20	712	44	Yes	28x30		
		6.08	A.P. #	25	705	54	Yes	10x20		30x45mm peeled off
		6.15		30	698	64	No			Scratches
		6.07		35	699	62	No			Scratches
		6.09		40	709	48	No			Scratches

*Reduced charge
//Ordinary charge

##Cemented plate

ENCLOSURE (A), continued

Table VII(A)
BALANCED FIRING ANGLE

Type	Thickness (mm)	Treatment	Angle	Note
BK_3	2		60°	
		Carburized	58°	Estimated
	4		54°	Estimated
		Carburized	50°	Estimated
	6		14°	
		Carburized	18°	
BK_8	2			
		Carburized		
	4		47°	
		Carburized	55°	Estimated
	6		29°	
		Carburized	20°	

Projectile used .... 7.7mm A.P.
Firing range .... 100 meters
Impact velocity .... 680 m/sec

ENCLOSURE (A), continued

Table VIII(A)
RESULTS OF PROJECTILE RESISTANCE TEST
A.P. SHELL (ORDINARY CHARGE)

Types of Targets	Thickness of Plate (mm)	Impact Velocity (m/sec)	Range (m)	Size of Hole (mm)
BK_3 2-1	2.11	771	90	15x18
BK_3 2-2	2.02	760	126	18x13
BK_3 C-2-1	2.49	764	112	18x19
BK_3 C-2-2	2.48	770	92	15x15
BK_8 2-1	2.25	767	105	17x18
BK_8 2-2	2.24	763	116	15x19
BK_8 C-2-1	2.10	754	158	15x15
BK_8 C-2-2	2.20	764	112	15x18
BK_3 4-1	4.08	760	126	18x13
BK_3 4-2	3.96	771	90	15x18
BK_3 C-4-1	4.25	765	110	14x21
BK_3 C-4-2	4.05	758	130	18x18
BK_8 4-1	4.09	764	112	24x20
BK_8 4-2	4.10	767	104	22x18
BK_8 C-4-1	3.82	775	78	30x20
BK_8 C-4-2	4.00	755	140	14x16
BK_3 6-1	5.93	767	104	22x38
BK_3 6-2	6.09	765	110	26x26
BK_3 C-6-1	6.07	779	66	24x27
BK_3 C-6-2	5.25	762	118	20x22
BK_8 C-6-1	5.95	766	106	25x23
BK_8 C-6-2	6.08	771	90	25x25

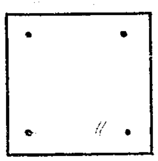
Note: All plates were penetrated.

Date: 8 June 1942
Weapon: Experimental (Air) 13mm fixed machine gun
Place: Firing Range of Branch Air Tech. Depot

ENCLOSURE (A), continued

Table X(A)
DISTRIBUTION OF HARDNESS

Type	Surface Treatment	Plate Classification	Hardness (Rockwell)	
			Cemented Surface	Rear Surface
BK_3		2-1	55, 54, 53.5, 53.5	54, 53.5, 53.5, 52
		2-2	53, 54, 53, 53	51.5, 50, 53, 51
		4-1	53, 54, 53.5, 52	51.5, 52, 53, 52.5
		4-2	53, 53, 52.5, 52	51, 53.5, 52.5, 52
		6-1	51, 54, 54, 51	50.5, 50.5, 52, 52
		6-2	50.5, 51.5, 52, 53	51, 51, 53.5, 53
	Cemented	C-2-1	51.5, 52, 53, 53	51, 50, 50.5, 50.5
		C-2-2	50.5, 52, 53.5, 53	53, 52.5, 52, 53
		C-4-1	52.5, 53, 52.5, 53	52.5, 50.5, 50, 51.5
		C-4-2	54, 52.5, 51, 53	50, 50.5, 51, 51
		C-6-1	57, 58, 58, 57	49.5, 49, 50, 50.5
		C-6-2	56, 57, 57, 57	51, 52, 51, 52
BK_8		2-1	55.5, 55, 55, 55	55, 54, 54, 54
		2-2	55, 56, 56.5, 57	54, 55.5, 56, 55
		4-1	55, 53, 53, 54	55, 53.5, 55, 53
		4-2	56, 53, 55, 55	53, 53.5, 54, 53.5
		6-1	56, 57, 57.5, 58	56, 56, 53.5, 55
		6-2	56, 56, 56, 56	55, 55, 53.5, 53
	Cemented	C-2-1	56, 57, 56, 55.5	54, 53, 54, 53
		C-2-2	56, 54, 55, 56	55.5, 55, 54, 53
		C-4-1	55.5, 54, 53, 54	54, 53.5, 53.5, 54
		C-4-2	58.5, 65, 58, 59	53, 51, 51, 53.5
		C-6-1	56, 58, 57, 57	54, 52, 53.5, 52
		C-6-2	58, 57, 57, 57	56, 56, 55.5, 55



Points Where Hardness is Measured

ENCLOSURE (A), continued

Table XI(A)
CEMENTED THICKNESS

Type	Cemented Thickness in Percent		
	2mm Plate	4mm Plate	6mm Plate
BK_3			16
BK_8	15	13 (Approx.)	15

Table XII(A)
NON-METALLIC INCLUSIONS
(Gakushimho)

Type	Impurities Number		Distribution Ratio (a)	Number in Field of Vision (b)	axb	Degree of $\frac{\Sigma ab}{\Sigma b}$ Purity	Non-metallic Objects (c)*	Non-metallic Objects $\frac{\Sigma abc}{\Sigma ab}$**
BK_3	A	0	0	34	0			
		1	1	14	14		6	
		2	2	2	4	$\frac{18}{50}$	3	
		3	4	0	0			4.5
		4	8	0	0			
		5	16	0	0			
	Total			50	18	= 0.36		
	B	0	0	10	0			
		1	1	20	20		4	
		2	2	20	40	$\frac{60}{50}$	4	
		3	4	0	0			4
		4	8	0	0			
		5	16	0	0			
	Total			50	60	= 1.2		
BK_8	A	0	0	25	0			
		1	1	0	0			
		2	2	12	24	$\frac{84}{50}$	4	
		3	4	11	44		3	
		4	8	2	16		3	3
		5	16	0	0			
	Total			50	84	= 1.68		
	B	0	0	18	0			
		1	1	0	0			
		2	2	6	12	$\frac{140}{50}$	3	3
		3	4	20	80		3	
		4	8	6	48		3	
		5	16	0	0			
	Total			50	140	= 2.8		

*Average Thickness **Total Average Thickness

ENCLOSURE (A), continued

Table XIII(A)
MEASUREMENT OF CRYSTALLIZATION
(Gakushinho)

Type	Degree of Crystal-ization (a)	Number in Field of Vision (b)	axb	$\frac{\Sigma ab^*}{\Sigma b}$	Estimate
BK_3	G 5	2	10	$\frac{61.5}{10}$	6.15
	G 6	3	18		
	G 6.5	3	19.5		
	G 7	2	14		
	Total	10	61.5	= 6.15	G 6.15
BK_8	G 6.5	5	32.5	$\frac{68.5}{10}$	6.85
	G 7	3	21		
	G 7.5	2	15		
	Total		68.5	= 6.85	G 6.85

*Average Degree of Crystallization

ENCLOSURE (A), continued

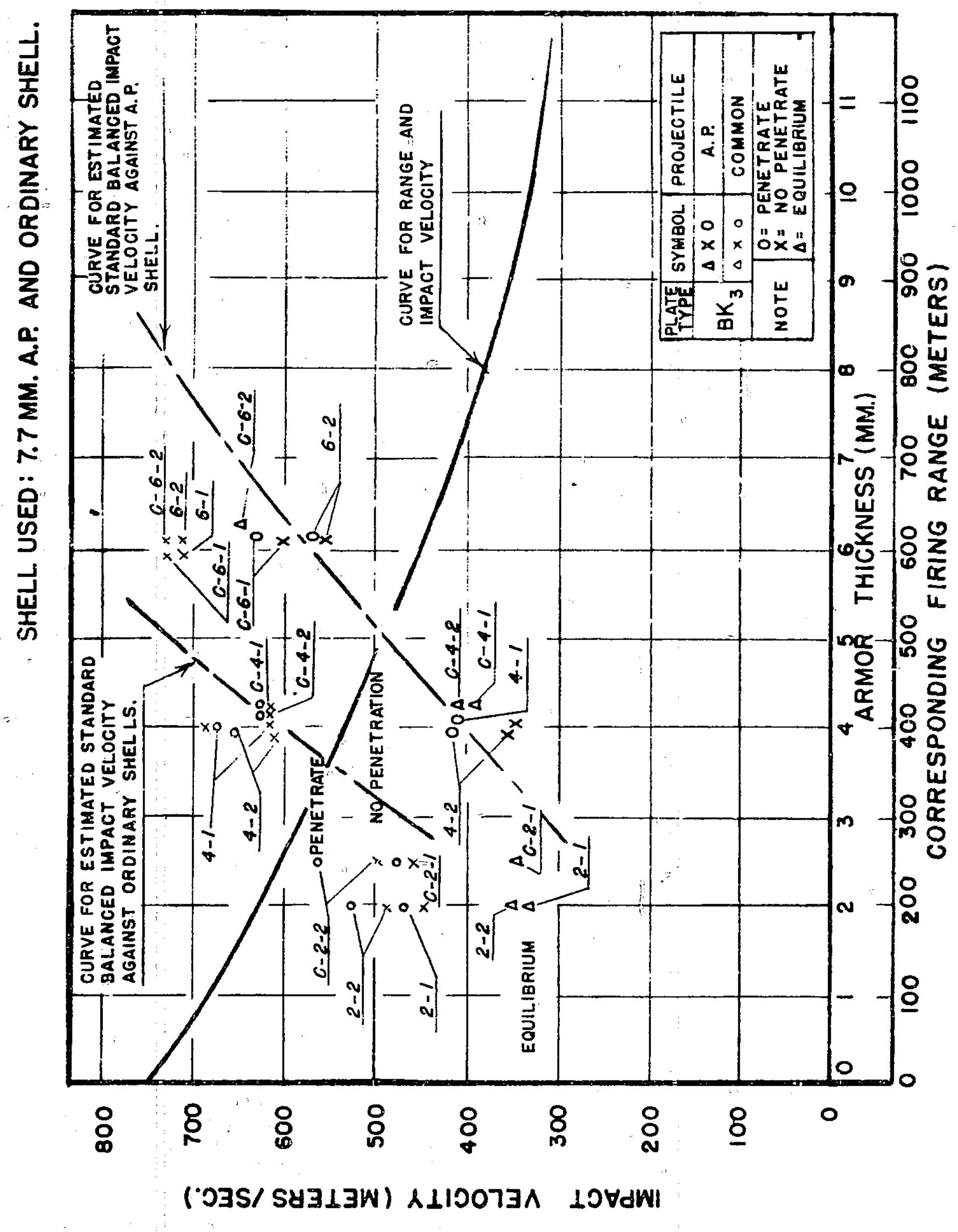


Figure 1(A)

BALANCED IMPACT VELOCITY AND RANGE CURVE

ENCLOSURE (A), continued

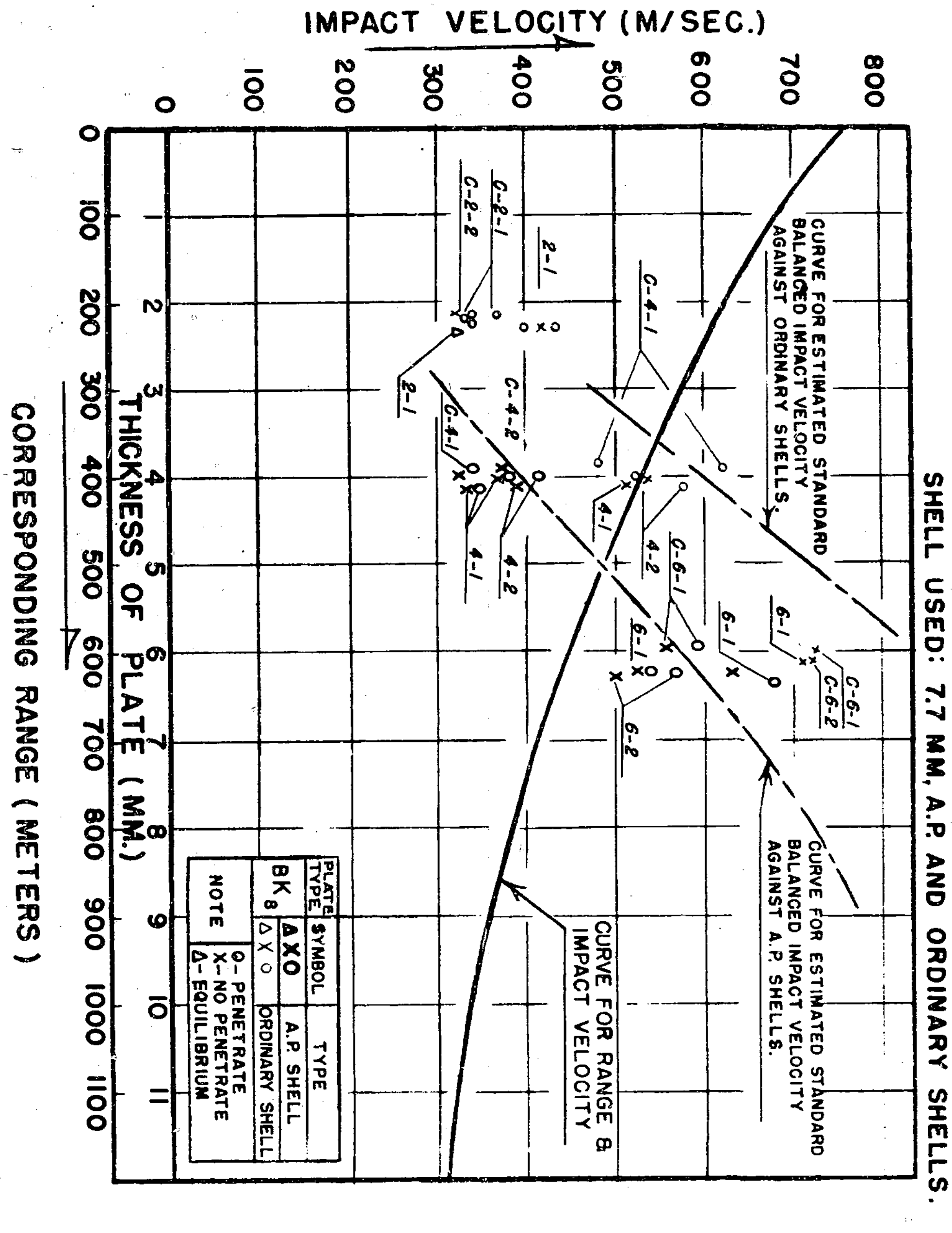


Figure 1(A) Cont.

BALANCED IMPACT VELOCITY AND RANGE CURVE

ENCLOSURE (A), continued

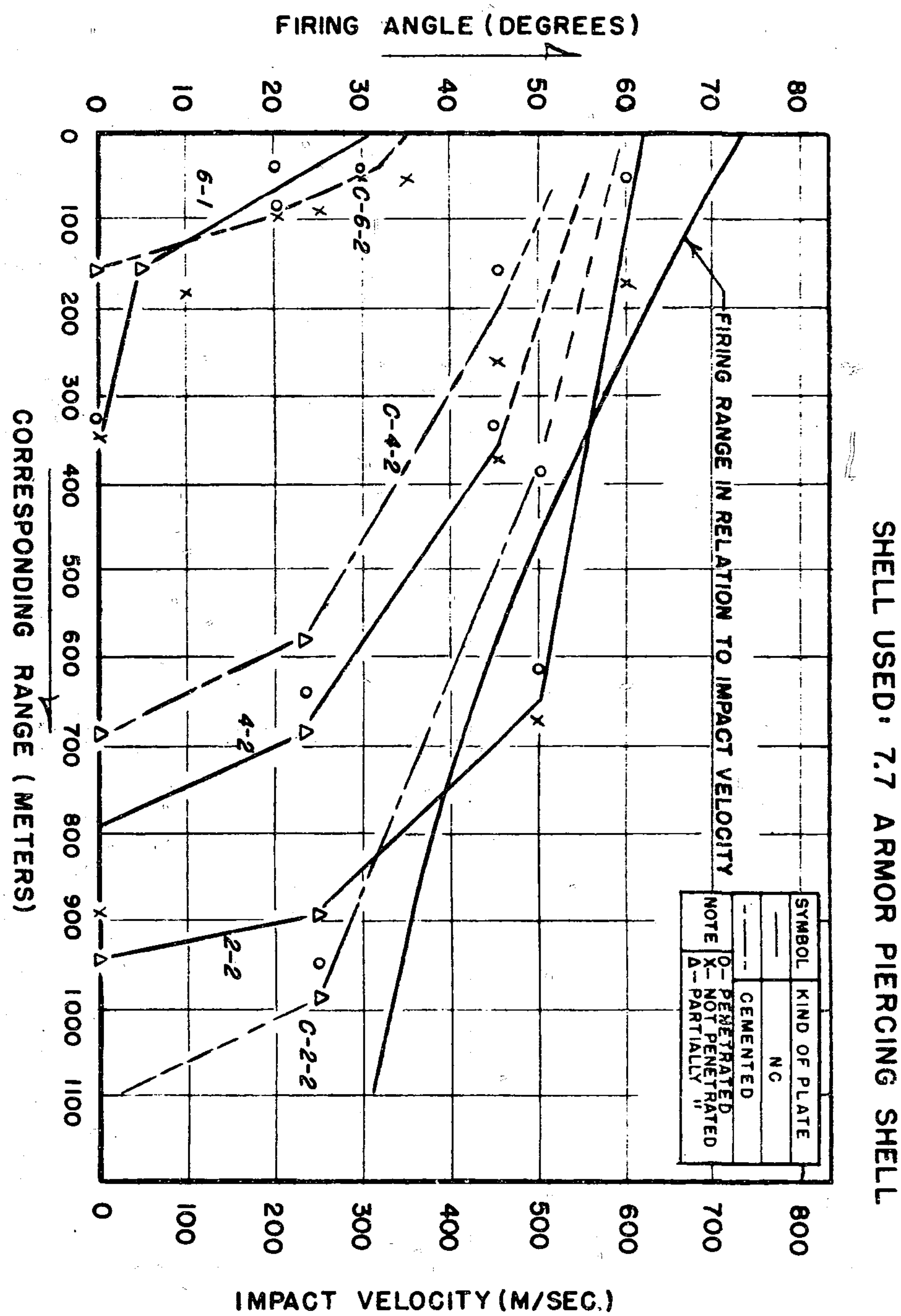


Figure 2(A)

GRAPH OF RANGE VS. FIRING ANGLE AND IMPACT VELOCITY

ENCLOSURE (A), continued

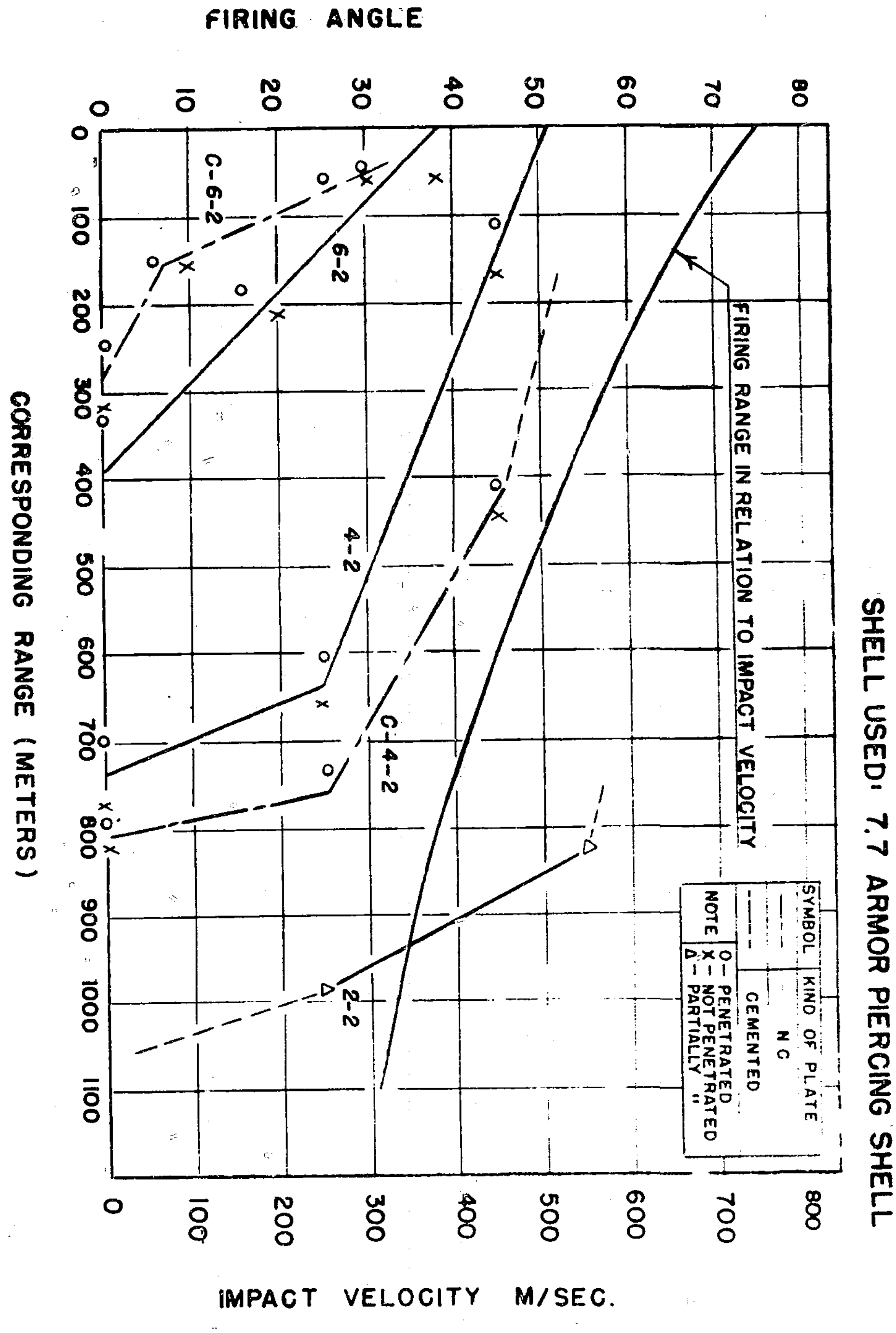
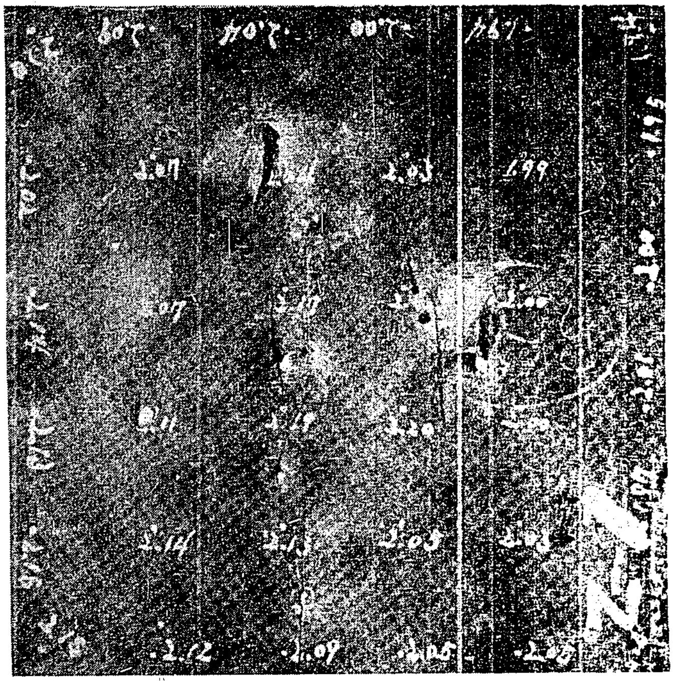


Figure 2(A) Cont.

GRAPH OF RANGE VS. FIRING ANGLE AND IMPACT VELOCITY

ENCLOSURE (A), continued



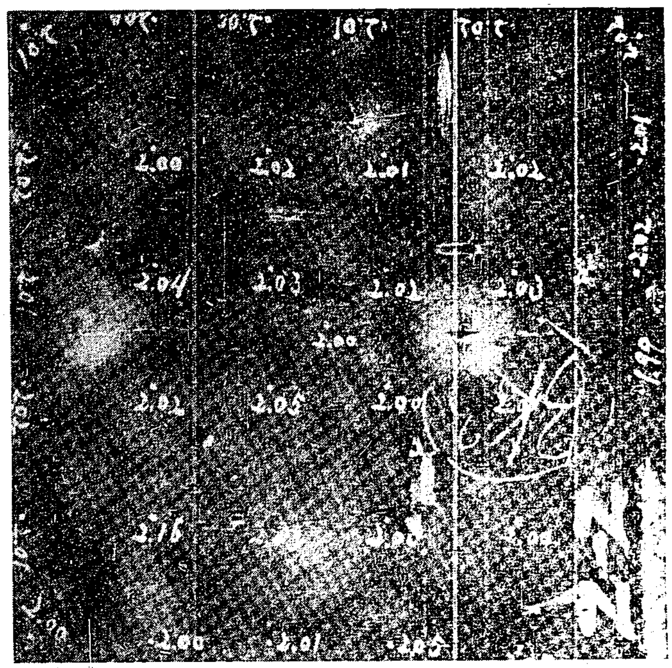
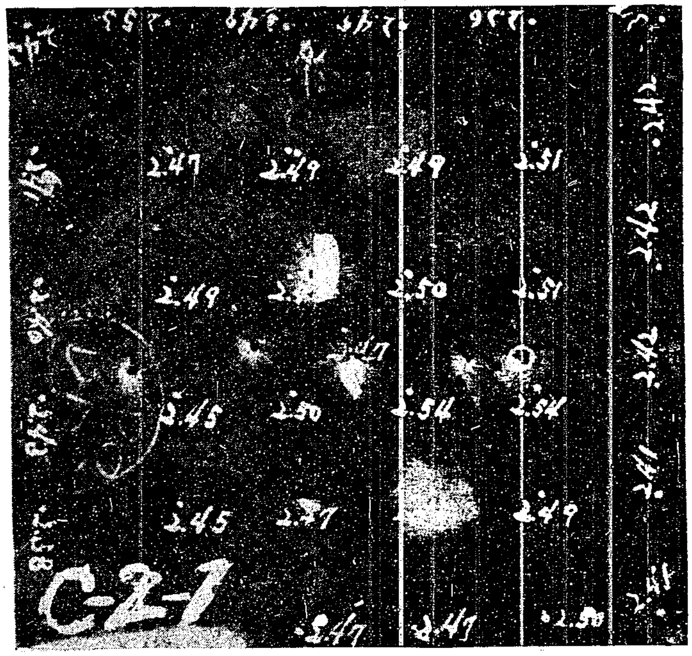


Figure 3(A)
BK_3 --- 2mm PLATE

ENCLOSURE (A), continued



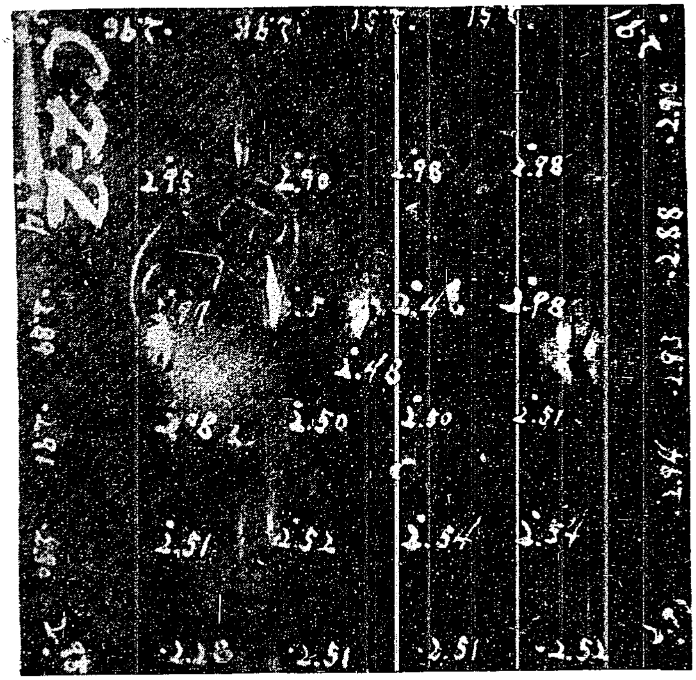


Figure 3(A) Cont.

BK3 --- 2mm (CEMENTED) PLATE

ENCLOSURE (A), continued

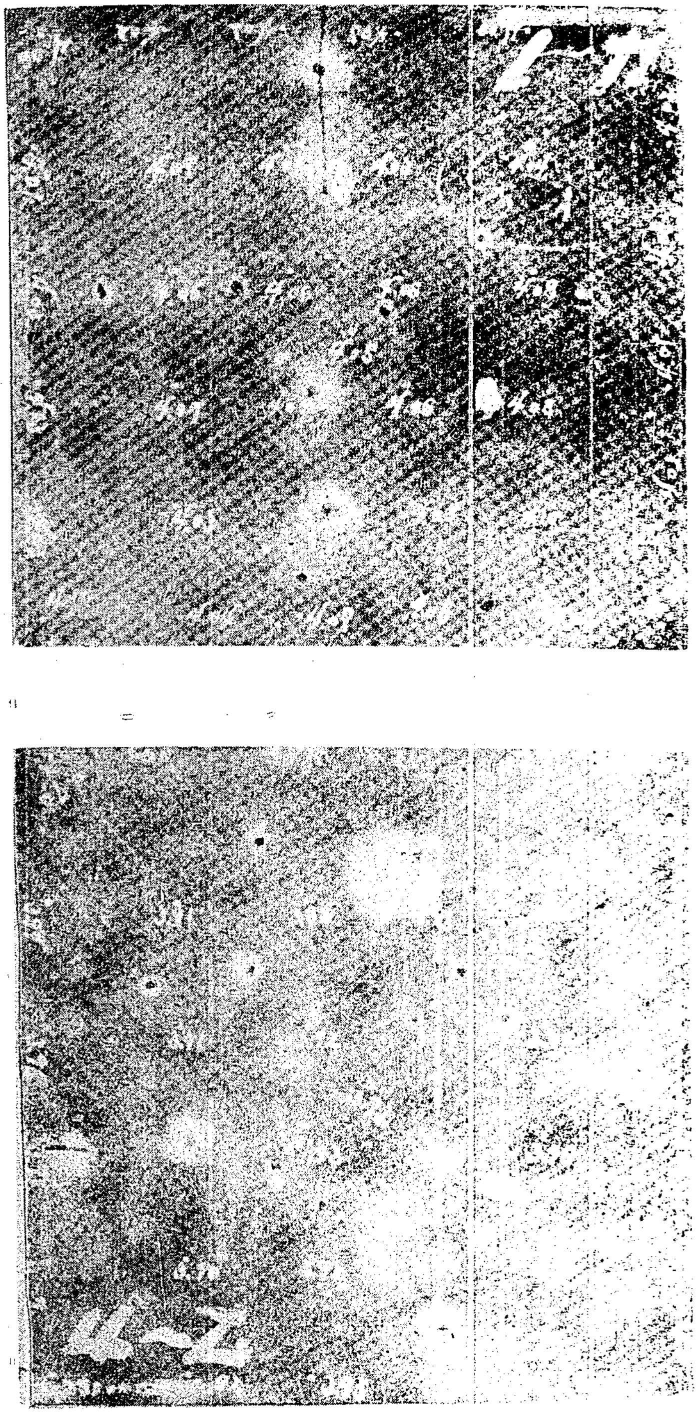


Figure 3(A) Cont.
BK_3 --- 4mm PLATE

ENCLOSURE (A), continued

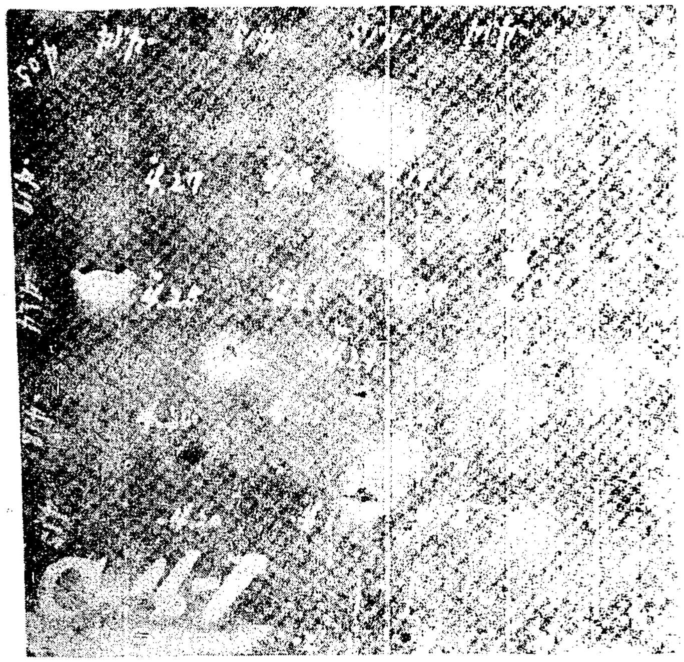


Figure 3(A) Cont.

BK_3 --- 4mm (CEMENTED) PLATE

ENCLOSURE (A), continued

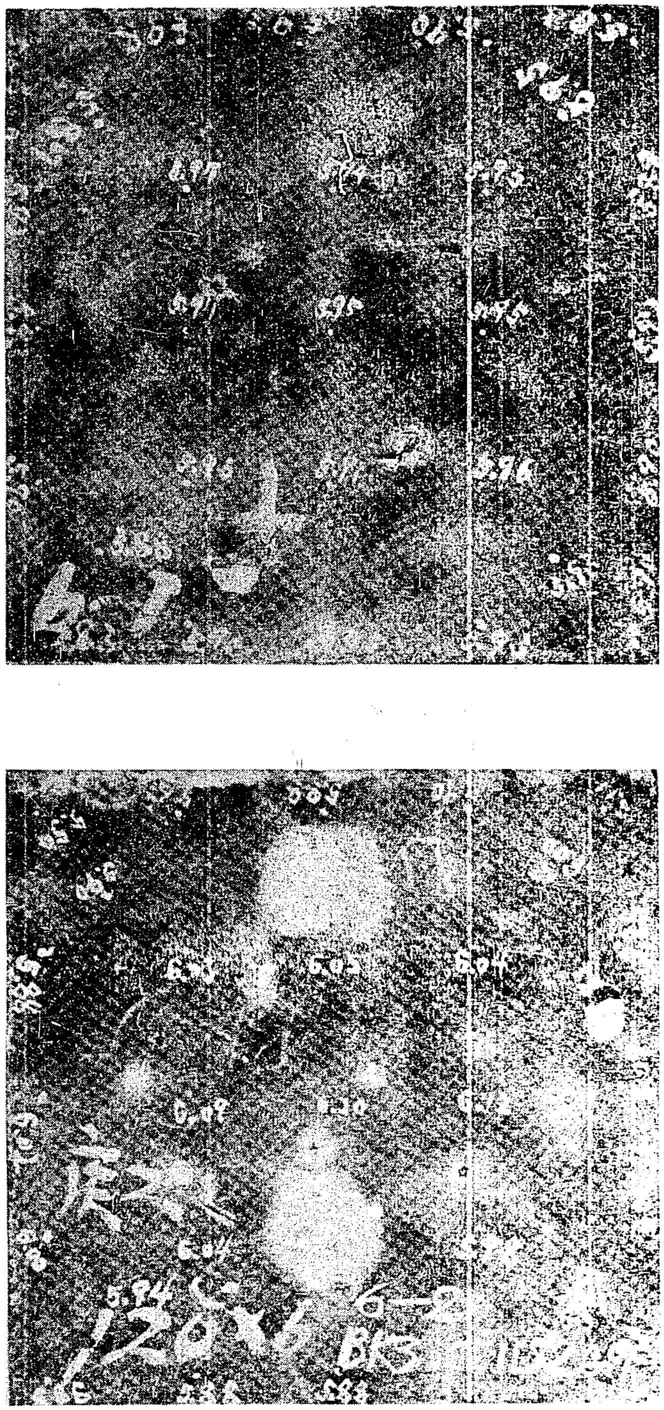
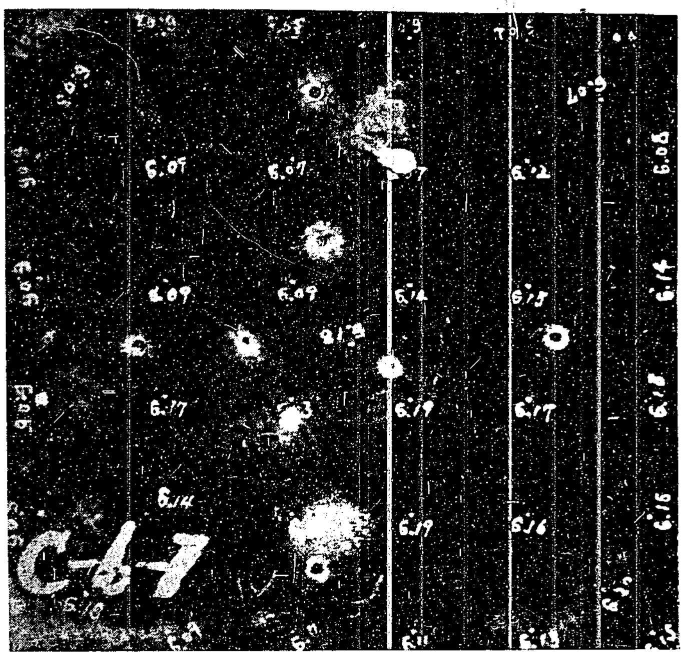


Figure 3(A) Cont.
BK_3 — 6mm PLATE

ENCLOSURE (A), continued



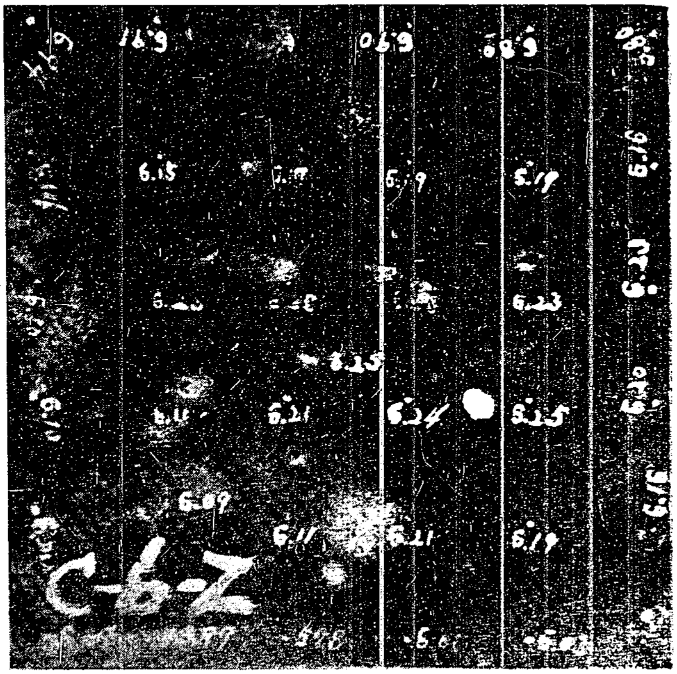


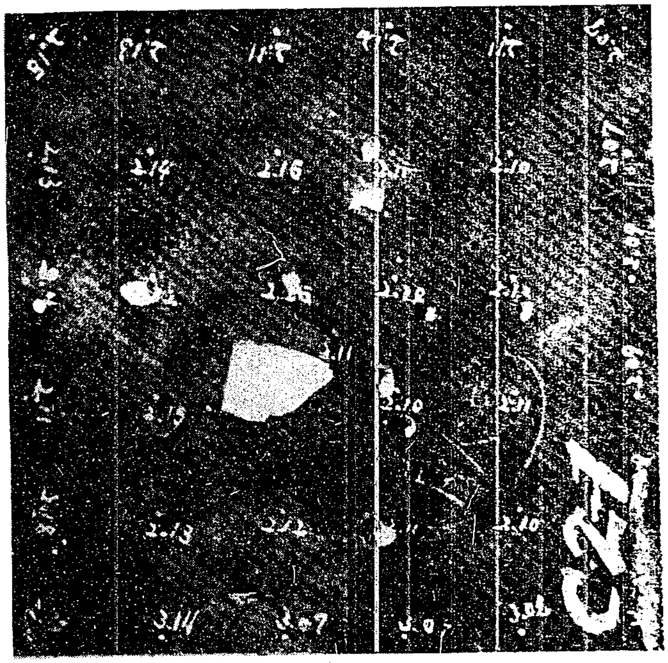
Figure 3(A) Cont.

BK_3 --- 6mm (CEMENTED) PLATE

ENCLOSURE (A), continued

Figure 4(A)
Bk8 --- 2nd PLATE

ENCLOSURE (A), continued



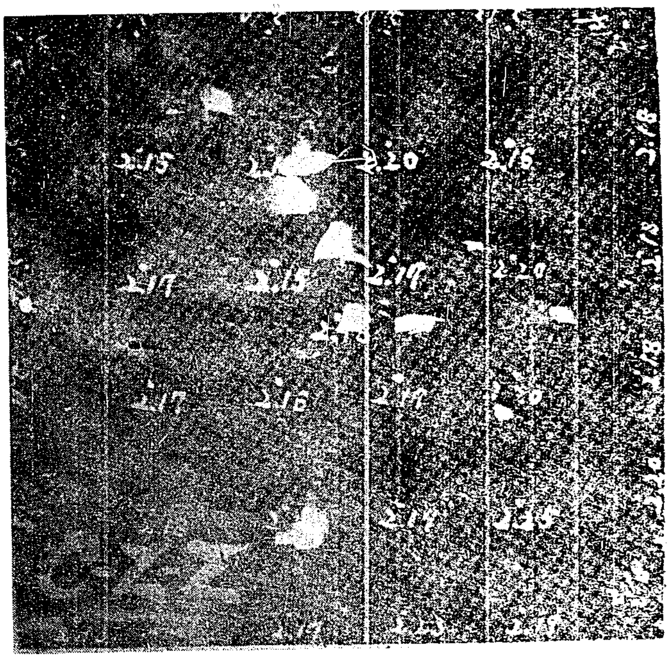


Figure 4(A) Cont.

BK_8 --- 2mm (CEMENTED) PLATE

ENCLOSURE (A), continued

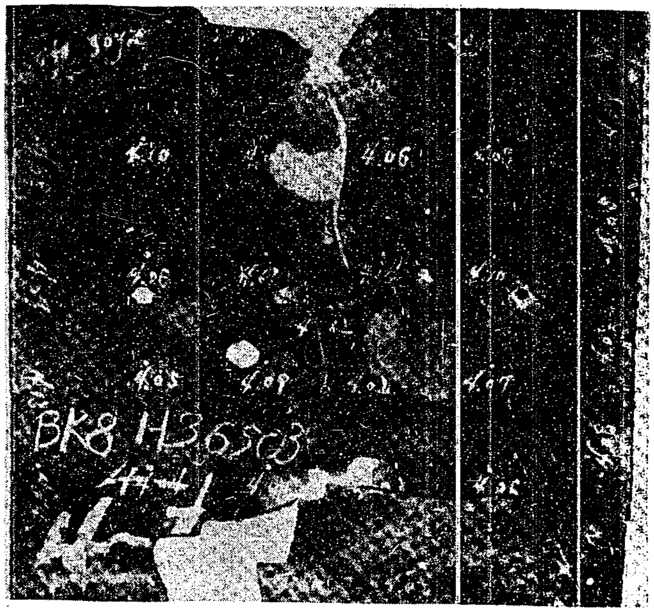


Figure 4(A) Cont.
BK_8 --- 4mm PLATE

ENCLOSURE (A), continued

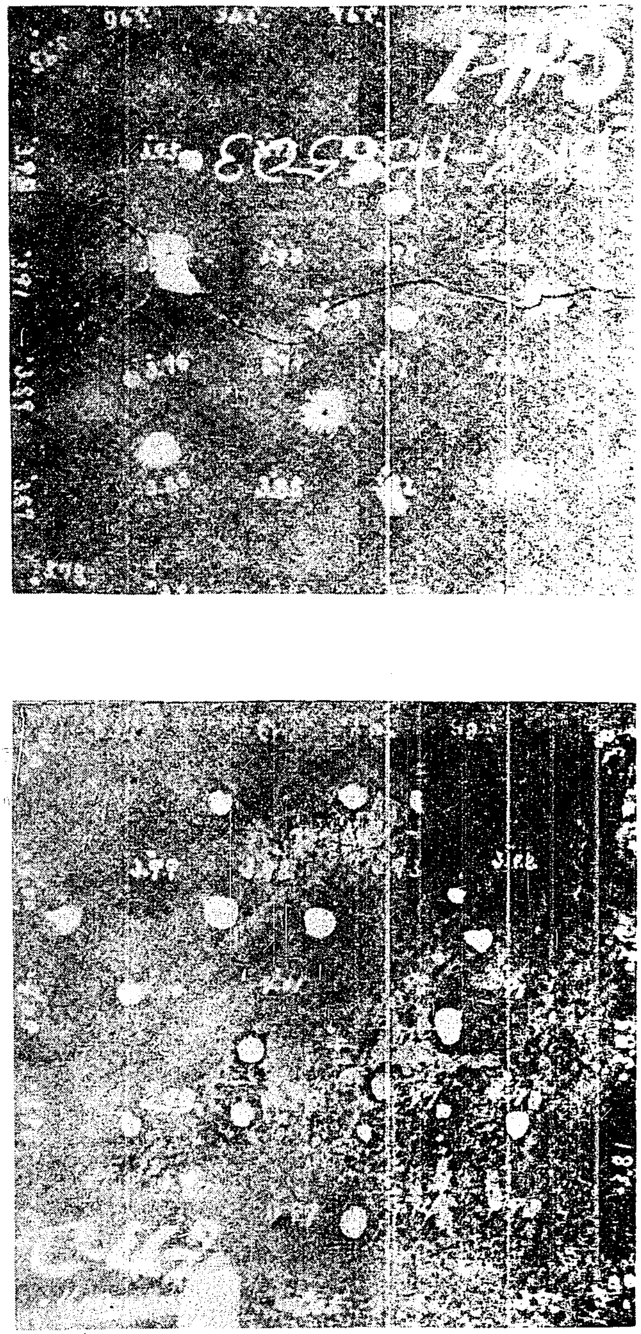


Figure 4(A) Cont.

BK_8 --- 4mm (CEMENTED) PLATE

ENCLOSURE (A), continued

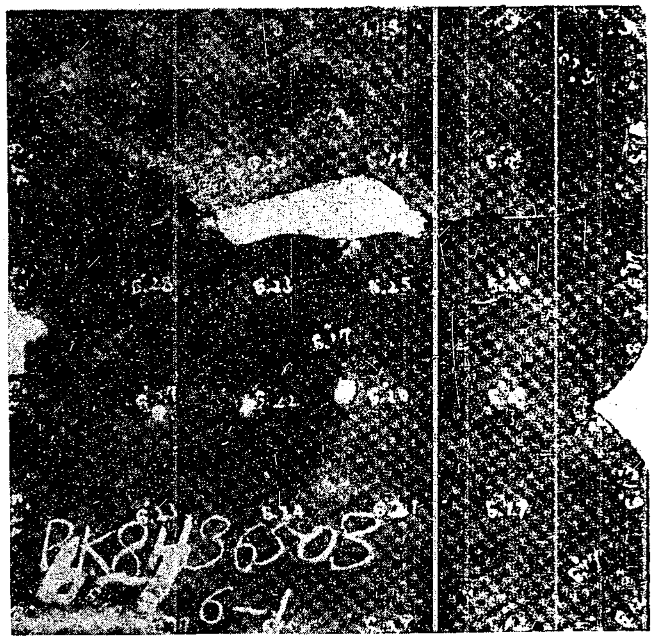
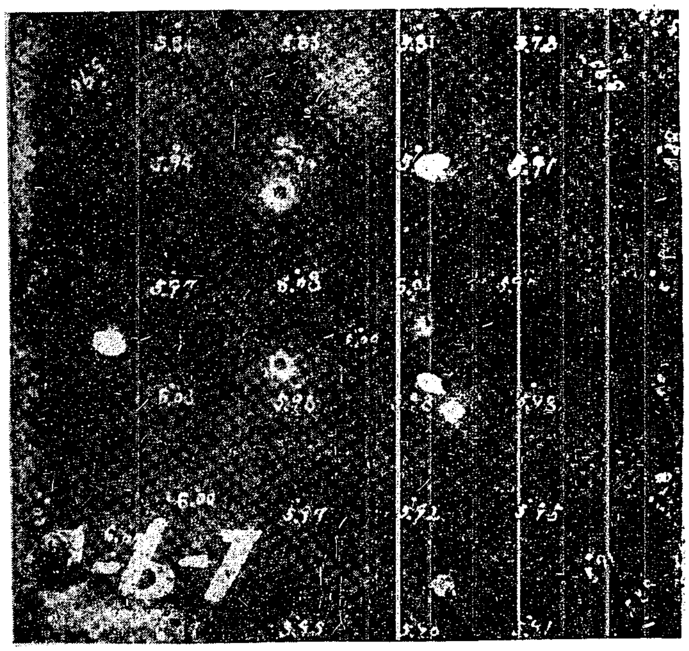


Figure 4(A) Cont.

BK_3 --- 6mm PLATE

ENCLOSURE (A), continued



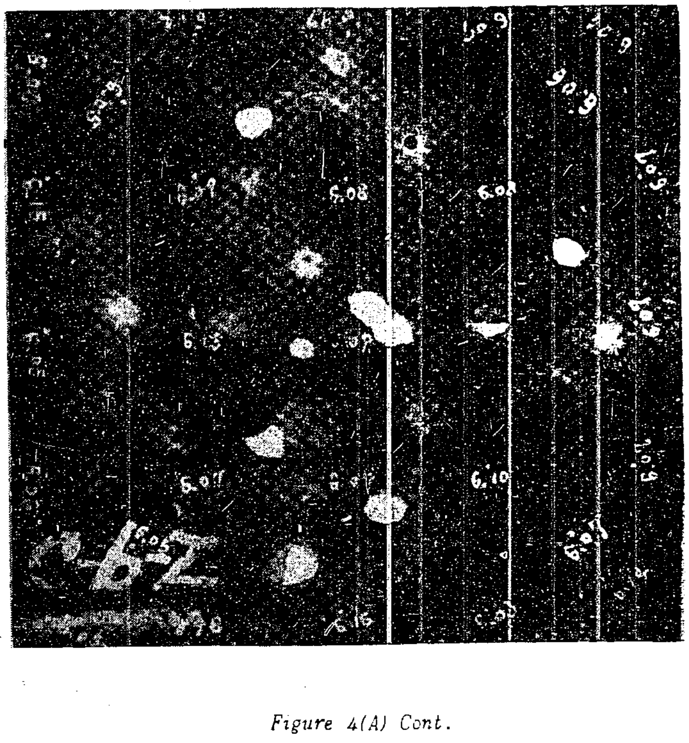


Figure 4(A) Cont.

BK8 --- 6mm (CEMENTED) PLATE

ENCLOSURE (A), continued

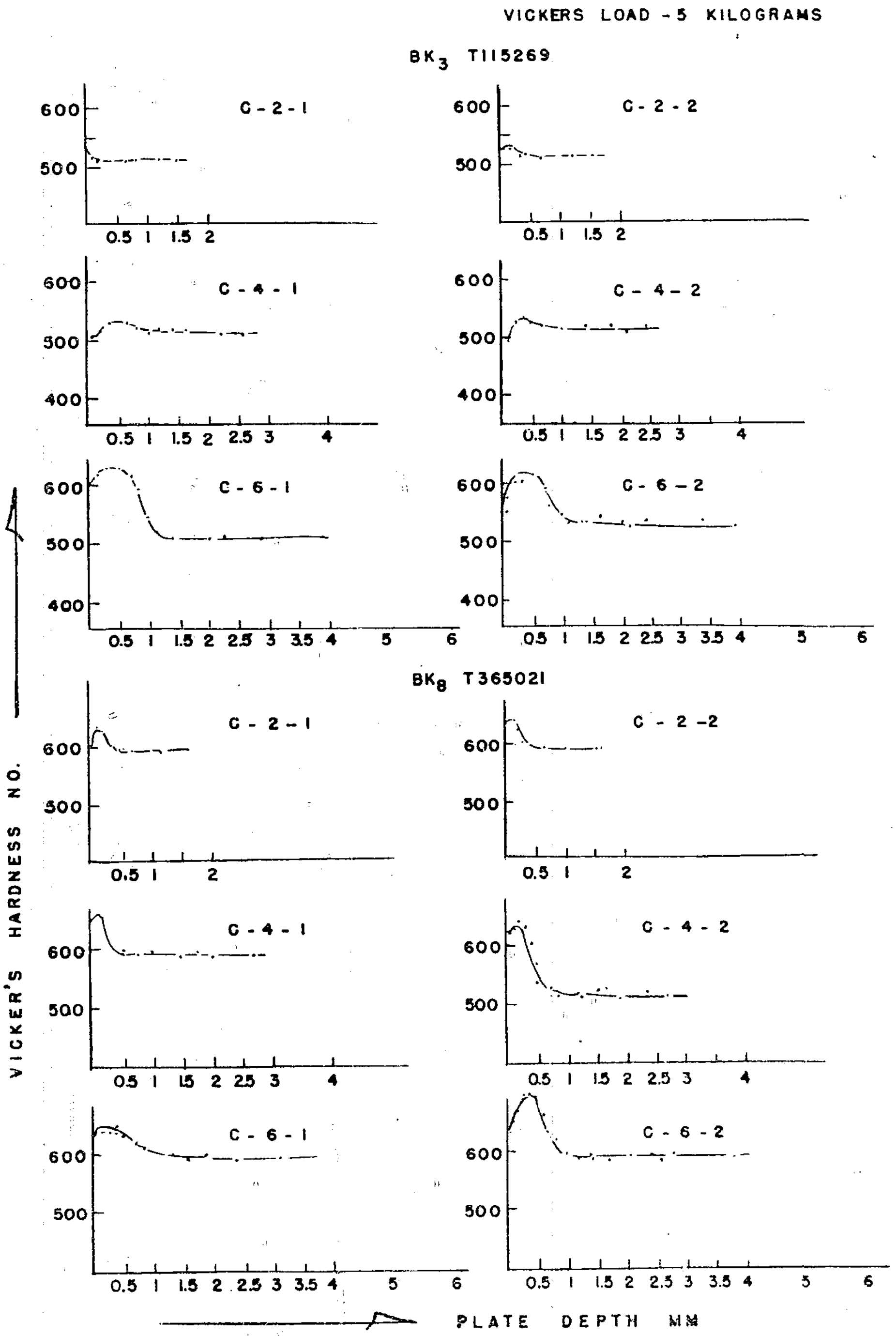


Figure 5(A)

CROSS-SECTION HARDNESS CURVES

ENCLOSURE (A), continued

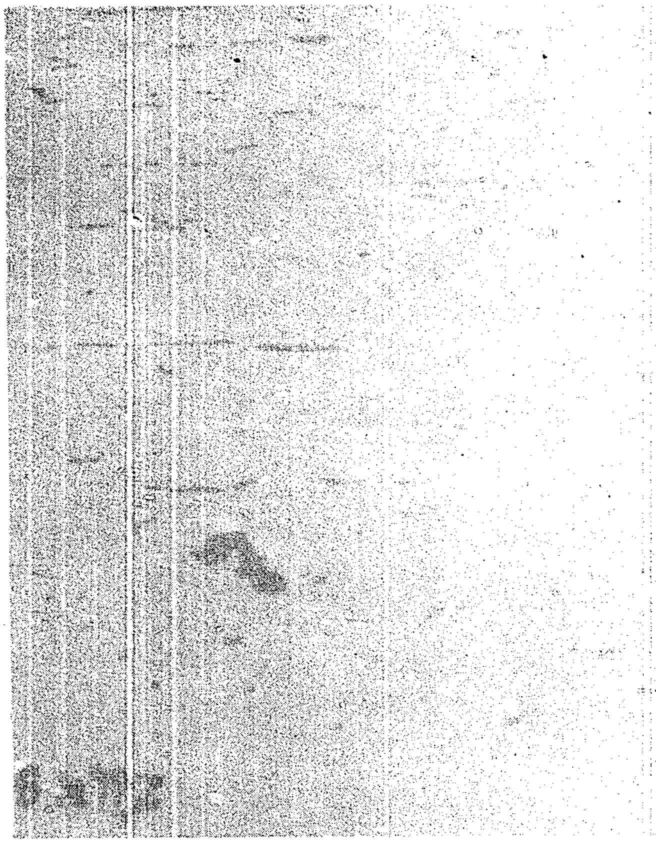


Figure 6(A)
NON-METALLIC FOREIGN INCLUSIONS

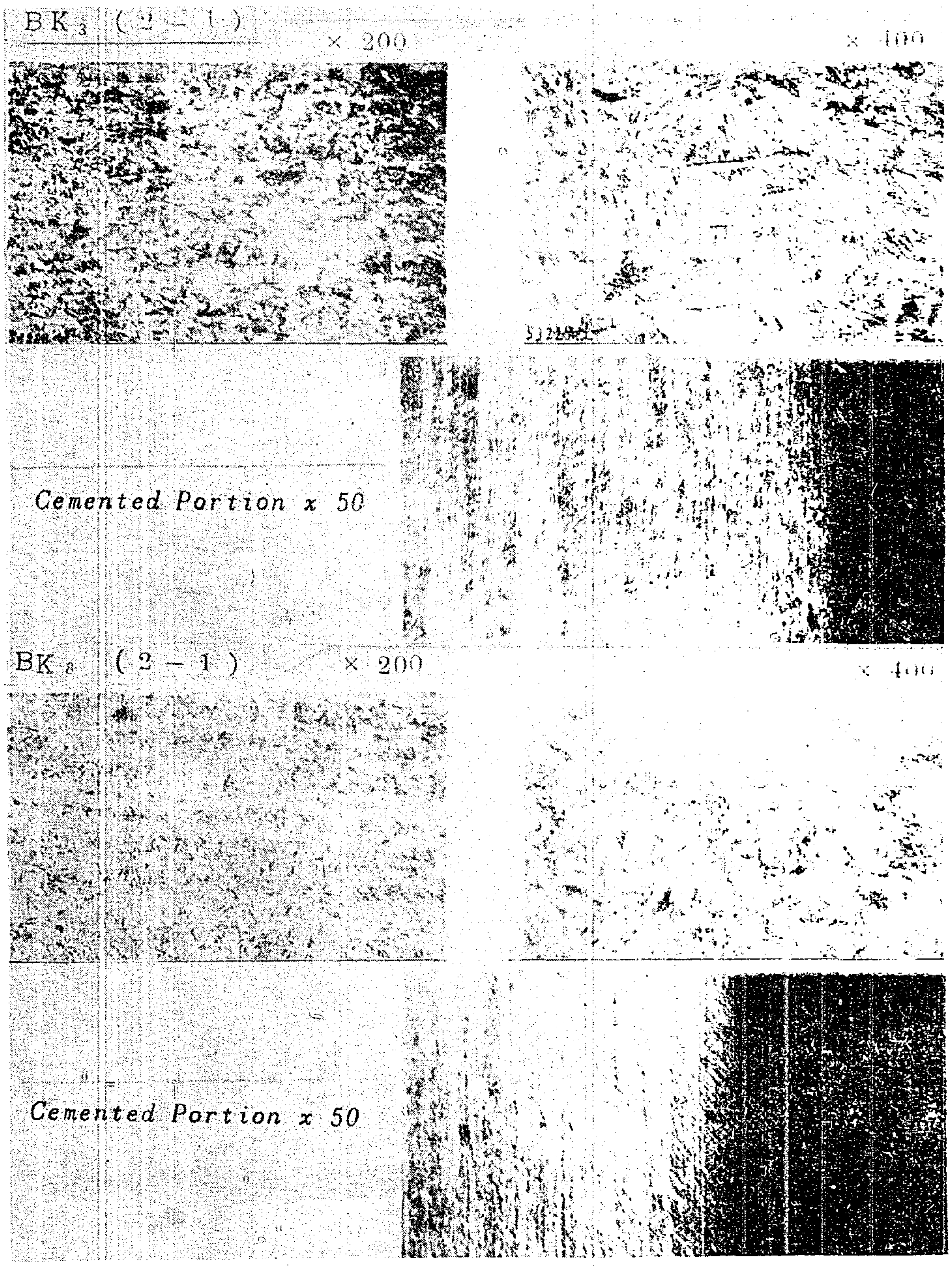


Figure 7(A)
MICROSCOPIC FORMATIONS

ENCLOSURE (A), continued

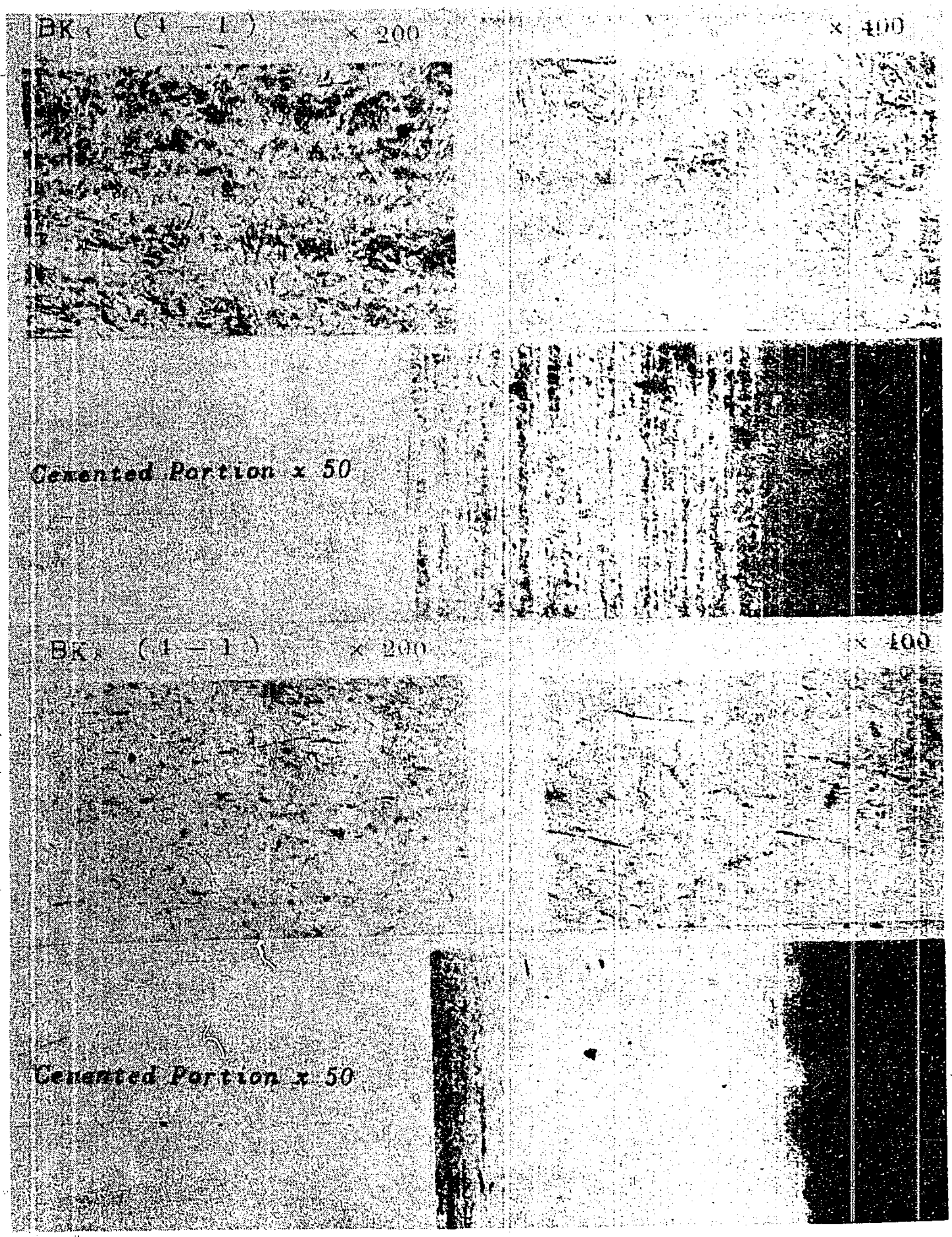


Figure 7(A) Cont.
MICROSCOPIC FORMATIONS

ENCLOSURE (A), continued

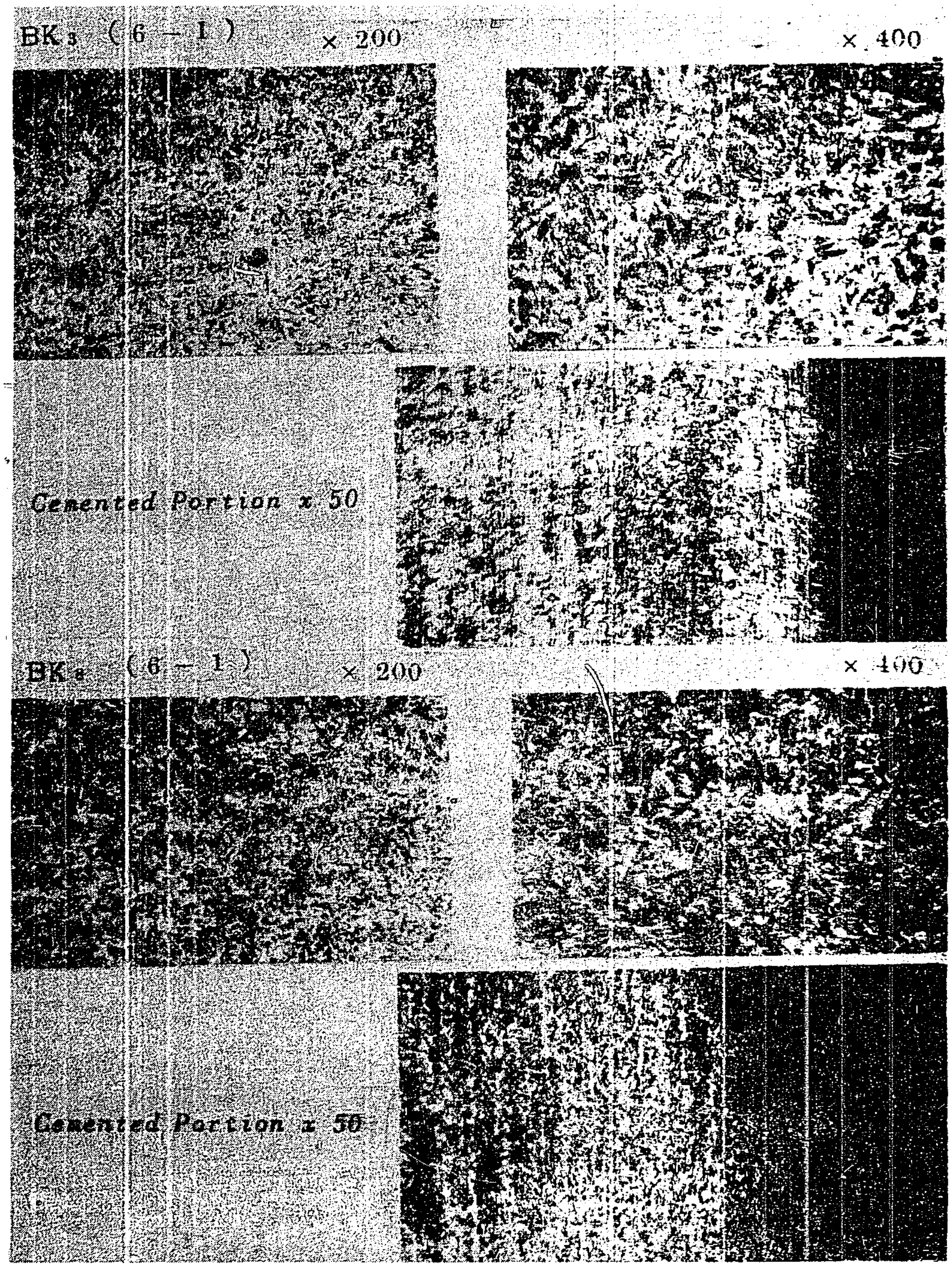


Figure 7(A) Cont.

MICROSCOPIC FORMATIONS

ENCLOSURE (A), continued

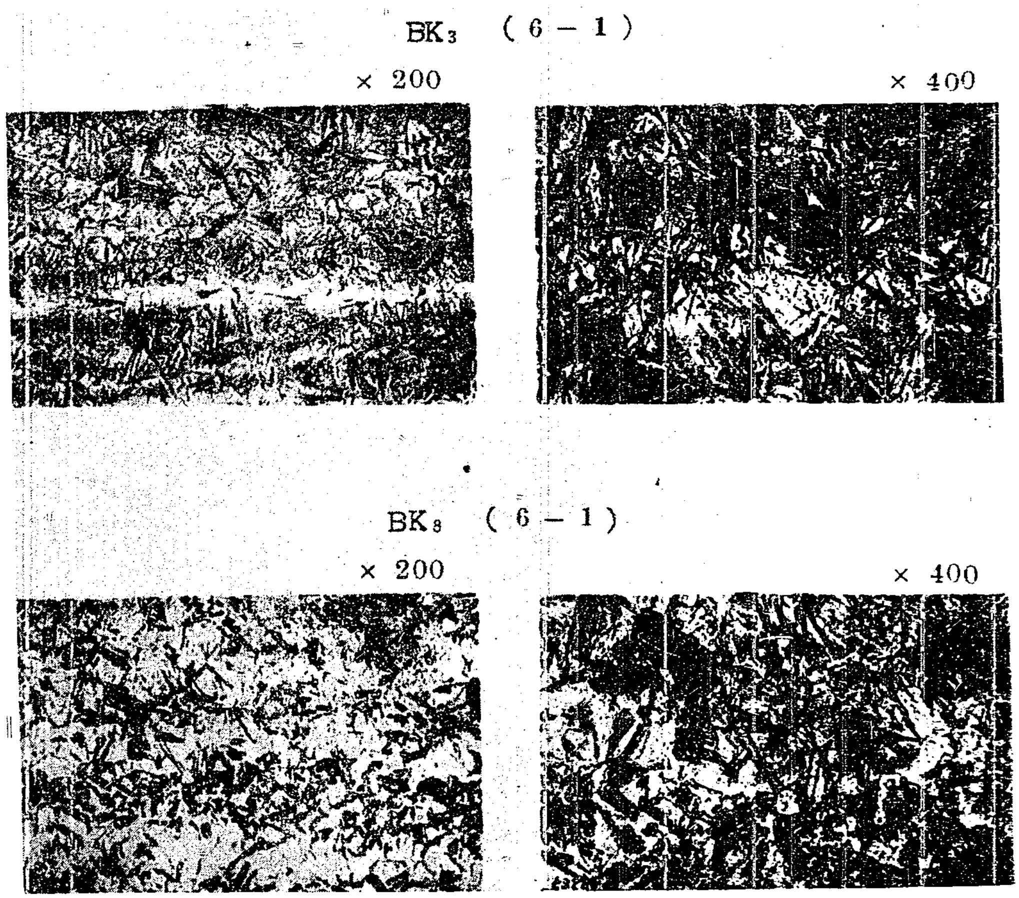


Figure 8(A)
MICROSCOPIC FORMATION WHEN ANNEALED

ENCLOSURE (A), continued

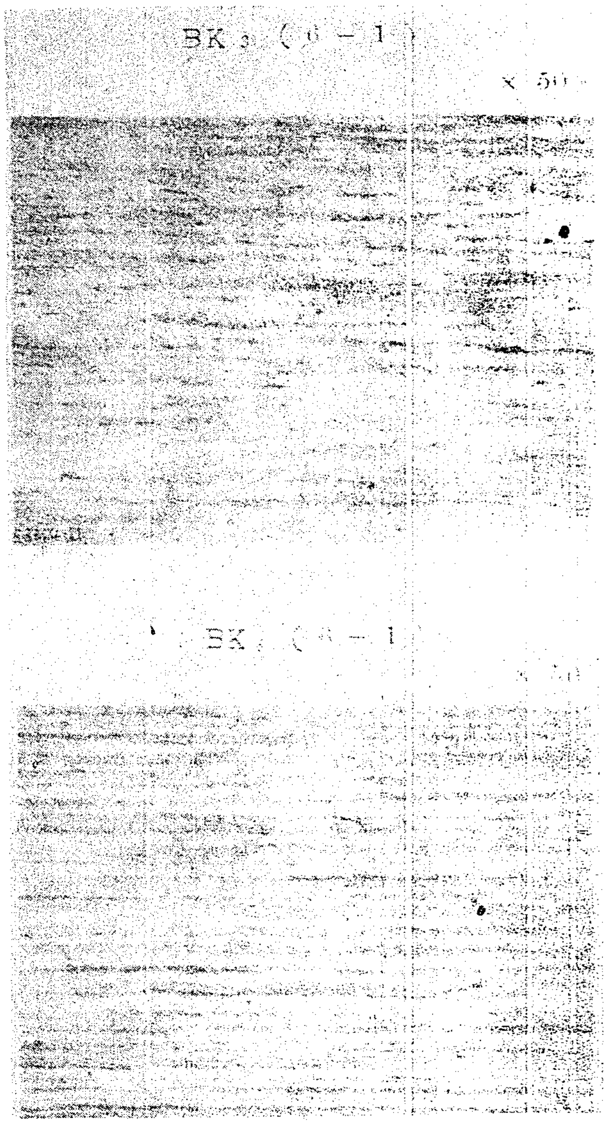


Figure 9(A)
BINDING AND BREAKING

ENCLOSURE (A), continued

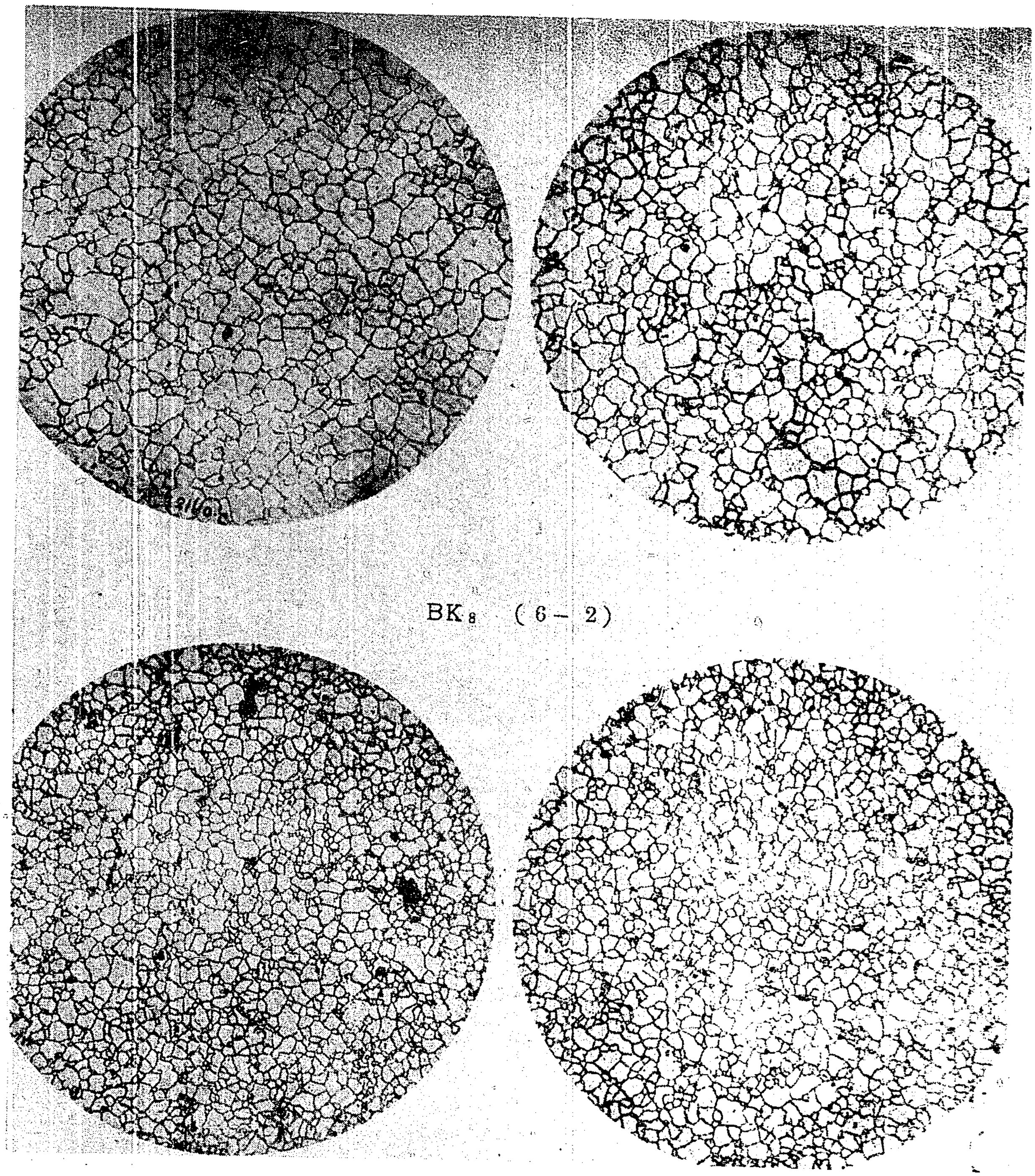


Figure 10(A)
DEGREE OF CRYSTALLIZATION

ENCLOSURE (A), continued

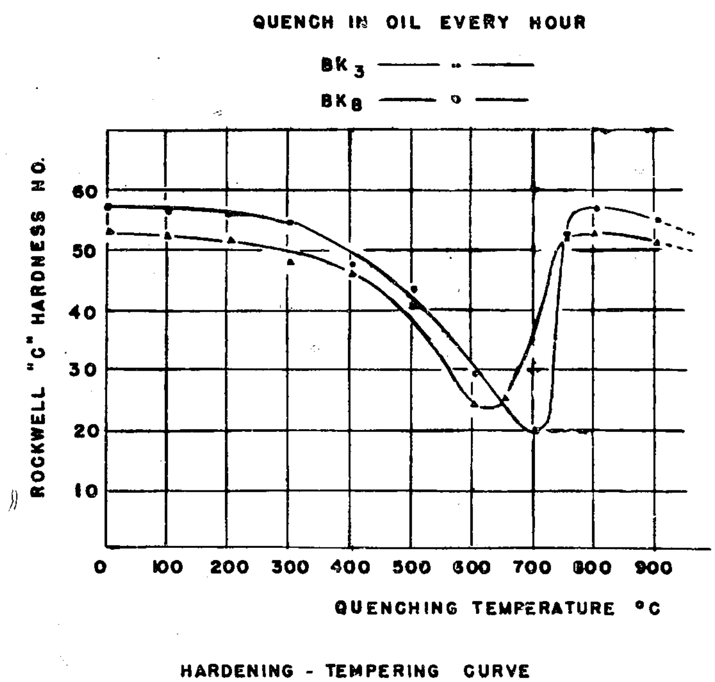


Figure 11(A)
HARDENING-TEMPERING CURVES

ENCLOSURE (B)

DISCUSSION OF THE TORSION NON-BALLISTIC TEST

A. SUMMARY

1. At the Metals Research Institute in SENDAI, Japan, Professors MURAKAMI and WATANABE, under the direction of Dr. HONDA, president of the university at SENDAI, developed a technique in which the ballistic quality of light steel armor plate against a 6.5mm rifle bullet could be predicted quantitatively by the use of a static torsion test. While the application of the test is somewhat limited and, because of the Allied occupation, additional results on other calibers and with different test conditions could not be obtained, it is considered that the technique merits consideration.

2. It was found that the torsional energy per unit area (integral of torsional stress vs. twist angle) for 50° of twist was inversely proportional to the limiting thickness of armor made from the same steel which would just resist the penetration of the bullet at normal obliquity at a constant standard velocity. When the torsion specimen broke below 50° twist, it usually did so with a helical granular fracture on a 45° plane. In such a case, the bullet would shatter the plate (or at least cause sections of plate to fly off). When the specimen broke after being twisted through an angle greater than 50°, it did so with a smooth fibrous fracture in a plane normal to the axis. (At angles near 50°, there was an occasional inconsistency or a fracture whose nature was a hybrid.)

B. LIMIT DETERMINATION

1. The limiting thickness of a given steel with a given heat treatment was determined by firing about five such plates of various thicknesses less than the limit. The residual velocity of the bullet was measured, and only two rounds usually were necessary on each plate. The residual velocity was then plotted against thickness and the curve extrapolated to zero residual velocity. Naturally, after the first one or two tests, it was possible to select thicknesses quite close to the limit, thus reducing to a minimum the error involved in extrapolating. The thickness at zero velocity was known as the critical gage.

2. The bullet used had a 6.5mm diameter and weighed 9 grams. It had a lead core in a cupro-nickel jacket. The mean velocity was about 760 meters/second, a rather high velocity, but this permitted more shock, closer control, and less proportional error. The muzzle was only about 10 feet from the plate.

3. The plates were prepared in various manners as discussed below. They were cut to about 9" x 9" and secured to a massive frame. A half dozen diaphrams, plates with small holes in the middle, were lined up behind the frame. These diaphrams permitted free passage of the bullet but screened out most of the plate fragments if any were thrown back. The bullet finally entered a ballistic pendulum about two feet behind the plate.

4. The pendulum was an ordinary type, suspended by rigid frames fore and aft. It swung free in the line of fire so that the recording apparatus on the side described an arc on the paper. The bullet was caught in a sand box. It penetrated a thin wood bulkhead and a layer of thin rubber which had self-sealing properties to prevent the sand from leaking out. The weight of the box was carefully controlled.

5. The pendulum had been calibrated so that the length of the described

ENCLOSURE (B), continued

arc could be converted directly to velocity. The lever arm of the pendulum was about three feet. The weight of the box is available in documents on the subject (see list of Japanese documents pertaining to light armor, Enclosure E) but was not discussed during interrogations.

6. The residual velocity was plotted against the plate thickness (which was obtained at will by varying the spacing of a small rolling mill), and the curve extrapolated as shown in Figure 1(B).

C. TORSION TEST

1. One of the objections to this experiment was the fact that torsion specimens could not be taken directly from the plates. The plates were always too thin. However, the specimens were obtained from the same heat of steel as the plates and were heat-treated along with the plates. They were machined after normalizing and were merely ground to accurate dimensions after the quench and temper. The shafts of the specimens were 10mm in diameter and about 10mm long with a generous fillet at each end. The specimens had cylindrical heads which were flattened on one side to fit the chucks on the machine. After the test, the Rockwell hardness was checked against that of the plate to prove similitude.

2. The machine was motor-driven and required roughly seven minutes to turn through 100°. The end opposite the power-end was suspended in frictionless bearings and bore a heavy pendulum which was forced upwards by the torque on the specimen. The angle of its rise indicated the moment of torque. The record was obtained by a drum which turned according to the twist angle, and a stylus which moved laterally according to the moment of torque (or torsional shear stress).

3. Three typical curves are shown in Figure 2(B). The solid line (b) indicates a satisfactory good steel. The sharp peaked line (a) shows a break at a low twist angle indicating brittleness which would result in shattering on ballistic test. The low long curve (c), indicates a plate too soft, having a low penetration resistance. The integreated areas below 50° twist for (c) are shaded in figure 2(B). The area under curve (b) from 0° to 50° is obviously larger than that for curve (c). Even though the area under curve (a) from 0° to the breaking angle may be satisfactory, the plate would exhibit brittle properties on a ballistic test. The area $\int_0^{50^\circ} S_T d\phi$ is the torsional energy per mm^2 required to twist the specimen through 50°. A minimum stress of 150 kg/mm^2 was considered desirable for good penetration resistance.

D. THE CORRELATION

1. The results of the tests discussed above were plotted for many medium-alloy steels with various heat treatments. The chart was similar to Figure 3(B). The data plotted with a band, as shown, and concentrated on one straight line. The most satisfactory plates had a critical gage limit of 4.5mm for the test conditions used. The above plot holds only for medium alloy, tempered, martensitic steel. It would not hold for austenitic steel, for example.

E. APPLICATION

1. The Japanese had applied the correlation discussed above to a series of tests in which they determined the optimum compositions and tempering temperatures for substitute alloys containing no nickel. A large number of specimens were tested in the torsion machine and a few finally emerged as satisfactory, all without firing a shot. A given analysis was tested

ENCLOSURE (B), continued

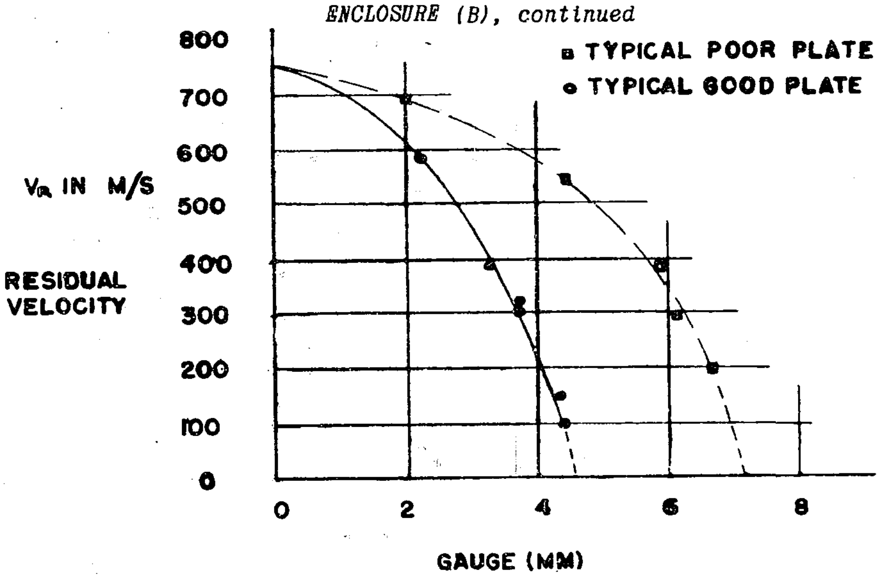


Figure 1(B)

VELOCITY - GAUGE CURVES FOR 6.5mm BULLET TESTS

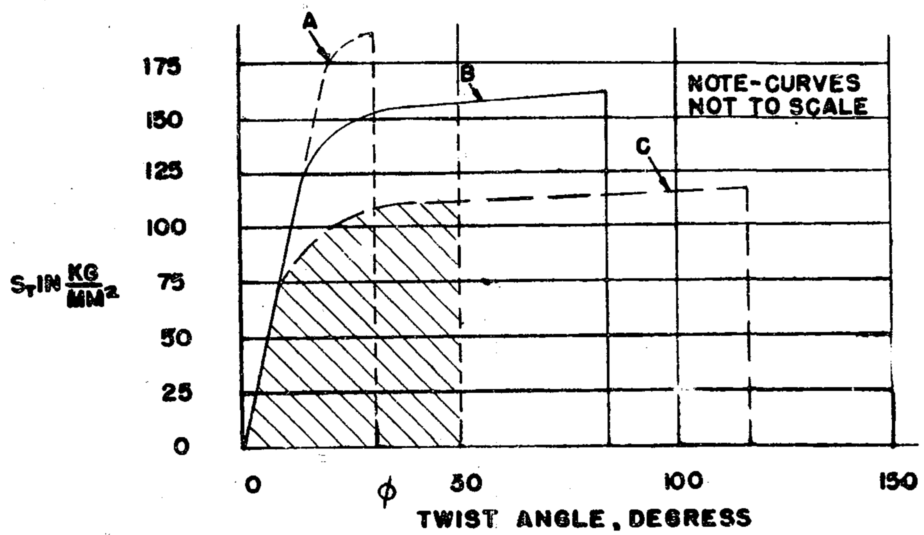


Figure 2(B)

RESULTS OF TORSION TEST

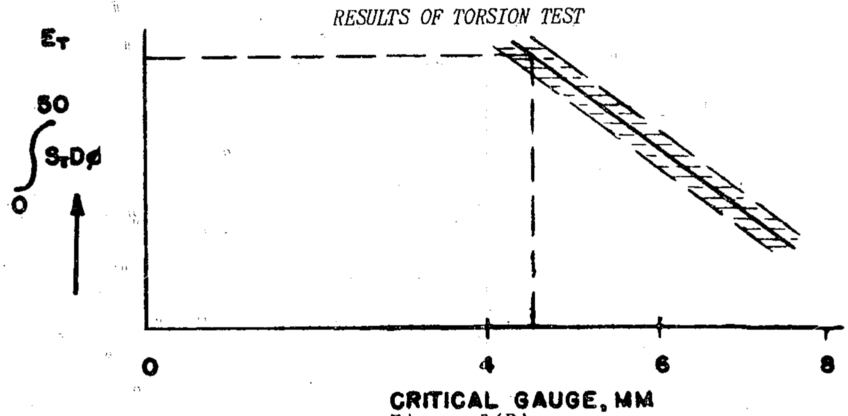


Figure 3(B)

CORRELATION OF TORSIONAL ENERGY AND CRITICAL GAUGE

ENCLOSURE (B), continued

at various tempering temperatures. The plots of maximum torsion angle versus tempering temperature were interesting in that they showed two distinct dips in many cases, one at a low temperature in the order of 175°C, and one about 550°C. This demonstrated the existence of two zones of temper embrittlement. The low temperature zone is not manifested on subsequent low temperature draws, but only on the initial tempering from the martensitic structure.

2. The purpose of this discussion is not to present the data obtained by the Japanese, since the application of these data would be limited. Rather, it is to present a technique which might be useful.

3. Further work had been started using 7.7mm steel bullets and work was planned with a 20mm AP projectile. The 20mm test required a special larger firing range, and it had not progressed to the point of obtaining any data when the war ended.

4. The following compositions and heat-treatments of steels gave good results on the torsion test.

Steels	Composition (%)						Heat Treatment				
	C	Cr	Mn	Mo	V	Si	Quenched			Tempered	
							°C	Time	Cool-ing	Range (°C)	Time
Cr-Mo	0.45	1.82	<0.4	0.59		<0.2	880°C	30'	oil	100°-150°	1hr.
	0.41	1.74		0.82		<0.2	850°C	30'	oil	100°-150°	1hr.
Cr-Mn-Mo	0.39	1.50	1.31	0.76		<0.2	880°C	30'	air-cool	250°-300°	1hr.
Mn-Mo	0.36		1.70	0.52		<0.2	860°C	30'	oil	100°-150°	3hrs.
	0.46		1.87	0.63		<0.2	860°C	30'	oil	100°-150°	3hrs.
	0.37		1.69	0.31		<0.2	860°C	30'	oil	100°-150°	3hrs.
	0.37		1.70	0.61		<0.2	860°C	30'	oil	100°-150°	3hrs.
Mn-V	0.41		1.61		0.22	<0.2	880°C	30'	oil	150°	3hrs.
	0.40		2.27		0.22	<0.2	880°C	30'	oil	150°	3hrs.
	0.31		1.68		0.23	<0.2	880°C	30'	oil	150°	3hrs.
Mn-Si	0.34		1.51			1.03	880°C	30'	oil	200°-250°	3hrs.
	0.42		1.51			1.09	880°C	30'	oil	150°	3hrs.
	0.48		1.60			0.23	880°C	30'	oil	150°	3hrs.

ENCLOSURE (C)

REDUCTION OF SLAB TO FINAL THICKNESS AS PERFORMED BY THE DAIDO STEEL MANUFACTURING CO., NAGOYA

A brief description of the process of reducing an ingot to the final thickness of armor at the Daido Steel Manufacturing Co., Hoshizaki, NOGOYA is given in the following outline:

I. Reducing Ingot to Slab

A. Size of ingot, see Figure (C)1.

B. Ingot forged by steam hammer to slab of approximate dimensions, 60-70mm x 250mm x 900mm.

C. The rolling of the slab to a 30mm thickness for carburizing is given in Figure 2(C). The standard draft per pass averaging about 10% of the thickness.

II. Carburizing

A. Sizing: Finished slab 30mm x 450mm x 1000mm is cut to 30mm x 390mm x 930mm for carburizing.

B. The slab is carburized for 100 hours at 900-950°C in a box as shown in Figure 3(C); the depth of carburization averaged about 20%.

III. Rolling Carburized Plate to Final Thickness

A. Rolling procedure: The carburized plate 30mm x 390mm x 930mm is rolled first to the desired width in one direction, then rotated 90° and rolled to the desired gauge. Sizes (mm) of production armor plate were as follows:

THICKNESS	WIDTH	LENGTH (as rolled)
16	800	930
16	450	1500
12	800	1170
8	800	1750
6	800	2470

B. The number of passes required to obtain specific thickness (mm) was as follows:

	No. of Passes													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Thickness	30	27	24	21	19	18	16	14	12	10	9	8	7	6
Draft	3	3	3	3	2	1	2	2	2	2	1	1	1	1

C. Calculated from the surface area, the following tables give the ratic of cross-rolling in reducing the carburized slab to a desired thickness and width.

ENCLOSURE (C), continued

Cross-Rolling Increase in Area and Ratio						
Original Plate Size (mm)	Size After First Rolling (mm)	Increase in Area (mm)	Rolling Ratio	Size After Second Rolling (mm)	Increase in Area (mm)	Rolling Ratio
30x390x930	26x450x930	60x930	1	16x450x1500	450x570	4
30x390x930	16x800x930	410x930	1			
30x390x930	16x800x930	410x930	2	12x800x1170	800x240	1
30x390x930	16x800x930	410x930	1	8x800x1750	800x820	2
30x390x930	16x800x930	410x930	1	6x800x2470	800x1540	3

IV. Discussion

From the above data it may be noted that cross-rolling was accomplished on all plates manufactured by Daido and that the amount of cross-rolling was dependent upon the desired thickness.

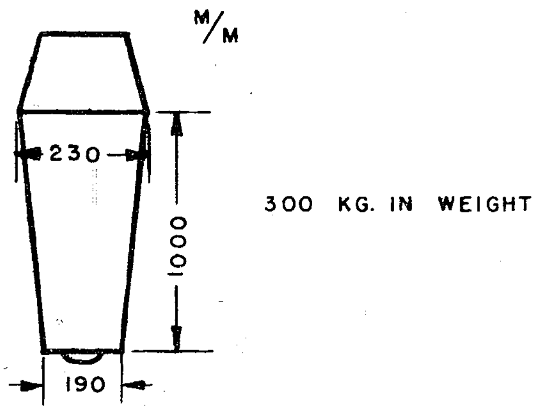
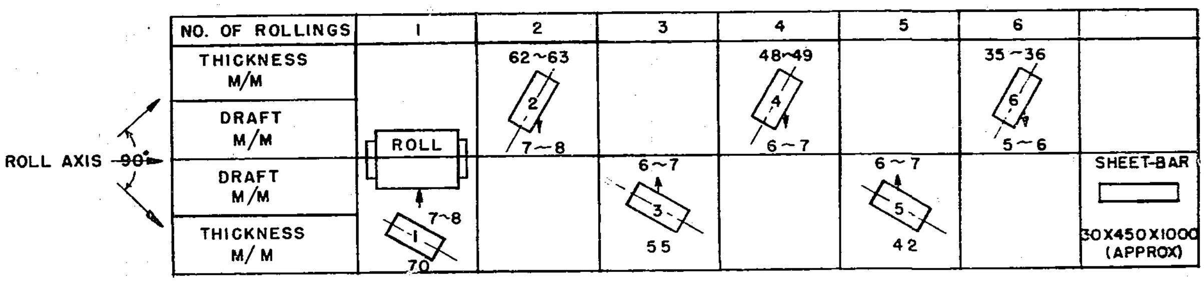


Figure 1(C)

INGOT

ENCLOSURE (C), continued



REMARKS:

1. THESE ROLLINGS ARE CARRIED ON BY ONE HEAT.
2. AT EACH ROLLING THE PLATE IS PASSED IN THE DIRECTION TURNED AT 45° TO THE ROLL AXIS: EACH ROLLING IS PERFORMED TURNING 90° SUCCESSIVELY.
3. AMOUNT OF CROSS ROLLING IS NATURALLY 50%.

Figure 2(C)
METHODS OF ROLLING

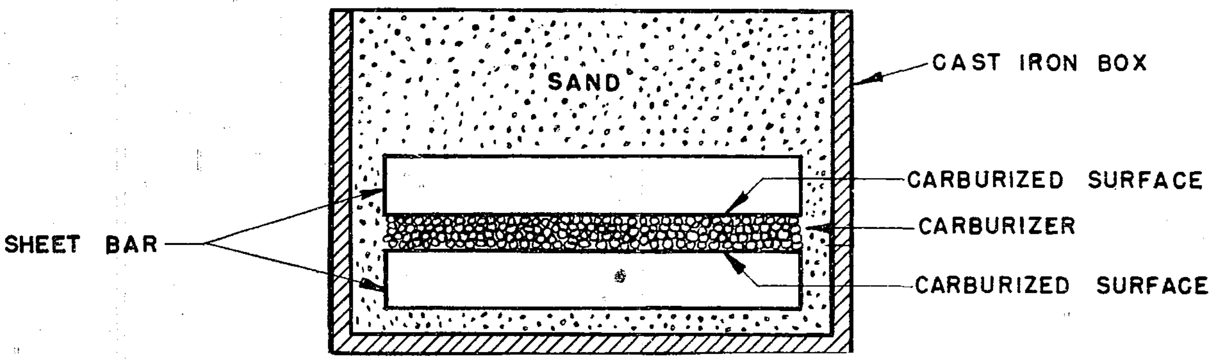


Figure 3(C)
CARBURIZING BOX

ENCLOSURE (D)

LIST OF JAPANESE LIGHT ARMOR SHIPPED TO
NAVAL PROVING GROUND, DAHLGREN, VA.

NavTechJap No.	Type	Thickness	No. of Plates
JE50-3142	Homogeneous	3/8 in to 1½ in	6
JE50-3143	Ducol (High Mn)	3/16 in to 1 in	8
JE50-3144	Carburized-Homogeneous	3/8 in to ½ in	9

ENCLOSURE (E)

LIST OF JAPANESE DOCUMENTS PERTAINING TO LIGHT ARMOR
FORWARDED TO WASHINGTON DOCUMENT CENTER

NavTechJap No.	ATIS No.	Title
ND50-3165	4120	Research on Rifle Shields, 1937
ND50-3166	4121	Firing Tests on Non-Nickel Shields, 1943
ND50-3163	4118	Study of Trajectory of a 5cm AP Projectile when Firing against Armor, 1943
ND50-3146	4115	Measurement of Penetration Resistance of Shield Plate versus Rifle Bullet, 1931
ND50-3162	4117	Experiment Mn-Va Steel Torsion Test of 1944
ND50-3164	4119	Measurement of the Penetration Resistance of Armor with Ballistic Pendulum, 1932-1943
ND50-3167	4122	Experiments of Special Steel Plates, 1940
ND50-3147	4116	Bullet Proof Glass, 1939-1943
ND50-3157	3833	25mm AP Projectiles versus Thin Armor. Manufacture & Ballistic Test of Composite Armor
ND50-3189	4380	Experiments on Pressure Resisting Qualities of Glass in Lookout Windows