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Report No. 710/500

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REPORT

Metallurgical Examination of Cast Gun Shield Armor
Four to Six Inches in Thickness

by

A. Hurlich
Asst. Metallurgist

May 17, 1943

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Report No. 710/500
Watertown Arsenal
Problem No. B-46

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May 17, 1943

ARMOR

Metallurgical Examination of Cast Gun Shield Armor Four to Six Inches in Thickness

OBJECT

To correlate the metallurgical and ballistic characteristics of 4 to 6 inch thick cast armor in order to determine the factors necessary to the production of successful cast armor of this thickness range.

CONCLUSIONS

1. Ballistic failure of 4-6" thick cast armor is associated with the presence of undesirable high temperature transformation products resulting from the use of steel of insufficient hardenability to completely quench harden through the thickness of the section.

2. A good correlation exists between the Izod or Charpy impact value and ballistic performance, poor ballistic performance being associated with low impact strength.

3. It is believed that metallurgical factors found responsible for poor ballistic properties of cast armor up to 2" in thickness apply equally as well to cast armor up to 6" in thickness.

4. The fracture test is a convenient and easily performed test to indicate the degree of quenching obtained in armor and correlates well with ballistic performance and impact tests.

a. Fibrous fractures are associated with completely quench hardened armor having satisfactory ballistic properties and high impact strength.

b. Crystalline fractures are associated with slack quenched material conteining free ferrite in the microstructure. Armor breaking with a crystalline fracture has poor ballistic properties and low impact strength.

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APPROVED:

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Colonel, Ordnance Dept.
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INTRODUCTION

Cast armor manufacturers have submitted numerous four to six inch thick cast armor plates to Aberdeen Proving Ground for ballistic testing. These plates represent sections of gun shield castings. Several of the test plates broke into pieces under the first impact of matching projectiles, while others successfully withstood the attack of several matching projectiles.

Small sections cut from ten plates ballistically tested at Aberdeen Proving Ground were forwarded to this Arsenal in an attempt to correlate their ballistic and metallurgical characteristics[1].

Previous studies of cast armor at this Arsenal have been confined to thicknesses not greater than two inches. It has been found that, in sections up to 2" in thickness, a good correlation exists between the metallurgical characteristics and the ballistic performance of cast armor. Ballistic failure has been associated with any one or a combination of the following factors:

1. Ferrite rejected upon quenching; a result of either insufficient hardenability for the section size or slack quenching.

2. Casting defects such as excessive shrinkage porosity, blow holes, hot tears, large amounts of deoxidation products in the steel, etc.

3. Excessive dendritic segregation of carbon and other alloying elements which depletes the matrix of hardening elements and consequently leads to ferrite rejection upon quenching.

4. Improper hardness range; too low hardness resulting in low ballistic limit and too high hardness resulting in PTP* and shock test failures.

This study was undertaken to determine if the same factors are operative in castings up to six inches in thickness.

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*PTP Test - Complete passage through the plate of a matching projectile.

1. A.P.G. 470.5/4239, W.A. 470.5/5465)
   A.P.G. 470.5/4824, W.A. 470.5/5763)
   A.P.G. 470.5/4871, W.A. 470.5/5804) See Appendix C
   A.P.G. 470.5/5700, W.A. 470.5/6250)
   A.P.G. 470.5/6681, W.A. 470.5/7086)

MATERIALS AND TEST PROCEDURE

Cast Armor Sections

Sections cut from 10 test plates representing gun shield castings were examined. These plates are as follows:

TABLE I

Cast Armor Sections Examined at Watertown Arsenal

Plate No.	Heat No.	Manufacturer	Thickness Inches
5423	3245	Continental Roll and Steel Foundry Co.	6
1-13-3372	3372	" " " " " "	6
1	8196	" " " " " "	4
1	8014	" " " " " "	4½
CRS-13	3372	" " " " " "	6
CRS-17-2	3445	" " " " " "	6
CRS-12-1	2212	" " " " " "	6
GSC-26	6848	General Steel Castings Corp.	6
1	6405	" " " "	4
21	6524	" " " "	6

Data covering the ballistic testing of the plates were abstracted from the Aberdeen Proving Ground firing records and are presented in Appendix A.

Chemical Analyses

The chemical analyses of the ten plates were determined at this Arsenal.

Hardness Surveys

Brinell hardness determinations were made on sections cut through the thickness of the plates, readings being taken at a distance of one inch below the surface of the plate and at the center of the cross-section.

Jominy Hardenability Tests

The standard three inch long, inch diameter bar was used for the Jominy hardenability test. The Jominy bars were immersed in an upright position to a depth of two inches in a pot of "neutro-pack" to prevent excessive oxidation. The bars were brought to temperature in one-half

hour and allowed to remain at temperature for two hours, then end-quenched according to the standard procedure. The Jominy bars from nine of the ten plates were austenitized at 1600°F, while that of General Steel Castings Corporation Heat 6848, Plate GSC-26, was austenitized at 1675°F because of its high chromium content. The austenitizing temperatures of the Jominy bars were in close agreement with the hardening temperatures employed by the cast armor manufacturers.

Fracture Tests

Sections approximately 1½" square were cut through the thickness of the plates, nicked in the middle to a depth of approximately 1/4", broken by a blow of a forge hammer, and the fractures examined and compared.

Physical Tests

Two .505" tensile test bars were machined from each armor section, halfway between the surface and the center and parallel to the plate surfaces. In addition, two .505" tensile bars were made from seven of the plates in a direction perpendicular to the plate surfaces, i.e., through the thickness, to detect possible variations in properties.

Three standard V-notch Charpy impact bars were made from each of four plates, Heat 3372 Plate 1-13-3372, Heat 6405 Plate 1, Heat 3245 Plate 5423, and Heat 6848 Plate GSC-26. The impact bars were taken halfway between the surface and the center and parallel to the plate surfaces. The four plates were selected as representing the various chemical analyses and ballistic properties. The fractures of all impact bars were examined and compared to those previously obtained by breaking nicked bars cut from the plates.

Reheat-Treatments

Sections three inches square and one inch thick, cut from Heat 3372 Plate 1-13-3372, Heat 6405 Plate 1, and Heat 3245 Plate 5423 were reheat-treated as follows:

Heat to 1600°F - 2 hrs. - water quench
Draw at 1275°F - 2 hrs. - air cool.

Three standard V-notch Charpy bars were then machined from each section. The locations of the impact bars were halfway between the original plate surfaces and the center and parallel to the plate surfaces.

The purpose of the reheat-treatments and the impact tests will be considered in the discussion of the results.

Metallographic Examinations

Metallographic examinations were made of specimens cut from all plates. The specimens were selected to reveal the microstructure throughout the thickness of the plates. The microstructures representative of the two outer thirds of the cross-section and of the center of the cross-section of the plates were photographed at magnifications of X200 and X1000. The former magnification was used to reveal the distribution and relative amounts of the various microconstituents and the latter to reveal the microstructural details.

Sections cut from all plates were macroetched in a solution of 50% water, 38% hydrochloric acid, and 12% sulfuric acid at a temperature of 75°C. for approximately thirty minutes.

Results and Discussion

1. Chemical Analyses

The chemical analyses as determined at this Arsenal and the "V" values* of the alloy contents of the ten test plates are listed in Table II.

TABLE II

Chemical Analyses of Cast Armor Plates

Plate No.	Heat No.	C	Mn	Si	S	P	Ni	Cr	Mo	"V" Value
5423	3245	.34	.87	.28	.035	.042	1.00	.07	.45	11.86
1-13-3372	3372	.32	.90	.35	.027	.044	.98	.11	.45	12.06
1	8196	.26	.85	.32	.034	.043	1.07	.20	.52	14.16
1	8014	.28	.81	.28	.038	.033	1.00	—	.50	12.92
CRS-13	3372	.29	.87	.35	.021	.043	.94	.13	.42	11.30
CRS-17-2	3445	.28	.83	.29	.028	.036	.99	.08	.44	11.59
CRS-12-1	2212	.30	.85	.30	.032	.037	.93	.055	.47	12.09
GSC-26	6848	.30	.68	.38	.031	.007	trace	2.39	.46	17.18
1	6405	.33	1.61	.48	.019	.013	.17	.10	.31	7.34
21	6524	.29	1.65	.38	.013	.012	.07	.085	.32	7.22

*For explanation of the "V" Values see Appendix A, page 4.

The average "V" value of the Ni-Mo steel manufactured by the Continental Roll and Steel Foundry Co. is 12.3. The "V" value of the Mn-Mo steel produced by General Steel Castings Corporation averages 7.3 and that of the Cr-Mo steel produced by the same company is 17.2.

2. Ballistic Tests

A short summary of the data covering the ballistic testing is given in Table III. More complete data abstracted from Aberdeen Proving Ground firing records may be found in Appendix A.

Table III

Summary of Ballistic Tests of Cast Armor Plates

Plate No.	Heat No.	Nominal Thickness Inches	Projectile Fired at Plate	Ballistic Characteristics of Plate
5423	3245	6	6" Navy A.P. MK27 at 15° obliquity.	Plate cracked full length on first impact.
1-13-3372	3372	6	6" Navy A.P. MK27 at 15° obliquity.	Plate cracked full length on first impact.
1	8196	4	3" A.P.C. M62 at 20° obliquity.	Satisfactory. Plate acceptable.
1	8014	4	3" A.P.C. M62 75 MM A.P. M72	Excessive spalling and cracking.
CRS-13	3372	6	6" Navy A.P. MK27 at 15° obliquity.	Plate broke into 3 pieces on second impact.
CRS-17-2	3445	6	6" Navy A.P. MK27 at 15° obliquity.	Plate broke into 3 pieces on first impact.
CRS-12-1	2212	6	6" Navy A.P. MK27 at 15° obliquity.	Spall - 14" diameter. 25" and 35" cracks extending to plate edges.
GSC-26	6848	6	6" Navy A.P. MK27 at 15° obliquity.	Resisted two impacts successfully.
1	6405	4	No firing data available.	
21	6524	6	4 Rounds - 6" Navy A.P. MK27 at 15° obliquity.	Plate cracked full length on fourth impact.

Seven of the nine plates whose ballistic test data were available have poor ballistic characteristics, back-spalling, cracking excessively, or breaking up under the impacts of matching, and in one case, of undermatching projectiles.

Of the two plates having satisfactory ballistic properties, one, General Steel Castings Corp. Heat 6848 Plate GSC-26, was tested with a matching projectile, while the other, Continental Roll and Steel Foundry Co. Heat 8196 Plate 1, was tested with an undermatching projectile. This latter plate is 4" in thickness and was tested with 3" A.P.C. projectiles, hence the test was not severe enough to adequately uncover the poor shock resisting properties of the material. The test conducted in this case was solely a penetration test.

3. Hardness Surveys

The results of the hardness surveys made along the cross-sections of the plates are given in Table IV.

Table IV

Brinell Hardness through Cross-Section of Cast Armor

Plate No.	Heat No.	Surface Hardness Reported by Mfgr.	Hardness 1" below Surface	Hardness at Center of Cross-Section
5423	3245	217-229	223	212
1-13-3372	3372	207-223	212	207
1	8196	183-196	207	201
1	8014	183-196	187	179
CRS-13	3372	191-197	197	192
CRS-17-2	3445	196-207	197	197
CRS-12-1	2212	-	192	183
GSC-26	6848	216	223	223
1	6405	-	235	217
21	6524	206	197	197

There is insufficient difference in hardness between the plates to draw any conclusions regarding the effect of variations in hardness upon the ballistic properties of 4-6" thick armor.

4. Jominy Hardenability Tests

The Jominy hardenability curves of the ten armor sections are shown in Figure 1 and the data are summarized in Table V.

Table V

End-Quench Hardenability of Cast Armor Sections

		Jominy Hardenability Data					Thickness of Plate Quenchable to 400 BHN in Center - Inches
			No. of 1/16ths of an Inch for a Drop				
Plate No.	Heat No.	Hardness 1/16" from Quenched End Rc	of 5 Rc	of 10 Rc	to 42 Rc (400BHN)	Hardness at 2½" from Quenched End Rc	
5423	3245	52	10	15	15	33.5	2.2
1-13-3372	3372	52.5	10	15	15	31	2.2
1	8196	49	8	12	10	28	1.7
1	8014	48.5	8	11	9	24.5	1.5
CRS-13	3372	52	12	16	15	26	2.2
CRS-17-2	3445	52	7	11	10	27.5	1.7
CRS-12-1	2212	51	8	10	10	23.5	1.7
GSC-26	6848	51.5	31	Max. drop is 7.5 Rc	Minimum hardness is 44 Rc	44	Greater than 6"
1	6405	53.5	12	18	19	36	2.7
21	6524	51.5	9	13	12	29.5	1.9

The thickness of plate quenchable to 400 BHN in the center was determined from recent experimental work performed by Battelle Memorial Institute and the Great Lakes Steel Corporation, both of whom correlated cooling velocities of the standard Jominy hardenability bar with cooling velocities at the center and midwall of plates. Their results are in substantial agreement for plate thicknesses in the range of 1 to 3 inches.

The necessity of having both sufficient hardenability and a severity of quench adequate to harden armor completely through has been emphasized frequently in previous work dealing with armor up to 2" in thickness. On the basis of experience, it has been recommended that armor steel should have a hardenability capable of producing a hardness

of at least 400 BHN in the center of the section upon water quenching. Although this Brinell value may be considered excessive by some, it represents a definitely conservative and safe limit and guarantees the production of satisfactory properties in armor after the proper tempering heat treatment.

As seen in Table V, with the sole exception of General Steel Castings Corporation Heat No. 6848, Plate GSC-26, none of the cast plates has hardenability sufficient to completely quench harden through its thickness. The plate having the next highest hardenability, General Steel Castings Corporation Heat No. 6405, Plate 1, is hardenable to 400 BHN in the center of a 2.7" thick plate, whereas its actual thickness is 4".

The nickel-molybdenum analysis of Continental Roll and Steel Foundry Co. has a hardenability capable of producing 400 BHN in the centers of plates having a maximum thickness of from 1.5" to 2.2"; the lower hardenability being associated with lower carbon contents. Heat 8014, Plate 1, having the lowest hardenability of the Ni-Mo steels, has a carbon content of 0.28%; whereas Heat 3245, Plate 5423, having the highest hardenability, has a carbon content of 0.34%.

When steels of such low hardenability are made in section sizes up to 6" in thickness, it is impossible to prevent the rejection of large quantities of ferrite upon quenching. It is worthy of attention that the Mn-Mo analysis having a "V" value of but 7.3 has approximately the same hardenability as the Ni-Mo analysis having a "V" value averaging 12.3. Raising the "V" value to 17.2 by utilizing chromium results in an enormous increase in hardenability.

Study of the hardenabilities of the several heats involved indicates the potent effects of the elements chromium, manganese, and carbon. Grossmann[2] has adequately demonstrated the extreme potency of molybdenum. Therefore, in consideration of the relative effects upon hardenability of the several elements, their strategic value, and the impracticability of raising the carbon content appreciably because of its adverse effect upon weldability, a steel of the following approximate composition is indicated for these applications:

C	Mn	Si	Cr	Mo
.35	1.50	.40	.80	.45

The "V" value of the above analysis is 12.2, which is considerably less than the strategic value of the chromium-molybdenum steel used by General Steel Castings Corp. and approximately equal to the value of the nickel-molybdenum analysis used by the Continental Roll and Steel Foundry Co. Further large reductions in strategic value could be obtained by a reduction in molybdenum content, offsetting this reduction by the use of more chromium. However, the ballistic properties of such materials have not

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2. M. A. Grossmann, "Hardenability Calculated from Chemical Composition" Metals Technology. Vol. 9, No. 4. T.P. 1437, June 1942, pages 1-29.

been investigated. An analysis of the following type could well be considered:

C	Mn	Si	Cr	Mo	"V" Value
.35	1.50	.40	1.25	.20	8.1

An investigation of a steel of this type is being initiated at this Arsenal. The study will include hardenability, tensile and impact properties in a six inch section, and microstructural investigations.

In a previous study[3] at this Arsenal, a 2" thick cast armor section, Heat No. 5531 MMC, Plate No. 657, manufactured by General Steel Castings Corp., was examined. The analysis of this plate was the following:

C	Mn	Si	S	P	Cr	Mo	"V" Value
.28	1.58	.40	.017	.020	.71	.52	13.8

The Jominy hardenability curve was approximately a straight line at 50-52 Rockwell "C" from the water quenched end to a distance of 40/16ths inches away, which represents greater hardenability than that possessed by Plate GSC-26.

Plate No. 657 possessed excellent ballistic and metallurgical properties in a 2" thick section. It is believed that the same analysis would also make satisfactory six inch armor even after a reduction in the molybdenum content.

5. Fracture Tests

Considerable work is being done at present at this Arsenal to correlate fractures with metallurgical and ballistic properties of armor. It has been found that, in armor, the fibrous fracture[4] is associated with a satisfactory microstructure of spheroidized sorbite or tempered martensite free of ferrite, and with satisfactory ballistic properties. On the other hand, the crystalline fracture[5] is associated with a poor microstructure containing ferrite rejected on the quench, and with poor shock properties.

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3. Cast Armor Report No. 32, Watertown Arsenal, April 25, 1942, "Metallurgical Data on Certain Cast Armor Test Plates Tested at Aberdeen Proving Ground as a Part of the Cast Armor Low Alloy Development Program".

4. The fibrous fracture is characterized by a nonreflecting, dark gray, pitted and rough surface. When the fracture is fibrous, the steel usually necks in at the plane of fracture, indicating good ductility.

5. The crystalline fracture is characterized by a bright silvery sheen caused by reflections from crystal facets. The fracture usually occurs on a flat plane with no necking at the edges of the fracture, indicative of brittle materials.

The fracture test specimens from the ten armor sections were nicked so that the fractured surfaces occurred in the middle of the cross-section of the original casting.

General Steel Castings Corporation Heat No. 6848, Plate GSC-26 developed a completely fibrous fracture, General Steel Castings Corporation Heat No. 6405, Plate 1 showed a mixed fracture composed of both fibrous and crystalline regions, while the remaining eight plates had completely crystalline fractures.

Referring back to Table V, it is seen that Plate GSC-26 has sufficient hardenability to quench harden completely through its cross-section; while Heat 6405, Plate 1 has the next highest hardenability, and considering that the thickness of this casting is 4", it is evident that Heat 6405, Plate 1 will more nearly quench through than any of the remaining eight plates. It has been found that mixed fractures result from quenching at cooling rates just insufficient to completely suppress the formation of high temperature transformation products. The mixed fracture is, therefore, indicative of somewhat too low hardenability or slack quenching, while the completely crystalline fracture indicates excessively low hardenability or very slow cooling rates.

Figure 2 is a photograph of the different types of fractures. Several attempts have been made to obtain more realistic photographs, but it is difficult to accurately reproduce the bright luster of the crystalline fracture. The eye can discern considerably more difference and greater color contrast between the crystalline and fibrous areas of the mixed fracture than can be portrayed in a photograph[6].

The results of the fracture test correlate well with the ballistic performance of the plates. Plate GSC-26, having a fibrous fracture, successfully resisted the impacts of two 6" Navy A.P. MK27 projectiles. Unfortunately, the ballistic data concerning Heat 6405, Plate 1 are at present unavailable, but it is believed that this plate would possess borderline ballistic properties. Of the eight remaining plates, all having crystalline fractures, seven failed the ballistic test by cracking, spalling, or breaking into pieces. The eighth, Heat 8196 Plate 1, was tested with undermatching projectiles and, therefore, was not subjected to an adequate shock test.

6. Physical Tests

The tensile properties and V-notch Charpy impact properties of the cast armor sections are shown in Table VI. The tensile results are the average of two tests and the V-notch Charpy values the average of three tests. The complete individual test results may be found in Appendix B.

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6. It has since been noticed that examination of the photographs of fractures by means of a low magnification handglass produces a marked stereoscopic effect that closely approaches the actual visual appearance. For example, examine Figures 2 and 3 with a handglass that magnifies 1½ to 2 times.

Table VI

Physical Properties of Cast Armor Sections

Plate No.	Heat No.	Properties Parallel to Plate Surfaces: Yield Point* p.s.i.	Tensile Strength p.s.i.	% Elong.	% R.A.	Charpy Ft.Lbs.	Properties through the Thickness: Yield Point* p.s.i.	Tensile Strength p.s.i.	% Elong.	% R.A.
5423	3245	84,500	105,250	19.0	52.2	12.3	75,750	103,000	17.8	49.1
1-13-3372	3372	63,750	101,000	17.8	42.9	9.5	67,750	101,000	15.0	28.8
1	8196	70,750	92,750	21.5	51.3	--	69,250	96,950	25.0	53.7
1	8014	65,750	88,500	22.5	55.9	--	65,250	92,750	21.5	56.5
CRS-13	3372	--	--	--	--	--	63,750	95,500	21.8	52.8
CRS-17-2	3445	--	--	--	--	--	61,250	65,000	2.8	6.9
							(Test bars broke at porosity.)			
CRS-12-1	2212	--	--	--	--	--	60,750	89,900	22.8	58.0
GSC-26	6848	81,000	107,000	20.8	47.2	82.8	79,750	107,750	19.5	49.4
1	6405	79,500	107,750	19.8	47.7	54.1	77,750	105,750	18.5	47.4
21	6524	66,750	93,500	17.5	33.9	--	63,750	92,750	17.7	39.7

Insufficient differences are found in the tensile properties to account for differences in ballistic performance. For example, Heat 3245 Plate 5423, which cracked full length as a result of one impact of a 6" Navy A.P. MK27 projectile and Heat 6848 Plate GSC-26, which successfully resisted two impacts of the same caliber projectile, have almost identical tensile properties.

The physical property which does, however, correlate excellently with ballistic performance is the standard V-notch Charpy impact test. Plates No. 5423 and 1-13-3372 both of which cracked badly during the ballistic test, have V-notch Charpy impact values of 12.3 and 9.5 ft.lbs. respectively. Plate GSC-26, having good ballistic properties, has a Charpy value of 82.8 ft.lbs.

A most important feature of the V-notch Charpy impact test is that the appearance of the fracture can be correlated with the metallurgical and ballistic characteristics of the armor. All the V-notch Charpy impact bars from Plates 5423 and 1-13-3372 have completely crystalline fractures, all from GSC-26 have completely fibrous fractures, and those from Heat 6405 Plate 1 have mixed fractures. The Charpy impact value of Heat 6405 Plate 1, namely 54.1 ft.lbs., is intermediate between the values obtained when the fracture is crystalline and when it is fibrous.

* Yield strength at 0.1% set.

Photographs of the fractured surfaces of typical V-notch Charpy bars, Figure 3, illustrate the relative impact ductility of the various steels. Specimens from Plate GSC-26 show considerable necking in along the sides of the fracture while those from steels breaking with crystalline fractures show no deformation whatsoever.

The Aberdeen Proving Ground firing records available at this Arsenal covering the ballistic testing of 4-6" thick cast armor were examined to obtain additional information regarding the correlation of impact strength and ballistic performance. The manufacturers reported both tensile and Izod values in the majority of cases. Whether the tests were conducted upon pieces machined from the plates or upon separately heat treated test coupons poured from the same heat as the armor sections is unknown, but nevertheless, a good correlation was found to exist between the Izod values and the ballistic properties of the armor.

Table VII presents the relationship between the Izod impact value and the ballistic performance of 19 cast armor sections.

Table VII

Correlation of Izod Impact Test and Ballistic Properties

Range of Izod Value - Ft.Lbs.	Total Number of Plates	No. Passed Ballistic Test	No. Failed Ballistic Test
60 - 86	6	6	0
40 - 60	6	4	2
Below 40	7	2	5
	Total No. of Plates 19		

From the above data, it would appear that satisfactory 4-6" thick cast armor having a hardness in the range of 180-220 Brinell should have an Izod impact value of at least 40 foot pounds. It will be shown subsequently that a high impact strength can be obtained from cast armor compositions by proper heat treatment of steels having sufficient hardenability to quench through the section.

Attempts have been made at this Arsenal to correlate Izod impact values reported by the manufacturers with ballistic performance of armor up to 2" in thickness, Although it appears reasonable to expect the existence of some correlation between these two factors, none was found. The fact that a direct correlation between Izod impact values and ballistic performance was found in cast armor 4-6" in thickness indicates the existence of factors affecting the impact test as conducted by the manufacturers on armor up to 2" in thickness.

It is known that the physical test specimens used to obtain the physical properties of cast armor up to 2" thick are machined from 1-1/4" to 2" square bars approximately 6" long that are cast as prolongations on the test plates or which are separately cast. It is obvious that, when quenched similarly, a 2" square section will cool considerably faster than a 36x36x2" plate, and that, therefore, the physical test coupon may completely quench harden while at the same time the plate fails to properly quench harden. Under these conditions, the manufacturer will report a high Izod impact value, obtained from a well heat-treated test coupon, and the plate may fail the shock test because of the presence of undesirable high temperature transformation products. An Izod impact test conducted on the plate itself will show a considerably lower value than that reported by the manufacturer on the C.A.S. form. It is, therefore, apparent that the reported Izod values will invariably, unless casting defects occur, represent optimum properties available upon proper heat treatment and not the actual properties of the ballistic test plate.

In the case of 4-6" thick armor, it is known that at least one manufacturer, namely the Continental Roll and Steel Foundry Co., obtains the Izod test bars directly from the test plates by removing cylindrical sections with a hollow-core drill. On the other hand, if a 6x6" test coupon were cast as prolongations on the test plates and heat treated similarly, the cooling rates in the center of a 6" cube will not usually be sufficiently greater than those in a 72"x60"x6" test plate to result in fully quenching the test coupon at the same time the test plate is being slack quenched. In other words, the effect of greater mass is to make the properties of the test coupon and the ballistic test plate more nearly alike than is the case of lighter gauge plate.

7. Re-heat Treatments

In order to demonstrate that both the appearance of the fractures and the low V-notch Charpy impact values of the steels breaking with crystalline fractures are due, not to poor steel quality, but to either insufficient hardenability to completely harden through upon quenching or to slack quenching, 1" thick sections of Heat 3245 Plate 5423, Heat 3372 Plate 1-13-3372, and Heat 6405 Plate 1 were reheat-treated. Reference to Table V shows that these three steels possess sufficient hardenability to completely quench out in more than 1" thick sections.

The heat-treatments and Brinell hardnesses developed upon quenching and tempering are as follows:

Plate No.	Heat No.	Brinell Hardness after 1600°F Water Quench	Brinell Hardness after 1275°F Draw	Original Brinell Hardness of Plate
5423	3245	444	229	212-229
1-13-3372	3372	444	217	207-223
1	6405	444	223	217-235

The development of a hardness of 444 BHN upon quenching indicates the formation of a martensitic structure. The hardnesses after tempering fall within the range of the original hardnesses of the plates.

Table VIII contains V-notch Charpy impact data comparing the properties of the as-received material with the reheat-treated 1" thick plates. The values represent the average of three tests on each plate.

TABLE VIII

V-Notch Charpy Impact Properties of Cast Armor

Plate No.	Heat No.	Type Analysis	As-Received Charpy Ft.Lbs.	Fracture	After Reheat-Treatment Charpy Ft.Lbs.	Fracture
GSC-26	6848	Cr-Mo	82.8	Fibrous	--	--
5423	3245	Ni-Mo	12.3	Crystalline	82.7	Fibrous
1-13-3372	3372	Ni-Mo	9.5	Crystalline	69.4	Fibrous
1	6405	Mn-Mo	54.1	Mixed	69.1	Fibrous

It is interesting to note that the Charpy impact values of the Ni-Mo and Mn-Mo steels after reheat-treatment in section thicknesses capable of being through quenched are of the same order of magnitude as that of Plate GSC-26, which is capable of quenching through in a 6" section size. This evidence emphasizes the extreme importance of having armor compositions of sufficiently high hardenability to completely quench harden through whatever maximum thickness is involved in the armor casting.

8. Macrostructure and Microstructure

Typical photographs of the macrostructure and microstructure of the 10 cast armor sections are shown in Figures 4 through 13. Data sheets opposite the photomicrographs summarize the metallurgical and ballistic characteristics of each plate.

The microstructures of the plates are exactly as predicted from the hardenability data. The only steel that contains no ferrite whatsoever in the microstructure is General Steel Casting Corporation Heat No. 6848, Plate GSC-26, which is the only one possessing adequate hardenability to quench through a 6" section, see Figure 11. General Steel Castings Corporation Heat No. 6405, Plate No. 1 which has the next highest hardenability, but still inadequate for the section size, has a microstructure

that is completely sorbitic for the outer two thirds of the cross-section but contains free ferrite in the middle third of the cross-section where the cooling rates were lowest while quenching, see Figure 12. The remaining eight plates contain considerable amounts of ferrite rejected during quenching throughout the cross-section. The middle third of the sections usually contain more ferrite than the two outer thirds because of slower cooling rates during quenching, permitting the formation of more high temperature transformation products.

Associated with the formation of ferrite is the precipitation of grain boundary carbides. It is believed that both the presence of free ferrite and grain boundary carbides are responsible for the poor properties of slack quenched material. Both ferrite and grain boundary carbides provide ready paths for the propagation of failure; the ferrite because it is a microconstituent of low strength, and the grain boundary carbides because of the low cohesive strength between the carbides and the adjacent material.

All the cast armor sections are sound with the exception of Continental Roll and Steel Foundry Company's Heat No. 3445, Plate CRS-17-2 which contains a large amount of porosity in the middle third of the section, probably resulting from a gassy heat since the porosity consists of more or less oval cavities rather than the dendritic formation associated with shrinkage porosity.

SUMMARY

The results of this investigation indicate that adequate hardenability is indispensible to the production of satisfactory armor. It is necessary to suppress the formation of high temperature transformation products during the quenching cycle, and since water quenching is customarily employed, the alloy content must be sufficient to provide sufficient hardenability to harden through on water quenching.

The degree to which armor hardens upon quenching can be determined by the Jominy hardenability test, fracture tests, impact tests, and by the use of the microscope. The method which appears to be most feasible and most conveniently performed is the fracture test. Experience in the interpretation of fractures can be very easily and speedily obtained and does not require any particular skill, technical training or expensive equipment. All that is required is the cutting of a suitably sized piece from the test plate or coupon, nicking it by means of flame cutting or sawing, and breaking it under a press or a forge hammer; all of which equipment is readily available at the manufacturers' plants.

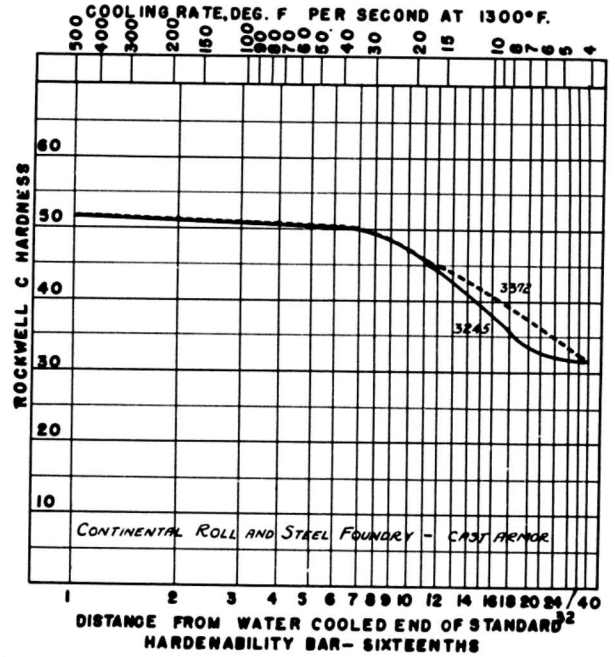


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	QUENCH TEMP	QUENCH TIME HOURS	G.S.
3245	5423	.34	.87	.28	.035	.042	1.00	.07	.45	1600	2	
3372	1-13-3372	.32	.90	.35	.027	.044	.98	.11	.45	1600	2	

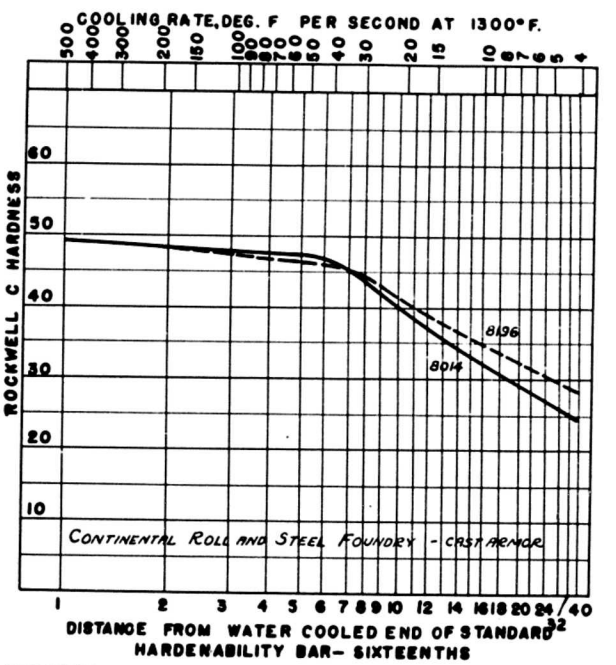


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	QUENCH TEMP	QUENCH TIME HOURS	G.S.
1	8196	.26	.85	.32	.034	.043	1.07	.20	.52	1600	2	
1	8014	.28	.81	.28	.038	.033	1.00		.50	1600	2	

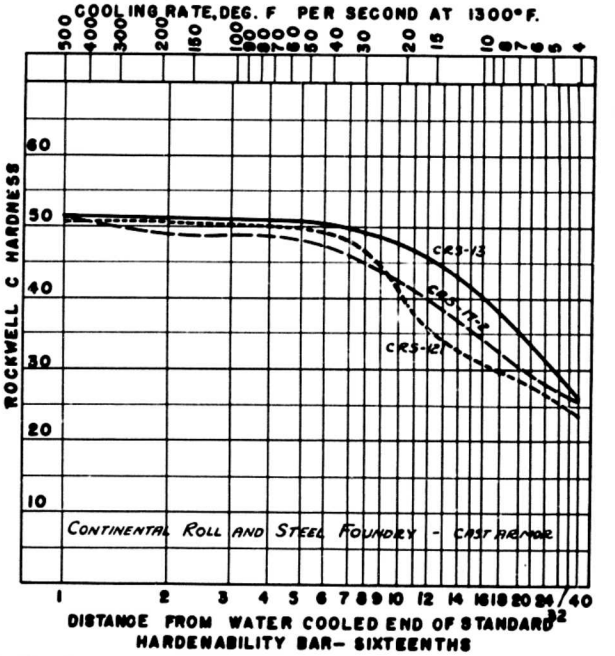


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	QUENCH TEMP	QUENCH TIME HOURS	G.S.
CRS-13	3372	.29	.87	.35	.021	.043	.94	.13	.42	1600	2	
CRS-17-2	3445	.28	.83	.29	.028	.036	.99	.08	.44	1600	2	
CRS-121	2212	.30	.85	.30	.032	.037	.93	.055	.47	1600	2	

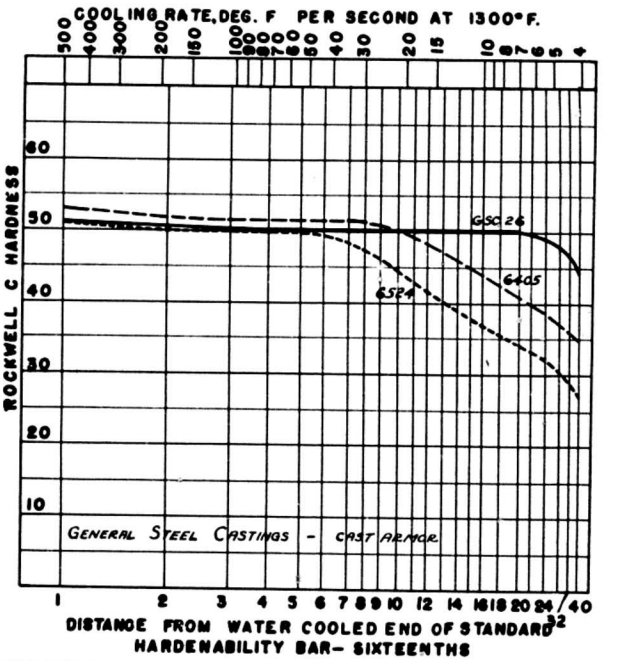


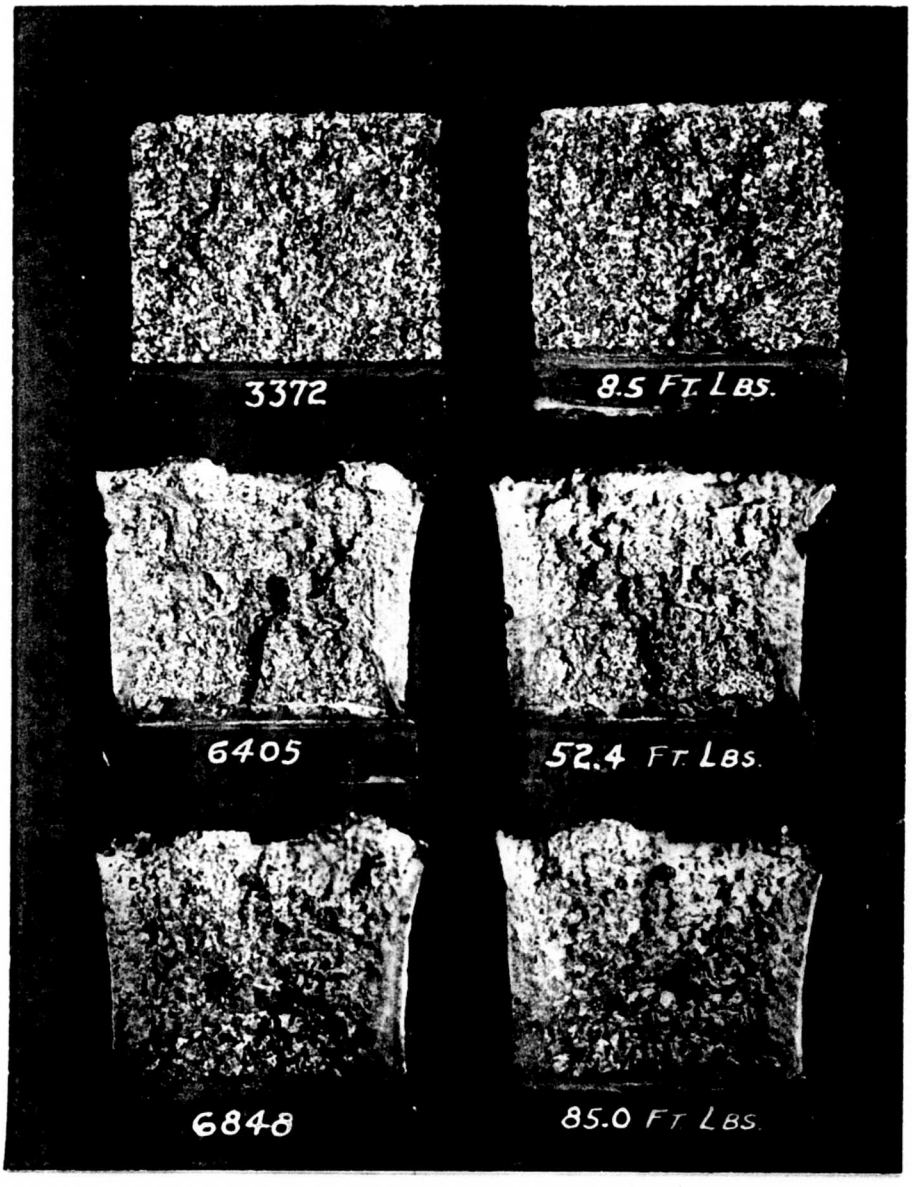
PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	QUENCH TEMP	QUENCH TIME HOURS	G.S.
GSC26	6848	.30	.68	.38	.031	.007	–	2.39	.46	1675	2	
1	6405	.33	1.61	.48	.019	.013	.17	.10	.31	1600	2	
21	6524	.29	1.65	.38	.013	.012	.07	.085	.32	1600	2	

FIGURE 1

ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

FRACTURED SECTIONS FROM CENTERS OF CROSS-SECTIONS OF 4" AND 6" CAST ARMOR SHOWING FIBROUS, MIXED, AND CRYSTALLINE FRACTURES
APRIL 15 1943 WTN.710-2069

FIGURE 2



Mag. 4X

Fractures of V-notch Charpy Bars Illustrating Comparative Impact Strengths of Material Breaking with Fibrous, Crystalline, and Mixed Fractures.

Plate	Heat	Fracture	Charpy, Ft.Lbs.
1-13-3372	3372	Crystalline	8.5
1	6405	Mixed	52.4
GSC-26	6848	Fibrous	85.0

WTN.639-5138

Figure

DATA SHEET NO. 1

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 3245 Plate No. - 5423 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.32	.86	.35	.029	.041	.99	--	.53
Watertown Arsenal	.34	.87	.28	.035	.042	1.00	.07	.45

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1850	32	28	Air
1250	6	10	Furnace
1575	30	24	Water & Oil
1125	8	20	Air to 600°
1175	6	24	Furnace

Physical Properties (Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	105,250	103,000
Y.P.	84,500	75,750
% Elong.	19.0	17.8
% R.A.	52.2	49.1
Charpy	12.3 ft.lbs.	

Ballistic Properties (A.P.G. Firing Record #P-13201)

1 Round 6" Navy A.P. MK27. 15° obliquity. S.V. - 1435 ft./sec. Partial penetration. Plate cracked full length from top to bottom. Crack extended through the thickness of the plate.

Brinell Hardness of Cross-Section

1" from surface - 223 Center - 212

Jominy Hardenability

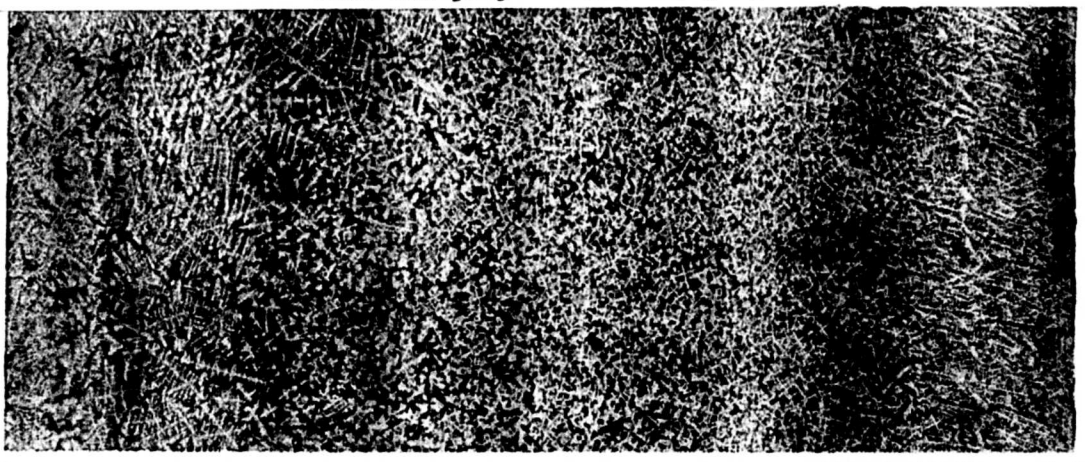
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
10	15	15	Plate Thickness) 2.2" Quenchable to) in 400 BHN in Center) still water

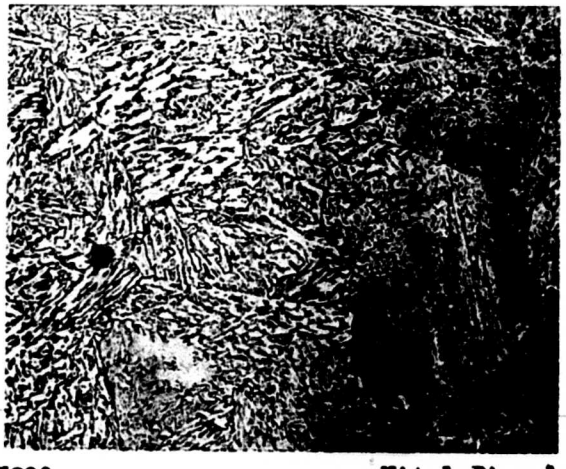
Microstructure and Remarks

A large amount of ferrite was rejected upon the quench throughout the cross-section, with less ferrite in the two outer thirds and more in the middle third of the section. The hardenability of the steel is insufficient to harden completely through a 6" section on water quenching. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties. The very low Charpy impact values confirm the poor shock properties of the material.

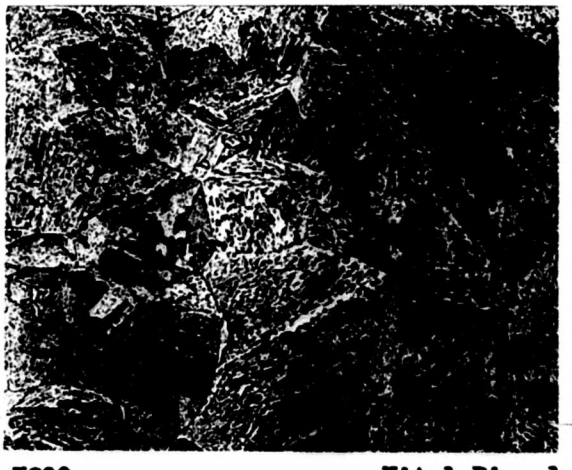
Continental Roll and Steel Foundry - 6" Cast Armor
Heat No. 3245 - Plate No. 5423



X1 Hot Acid Macroetch
Sound steel. Satisfactory macrostructure.



X200 Nital Picral
Middle of cross-section. Dendritic segregation and considerable ferrite.



X200 Nital Picral
Outer third of cross-section. Less ferrite than in midsection.

X1000 Nital Picral
Middle of cross-section. Large amount of free ferrite.

X1000 Nital Picral
Outer third of cross-section. Sorbite, ferrite, and grain boundary carbides.

WTN.639-5139

Figure 4

DATA SHEET NO. 2

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. 3372 Plate No. 1-13-3372 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.28	.89	.33	.031	.041	.96	--	.53
Watertown Arsenal	.32	.90	.35	.027	.044	.98	.11	.45

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1850	32	28	Air
1250	6	10	Furnace
1575	30	24	Water & Oil
1125	8	20	Air to 600°
1175	6	24	Furnace

Physical Properties(Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	101,000	101,000
Y.P.	63,750	67,750
% Elong.	17.8	15.0
% R.A.	42.9	28.8
Charpy	9.5 ft.lbs.	

Ballistic Properties(A.P.G. Firing Record #P-13298)

1 Round 6" Navy A.P. Mk27. 15° obliquity. S.V. - 1435 ft./sec. Partial penetration. Plate cracked full length, crack extending through the thickness.

Brinell Hardness of Cross-Section

1" from surface - 212 Center - 207

Jominy Hardenability

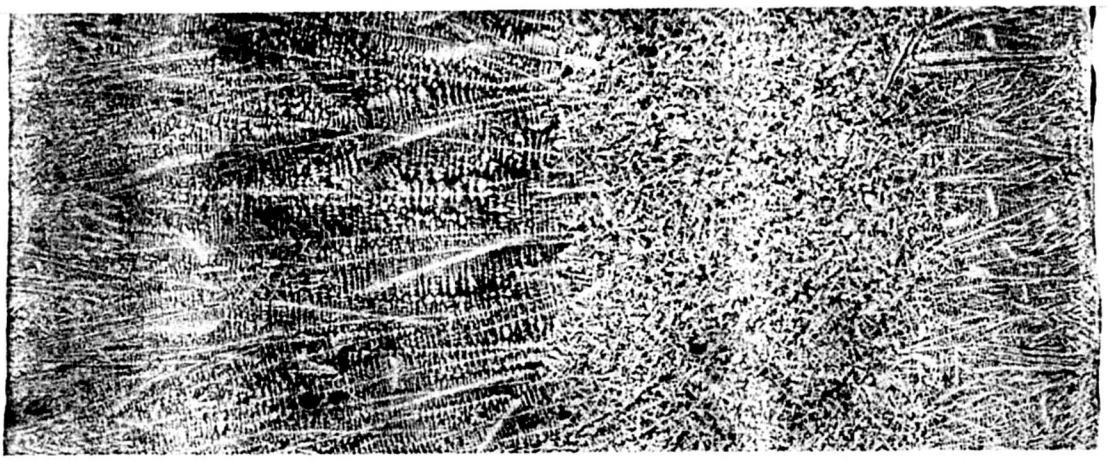
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
10	15	15	Plate Thickness) 2.2" Quenchable to) in 400 BHN in center) still water

Microstructure and Remarks

A large amount of ferrite was rejected on the quench in the middle third of the section with less ferrite in the two outer thirds. The steel has insufficient hardenability to completely harden through in a 6" section size. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties. The very low Charpy impact values corroborate the latter statement.

Continental Roll and Steel Foundry - 6" Cast Armor
Heat No. 3372 - Plate No. 1-13-3372



X1 Hot Acid Macroetch
Sharp dendritic macrostructure. Sound steel.

X200 Nital Picral
Middle of cross-section. Dendritic segregation and large amount of free ferrite.

X200 Nital Picral
Outer third of cross-section. Small amount of free ferrite.

X1000 Nital Picral
Middle of cross-section. Sorbite with large amount of ferrite.

X1000 Nital Picral
Outer third of cross-section. Sorbite and grain boundary carbides. Very little free ferrite.

WTN.639-5140

Figure 5

DATA SHEET NO. 3

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 8196 Plate No. - 8196-1 Thickness - 4"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.27	.81	.35	.039	.043	1.01	--	.57
Watertown Arsenal	.26	.85	.32	.034	.043	1.07	.20	.52

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1700	26	28	Air
1250	6	10	Furnace
1275	30	24	Water
1100	8	20	Air to 600°
1225	6	24	Furnace

Physical Properties (Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	92,750	96,950
Y.P.	70,750	69,250
% Elong.	21.5	25.0
% R.A.	51.3	53.7

Ballistic Properties (A.P.G. Firing Record 5460)

4 Rounds 3" A.P.C. M62 at 20° obliquity.

3 Partial penetrations at 1713, 1833, 2027 ft./sec.

1 Complete penetration at 2615 ft./sec. Plate acceptable.

Brinell Hardness of Cross-Section

1" from surface - 207 Center - 201

Jominy Hardenability

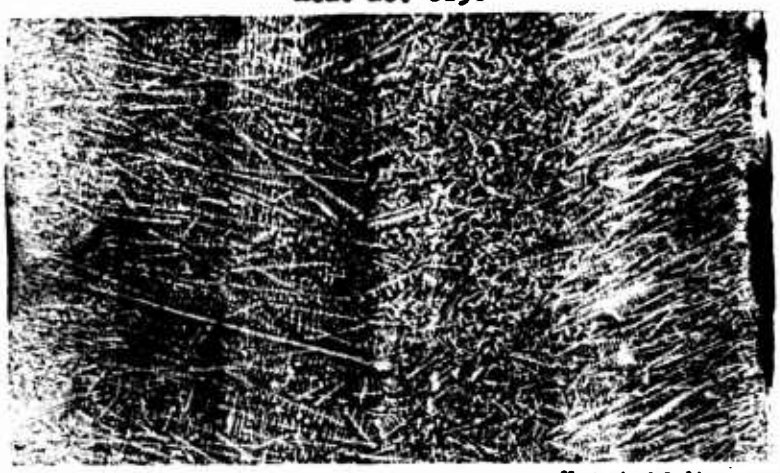
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
8	12	10	Plate Thickness Quenchable to 400 BHN in Center) 1.7" in still water

Microstructure and Remarks

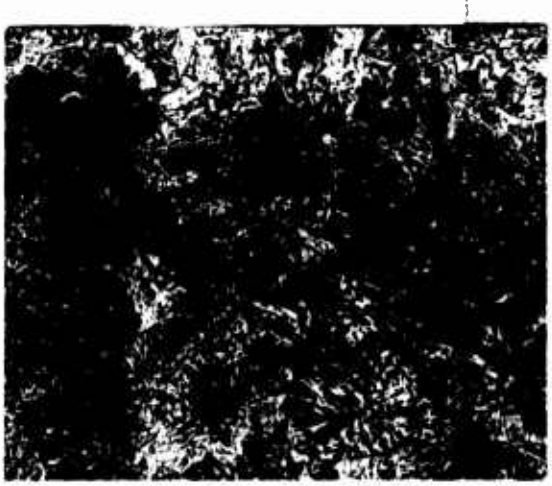
The microstructure contains a considerable amount of ferrite rejected upon the quench as well as grain boundary carbides. The steel has insufficient hardenability for a 4" section to harden through upon quenching. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

Continental Roll and Steel Foundry - 4" Cast Armor
Heat No. 8196



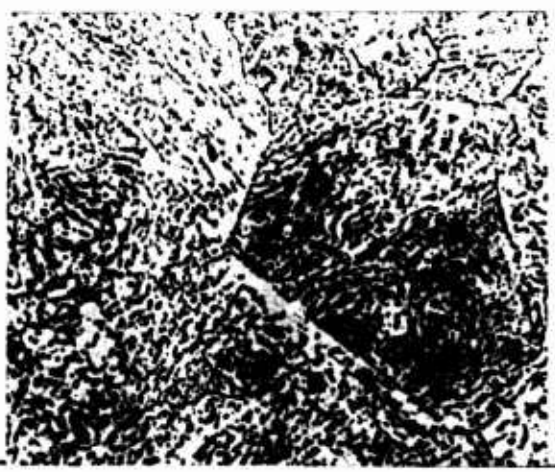
X1 Hot Acid Macroetch
Sharp dendritic structure with heavy interdendritic attack upon etching.

X200 Nital Picral
Middle of cross-section. Dendritic segregation and large amount of ferrite.



X200 Nital Picral
Outer third of cross-section. Less ferrite than in midsection.

X1000 Nital Picral
Middle of cross-section.
Spheroidized carbides and ferrite.



X1000 Nital Picral
Outer third of cross-section.
Sorbite, ferrite, and grain boundary carbides. Less ferrite than in mid-section.

WTN.636-5141

Figure 6

DATA SHEET NO. 4

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 8014 Plate No. - 8014-1 Thickness - 4½"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Mo
Company	.26	.81	.31	.044	.039	1.00	.56
Watertown Arsenal	.28	.81	.28	.031	.033	1.00	.50

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1700	26	28	Air
1250	6	10	Furnace
1575	30	24	Water & Oil
1100	8	20	Air to 600°
1225	6	24	Furnace

Physical Properties (Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	88,500	92,750
Y.P.	65,750	65,250
% Elong.	22.5	21.5
% R.A.	55.9	56.5

Ballistic Properties (A.P.G. 470.5/423°) (W.A. 470.5/5465)

a. 3" A.P.C. M62 20° obliquity — S.V. 2597ft./sec. CP. PTP. BS 6x7-1/4".

b. 75 MM A.P. M72 20° obliquity — Army B.L. - 1876 ft./sec. Navy B.L. - 2032 ft./sec.

c. 75 MM A.P. M72 Normal — Army B.L. - 1602 ft./sec. Navy B.L. - 1852 ft./sec.

Plate cracked through between rounds and back spalled on practically every complete penetration.

Brinell Hardness of Cross-Section

1" from surface - 187 Center - 179

Jominy Hardenability

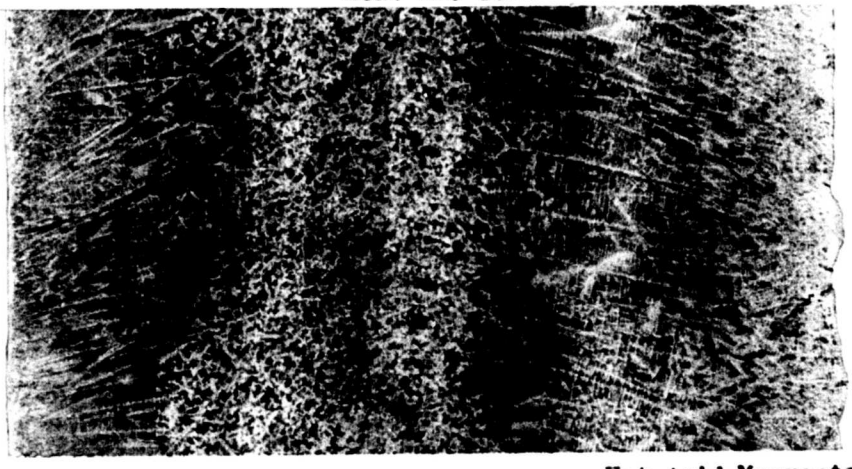
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
8	11	9	Plate Thickness) 1.5" Quenchable to) in 400 BHN in Center) still water

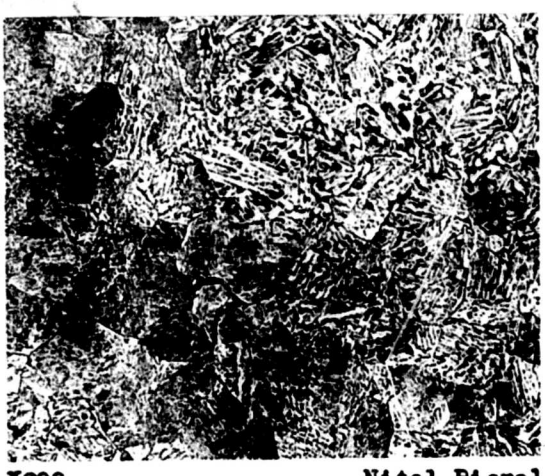
Microstructure and Remarks

The microstructure contains a considerable amount of ferrite rejected upon the quench as well as grain boundary carbides. The steel has insufficient hardenability to harden through upon quenching. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

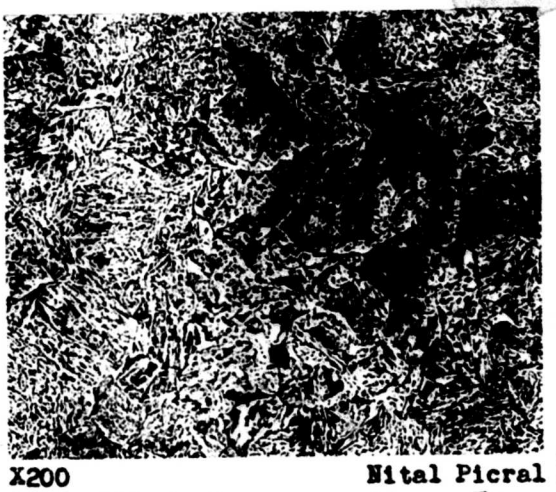
Continental Roll and Steel Foundry - 1½" Cast Armor
Heat No. 8014



X1 Hot Acid Macroetch
Diffused macrostructure, large dendrites.

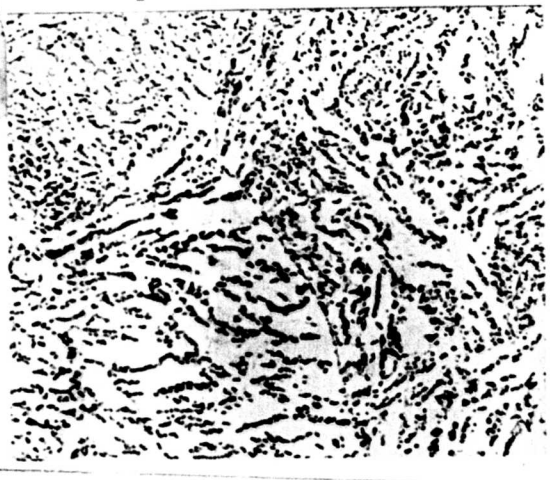


X200 Nital Picral
Middle of cross-section. Dendritic segregation and free ferrite.



X200 Nital Picral
Outer third of cross-section. Free ferrite present.

X1000 Nital Picral
Middle of cross-section. Sorbite ferrite, and grain boundary carbides.



X1000 Nital Picral
Outer third of cross-section. Sorbite and ferrite.

WTN.639-5142

Figure 7

DATA SHEET NO. 5

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 3372 Plate No. - CRS-13 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.28	.89	.33	.031	.041	.96	---	.53
Watertown Arsenal	.29	.87	.35	.021	.043	.94	.13	.42

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1575	28	24	Furnace
1575	32	24	Sol.Oil
1125	8	20	Air
1210	6	24	Furnace

Physical Properties (Average)

Through the Thickness

T.S.	95,500
Y.P.	63,750
% Elong.	21.8
% R.A.	52.8

Ballistic Properties (A.P.G.Firing Record#P-15537)

6" Navy A.P.MK27

Round	Velocity	Depth of Penetration	Effect on Plate
1	1432	5-7/8"	22" crack.
2	1425	---	Plate broke into three pieces.

Brinell Hardness of Cross-Section

1" from surface - 197 Center - 192

Jominy Hardenability

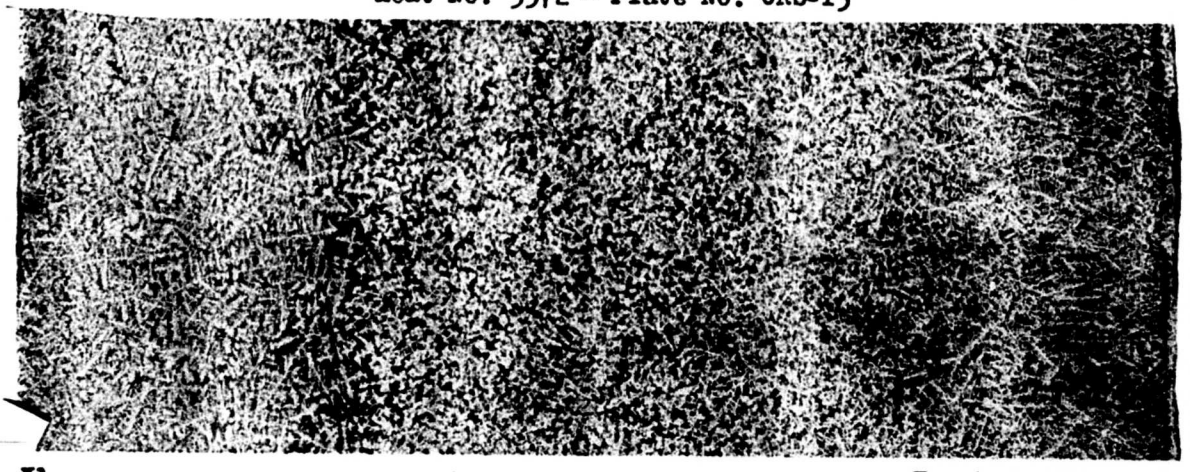
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
12	16	15	Plate Thickness Quenchable to 400 BHN in Center) 2.2" in still water

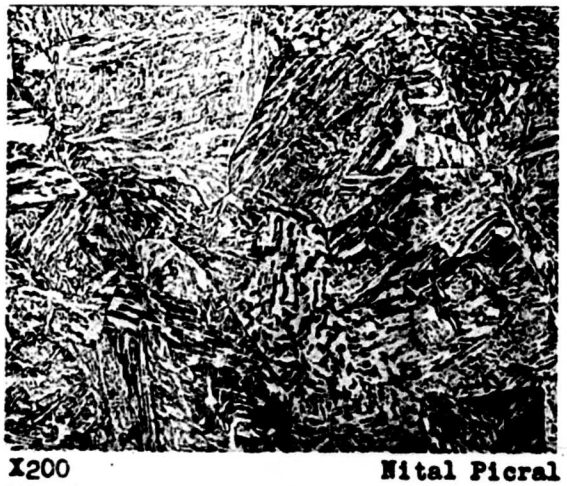
Microstructure and Remarks

The microstructure contains a large amount of ferrite in the middle third of the cross-section and less ferrite in the two outer thirds. The steel has insufficient hardenability to harden completely through a 6" section. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

Continental Roll and Steel Foundry - 6" Cast Armor
Heat No. 3372 - Plate No. CRS-13

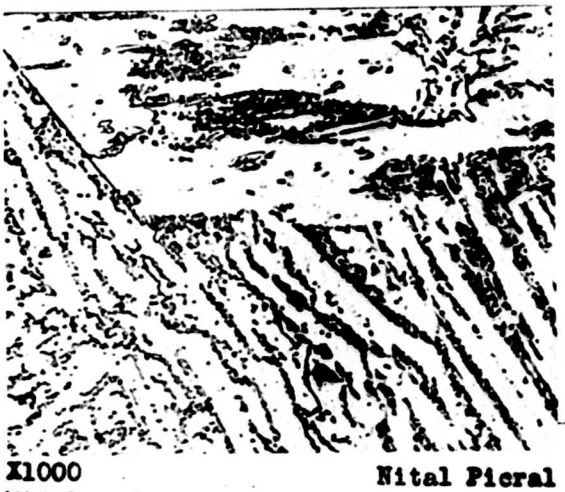


X1 Hot Acid Macroetch
Diffuse macrostructure. Slight shrinkage porosity.



X200 Nital Picral
Middle of cross-section. Coarse structure with considerable ferrite.

X200 Nital Picral
Outer third of cross-section. Coarse structure with less ferrite.



X1000 Nital Picral
Middle of cross-section. Sorbite with large amount of ferrite.

X1000 Nital Picral
Outer third of cross-section. Carbides and ferrite. Less ferrite than in midsection.

WTN.639-5143

Figure 5

DATA SHEET NO.6

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 3445 Plate No. - CRS-17-2 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.27	.81	.30	.028	.039	.94	--	.54
Watertown Arsenal	.28	.83	.29	.028	.036	.99	.08	.44

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1575	32	24	Furnace
1575	32	24	Sol. Oil
1100	8	20	Air
1200	6	24	Furnace

Physical Properties (Average)

Through the Thickness

T.S.	65,000
Y.P.	61,250
% Elong.	2.8
% R.A.	6.9

(Tensile bars broke at porous areas)

Ballistic Properties (A.P.G. Firing Record#P-16747)

1 Impact of 6" Navy A.P. MK27. S.V. - 1418 ft./sec. Broke plate into three pieces. Complete penetration with projectile passing through the plate.

Brinell Hardness of Cross-Section

1" from surface - 197 Center - 197

Jominy Hardenability

Distance from Quenched End - 1/16ths of inch

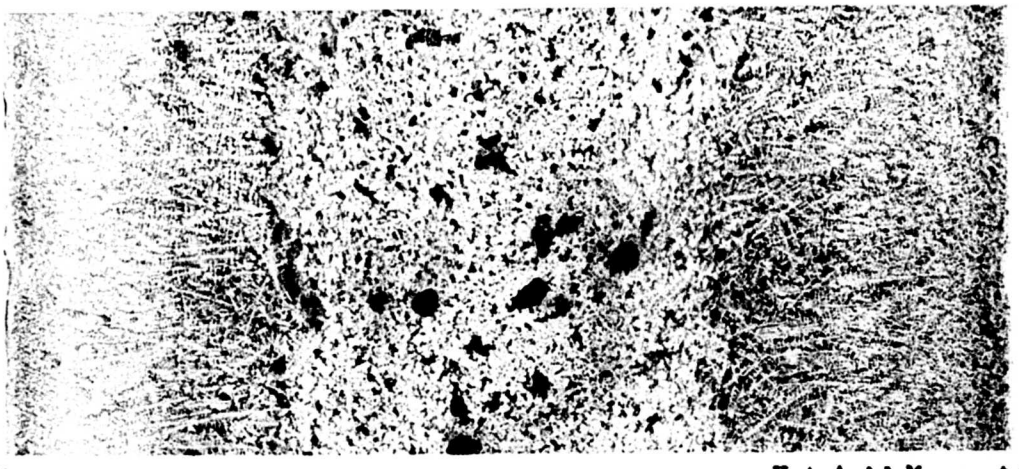
Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
7	11	10	Plate Thickness) 1.7" Quenchable to) in 400 BHN in Center) still water

Microstructure and Remarks

The middle third of the section is extremely porous, probably resulting from an incomplete deoxidation of the heat. A large amount of ferrite was rejected upon the quench because of insufficient hardenability for a 6" section size. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

Continental Roll and Steel Foundry - 6" Cast Armor

Heat No. 3445 - Plate No. CRS-17-2



X1 Hot Acid Macroetch

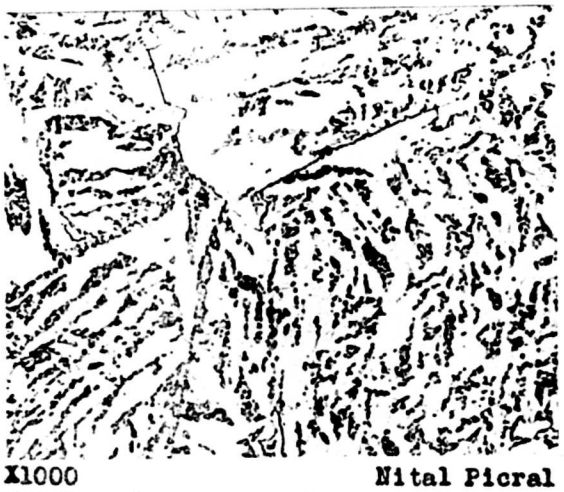
Considerable amount of porosity in middle third of cross-section.

X200 Nital Picral

Middle of cross-section. Coarse structure with large amount of ferrite.

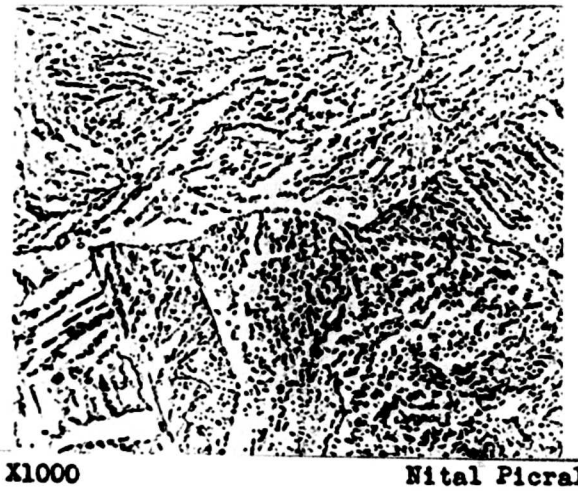
X200 Nital Picral

Outer third of cross-section. Coarse structure with less ferrite than in midsection.



X1000 Nital Picral

Middle of cross-section. Sorbite and large amount of free ferrite.



X1000 Nital Picral

Outer third of cross-section. Sorbite, ferrite, and grain boundary carbides. Less ferrite than in midsection.

WTN.639-5144

Figure 9

DATA SHEET NO. 7

CONTINENTAL ROLL AND STEEL FOUNDRY CO.

Heat No. - 2212 Plate No. - CRS-12-1 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.31	.79	.29	.034	.035	.98	--	.52
Watertown Arsenal	.30	.85	.30	.032	.037	.93	.055	.47

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
1575	28	24	Furnace
1575	32	24	Sol. Oil
1125	8	20	Air
1210	6	24	Furnace

Physical Properties (Average)

Through the Thickness

T.S.	89,900
Y.P.	60,750
% Elong.	22.8
% R.A.	58.0

Ballistic Properties

6" Navy A.P. MK27. 15° obliquity. 1 Round. S.V. - 1418 ft./sec. Complete penetration. 14" diameter backspall. 25", 35" long cracks to edge of plate - cracks extending through the thickness.

Brinell Hardness of Cross-Section

1" from surface - 192 Center - 183

Jominy Hardenability

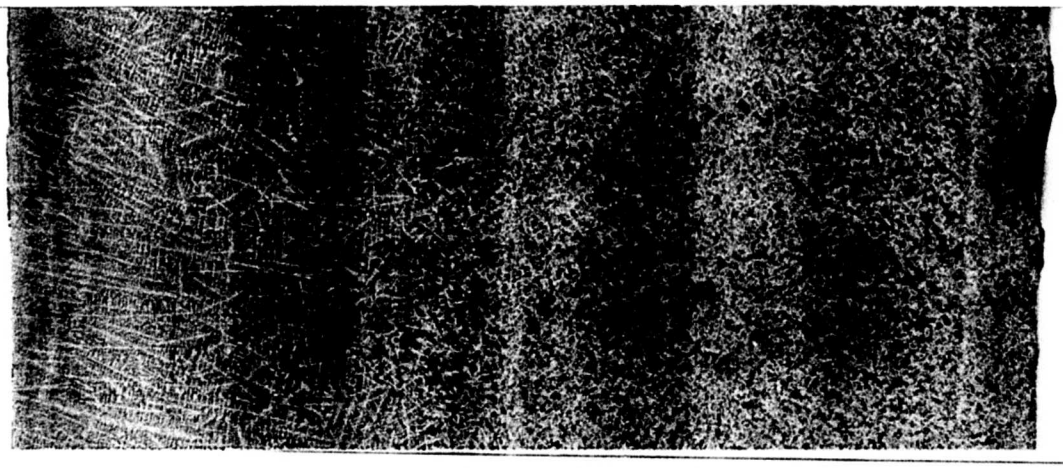
Distance from Quenched End - 1/16ths of inch

Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	
8	10	10	Plate Thickness) 1.7" Quenchable to) in 400 BHN in Center) still water

Microstructure and Remarks

The microstructure contains a large amount of rejected ferrite in the middle third of the cross-section with less ferrite in the two outer thirds. The steel has insufficient hardenability to harden completely through a 6" thick section. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

Continental Roll and Steel Foundry - 6" Cast Armor
Heat No. 2212 - Plate No. CRS-12-1

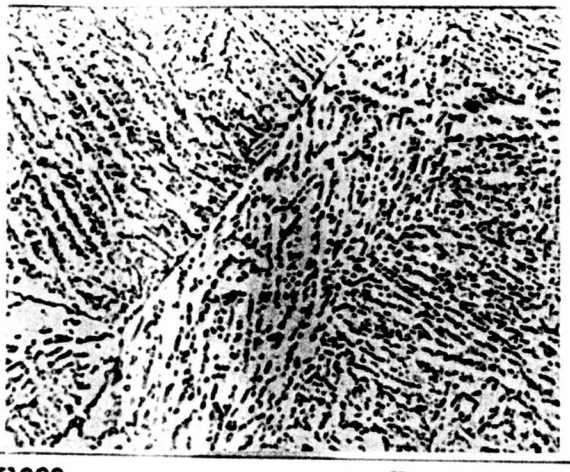


X1 Hot Acid Macroetch
Relatively diffuse macrostructure. Very slight porosity.

X200 Nital Picral
Middle of cross-section. Large amount of free ferrite.

X200 Nital Picral
Outer third of cross-section. Small amount of free ferrite.

X1000 Nital Picral
Middle of cross-section. Carbides, ferrite, and grain boundary carbides.



X1000 Nital Picral
Outer third of cross-section. Sorbite, grain boundary carbides, and small amount of free ferrite.

WTN.639-5145

Figure 10

DATA SHEET NO. 8

GENERAL STEEL CASTINGS CORP.

Heat No. - 6848 Plate No. - GSC-26 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.28	.70	.34	.015	.012	--	2.38	.53
Watertown Arsenal	.30	.68	.38	.031	.007	--	2.39	.46

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
2000		20	Air
1250		8	Air
1675		8	Water
1225		24	Air

Physical Properties (Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	107,000	107,750
Y.P.	81,000	79,750
% Elong.	20.8	19.5
% R.A.	47.2	49.4
Charpy	82.8 ft.lbs.	

Ballistic Properties (A.P.G. Firing Record #P-15472)

2 Rounds 6" Navy A.P. MK27.

Round	Velocity	Depth of Penetration	Effect on Plate
1	1434	Partial to 5½".	1-1/4" bulge on back.
2	1481	Partial to 5-3/4".	1-1/4" bulge on back, 4½" crack on bulge.

Brinell Hardness of Cross-Section

1" from surface - 223 Center - 223

Jominy Hardenability

Distance from Quenched End - 1/16ths of inch

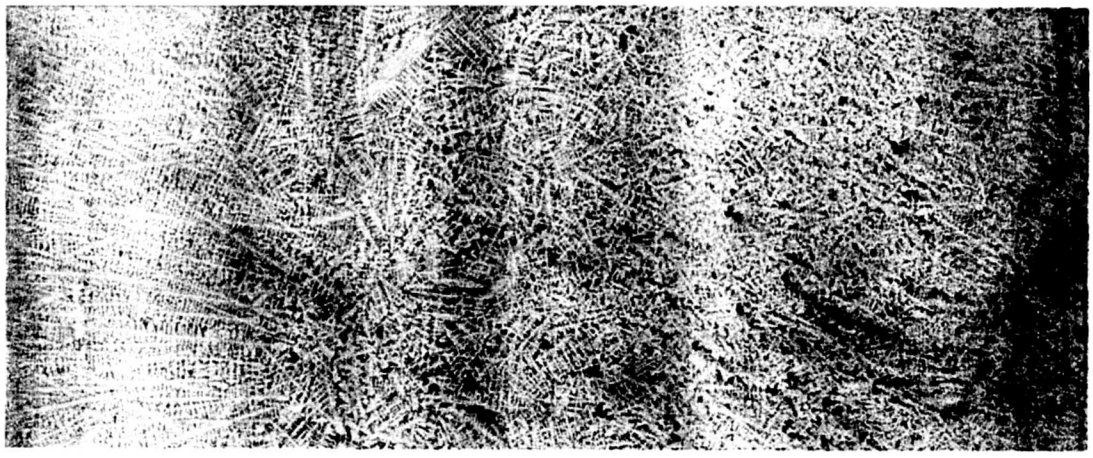
Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)	Plate Thickness Quenchable to 400 BHN in Center
31	Max. drop is 7 Rc	44 Rc at 40/16"	Greater than 6 " in still water.

Microstructure and Remarks

The microstructure throughout the 6" cross-section consists of finely spheroidized sorbite with no ferrite rejected upon the quench. The hardenability is sufficient to completely harden a 6" thick section. The fracture is fibrous, indicating satisfactory microstructure and good shock resisting properties. The high Charpy impact values corroborate the latter statement.

General Steel Castings - 6" Cast Armor

Heat No. 6848 - Plate No. GSC-26

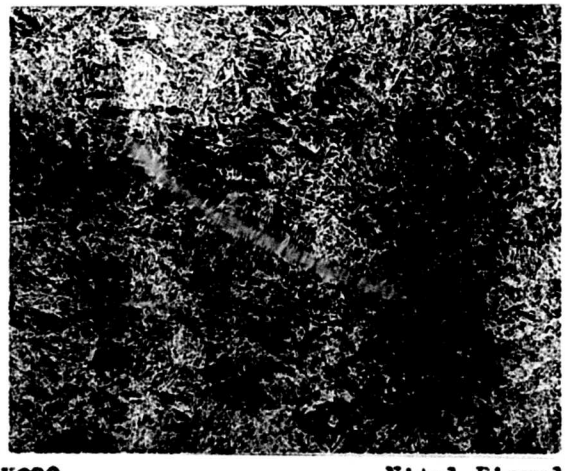


X1 Hot Acid Macroetch

Relatively diffuse macrostructure. Slight shrinkage porosity.

X200 Nital Picral

Middle of cross-section.

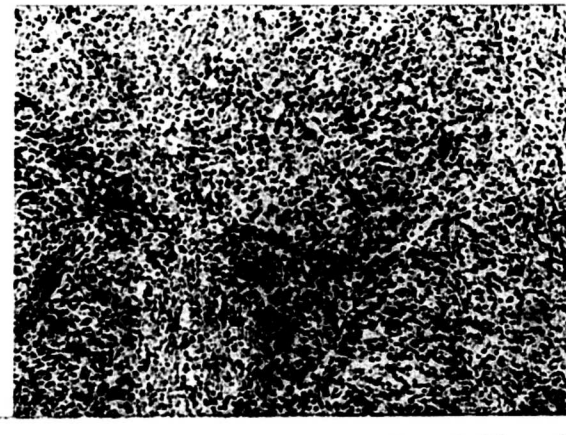


X200 Nital Picral

Outer third of cross-section. Uniform microstructure.

X1000 Nital Picral

Middle of cross-section. Uniformly spheroidized sorbite.



X1000 Nital Picral

Outer third of cross-section. Uniformly spheroidized sorbite.

WTN.639-5-46

Figure 11

DATA SHEET NO. 9

GENERAL STEEL CASTINGS CORP.

Heat No. - 6405 Plate No. - 1 Thickness - 4"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company								
Watertown Arsenal	.33	1.61	.48	.019	.013	.17	.10	.31

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant

Physical Properties (Average)

	Parallel to Plate Surfaces	Through the Thickness
T.S.	107,750	105,750
Y.P.	79,500	77,750
% Elong.	19.8	18.5
% R.A.	47.7	47.4
Charpy	54.1 ft.lbs.	

Ballistic Properties (A.P.G. Firing Record#)

Brinell Hardness of Cross-Section

1" from surface - 235 Center - 217

Jominy Hardenability

Distance from Quenched End - 1/16ths of inch

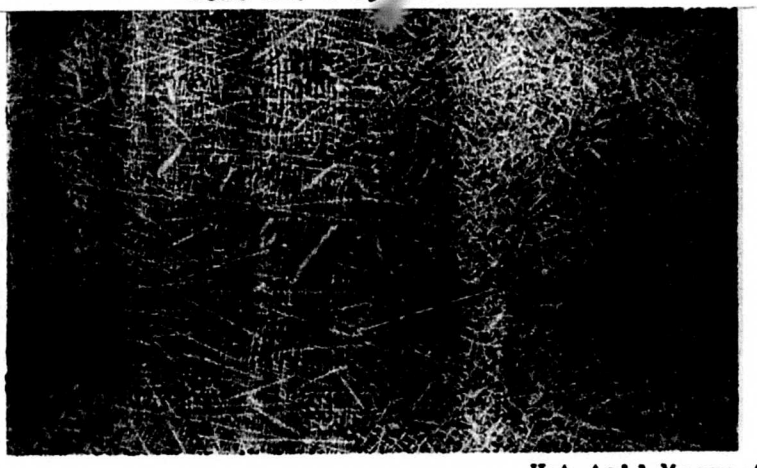
Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)
12	18	19

Plate Thickness) 2.7" Quenchable to) in 400 BHN in Center) still water

Microstructure and Remarks

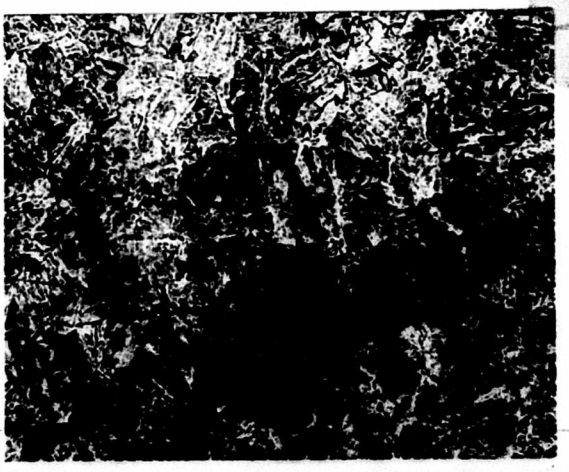
A relatively small amount of ferrite was rejected on the quench in the middle third of the cross-section. The two outer thirds of the section consisted of uniformly spheroidized sorbite with no free ferrite. The hardenability is insufficient to completely harden through a 4" section, but is such that the two outer thirds of the section cooled fast enough to transform completely without forming ferrite. The fracture of the steel is mixed, i.e., consisting of patches of crystalline areas dispersed through fibrous areas, indicating borderline hardenability, moderate shock resisting properties and somewhat unsatisfactory microstructure.

General Steel Castings - 4" Cast Armor
Heat No. 6405 - Plate No. 1

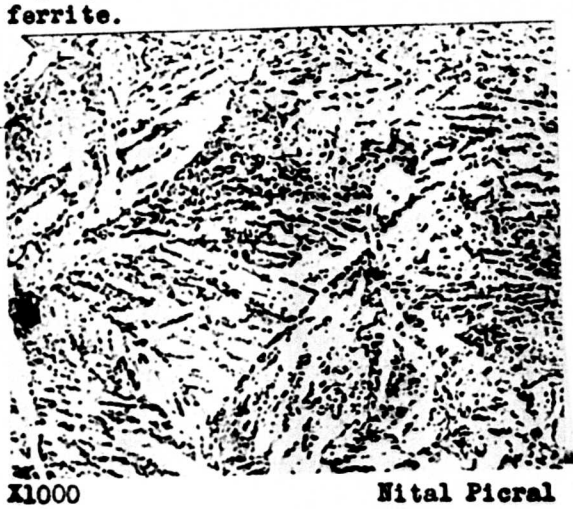


X1 Hot Acid Macroetch
Sharp dendritic macrostructure. Sound metal.

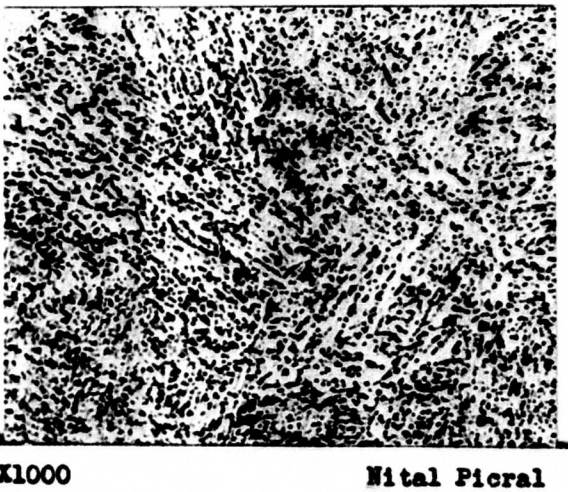
X200 Nital Picral
Middle of cross-section. Dendritic segregation. Small amount of free ferrite.



X200 Nital Picral
Outer third of cross-section. No free ferrite.



X1000 Nital Picral
Middle of cross-section. Sorbite and some free ferrite.



X1000 Nital Picral
Outer third of cross-section. Uniformly spheroidized sorbite. No free ferrite.

WTN.639-5147

Figure 12

DATA SHEET NO. 10

GENERAL STEEL CASTINGS CORP.

Heat No. - 6524 Plate No. - 21 Thickness - 6"

Chemical Analysis

	C	Mn	Si	S	P	Ni	Cr	Mo
Company	.27	1.50	.43	.015	.009	--	.07	.36
Watertown Arsenal	.29	1.65	.38	.013	.012	.07	.085	.32

Heat Treatment

Temp.	Hrs. Rise	Hrs. Soak	Coolant
2000		20	Air
1250		6	Air
1575		8	Water
1200		24	Air

Physical Properties (Average)

	Parallel Plate Surfaces	Through the Thickness
T.S.	93,500	92,750
Y.P.	66,750	63,750
% Elong.	17.5	17.7
% R.A.	33.9	39.7

Ballistic Properties (A.P.G. Firing Record #P-11981)

6" A.P. Projectile - 4 Rounds - 15° obliquity.

Round	Velocity	Depth of Penetration	Effect on Plate
1	1435	5-3/4"	Slight bulge on back.
2	1442	5-3/4"	Slight bulge on back.
3	1470	Complete	14" horizontal crack.
4	1568	Complete	Plate cracked full length between rounds 1, 3, and 4. Cracks radiating on front and back from round 4.

Brinell Hardness of Cross-Section

1" from surface - 197 Center - 197

Jominy Hardenability

Distance from Quenched End - 1/16ths of inch

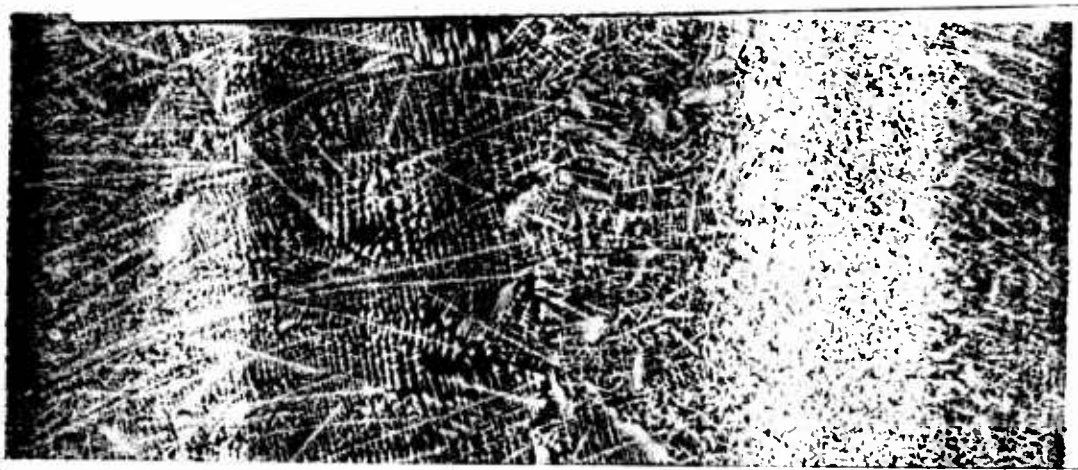
Drop 5 Rc	Drop 10 Rc	To 42 Rc (400 BHN)
9	13	12

Plate Thickness) 1.9"
Quenchable to) in
400 BHN in Center) still water

Microstructure and Remarks

The microstructure contains large amounts of ferrite rejected on the quench in the middle third of the cross-section with less ferrite in the outer two thirds. The steel has insufficient hardenability to harden completely through a 6" thick section. The fracture of the steel is crystalline, indicating unsatisfactory microstructure and poor shock resisting properties.

General Steel Castings - 6" Cast Armor
Heat No. 6524 - Plate No. 21



X1 Hot Acid Macroetch
Interdendritic regions attacked on macroetching.

X200 Nital Picral
Middle of cross-section. Large amount of free ferrite.

X200 Nital Picral
Outer third of cross-section. Small amount of free ferrite.

X1000 Nital Picral
Middle of cross-section. Carbides and ferrite.

X1000 Nital Picral
Outer third of cross-section. Carbides and ferrite. Less ferrite than in midsection.

Figure 13

APPENDIX A

BALLISTIC TEST DATA

Continental Roll and Steel Foundry Co.

Heat No. - 3245 Plate No. - 5423 A.P.G. Firing Record No. P-13201

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft.Sec.	Depth of Penetration	Effect on Plate
1	1435	Partial to 5-1/2".	Plate cracked full length from top to bottom, crack extending through the thickness. Plate unsatisfactory.

Continental Roll and Steel Foundry Co.

Heat No. - 3372 Plate No. - 1-13-3372 A.P.G.FiringRecord# P-13298

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft.Sec.	Depth of Penetration	Effect on Plate
1	1435	Partial to 5-1/4".	Plate cracked full length from top to bottom, crack extending through the thickness. Face spall - 8½" x 8", Plate unsatisfactory.

Continental Roll and Steel Foundry Co.

Heat No. - 8196 Plate No. - 1 A.P.G. Firing Record No. 5460

Thickness - 4"

3" A.P.C. M62 Projectile at 20° obliquity.

Round	Velocity Ft.sec.	Penetration	
1	1713	Partial	
2	1833	Partial	
3	2027	Partial	
4	2615	Complete	Plate Acceptable

Continental Roll and Steel Foundry Co.

Heat No. - 8014 Plate No. - 1 A.P.G. 470.5/4239
W.A. 470.5/5465

Thickness - 4½"

3" A.P.C. M62 Projectile at 20° obliquity.

Round	Velocity Ft./sec.	Penetration	
1	1665	Partial	
2	1850	Partial	
3	2050	Partial	Plate met requirements satisfactorily.

Further ballistic testing gave following results:

3" A.P.C. M62, 20° obliquity - S.V. 2597ft/sec. C.P. Back spall 6" x 7-1/4".

75 MM A.P. M72 - 20° obliquity — Army B.L. - 1876 ft/sec. Navy B.L. - 2032 ft/sec.

75 MM A.P. M72 - Normal — Army B.L. - 1602 ft/sec. Navy B.L. - 1852 ft/sec.

Plate cracked through between rounds. Back spalling resulted from practically every complete penetration.

Continental Roll and Steel Foundry Co.

Heat No. - 3372 Plate No. - CRS-13 A.P.G. Firing Record No. P-15537

Thickness - 6½-6-5/8"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft./sec.	Depth of Penetration	Effect on Plate
1	1432	Partial to 5-7/8".	Plate cracked to edge - 22" in length.
2	1425	—	Plate broke into three pieces. Plate unsatisfactory.

Continental Roll and Steel Foundry Co.

Heat No. - 3445 Plate No. - CRS-17-2 A.P.G.FiringRecord# P-16747

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft./sec.	Depth of Penetration	Effect on Plate
1	1418	Complete	Plate broke into three pieces. Projectile passed through plate. Plate unsatisfactory.

Continental Roll and Steel Foundry Co.

Heat No. - 2212 Plate No. - CRS-12-1

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft./sec.	Depth of Penetration	Effect on Plate
1	1418	Complete	Back spall - 14" diameter. Cracks from impact 25", and 35" long to edges of plate, cracks extending through the thickness. Plate unsatisfactory.

General Steel Castings Corp.

Heat No. - 6848 Plate No. - GSC-26 A.P.G. Firing Record No. P-15472

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft./sec.	Depth of Penetration	Effect on Plate
1	1434	Partial to 5-1/2".	1-1/4" bulge. No cracks.
2	1481	Partial to 5-3/4".	4½" crack on bulge in rear of plate. Plate satisfactory.

General Steel Castings Corp.

Heat No. - 6524 Plate No. - 21 A.P.G. Firing Record No. P-11981

Thickness - 6"

6" Navy A.P. MK27 Projectile at 15° obliquity.

Round	Velocity Ft./sec.	Depth of Penetration	Effect on Plate
1	1435	Partial to 5-3/4".	No cracks.
2	1442	Partial to 5-3/4".	No cracks.
3	1470	Complete.	14" crack to edge of plate, crack extending through the thickness.
4	1568	Complete.	Cracked full length of plate through Rounds No. 1, 3, and 4. 4 cracks radiating from back of Round 4, 12" long to edge of plate, 4" long, 30" long to Round 3, 33" long to crack from Round 3 to edge of plate.

"V" Values of Alloy Steels

The scarcity factors for alloys used in alloy steels, released by the War Production Board for March 1943, are as follows:

Element	Scarcity Factor	Permissible Exemption Factor
Manganese	0.97	0.75
Silicon	3.70	0.25
Nickel	3.77	0.25
Chromium	3.35	0.10
Molybdenum	22.56	0.06

Example:

To compute the "V" value for a steel of the following analysis:

C	Mn	Si	Ni	Cr	Mo
.30	.90	.35	.50	.50	.40

Manganese - 0.97 x (.90-.75) = 0.15
Silicon - 3.70 x (.35-.25) = 0.37
Nickel - 3.77 x (.50-.25) = 0.94
Chromium - 3.35 x (.50-.10) = 1.34
Molybdenum - 22.56 x (.40-.06) = 7.67

"V" value of the steel = 10.47

High "V" values indicate greater use of the more strategic alloying elements. This should be avoided if steels of lower "V" value can be successfully substituted.

APPENDIX B

PHYSICAL TEST DATA

Results of Individual Physical Tests on Cast Armor Sections

Continental Roll and Steel Foundry Co.

Heat No. - 3245 Plate No. - 5423 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	86,500	106,750	18.5	51.3	75,500	103,250	19.0	50.2
Test 2	82,500	103,750	19.5	53.0	76,000	102,750	16.5	48.0
Average	84,500	105,250	19.0	52.2	75,750	103,000	17.8	49.1

V-Notch Charpy Impact

Specimens taken halfway between plate surface and middle of cross-section and parallel to plate surfaces.

As-Received	After Reheat-Treatment 1600°F Quench, 1275°F Draw of 1" Thick Section
ft.lbs.	ft.lbs.
12.4	81.1
16.8	84.0
7.7	83.0
Average - 12.3 ft.lbs.	Average - 82.7 ft.lbs.

Continental Roll and Steel Foundry Co.

Heat No. - 3372 Plate No. 1-13-3372 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	63,500	99,750	16.5	37.8	65,500	101,250	15.0	28.8
					Disregard - Broke at porosity.			
Test 2	64,000	102,500	19.0	48.0	70,000	101,000	12.0	16.2
Average	63,750	101,000	17.8	42.9	67,750	101,000	15.0	28.8

V-Notch Charpy Impact

Specimens taken halfway between plate surface and middle of cross-section and parallel to plate surfaces.

As-Received ft.lbs.	After Reheat-Treatment 1600°F Quench, 1275°F Draw of 1" Thick Section ft.lbs.
8.3	65.6
11.8	69.4
8.5	73.2
Average - 9.5 ft.lbs.	Average - 69.4 ft.lbs.

Continental Roll and Steel Foundry Co.

Heat No. - 8196 Plate No. - 8196-1 Thickness - 4"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	71,000	87,500	23.5	55.7	70,500	98,200	21.5	48.5
Test 2	70,500	98,000	19.5	46.9	68,000	95,750	28.5	58.8
Average	70,750	92,750	21.5	51.3	69,250	96,950	25.0	53.7

Continental Roll and Steel Foundry Co.

Heat No. - 8014 Plate No. - 8014-1 Thickness - 4½"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	69,000	91,750	22.5	55.9	67,000	92,500	21.5	58.3
Test 2	62,500	85,250	7.5	20.5	63,500	93,000	21.5	54.6
	Disregard - Broke at porosity.							
Average	65,750	88,500	22.5	55.9	65,250	92,750	21.5	56.5

Continental Roll and Steel Foundry Co.

Heat No. - 3372 Plate No. - CRS-13 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	No tests performed.				64,500	96,500	22.0	48.5
Test 2					63,000	94,500	21.5	57.2
Average					63,750	95,500	21.8	52.8

Continental Roll and Steel Foundry Co.

Heat No. - 3445 Plate No. - CRS-17-2 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	No tests performed.				61,000	62,750	3.0	9.5
Test 2					61,500	67,750	2.5	4.2
Average					61,250	65,000	2.8	6.9

Both test bars broke at porous areas.

Continental Roll and Steel Foundry Co.

Heat No. - 2212 Plate No. - CRS-12-1 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	No tests performed.				61,000	90,000	22.0	57.2
Test 2					60,500	89,700	23.5	58.8
Average					60,750	89,900	22.8	58.0

General Steel Castings Corp.

Heat No. - 6848 Plate No. - GSC-26 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	80,000	106,500	20.0	46.9	80,500	108,000	19.0	48.0
Test 2	82,000	107,500	21.5	47.4	79,000	107,500	20.0	50.8
Average	81,000	107,000	20.8	47.2	79,750	107,750	19.5	49.4

V-Notch Charpy Impact

Specimens taken halfway between plate surface and middle of cross-section and parallel to the plate surfaces.

Ft.Lbs.
83.0
85.0
79.5

Average- 82.8 ft.lbs.

General Steel Castings Corp.

Heat No. - 6405 Plate No. - 1 Thickness - 4"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	80,500	108,250	19.5	48.0	79,000	106,500	18.5	47.4
Test 2	78,500	107,250	20.0	47.4	76,500	105,000	15.0	24.0
					Disregard - Broke at porosity.			
Average	79,500	107,750	19.8	47.7	77,750	105,750	18.5	47.4

V-Notch Charpy Impact

Specimens taken halfway between plate surface and middle of cross-section and parallel to plate surface.

As-Received ft.lbs.	After Reheat-Treatment 1600°F Quench, 1275°F Draw of 1" Thick Section ft.lbs.
48.4	69.4
52.4	69.4
61.5	68.4
Average- 54.1 ft.lbs.	Average - 69.1 ft.lbs.

General Steel Castings Corp.

Heat No. - 6524 Plate No. - 21 Thickness - 6"

Tensile Properties

	Direction Parallel to Plate Surfaces				Direction Through the Thickness			
	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.	Yield Point p.s.i. 0.1% Set	Tensile Strength p.s.i.	% Elong.	% R.A.
Test 1	67,000	93,750	16.5	28.8	64,000	92,750	18.5	40.9
Test 2	66,500	93,000	18.5	39.0	63,500	92,500	17.0	38.4
Average	66,750	93,500	17.5	33.9	63,750	92,750	17.7	39.7

APPENDIX C

CORRESPONDENCE

COPY

RESTRICTED

WAR DEPARTMENT
THE PROVING CENTER
ABERDEEN PROVING GROUND
MARYLAND

Armor Division

A.P.G. 470.5/4239
W.A. 470.5/5465

November 6, 1942

Subject: 4" Cast Armor from Continental Roll and Steel Foundry Corp.

To: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attention: Laboratory

1. This station is forwarding one section of a 4½"x60"x72" cast plate (Ht. 8014) submitted by the Continental Roll and Steel Foundry Corporation to represent a section of the 16" gun shield. This plate was tested according to instructions received from the Chief of Ordnance. The acceptance test consisted of the firing of three (3) rounds of 3" A.P.C. M62, 20° from normal, at the following velocities: 1665 f/s., 1850 f/s., 2050 f/s. The only requirement is that the plate resist complete penetration at these velocities. The plate met this requirement satisfactorily.

2. In addition to the prescribed test additional firing for information was done, with the following results:

a. 3" A.P.C. M62	20° from normal	S.V. 2597	CP PTP BS 6"x7-1/4".
b. 75mm.A.P. M72	20° from normal	Army B.L. 1876 f/s. Navy B.L. 2032 f/s.	
c. 75mm.A.P. M72	Normal	Army B.L. 1602 f/s. Navy B.L. 1852 f/s.	

In the course of obtaining this additional information, the plate cracked through between the various rounds, and the section being forwarded to your station was separated from the plate by cracking occurring during the firing. In addition, back spalling was obtained on practically every complete penetration.

3. It is requested that your station conduct a complete metallurgical investigation of this section of plate, and the conclusions reached be sent this station as soon as possible.

For the Commanding General:

G. G. EDDY
Col., Ord. Dept.
Assistant.

2 Incls:
Incl 1: 1pc.4½"armor
(approx.165#)
APG Shipping Order#5795 s/c
Incl 2: CAS-2 form for plate 8014

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WAR DEPARTMENT

ABERDEEN PROVING GROUND

MARYLAND

RESTRICTED

Armor Plate Branch
IWT/beh

January 1, 1943

A.P.G. 470.5/4824
W.A. 470.5/5763

Subject: Metallurgical Analysis of Continental Roll & Steel Foundry plate

To: The Commanding Officer
Watertown Arsenal
Watertown, Mass.

Attention: Captain N. A. Matthews

1. We are shipping to your station today, one 12" x 12" x 4" sample of Continental Roll & Steel Foundry plate. This plate is identified as follows:

Heat #8196

2. It is requested that immediate metallurgical analysis be performed on the above specimen and the results reported to this station.

For the Commanding General:

(s) H. J. Rouse

for G. G. Eddy
Col., Ord. Dept.
Assistant

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WAR DEPARTMENT

THE PROVING CENTER

ABERDEEN PROVING GROUND

MARYLAND

RESTRICTED Armor Plate Branch

A.F.G. 470.5/4871
W.A. 470.5/5804

January 6, 1943

Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attention: Captain N. A. Matthews

1. We are shipping to your station today two (2) samples of General Steel Castings plates and two (2) samples of Continental Roll & Steel Foundry plates. These specimens are identified as follows:

General Steel Castings

1 - 12"x12"x4" Plate #1 Heat #6405
1 - 12"x12"x6" Plate #21 Heat #6524

Continental Roll and Steel Foundry

1 - 12"x12"x6" Plate #3245 Heat #5423
1 - 12"x12"x6" Plate #3372 Heat #1-13-3372

2. The 4" General Steel Castings specimen is forwarded as requested in Watertown Arsenal letter 470.5/5465. The 6" General Steel Casting plate was submitted to this station for development of low alloy armor for 6" gun shields. The Continental Roll & Steel Foundry plates were tested at 15° from normal with 6" A.P. projectiles. Both plates cracked almost in two on the first round at velocities of 1435 f/s. and 1436 f/s. respectively.

3. It is requested that immediate metallurgical analysis be performed on the above specimens and the results be reported to this station.

For the Commanding General:

(s) M. J. Zweig
Capt., Ord. Dept.

for G. G. Eddy
Colonel, Ord. Dept.
Assistant

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WAR DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

RESTRICTED

Armor Plate Branch
GA/beh
Extension 3138

A.P.G. 470.5/5700
W.A. 470.5/6250(r)

February 20, 1943

Subject: Metallurgical Investigation of 6" Armor

To: The Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attention: Laboratory

1. This station is forwarding to your station via express, shipping Order 11486, the following samples of 6" cast armor:

1 sample 6" x 6" x 6" labeled on face side CRS 12
1 sample 6" x 6" x 6" " " " " CRS 13
1 sample 6" x 6" x 6" " " " " GSC 26

2. These samples are from 6" armor plates representing 6" Gun Shields for the Barbette Carriage T2. Those samples stenciled CRS 12 and CRS 13 are from Continental Roll and Steel Foundry plates which failed badly. The ballistic results of 6" plates submitted by Continental Roll and Steel can be found in the following Aberdeen firing records:

P9123	P10905	P13201
P9624	P11779	P13298
		P14730

3. Since most of those 6" plates submitted by Continental Roll and Steel Foundry have failed, complete tests of these samples for chemical analysis and physical properties are requested by this station. The General Steel Castings sample (GSC26) should be given the same tests and a comparison made to the Continental Roll and Steel Foundry samples, since the General Steel plate passed the requirements.

4. It is further requested you send this station a written report on the results of your investigation.

For the Commanding General:

(s) H. J. Rouse

for G. G. Eddy
Col., Ord. Dept.
Assistant

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WAR DEPARTMENT

TANK PROVING CENTER

ABERDEEN PROVING GROUND

MARYLAND

Armor Dev. Branch
Project A-1-5
GA/beh
3136

A.P.G. 470.5/6081
W.A. 470.5/7086

March 10, 1943

Subject: Metallurgical Investigation of 6" Armor

To: The Commanding Officer
Watertown Arsenal
Watertown, Mass.

Attention: Laboratory

1. This station is forwarding to your station via express, Shipping Order 12,288, the following sample of 6" cast armor:

1 sample 6"x6"x6" stenciled CRS-17-2

2. This sample is from a 6" cast plate and represents a 6" Gun Shield for the Barbette Carriage T2. The plate was submitted by Continental Roll and Steel Foundry and failed the ballistic test badly on March 5, 1943.

3. It is requested by this station that a complete metallurgical investigation be made and the results sent to this station.

For the Commanding General:

(s) H. J. Rouse

for G. G. Eddy
Col., Ord. Dept.
Director, Proving Center

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