WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/705

Metallurgical Examination of 2" Cast Armor Shock Tested with 105mm. Proof Projectiles

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DATE 22 December 1944

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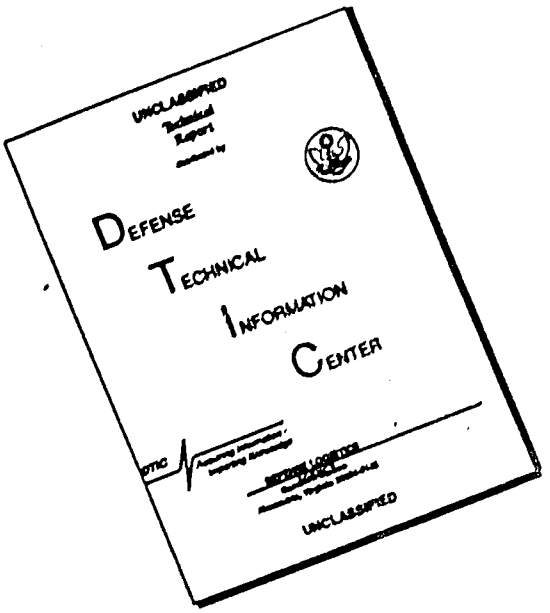

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Final Report on Problem B-4.50

22 December 1944

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ABSTRACT

In general, correlations were established between ballistic shock properties and metallurgical properties, namely, V-notch Charpy impact values, fibre fracture test, and hardness. As a result of this investigation, it is indicated that 2" thick cast armor, heat treated to a fibrous condition at about 245-260 Brinell hardness may be subjected to a striking velocity of about 1200 feet per second, with a 105mm. proof projectile without causing undue cracking.

1. At the request of the Ordnance Research Center, Aberdeen[1], metallurgical examination was made on a series of eight 2" thick cast armor plates which have been tested with 105mm. proof projectiles in order to determine a correlation between ballistic shock properties and metallurgical properties. Four of these samples represented plates which showed good shock resistance and three of the samples represented plates which had poor shock resistance against this proof projectile. In addition, one 2-1/4" thick rolled homogeneous plate which was subjected to the impact of the 105mm. proof projectile was examined. The samples submitted for this investigation included those removed from areas near and including the edge of the plate and also from areas near the impacts on the test plate.

2. Metallurgical examination included the following tests:

a. Chemical analyses.

b. Fibre fracture tests.

c. Brinell hardness tests.

d. V-notch Charpy impact tests.

e. Tensile tests.

f. Microscopic examination.

1. Wtn 470.5/8371(r) - APG 470.5/450(r), 9 August 1944.

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3. The results of the metallurgical examination are given in detail as follows:

a. Chemical analyses. Chemical analyses of the series of samples tested are given in Table I. Generally speaking, the acid open hearth steels made by Continental Foundry and Machine Company contain a higher sulphur and phosphorus content than the basic open hearth steels produced by General Steel Castings and the American Steel Foundries.

b. Fibre Fracture Tests. As noted in Table II, the fracture of the cast plates which were unsatisfactory under the ballistic shock tests consisted of a fibrous matrix with scattered fine crystallinity distributed over the section. The satisfactory cast plates had a fracture consisting of a fibrous zone near each face of the plate although the center of the section exhibited shrinkage or crystallinity. The fracture of the 2-1/4" thick rolled homogeneous plate consisted of crystallinity in the central section with a zone of fibre near both surfaces. It was determined that crystallinity in the series of plates was due to improper quench hardening and also to temper brittleness resulting from slow rates of cooling from the tempering temperature. These results will be discussed under the discussion of the V-notch impact tests.

c. Cross-Sectional Brinell hardness tests. Cross-sectional Brinell hardness tests which were made on properly surface ground cross sections are tabulated in Table II. With the exception of sample Nos. 1714 and 4-46509, the Brinell hardness values were fairly uniform across the section. A noticeable decrease in the Brinell hardness was evident in the center of the cross section of the above mentioned plates. This may have been due to improper quench hardening of the plates.

d. V-Notch Charpy Impact tests.

(1) Tests made on samples "as-received". The results of the V-notch Charpy impact tests are given in Table II. Of the series of samples taken from areas near or including the edge of the plate, it is shown that sample Nos. 4608-1, 4620-1, and 1917-1 which satisfactorily resisted the ballistic shock test had, in general, somewhat higher V-notch impact values at room temperature than sample Nos. 4643-1 and 4608-1 which failed the shock test. This relationship was not definitely established in the case of sample No. 4693-1. This discrepancy may be due to the improper sampling of this particular series of plates. Furthermore, a good correlation was made between Charpy impact values of sections removed from areas near ballistic impacts on the test plates which had satisfactory and poor shock resistance under the impacts of the proof projectile. For example, plate No. 1714 which resisted the shock test satisfactorily had a fibrous fracture at a Brinell hardness of 258 and good V-notch Charpy impact values at +70°F. and -40°F. This plate, undoubtedly, would have good shock resistance at subzero temperatures. On the other hand, the poor quality plate No. 1720 which showed 20% crystallinity distributed throughout the fracture, had relatively low V-notch impact values at +70°F. and -40°F. The combination of high carbon, high hardness and crystallinity

in this plate resulted in poor ballistic shock properties. The rolled plate No. 4-46509 had poor metallurgical properties, namely, crystallinity in the center of the section and pronounced directional properties as indicated by the V-notch Charpy impact values. The V-notch Charpy impact values as determined by the transverse bar are very low at +70°F. and -40°F. A "woody" condition was observed in the longitudinal fracture of this plate. Crystallinity, which is evident in the central area of the fracture, is not always revealed in the fracture of the longitudinal impact bar (notch perpendicular to final direction of rolling). It is believed that the crystallinity is masked by the "woody" condition.

(2) Tests made on small samples retempered at 1175°F. for temper brittleness susceptibility. Small samples were removed from the center section of the series of plates tested and retempered at 1175°F. for 3 hours and subsequently quenched in water (the tempering temperature, 1175°F. was used by the manufacturers in the tempering of these plates). Of the series of cast plates, the satisfactory plate No. 7974-C214 and the cracked plate No. 1720 were embrittled by temper brittleness. In this connection, it was noted that there was a noticeable increase in the impact value of these retempered samples, especially at -40°F. The fact that the impact values of the remaining six cast plates were not greatly improved after retempering indicates that the crystallinity noted in the fractures of these plates was due to improper quench hardening. The decrease in the impact value of retempered sample Nos. 4620-1 and 1917-1 at -40°F. after retempering may be due to the presence of discontinuities in the samples. Crystallinity in the rolled plate No. 4-46509 was due chiefly to temper brittleness resulting from a slow rate of cooling from the tempering temperature and in some degree to improper quench hardening.

e. Tensile Tests. In most cases, no correlation was evident between tensile tests and ballistic impact properties. It was noted, however, that the satisfactory plate Nos. 4620-1 and 1714 had a relatively high percentage of reduction of area. The rolled plate No. 4-46509 had pronounced directional properties as noted by the difference between the ductility of the longitudinal and transverse samples.

f. Microscopic Examination. Photomicrographs illustrating the microstructure of the plates examined are shown in Figures 1, 2, 3, and 4. Some ferrite segregation and a fairly uniform distribution of carbides were present near the surface of plate No. 4643-1 while intermediate temperature transformation products were evident in the central area of the section. Intermediate temperature transformation products were evident throughout the cross section of plate No. 4693-1. Patches of ferrite with some grain boundary carbides were present in the cross section of sample No. 4608-1, see Figure 1. Intermediate temperature transformation products associated with small areas of ferrite were found throughout the cross section of sample Nos. 4620-1 and 1917-1. Sample No. 7974-C214 was definitely improperly quench hardened since a large amount of ferrite was detected from areas near the surface and extending across the section of the plate, see Figure 2.

A tempered martensitic structure was evident in sample Nos. 1714 and 1720. It was noted that sample No. 1714 had a pronounced acicular structure. The presence of ferrite and intermediate temperature transformation products in the center of the 2-1/4" thick rolled homogeneous plate No. 4-46509 indicated that this plate was improperly quench hardened. This correlated with the crystallinity found in the center of the fracture and also to the decrease in hardness in this area. A small amount of ferrite and tempered martensite was evident near the surface of this plate, see Figure 3.

4. The results of this investigation indicated that a 2" thick cast plate, if heat treated to a fibrous condition at about 245-260 Brinell hardness, may be subjected to a striking velocity of about 1200 feet per second with a 105mm. proof projectile without causing undue cracking. In general, correlations were established between ballistic shock properties and metallurgical properties, namely, V-notch Charpy impact values determined at room temperature, fibre fracture test and hardness. Fine crystallinity distributed throughout the fibrous matrix of some of the fractures of the unsatisfactory plates was due to improper quench hardening. This was confirmed by the presence of intermediate temperature transformation products and ferrite segregations. In several cases, the samples containing ferrite segregations were also susceptible to temper embrittlement. The results of the tests made on the series of samples removed from near and including the cast edge of the plates are incorporated in this investigation, although in several cases, definite conclusions could not be drawn in regard to correlation between ballistic and metallurgical properties due to the improper sampling of the plates. These particular series of test plates were returned to the manufacturer and, therefore, no additional samples could be procured for further investigation.

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TABLE I

Chemical Analyses

Sample No.	Manufacturer	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	Al	Ti	B
4643-1	Continental Fdry. & Mach. Co.	.31	1.44	.46	.040	.039	.77	.56	.39	nil	.05	.009	trace	trace
4693-1	"	.32	1.46	.46	.027	.029	.76	.56	.36	nil	.06	.01	trace	trace
4608-1	"	.31	1.42	.40	.036	.036	.83	.52	.45	nil	.06	.015	trace	trace
4620-1	"	.29	1.30	.39	.037	.036	.73	.51	.39	nil	.07	.015	trace	trace
1917-1	"	.31	1.26	.39	.028	.039	.65	.52	.38	nil	.05	.01	trace	trace
7974-C214	American Steel Foundries	.26	1.36	.49	.020	.012	.11	.40	.28	nil	.095	.025	trace	trace
1714	General Steel Castings	.24	.61	.39	.021	.018	trace	2.80	.52	nil	.11	.05	trace	trace
1720	"	.32	.68	.43	.020	.018	trace	2.78	.54	nil	.11	.05	trace	trace
4-46509	Republic Steel Corp.	.23	1.04	.25	.017	.015	.95	.53	.39	trace	.035	.02	trace	.0019

Plate No.	Thickness Inches	Manufacturer	Chemical Analysis C	Mn	Si	Ni	Cr	Mo	Fibre Fracture Test
4643-1*	2	Continental Foundry & Machine Co.	.31	1.44	.46	.77	.56	.39	Mixed fracture, scattered fine crystallinity over 60% of section.
[illegible]93-1*	2	"	.32	1.46	.46	.76	.56	.36	Essentially fibrous, scattered fine crystallinity throughout central third of section. 30% crystallinity in this area.
[illegible]09-1*	2	"	.31	1.42	.40	.83	.52	.45	Mixed fracture with crystallinity over 30% of area.
4630-1*	2	"	.29	1.30	.39	.73	.51	.39	Essentially fibrous with trace of crystallinity at exact center of section.
[illegible]917-1*	2	"	.31	1.26	.39	.65	.52	.38	Mixed fracture. Entirely fibrous in 1/2" from each face. Central third bright crystalline, 15% of area.
7974* 3214	2	American Steel Foundries	.26	1.36	.49	.11	.40	.28	Fibrous in 1/4" from each face central third containing bright patches of crystallinity amounting to 30% of area.
1714	2	General Steel Castings	.24	.61	.39	trace	2.80	.52	Fibrous, with shrinkage over 30% of central area.
1720	2	"	.32	.68	.43	trace	2.78	.54	20% crystallinity & 10% shrinkage throughout section. Balance - fibre.
4-40509	2-1/4	Republic Steel Corp.	.23	1.04	.25	.95	.53	.39	Fibrous in 3/8" from each face, and in 1/2" from other face. Balance - crystal

*The samples submitted for metallurgical examination were removed from areas near
**Tensile tests were taken halfway between center and surface of sample.
***The critical velocity is defined as the average of two velocities not over 50 f/

NOTE: Longitudinal bar - notch perpendicular to final rolling direction.
Transverse bar - notch parallel to final rolling direction.

TABLE II

Summary of Physi[cal and Ball]
Made on 2" Cast [and 2-1/4" R]
Shock Tested wit[h 105mm. Proc]

Fracture Test	Cross Sectional Brinell Hardness Range	Ave.	Tensile Test** Y.S.P. .1% Set Lbs/Sq.In.	Y.P. Lbs/Sq.In.	T.S. Lbs/Sq.In.	% Elong.	% Red. Area	+70°F.
ture, scattered allinity over tion.	241/248	243	93,000	—	117,100	20	49.8	[illegible]
y fibrous, scat- crystallinity central third . 30% crystal- this area.	240/240	240	90,500	—	117,000	17.9	43.6	53.2[illegible]
ture with crys- over 30% of	235/235	235	90,500	—	114,000	19.3	42.8	42.8(F)
y fibrous with rystallinity in er of section.	229/241	235	86,500	—	113,800	20.7	52.5	53.5[illegible]
ture. Entirely " from each al third bright e, 35% of area.	223/229	227	78,000	—	112,400	21.4	48.2	60.9(F)
" from each l third com- ght patches linity amount- of area.	240/248	245	90,000	—	116,200	15.0	35.8	53.0(F)
ith shrinkage f central area.	229/269	258	—	87,000	125,000	19.3	53.3	56.8(F)
llinity & 10% throughout sec- nce - fibre.	277/293	285	114,000	—	142,000	11.4	31.7	48.4(Fc
3/4" from one in " from other nce - crystalline.	269/311	287	129,370 Long.	—	146,000 Long.	18.6 Long.	62.3 Long.	74.2(Y) Long. Bu
			126,870 Trans.		146,000 Trans.	14.3 Trans.	43.1 Trans.	58.7(F w Trans. B

[illegible] areas near the east edge of the plate.
[illegible]le.
not over 50 f/s apart, one of which causes cracking and one of which does not.
[illegible]on.

Descri
F =
Fc =
Cbf =
The [illegible]

TABLE II

[illegible] and Ballistic Tests
[illegible] 2-1/4" Rolled Armor
105mm. Proof Projectiles

V-NOTCH CHARPY RESULTS						
As-Received					After Retempering	
[illegible]		Center				
[illegible]	-40°F.	[illegible]°F.	-40°F.	Tempering Temperature	Time at Tempering Temperature	
[illegible]	[illegible]	[illegible]	[illegible](F 1/2)	1175°F.	3 hrs.	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]°F.	3 hrs.	
[illegible]	[illegible]	[illegible](Fc 1/5)	34.[illegible]	1175°F.	3 hrs.	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] hrs.	
63.9([illegible])	[illegible]	[illegible]	[illegible](Fc [illegible])	1175°F.	3 hrs.	
[illegible]	[illegible]	[illegible](Fc 4/5)	[illegible]	1175°F.	3 hrs.	
[illegible]	[illegible](F)	[illegible](F)	60.5(F)	1175°F.	3 hrs.	
[illegible]	[illegible](Fc 3/4)	[illegible](Fc 3/4)	19.4(Fc 3/4)	1175°F.	3 hrs.	
[illegible] Long. Bar [illegible] Trans. Bar	[illegible](F) Long. Bar 33.2(F woody) Trans. Bar	70.0(F) Long. Bar 34.5(Fc woody) Trans. Bar	70.3(F) Long. Bar 19.4(Cb) Trans. Bar	1175°F.	3 hrs.	

[illegible] of [illegible] Charpy Bar Fractures:
[illegible] = Fibrous.
[illegible] = Fibrous matrix with spots of crystallinity.
[illegible] = Bright crystalline patch surrounded by fibrous border.
The fraction following the fracture symbol refers to the estimated surface area which [illegible]

3

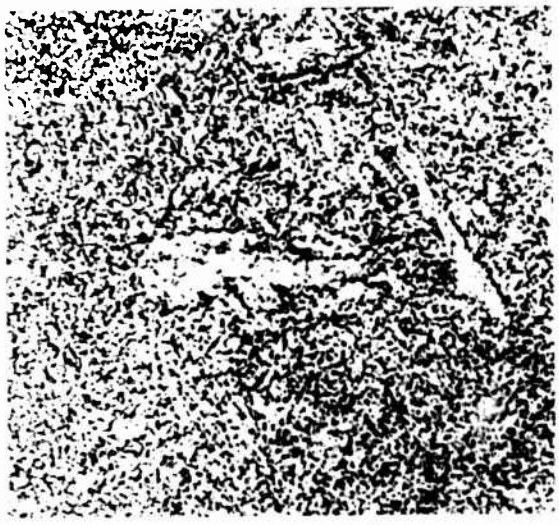
Y [illegible] [illegible]ULTS

[illegible]ter Retempering (Center of [illegible])

[illegible]	[illegible] at [illegible] [illegible]ature	Coolant	+[illegible]°F.	-[illegible]°F.	Results of Shock Test Critical Velocity***
[illegible]	3 [illegible]rs.	water	4[illegible].[illegible](F)*	[illegible].3([illegible] 3/4)*	[illegible]72 f/s Poor
[illegible]	[illegible]	[illegible]	41.[illegible](F)	3[illegible].[illegible] ([illegible]/[illegible])	[illegible]30 f/s Unsatisfactory
[illegible]	[illegible] rs.	water	40.[illegible](F)	[illegible].[illegible](Fc 3/4)	[illegible] f/s Unsatisfactory
[illegible]	[illegible] rs.	[illegible]	[illegible] ([illegible])	[illegible].[illegible]([illegible])	115[illegible] f/s Satisfactory
[illegible]	3 rs.	[illegible]	[illegible]([illegible])	[illegible].1(Fc 3/4)	115[illegible] f/s Satisfactory
[illegible]	3 [illegible]rs.	water	[illegible]([illegible])	[illegible].2(Cbf)	1[illegible]25 f/s Satisfactory
[illegible]	3 rs.	water	[illegible].3([illegible])	[illegible].3(F)	1[illegible]6[illegible] f/s Satisfactory No Crack on Bulge
[illegible]	3 rs.	water	3[illegible].[illegible]([illegible])	37.[illegible](Fc 1/2)	116[illegible] f/s Unsatisfactory 12" Crack on Bulge
[illegible]	3 [illegible]rs.	water	[illegible]([illegible]) Long. Bar 43.[illegible](F [illegible]) Trans. Bar	1[illegible].7(F) Long. Bar 32.6(Fc 1/4 woody) Trans. Bar	Velocity of Impact 141[illegible] f/s Unsatisfactory 1[illegible]" Crack on Bulge

[illegible] area which is crystalline.

Microstructure of 2" Cast Armor



Continental 4643-1
Near Surface
Ferrite and fairly uniform distribution of carbide.

Continental 4643-1
Near Center
Intermediate temperature transformation products.

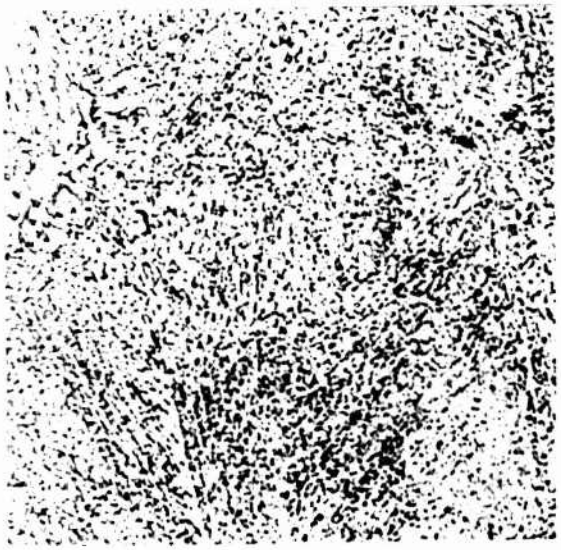
Continental 4693-1
Typical intermediate temperature transformation products throughout section.

Continental 4608-1
Typical ferrite and some boundary carbides throughout section.

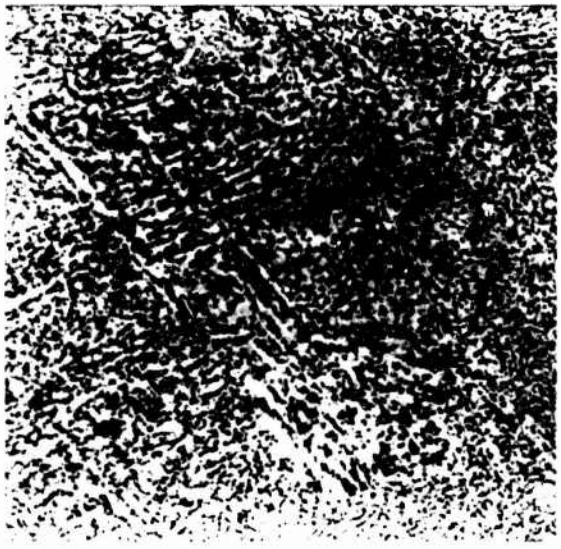
Magnification X1000 - Etched in Picral

FIGURE 1.

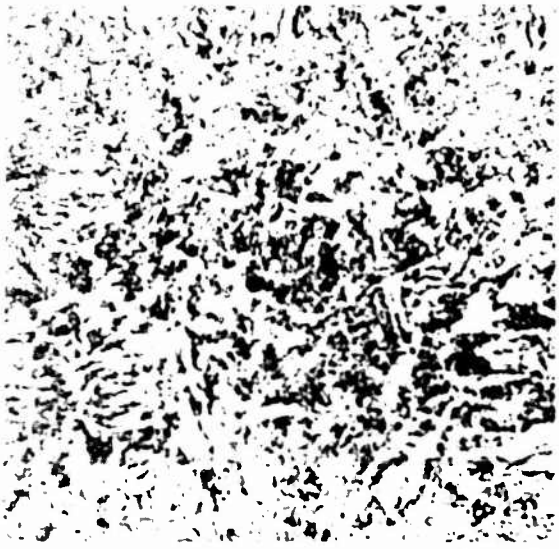
Microstructure of 2" Cast Armor



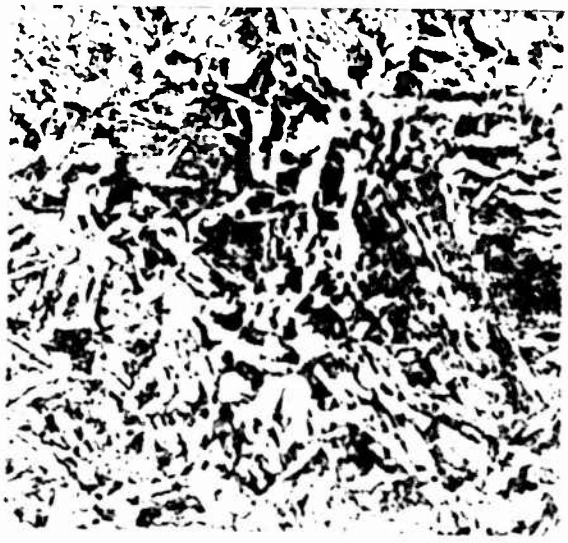
Continental 4620-1
Typical intermediate temperature transformation products throughout section.



Continental 1917-1
Typical intermediate temperature transformation products throughout section.



American Steel Foundries 7974-C214
Near Surface
Ferrite and carbides.

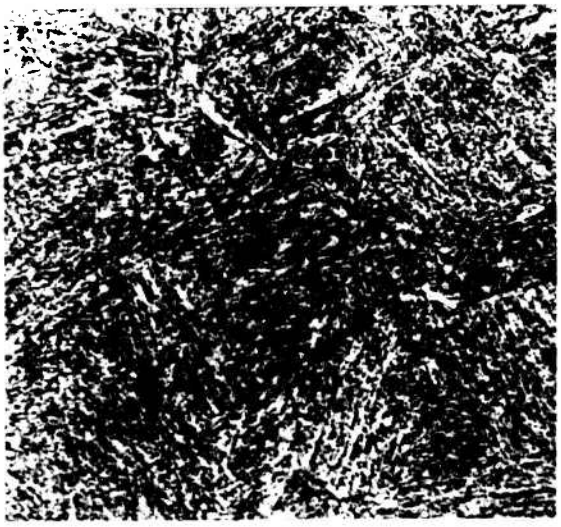


American Steel Foundries 7974-C214
Near Center
Ferrite and carbides.

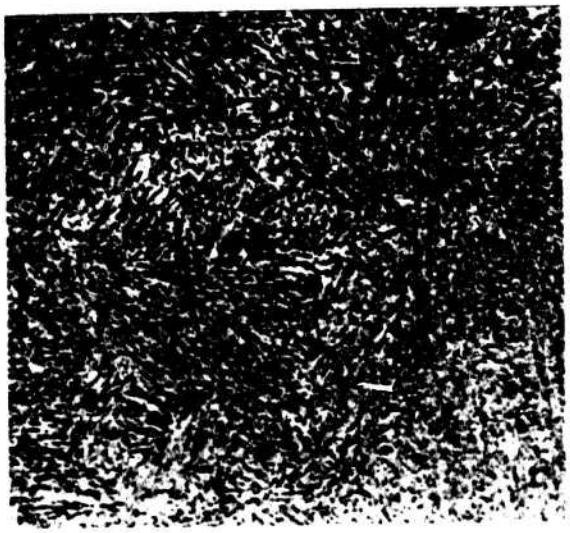
Magnification X1000 - Etched in Picral

FIGURE 2.

Microstructure of 2" Cast Armor and 2-1/4" Rolled Armor



General Steel Castings 1714
Tempered martensite throughout section, coarse acicular structure.



General Steel Castings 1720
Tempered martensite throughout section, fine acicular structure.

Republic 4-46509
Some ferrite and tempered martensite.

Republic 4-46509
Ferrite and intermediate temperature transformation products.

Magnification X1000 - Etched in Picral

FIGURE 3.