

RESTRICTED SECTION

WATERTOWN ARSENAL
WATERTOWN, MASS.



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Fig # 2a

AD-4556-186

AD-4556-186

WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL 7-0/512

Vol. 2

Brittleness in Cast and Rolled Armor Plate

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APR 23 85

BY

A. L. [unclear]
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DATE 27 December 1943

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TABLE I

List of Coupons Submitted to Watertown Arsenal for Notched Impact Studies

Manufacturer	Coupon No.	Heat Treatment	Temperature	Rise	Time at Temperature	Coilant
<u>CAST ARMOR</u>						
American Steel Foundries	C-371A	Normalize	1650°F	*	2 hrs.	Air
	C-371A	Harden	1525°F	*	40 min.	Water
		Draw	1150°F	*	4 hrs.	Water
"	C-371B C-371B	Normalize	1650°F	*	2 hrs.	Air
		Harden	1525°F	*	40 min.	Water
		Draw	1150°F	*	4 hrs.	Furnace to 300°F
Continental Roll and Steel Co.	5315A-1 5315A-2	Normalize	1625°F	3 hrs.	10 hrs.	Air
		Harden	1575°F	3 hrs.	10 hrs.	Water plus 1-1/2% soluble oil
		Draw	1220°F	3 hrs.	12 hrs.	Water
"	5315A-3 5315A-4	Normalize	1625°F	3 hrs.	10 hrs.	Air
		Harden	1575°F	3 hrs.	10 hrs.	Water plus 1-1/2% soluble oil
		Draw	1220°F	3 hrs.	12 hrs.	Slowly cool from 1200°F to 300° at rate of 39°F per hour
McGonway and Torley	494-1	Normalize	1800°F	5 hrs.	4 hrs.	Air
		Harden	1600°F	4 hrs.	4 hrs.	Water
		Draw	1180°F	2 1/2 hrs	4 hrs.	Water
"	494-2 494-3	Normalize	1800°F	5 hrs.	4 hrs.	Air
		Harden	1600°F	4 hrs.	4 hrs.	Water
		Draw	1180°F	2 1/2 hrs.	4 hrs.	Slowly cooled over a period of 30 hrs. to 300°F

* Data were not furnished by the manufacturer.

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INTRODUCTION

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In 1942, when consideration was given to the use of ferritic electrodes for welding the new alloy armor plate compositions, an inquiry¹ was sent to the Watertown Arsenal by the Office, Chief of Ordnance relative to the possibility of the occurrence of temper brittleness in this type of armor when subjected to a stress relieving treatment.

According to a suggestion¹ made by Watertown Arsenal, this subject of temper brittleness was presented to the Ferrous Metallurgical Advisory Board which recommended a program covering -

1. Ballistic tests to be made on production plates cooled both quickly and slowly from the draw temperature.
2. Impact tests to be made on samples cut from cast coupons, cast from the same heat and given the same heat treatment as the cast ballistic plates and also on sections from the rolled ballistic plates.

Accordingly, the Tank-automotive Center instructed² a selected group of armor plate manufacturers to send a series of test plates cooled quickly and slowly from the draw temperature to Aberdeen Proving Ground³ for test. The results of these ballistic tests are given in APG Report No. AD-379, a summary of which is given in Table I, Inclosure A. Furthermore, a series of cast coupons, similarly heat treated as the cast plates and also small sections from the rolled plates were sent to Watertown Arsenal for notched impact studies.

A list of the coupons submitted and their heat treatments are given in Table I.

-
1. O.O. 470.5/3423(r) - Wtn 470.5/5132(r), See Appendix A.
 2. O.O.M. 470.5/665(r), See Appendix A.
 3. O.O.M. 451.25/2-249, See Appendix A.



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Watertown Arsenal Laboratory
Report Number WAL 710/572
Problem Number B-4.10

27 December 1943

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ARMOR

OTIC

Temper Brittleness in Cast and Rolled Armor Plate

APR 23 1985

OBJECT

To determine if the present low alloy cast and rolled armor is subject to temper brittleness as a result of slow cooling from the final draw temperature.

CONCLUSIONS

1. The results of this investigation indicated that cast and rolled low alloy armor slowly cooled from the draw temperature were more susceptible to temper brittleness (as measured by the V-notch Charpy test) than the same material quickly cooled from the draw.
2. The embrittling effect noted in the ballistic tests of some of the rolled armor plates, (reference APG Report No. AD-379) which were slowly cooled from the draw may have been due to the fact that these rolled plates were subjected to a more severe ballistic test as compared to the cast plates which were also slowly cooled from the draw.
3. In general and in contrast to some fairly well accepted beliefs, in the steel studied, molybdenum does not seem to be effective in eliminating, or reducing temper brittleness in material slowly cooled from the draw temperature.
4. The considerable variation in the V-notch Charpy value of each type analysis is due to the fact that the samples as received were incompletely quenched hardened to various degrees—resulting in fractures which varied from 100% crystalline to nearly completely fibrous.
5. Generally speaking, the relatively low Charpy impact values obtained at subzero temperatures were related to the heterogeneous microstructures resulting from inadequate hardening of the steel during the quench.

E. L. Reed.
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Research Metallurgist

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H. H. ZORNIG
Colonel, Ord. Dept.
Director of Laboratory

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TABLE I (CONT'D)

Manufacturer	Coupon No.	Heat Treatment	Temperature	Rise	Time at Temperature	Coolant
CAST AEGOR						
General Steel Casting Co.	7110-1	Normalize	2000°F	*	10 hrs.	Air
	7110-2	Anneal	1250°F	*	4 hrs.	Air
		Harden	1600°F	*	4 hrs.	Water
		Draw	1125°F	*	4 hrs.	Air
"	7110-3 7110-4	Normalize	2000°F	*	10 hrs.	Air
		Anneal	1250°F	*	4 hrs.	Air
		Harden	1600°F	*	4 hrs.	Water
		Draw	1125°F	*	4 hrs.	**Furnace
Pacific Car and Foundry Co.	1	Normalize	1850°F	4 hrs.	6 hrs.	Air
		Harden	1625°F	2 1/2 hrs.	3 hrs.	Water
		Draw	1200°F	3 hrs.	4 hrs.	Air
	2 3	Normalize	1850°F	4 hrs.	6 hrs.	Air
		Harden	1625°F	2 1/2 hrs.	3 hrs.	Water
		Draw	1200°F	3 hrs.	4 hrs.	Furnace cool to 240°F
Wehr Steel Co.	TBB-1-582 TBB-1-583	Normalize	1750°F	*	8 hrs.	Air
		Harden	1576°F	*	6 hrs.	Water
		Draw	1150°F	*	6 hrs.	Air
		Redraw	1150°F	*	6 hrs.	Furnace cool to 300°F then out in still air
"	TBB-1-584	Normalize	1750°F	*	8 hrs.	Air
		Harden	1576°F	*	6 hrs.	Water
		Draw	1150°F	*	6 hrs.	Air

* Data were not furnished by manufacturer.

** Temperature to which samples were cooled in furnace was not stated.

TABLE I (CONT'D)

Manufacturer	Compon No.	Heat Treatment	Temperature		Rise	Time at Temperature	Coolant
			Temperature	CAST AIRBOR			
Union Steel Castings Co.	829	Harden Draw Redraw	1700°F	*	*	4 hrs.	Water
			1225°F	*	*	4 hrs.	Water
			1225°F	*	*	4 hrs.	Water
"	830 831	Harden Draw Redraw	1700°F	*	*	4 hrs.	Water
			1225°F	*	*	4 hrs.	Water
			1225°F	*	*	4 hrs.	Air
			<u>ROLLED AIRBOR</u>				
Henry Disston & Sons, Inc.	AR1990-1	Harden Draw	1575°F	*	*	2 hrs.	Water spray
			1150°F	*	*	2 hrs.	Air
"	AR1990-2 AR1990-3	Harden Draw	1575°F	*	*	2 hrs.	Water spray
			1150°F	*	*	2 hrs.	Furnace cooled to 300°F time required 21 hrs.
Great Lakes Steel Corp.	1	Harden Draw	1650°F	*	*	2 hrs.	Water
			1230°F	*	*	2 hrs.	Air
"	2 3	Harden Draw	1650°F	*	*	2 hrs.	Water
			1230°F	*	*	2 hrs.	**Furnace
Standard Steel Spring Co.	1728	Harden Draw	1650°F	1½ hrs.	1½ hrs.	½ hr.	Water
			1190°F	2 hrs.	2 hrs.	1½ hrs.	Water
"	1729 1730	Harden Draw	1650°F	1½ hrs.	1½ hrs.	½ hr.	Water
			1190°F	2 hrs.	2 hrs.	1½ hrs.	**Furnace

* Data were not furnished by manufacturer.

** Temperature to which samples were cooled in furnace was not stated.

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A preliminary report⁴ on the results of this investigation was sent to the Tank-Automotive Center in September 1943.

Ballistic and metallurgical data are recorded in Inclosure A.

Correspondence relating to this investigation is given in Appendix A.

TEST PROCEDURE

1. Metallurgical Examination

Six standard V-notch Charpy impact bars were machined from test coupons quickly cooled and coupons slowly cooled from the draw temperature. These impact bars were taken halfway between the surface and center and parallel to one surface, see Figure 1, Inclosure A. The notches in the Charpy bars were carefully lapped in order to remove any longitudinal milling marks or other surface defects, see Inclosure A.

Two V-notch Charpy impact values were determined at room temperature (70°F), 0°F and at -40°F.

The V-notch Charpy test was selected because it is particularly indicative of ductility under the ballistic shock test.

In addition, microscopic examination was made on samples taken from halfway between the surface and center of the test coupons. The microstructure of the samples was compared with fracture tests made on sections approximately 1½" x 3" x 6" which were nicked perpendicularly to the center of the longitudinal dimension and broken by the impact of a forge hammer.

Brinell hardness surveys were made on the cross sections of each test coupon.

2. Ballistic Tests

A summary of the ballistic tests on the selected test plates as reported by Aberdeen Proving Ground is given in Table I, Inclosure A.

RESULTS AND DISCUSSION

1. Metallurgical Examination

a. Chemical Analyses

The chemical analyses of the test coupons as reported by the armor plate manufacturers are given in Table II.

4. Wtn 470.5/6930, 30 September 1943, See Appendix A.

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TABLE II

Chemical Analyses

<u>Manufacturer</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Mo</u>	<u>Cu</u>	<u>Zr</u>
<u>CAST ARMOR</u>										
American Steel Foundries	.29	1.57	.52	.026	.025	.30	-	.09	-	-
Continental Roll & Steel Foundry Co.	.31	1.21	.37	.037	.042	.46	.36	.50	-	-
McConway & Torley	.29	1.50	.48	.040	.040	-	-	.47	-	-
General Steel Castings Co.	.29	1.56	.39	.015	.016	.50	-	.31	-	-
Pacific Car & Foundry Co.	.22	1.18	.54	.013	.014	-	-	.40	1.28	-
Wehr Steel Co.	.27	.60	.50	.039	.033	.66	.62	.31	-	-
Union Steel Castings Co.	.29	1.70	.40	.019	.037	-	-	.55	-	-
<u>ROLLED ARMOR</u>										
Henry Disston & Sons, Inc.	.22	.81	.23	.015	.016	.53	1.09	.31	.08	-
Great Lakes Steel Corp.	.29	1.10	.81	.025	.025	.61	-	.25	-	.08
Standard Steel Spring Co.	.26	1.68	.25	.017	.015	-	-	.27	-	-

b. Mechanical Tests

(1) V-Notch Charpy Impact Tests

A summary of the results of the V-notch impact tests made at room temperature and at subzero temperatures on samples cooled quickly and samples cooled slowly from the drawing temperature is given in Table III and also shown graphically in Figures 1 and 2. The individual Charpy values are given in Table II, Inclosure A.

A survey of these results indicates that the samples cooled slowly from the draw temperature were relatively more brittle than the samples quickly cooled from the draw temperature.

The differences between the Charpy values of the quickly and the slowly cooled cast and rolled samples containing low and medium high molybdenum were somewhat erratic. (See Table III.) Furthermore, contrary to recent investigations, it was found that in most cases, that there was no marked increase in the difference between the V-notch Charpy values of the quickly and the slowly cooled samples with respect to a decrease in temperature.

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The variation in the V-notch Charpy value of each type of analysis determined at room temperature is attributed to the fact that the coupons were to various degrees, incompletely quench hardened. Due to the notch sensitivity of free ferrite present in the improperly quenched samples, considerable discrepancy was noted in the check Charpy values of this material.

The relatively low Charpy values obtained at subzero temperatures are associated in most cases with segregations of ferrite or carbide in the microstructure. This is especially true in samples submitted by the American Steel Foundries and the Pacific Car and Foundry Co. The fact that there was a slight increase in the Charpy values of the Disston composition at 0°F and -40°F is of particular interest although no explanation is offered at this time to account for this discrepancy. It was further observed that the impact values of the General Steel Castings samples decreased gradually with respect to a decrease in temperature as compared to the other samples. This was due to the fact that these particular samples were more thoroughly quenched out. In fact, the fracture of the coupon was essentially all fibrous.

No definite correlation seemed to exist between the molybdenum content and susceptibility to temper brittleness in samples slowly cooled from the draw. For example, the Charpy values of the samples submitted by the McConway & Torley Co. containing .47% molybdenum were not superior to the impact values of the American Steel Foundries composition which contained only 0.09% molybdenum. Incidentally, the Union Steel Castings composition containing .55% molybdenum did not possess superior impact resistance as compared to the values obtained by the American Steel Foundries analysis. These results are contrary to those reported in investigations carried out in England some years ago which revealed molybdenum additions were effective in decreasing the susceptibility to temper brittleness of steels slowly cooled from the draw. The results of an investigation on temper brittleness in steels recently made by the Climax Molybdenum Company⁵ were also in agreement with the English investigators.

c. Hardness Tests

A summary of Brinell hardness tests made on the cross sections of the coupons is given in Table III*.

The hardness of the samples slowly cooled from the draw temperature submitted by Union, General and Disston were somewhat lower than the samples quickly cooled from the draw. (See Table III and Figure 2.)

The samples submitted by the American Steel Foundries and the Pacific Car and Foundry Co. were relatively soft as compared to the other samples tested. The low hardness values obtained on these two

5. "Temper Brittleness - Manganese and Manganese Molybdenum Wrought Steels", Report No. 2588, 6 March 1943, Climax Molybdenum Company.

*Individual hardness readings are presented in Table III, Inclosure A.

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compositions were correlated with the presence of ferrite. The hardness values obtained on the cross sections of the series of samples were fairly uniform.

d. Fracture Tests

A summary of the fracture tests made on the coupons as received in order to determine the presence of fibre is given in Table III. A survey of these results indicates that the cast samples were not thoroughly quenched out, thus revealing various amounts of crystallinity in the resulting fractures.

Pronounced porosity and piping were detected in the center of the cross section of the coupons submitted by McConway and Torley. The balance of the cast coupons were free from these defects. The rolled plates were free from pronounced segregations of nonmetallic inclusions according to the fracture test.

e. Microstructure

The microstructures of the coupons received for this investigation are shown in Figures 3, 4, and 5. These results are summarized in Table III.

The coupons submitted by the American Steel Foundries and the Pacific Car and Foundry Co. contained a considerable amount of ferrite as noted in Figures 3 and 4. This is reflected in the poor impact values at low temperature. Evidence of ferrite was noted in the samples heat treated by Continental, McConway, Wehr, Union and Disston.

In a few cases, the microstructure of the samples slowly cooled from the draw varied from that of samples cooled quickly from the draw. For example, the slowly cooled sample from Continental contained more grain boundary carbides than the quickly cooled sample. Also the slowly cooled sample from the General Steel Castings Co. and the Henry Disston & Sons, Inc. had less ferrite in the microstructure than the quickly cooled sample.

2. Ballistic Tests

The results of the ballistic tests on $1\frac{1}{2}$ " thick cast and rolled plates quickly and slowly cooled from the draw as reported by Aberdeen Proving Ground, reference Table I in Inclosure A, indicated that no detrimental effect was noted on any of the cast plates slowly cooled from the drawing temperature. Furthermore, tests made on the rolled plates showed some indication of embrittlement but these tests were not conclusive. It is possible that the embrittlement noted was due to the fact that these rolled plates were subjected to a more severe ballistic test than the cast plates, especially the shock test using the 75 mm. PPT21 projectile.

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SUMMARY

The low alloy cast and rolled armor plate investigated was relatively more brittle as measured by the V-notch Charpy impact test after slow cooling from the tempering temperature as compared to samples of the same material cooled quickly from the tempering temperature. These slowly cooled samples were temper brittle although in several cases (Union, General, and Disston), the hardness values were somewhat lower than those of the quickly cooled samples. Ordinarily, an increase in impact value would be expected with a decrease in hardness.

Furthermore, other variables such as chemical composition, incomplete quenching of the coupons and steel manufacture were considered in the interpretation of the results.

The Charpy impact values of the samples supplied by the McConway & Torley and Union Steel Castings were relatively low considering that the microstructure of these samples was typical of good quality plate. This discrepancy may have been related to the fact that these steels contained relatively high manganese and also that they were made by the acid practice. It was noted in this investigation that with the exception of the Continental Roll and Steel Foundry samples, acid steels have a somewhat lower impact value than basic steels. This observation has also been made by other investigators. The fact that the Charpy impact values of the McConway & Torley samples did not substantially decrease at subzero temperatures correlates with the satisfactory metallographic structure.

The low impact values of the Wehr Steel samples were due to the presence of ferrite in the microstructure. Incidentally, this cast steel was made in the acid electric furnace.

It was noted that there was a pronounced decrease in the Charpy impact values of the incompletely quenched samples when tested at subzero temperatures. Generally speaking, the more thoroughly quenched samples showed a more gradual decrease in impact values at subzero temperatures.

In several cases, there was no correlation between microstructure and fracture of the coupon tests. This was true in the case of studies made on the Union and McConway & Torley samples. In these samples, the crystallinity was noted more especially in the central portions of the coupon. The microsections and V-notch Charpy tests were made on sections taken from halfway between the center and the surface where more fibre was evident.

The General Steel Castings and Disston compositions had the highest average impact properties at subzero temperatures.

The Disston samples, both quickly and slowly cooled from the tempering temperature, showed a slight increase in the Charpy impact value.

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The samples submitted by the American Steel Foundries, Union Steel Castings and the Great Lakes Steel Corporation developed a marked tendency to temper brittleness. This is evident although the molybdenum content varied in these samples from 0.09% to 0.55%. It was found that irrespective of the effect of any other variation, molybdenum does not eliminate temper brittleness. These results are not in agreement with those of the English investigators who have reported that molybdenum additions tend to decrease the susceptibility of steels slowly cooled from the draw.

Ballistic tests showed no detrimental effects on cast plates slowly cooled from the draw, including one series containing .09% molybdenum.

Ballistic tests made on rolled plates showed some indication of embrittlement but these tests were not conclusive.

TEMPER BRITTLENESS PROGRAM V-NOTCH CHARPY VALUES OF CAST & ROLLED ARMOR QUICKLY & SLOWLY COOLED FROM THE DRAWING TEMPERATURE

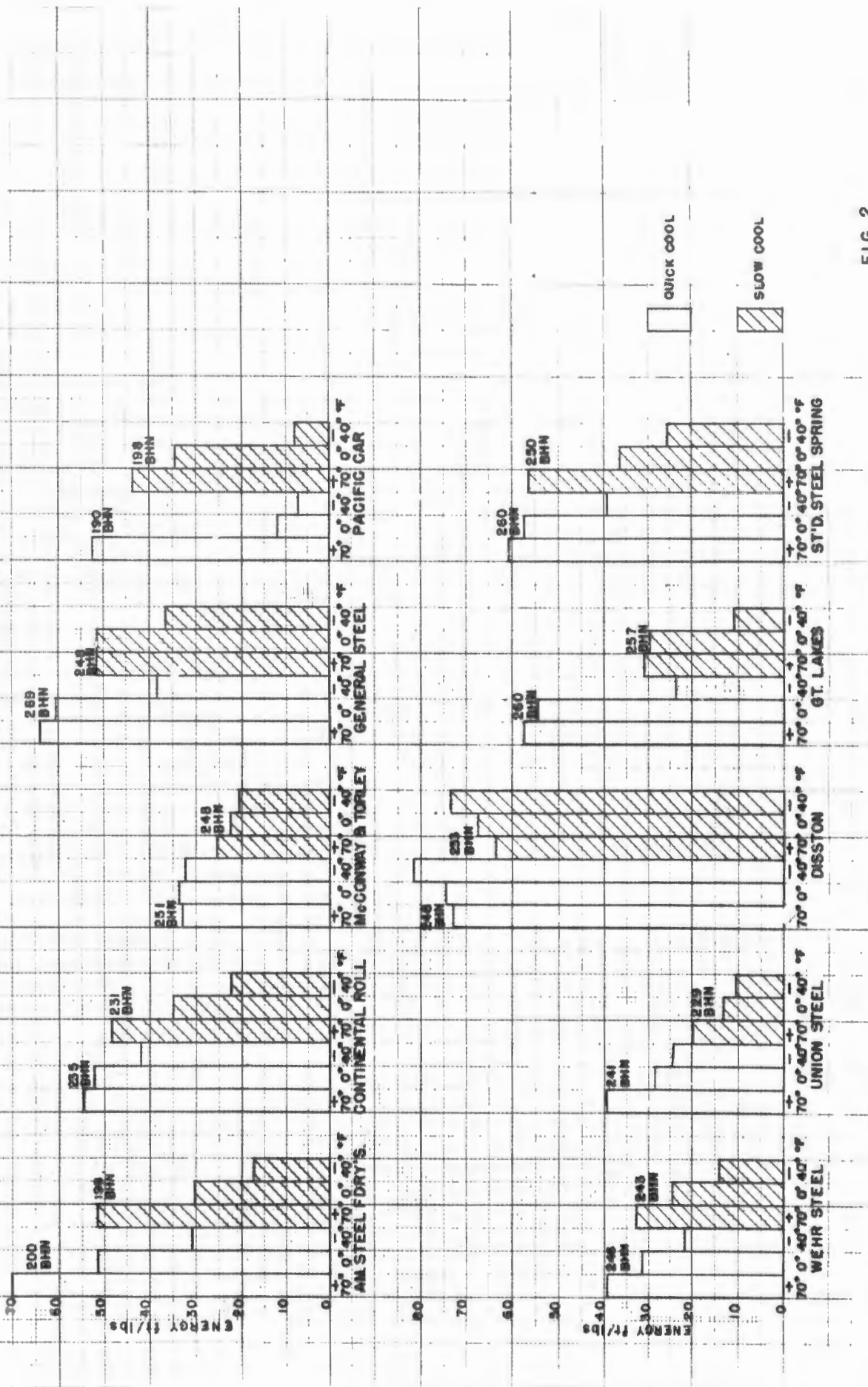
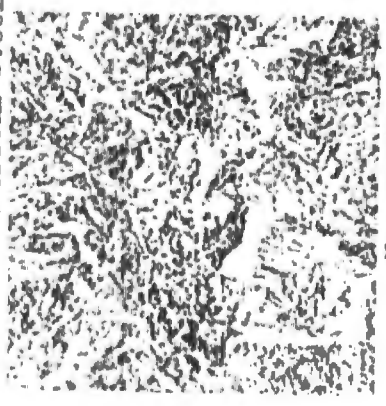


FIG. 2

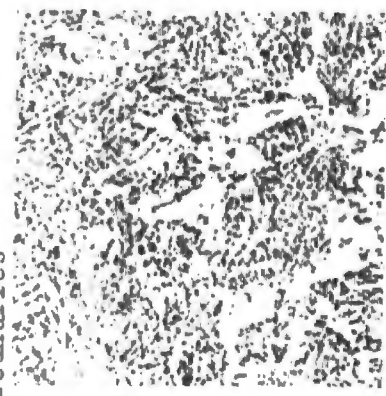
FIG. 2

Microstructure of Cast Armor
 Cooled quickly and slowly from the Drawing Temperature
 All photomicrographs X1000 - Picral etch

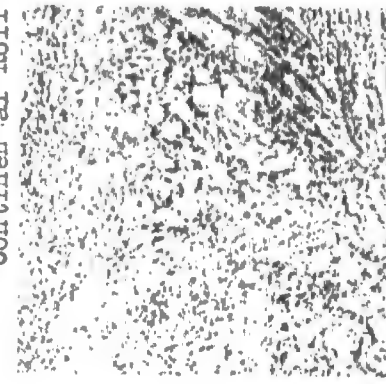
American Steel Foundries



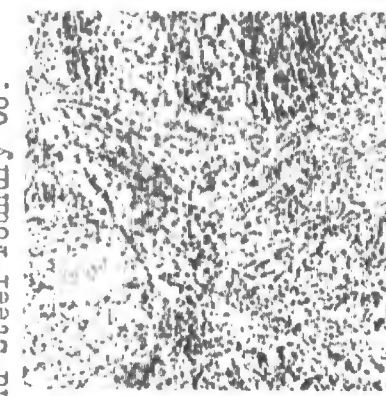
No. C37LA
 Water quenched from draw.
 Sorbite and ferrite.



No. C37LB
 Furnace cooled from draw.
 Sorbite and ferrite.

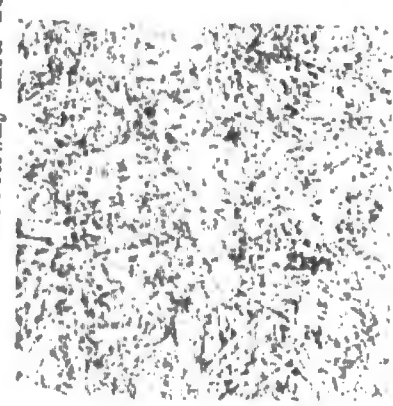


No. 5315A1
 Water quenched from draw.
 Sorbite, trace of ferrite.

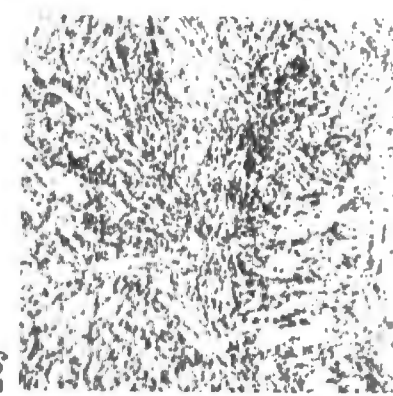


No. 5315A3
 Furnace cooled from draw.
 Sorbite, grain boundary carbides.

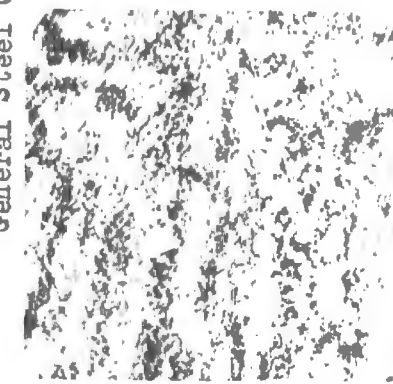
McConway and Torley



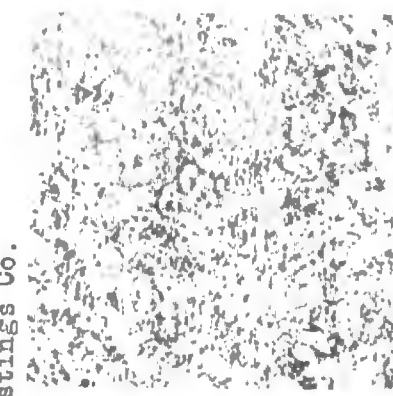
No. 494-1
 Cooled from draw.
 Very little



No. 494-2
 Slowly cooled from draw.
 Tempered martensite.



No. 7110-2
 Air cooled from draw.
 Segregated inclusions

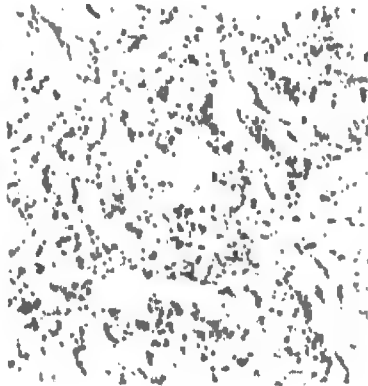


No. 7115-1
 Furnace cooled from draw.
 Inclusions

Microstructure of Cast Armor
Cooled Quickly and Slowly from the Drawing Temperature

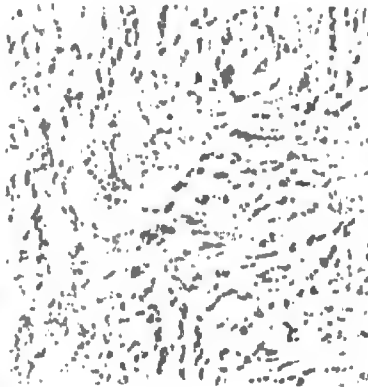
All photomicrographs X1000 - Picral etch

Pacific Car and Foundry Co.



No. 1

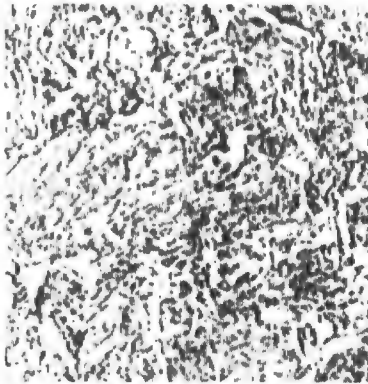
Air cooled from draw.
Small spheroidized carbide and ferrite.



No. 2

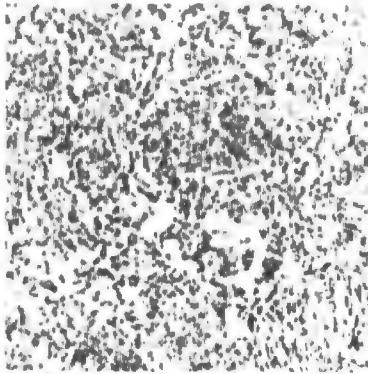
Furnace cooled from draw.
Small spheroidized carbide and ferrite.

Wehr Steel Co.



No. TBR-1-584

Air cooled from draw.
Sorbite and ferrite.



No. TBR-1-583

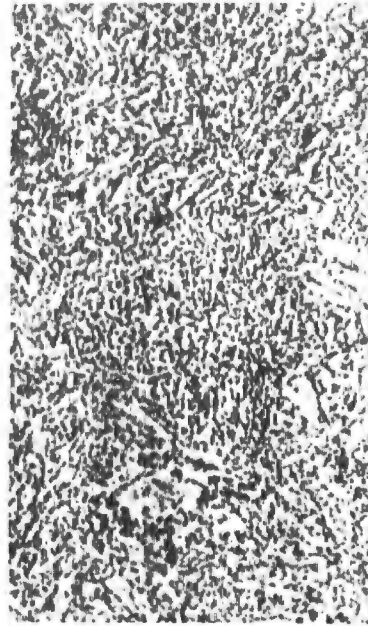
Furnace cooled from draw.
Sorbite and ferrite.

Union Steel Castings Co.



No. 829

Water quenched from draw.
Sorbite and small amount of ferrite

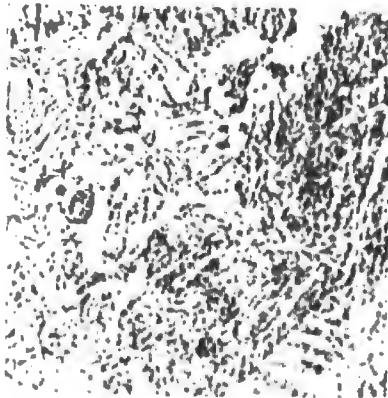


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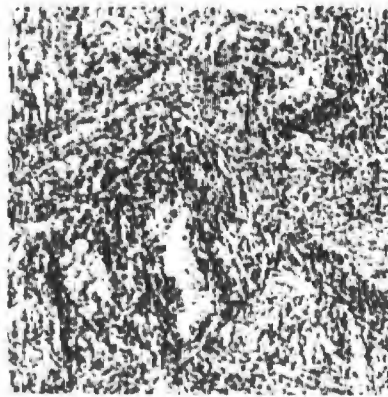
Air cooled from draw.
Sorbite and small amount of ferrite

Microstructure of Rolled Armor
 Cooled Quickly and Slowly from the Drawing Temperature
 All photomicrographs X1000 - Picral etch

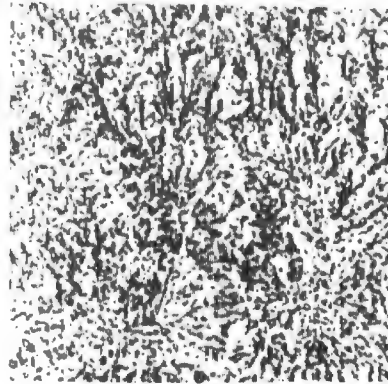
Henry Disston and Sons Inc.



No. ARI990-1
 Air cooled from draw.
 Sorbite and ferrite.

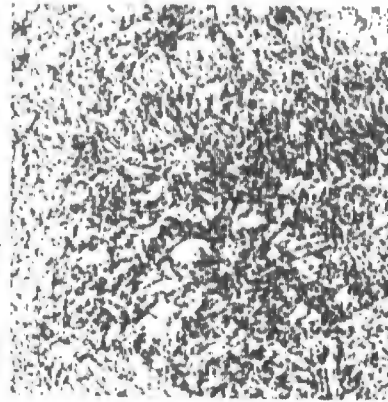


No. ARI990-2
 Furnace cooled from draw.
 Sorbite, trace of ferrite.



No. 1
 Air cooled from draw.
 Sorbite.

Great Lakes Steel Corp.



No. 2
 Furnace cooled from draw.
 Sorbite.

Standard Steel Spring Co.



No. 1728
 Water quenched from draw.
 sorbite and ferrite.



No. 1729
 Furnace cooled from draw. Sorbite,
 some ferrite. Acicular pattern.

WTN.039-0025

INCLOSURE A

TABLE I - Inclosure A

Ballistic Tests

Reference, APG Report No. Ad-379

C Mn Si Cr Ni Mo
 .29 1.57 .52 .30 - .09

CAST - ~~Ad-379~~

American Steel Foundries

Shock - 75 mm. PP T21

PTP - 37 mm. AP M74

Plate	Heat Treatment	Thickness	Locality	Bow	DP	Bulge	Remarks
C-371-A	**AC	1.53	1041	1-13/16	5/16	H-1-1/32 V-1-3/64	Cracking - 2", 2" at 45° on back
C-371-Ba	FC	1.58	1064	1-13/16	5/16	H-1-1/32 V-63/64	No cracking
C-37-BB	FC	1.56	1037	1-9/16	1/4	H-1-1/32 V-31/32	No cracking
Continental Roll & Steel Foundry							
5315B	AC	1.79	1260	PP	3/8	H-13/16	No cracking
5315C	FC	1.76	1248	PP	5/16	V-3/4	"
5315D	FC	1.86	1243	PP	1/2	V-19/32	"
McConvey Torley							
1	AC	1.60	1086	CP	1-3/4	H-7/8	Cracks: 2" 1-3/4" back-2 1/2", 2-3/4", 2", 2-3/4"
2	FC	1.68	1120	CP	3/8	V-1 1/2	Punching S. Face-4-1/4, 3-1/4, 1-3/4, 2 Back-8, 5, 2-3/4, 2 F
3	FC	1.55	1043	CP	1-7/16	V-1	Face-5, 2, 4, 4 1/2 Back-5, 3-3/4, 4 1/2, 2 1/2

**AC - Air Cooled
 FC - Furnace Cooled

*H-Horizontal Measurement
 V-Vertical

Locality

Exit Diameter

2494

3 small petals remain
2-1/8x2-3/16"

2500

2-1/4x2-5/16" no petals

2482

2-3/16x2" one small petal on

2440

2-1/4x2-5/16" one petal on

2446

2-1/4x2-1/4" one petal on

2449

2-1/4x2-1/4" no petals on

2438

2x2-1/8" no petals

2433

2 1/2 x 2-1/8 no petals

2429

2-1/4x2-1/4 - one petal on

CAST ANALYSIS

TABLE I - Inclosure A (Cont'd)

General Steel Castings		C	Mn	Si	Cr	Ni	Mo
		.29	1.56	.39	.50	-	.31
Shock - 75 mm. PP T21							
Plate	Heat Treatment	Thickness	Bow	DP	Bulge	Remarks	Locality
8	AC	1.48	1	3/16	H-3/4 V-11/16	Small crack - 1/8"	2520
9	FC	1.50	1 1/2	3/16	H-7/8 V-7/8	S.O. Crack about 1/4" on bulge	2488
11	FC	1.53	PP 1-9/16	3/16	H-13/16 V-11/16	No cracking	2451
Pacific Car & Foundry							
		C	Mn	Si	Cr	Ni	Cu
		.22	1.18	.54	-	.40	1.28
1	AC	1.57	1-11/16	5/16	H-1" V-1"	No cracking	2496
2	FC	1.53	1-7/8	5/16	H-1-5/64 V-1-1/64	No cracking	2481
3	FC	1.62	1-13/16	5/16	H-1-5/64 V-1-1/64	No cracking	2526

Wehr Steel		C	Mn	Si	Cr	Ni	Mo
		.27	(.60-.80)	.50	.66	.62	.31
584-1	AC	1.57	1099 PP 1-1/4	3/16	H-7/8 V-1-3/16	Face-1 1/2, 1 Back-3/8, 1-3/4, 2, 2 1/2, 2-1/4	2496

Coreprints in front

PTP - 37 mm. AP M74

Exit Diameter

2-3/16x2-3/8 - one petal intact

2-1/4x2-1/4 - two petals intact

2-3/16x2-1/4 - Incl. BS

2-3/16x2-1/8 No petals

2-1/8x2-1/8 - two small petals remain

2-1/8x2-1/16 no petals

2-7/16x2-3/8 no petals

TABLE I - Inclosure A (Cont'd)

CAST ANALYSIS

Wehr Steel (Cont'd)	C	.27	Mn	(.60-.80)	Si	.50	Cr	.66	Ni	.62	Mo	.31
---------------------	---	-----	----	-----------	----	-----	----	-----	----	-----	----	-----

Shock - 75 mm. PP F21

FTP - 37 mm. AP M74

Plate	Heat Treatment	Thickness	Loc-ity	DP	Bow	Bulge	Remarks	Loc-ity	Exit Diameter
583-1	FC	1.57	1092 PF	1-5/16	5/16	H-7/8 V-1-3/16	Back-3/8, 1 1/2, 3, 3 Front-1-3/4, 1-1/8, 1-1/4 Core prints in front	2494	2-1/4x2-5/16
582-1	FC	1.56	1052 CP	1-11/16	-	H-1-1/4 V-1-3/16	Front-1, 1-3/4, 3 Back-5, 6, 3 1/2 Coreprints in front	2499	2-3/8x2-3/8 no petals
829 U	FC	1.42	990	1-1/8	3/16	V-5/8	Cracking started		2-3/8x2-1/4 no petals
830 U	AC	1.56	1060	15/16	1/4	V-11/16	Cracking on bulge		2-7/16x2-3/16 no petals
831 U	AC	1.75	1163	11/16	1/4	V-5/8	No cracking		2-1/4x2-3/8

Union Steel Castings	C	.29	Mn	1.70	Si	.40	Cr	-	Ni	-	Mo	.55
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TABLE I - Inclosure A (Cont'd)

Disston C Mn Si Cr Ni Mo Cu
 .22 .81 .23 .53 1.09 .31 .08

ROLLED ARBOR

Plate	Heat Treatment	Thickness	Loc-ity	BoV	IP	Bulge	Remarks	Ve-locity	Exit Diameter
1	AC	1 1/2	1233	2	5/16	V-1-1/16	No cracking	2523	2-7/16x2-1/2 with petals
2	FC	1 1/2	1236	2-1/8	7/16	V-1-1/8	No cracking	2521	2-7/16x2-1/4 with petals
3	FC	1 1/2	1226	2-1/16	3/8	V-1	Hairline 5/8" crack on bulge	2540	2-1/4x2-1/4 with petals
Shock - 75 mm. PP T21									
Great Lakes									
				C	Mn	Si	Cr	Ni	Zr
1	AC	1.56	1262	2-1/16	3/8	V-15/16	No cracking	2572	2-5/16x2-7/16 one petal on
2	FC	1.55	1260	2	5/16	V-1	1-3/4" Horiz. Crack Back	2549	2-3/8x2-3/8 two petals on
3	FC	1.54	1274	3-1/4	-	-	Face-12", 10 1/2, 9 1/2 Back-13, 11, 9 1/2	2557	2-5/16x2-5/16 all petals off
Standard Steel Spring									
				C	Mn	Si	Cr	Ni	Mo
SGJ-1728	AC	1.47	1235	2-1/16	5/16	H-1-5/32 V-1-9/64	No cracking	2562	2x1-3/4, 2 petals off
SGJ-1729	FC	1.48	1238	1-15/16	7/16	H-1-15/64 V-1-3/16	1/2" surface crack on bulge	2535	2-1/4x2-1/4 3 petals on
SGJ-1730	FC	1.48	1233	1-7/8	7/16	H-1-15/64 V-1-11/64	1/2" crack at 45° on bulge	2514	2-5/16x2-1/4 all petals off

TABLE II -- Inclosure A

Results of V-Notch Charpy Tests on
Cast and Rolled Armor Cooled Quickly and Slowly
from the Drawing Temperature

Manufacturer	Sample No.	Draw Temp. and Subsequent Cooling Rate	V-Notch Charpy Impact Values			Ave. BHN Cross Section cf Test Coupons
			Room Temp. +70°F.	0°F.	-40°F.	
CAST ARMOR American Steel Foundries	C-371A	1150°F, water quenched	72.8	51.0	29.5	200
			Ave. 67.1	Ave. 51.4	Ave. 30.5	
	C-371B	1150°F, furnace cooled to 300°F.	50.7	31.1	15.5	198
		Ave. 52.9	Ave. 29.5	Ave. 18.7		
Continental Roll & Steel Foundry Co.	5315A1	1220°F, water quenched	56.4	47.0	46.8	235
			Ave. 53.1	Ave. 58.2	Ave. 37.1	
	5315A3	1220°F, furnace cooled to 300°F, 39°/hr.	51.1	42.0	19.4	231
		Ave. 48.5	Ave. 35.2	Ave. 26.2		
McGenway & Torley	494-1	1180°F, water quenched	35.8	33.6	33.1	251
			Ave. 30.4	Ave. 34.2	Ave. 31.7	
	494-2	1180°F, slowly cooled to 300°F, in period of 30 hrs.	24.6	22.9	18.1	248
		Ave. 26.5	Ave. 22.6	Ave. 23.0		
General Steel Castings Co.	7110-2	1125°F, air cooled	64.3	57.4	35.5	269
			Ave. 63.7	Ave. 60.3	Ave. 41.6	
	7110-3	1125°F, furnace cooled	50.5	46.3	36.1	241
		Ave. 52.3	Ave. 51.4	Ave. 37.7		
				Ave. 36.9		

TABLE II - Inclosure A (Cont'd)

Manufacturer	Sample No.	Draw Temp. and Subsequent Cooling Rate	V-Notch Charpy Impact Values			Ave. BHN Cross Section of Test Coupons
			Room Temp. +70°F.	0°F.	-40°F.	
Pacific Car & Foundry Co.	1	1200°F, air cooled	32.6 72.3 Ave. 52.5	14.6 9.4 Ave. 12.0	7.4 7.4 Ave. 7.4	190
	2	1200°F, furnace cooled to 240°F.	56.9 29.8 Ave. 43.4	40.7 27.4 Ave. 34.1	8.1 8.1 Ave. 8.1	198
Mehr Steel Co.	TBR-1-584	1150°F, air cooled	40.7 38.2 Ave. 39.5	31.5 23.9 Ave. 31.3	23.9 19.1 Ave. 21.5	246
	TBR-1-583	1150°F, furnace cooled to 300°F.	34.2 31.4 Ave. 32.8	27.4 21.5 Ave. 24.5	14.0 14.2 Ave. 14.1	243
Union Steel Castings Co.	829	1225°F, water quenched	40.4 37.9 Ave. 39.2	30.3 27.3 Ave. 28.8	25.8 23.6 Ave. 24.7	241
	830	1225°F, air cooled	20.5 19.0 Ave. 19.8	13.0 12.7 Ave. 12.9	10.0 11.1 Ave. 10.6	243
ROLLED ARMOR Henry Disston & Sons, Inc.	AR1990-1	1150°F, air cooled	67.9 77.5 Ave. 72.7	77.0 72.2 Ave. 74.6	81.5 81.5 Ave. 81.3	248
	AR1990-2	1150°F, furnace cooled to 300°F in 21 hrs.	62.4 64.0 Ave. 63.2	76.1 58.0 Ave. 67.1	73.5 72.7 Ave. 73.1	233

TABLE II -- Inclosure A (Cont'd)

Manufacturer	Sample No.	Draw Temp. and Subsequent Cooling Rate	V-Notch Charpy Impact Values			Ave. BHN Cross Section of Test Coupons
			Room Temp. +70°F.	0°F.	-40°F.	
Great Lakes Steel Corp.	1	1230°F, air cooled	57.8	54.0	25.3	260
			Ave. 56.6	Ave. 54.8	ave. 23.1	
	2	1230°F, furnace cooled	30.0	30.6	10.0	267
			Ave. 30.8	ave. 28.6	11.2	
Standard Steel Spring Co.	1728	1190°F, water quenched	62.8	58.6	38.7	262
			Ave. 60.5	Ave. 57.5	ave. 39.4	
	1729	1190°F, furnace cooled	56.0	36.1	26.5	250
			Ave. 56.2	ave. 36.9	ave. 25.4	

TABLE III - Inclosure A

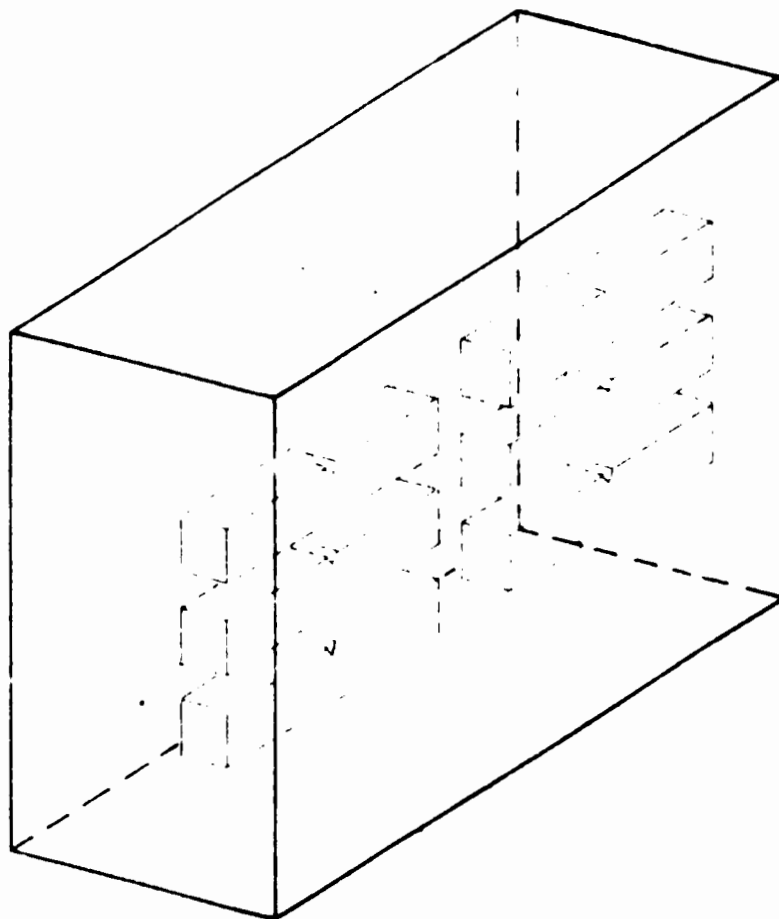
Brinell Hardness Values

<u>Manufacturer</u>	<u>Sample No.</u>	<u>Type</u> <u>Chemical Composition</u>	<u>Rate of</u> <u>Cooling</u> <u>from Draw</u>	<u>Brinell Hardness</u>		
				<u>Three Values</u>	<u>Average</u>	
<u>CAST</u> <u>AMERICAN</u>						
American Steel Foundries	371-A 371-B	Mn-Cr-Mo Mn-Cr-Mo	fast slow	212 201	187 197	201 198
Continental Roll & Steel Foundry Co.	5315A1 5315A3	Mn-Cr-Ni-Mo Mn-Cr-Ni-Mo	fast slow	235 229	235 229	235 231
McConway & Torley	494-1 494-2	Mn-Mo Mn-Mo	fast slow	255 255	- 255	248 248
General Steel Castings Co.	7110-2 7110-3	Mn-Cr-Mo Mn-Cr-Mo	fast slow	269 235	269 241	269 241
Pacific Car & Foundry Co.	1 2	Mn-Mo-Cu Mn-Mo-Cu	fast slow	192 197	192 201	187 198
Wehr Steel Co.	TRR-1-584 TRR-1-583	Cr-Ni-Mo Cr-Ni-Mo	fast slow	241 241	248 241	246 243
Union Steel Castings Co.	829 830	Mn-Mo Mn-Mo	fast slow	241 229	241 229	241 229
<u>ROLLED</u> <u>AMERICAN</u>						
Henry Disston & Sons, Inc.	AR1990-1 AR1990-2	Cr-Ni-Mo Cr-Ni-Mo	fast slow	248 229	248 235	248 233
Great Lakes Steel Corp.	1 2	Si-Cr-Mo-Zr Si-Cr-Mo-Zr	fast slow	255 255	262 262	260 257
Standard Steel Spring Co.	1728 1729	Mn-Mo Mn-Mo	fast slow	262 248	262 255	262 250

Method of Lapping Notches in V-Notch Charpy Bars

The bar is inspected to determine whether or not it has been machined within the tolerances permitted. The notches are finished with the milling cutter within the dimensions shown in Figure 1 of this inclosure. After finishing with the milling cutter, the notches are lapped by means of a revolving wire covered with a fine abrasive and held in a small drill press. This wire should be a piano wire of .01 radius. The wire is rotated at a speed of about 500 revolutions per minute and the bar is held in contact with the wire for approximately one or two minutes. This method of lapping the bottom of the notch with a revolving wire is usually sufficient to remove any longitudinal milling marks or other surface defects.

LOCATION OF 6 V-NOTCH
CHARPY BARS MACHINED
FROM TEST COUPONS



STANDARD V-NOTCH CHARPY BAR

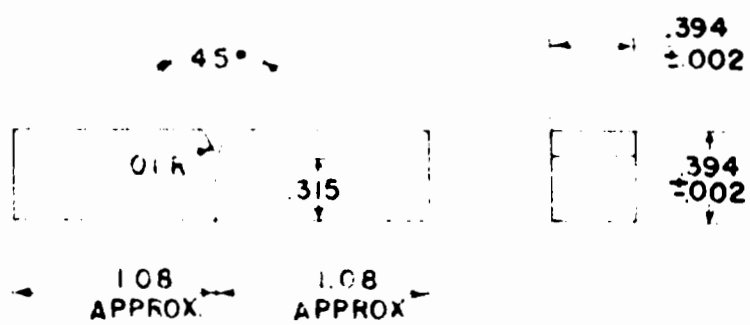


FIG.1 INCLOSURE A

APPENDIX A

Correspondance

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WAR DEPARTMENT

OFFICE OF CHIEF OF ORDNANCE

WASHINGTON

RANDALL/dmf

Wtn 470.5/5132(r)
O.O.470.5/3423(r)
Attn: SPOIT, Armor & Material

August 25, 1942

Subject: Temper Brittleness of Armor Material

To: Commanding General
Watertown Arsenal
Watertown, Massachusetts

1. In view of consideration which is being given to the use of ferritic electrodes for the welding of armor together with the possibility that such a procedure will require a thermal stress relieving treatment, this office would appreciate your comments and any detailed data available on the subject of temper brittleness of armor materials. For your information, attached is a tabulation of a number of current rolled and cast armor compositions.

2. If data is not available regarding the temper brittleness phenomenon in these alloys, and if there seems reason to believe that this difficulty might occur in connection with the use of practical stress relieving or drawing treatments, it is requested that your office submit recommendations for a test program.

3. Consideration of lower drawing temperatures by certain manufacturers of armor also makes it necessary to obtain data on this subject. Accordingly, this office will appreciate receiving your recommendations at the earliest possible date.

By order of the Chief of Ordnance:

LOREN M. JENKS
Assistant.

1 Inclosure
Tabulation(not included
in this rpt.)

Page 1 - Appendix A

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Wtn 470.5/5132(r)
O.O.470.5/3423(r)

1st Ind.

NAM/amv

Watertown Arsenal, Watertown, Massachusetts, August 31, 1942
To: Chief of Ordnance, U.S.A., Pentagon Building, Washington, D.C.
attn: SPOIT - Armor and Material

1. The Ferrous Metallurgical Advisory Board will consider the subject of temper brittleness in general and specifically with reference to the basic letter at its meeting on September 9, 1942.
2. Depending upon the Board's decision, it will probably be necessary to conduct a program to determine the effect of slow cooling from the stress-relieving temperatures on the ballistic properties of the various low alloy compositions.
3. Molybdenum in amounts exceeding .35% supposedly will counterset the tendency for temper brittleness. The American Steel Foundries composition, the Disston composition, and the Great Lakes Steel Corporation compositions are below the minimum figure.
4. Please return this file for a report of the Board's recommendation and an outline of a program to investigate this problem.

For the Commanding Officer:

G. L. COX,
Lt. Col., Ord. Dept.,
Assistant.

1 Inclosure n/c
Tabulation(not included
in this rpt.)

Page 2 - appendix A

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Wtn 470.5/5132(r)

O.O.470.5/3423(r)

SPOIT, Armor & Material

2nd Ind.

RANDALL/dmf

War Department, Ordnance Office, Washington, D. C., September 4, 1942.

To: Commanding Officer, Watertown Arsenal, Watertown, Massachusetts

1. As requested in paragraph 4 of the first indorsement, this file is being returned for consideration by the Ferrous Metallurgical Advisory Board at its meeting on September 9, 1942.

2. This office will await with great interest the outcome of this meeting, and requests that it be advised as promptly as possible of the decisions made.

By order of the Chief of Ordnance:

LOREN M. JENKS

Assistant

1 Inclosure n/c

Tabulation(not included
in this rpt.)

Wtn 470.5/5132(r)

O.O.470.5/3423(r)

3rd Ind.

NAM/amv

Watertown Arsenal, Watertown, Massachusetts, September 10, 1942.

To: Chief of Ordnance, U.S.A., Pentagon Building, Washington, D. C.

Attn: SPOIT - Armor and Material

1. The Ferrous Metallurgical advisory Board has considered the question of temper brittleness in the subject steels as it might be affected by a slow cool following a stress relieving treatment. The following opinions were expressed and recommendations presented:

a. Although a lowering of Izod impact properties may result upon slow cooling, it was not felt that brittleness induced would cause ballistic failures in steels containing over .15-.20% molybdenum.

b. No failures are known which have been attributed to temper brittleness. It is common practice to rapidly cool from the draw at least by air cooling as a safeguard against temper brittleness.

c. The board recommended a program of ballistic tests on these materials not only to resolve this problem but to obtain basic, general information on these low alloy steels with respect to temper brittleness tendencies.

Page 3 - Appendix A

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2. Accordingly, the following program is suggested:

a. Cast Armor

(1) Include tests of material from American Steel Foundries and Ford Motor Company.

(2) Delete tests from Sivyer Steel Castings Company. This company has already obtained satisfactory results on its product furnace cooled from the tempering temperature.

(3) From all manufacturers listed request three (3) test plates (1½ or 2" but all of same thickness) to be poured from one representative heat to be heat treated identically and simultaneously except with respect to the cooling treatment following the draw. Cool one plate from the draw according to standard practice. Furnace cool the other two (2) plates at as slow a cooling rate as practical down to at least 300°F.

(4) Provide Watertown Arsenal with four (4) separately cast test coupons from the above heat, heat treated as above, two (2) of which have been cooled according to normal practice (air or water) and the other two (2) of which have been furnace cooled along with the test plates. The coupons should be large enough to yield at least six (6) Izod specimens from each.

b. Rolled Armor

(1) Add Ford Motor Company to the list.

(2) Delete Youngstown Sheet and Tube from the list since they do not roll 1½" thickness and their analysis is similar to that of Jones and Laughlin.

(3) Request three (3) 1½" thick primary plates from each producer to be from the same heat and ingot position.

(4) Heat treat the three plates identically and simultaneously except for the cooling from the tempering treatment. Cool one plate after the draw according to standard practice (air or water) and furnace cool the other two (2) plates at as slow a rate as practical down to at least 300°F.

(5) Provide Watertown Arsenal with sufficient material cut from each plate after final heat treatment to provide at least six (6) longitudinal and transverse Izod impact specimens.

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c. Ballistic Tests

(1) Shock test will be the prime factor. Test at specified velocities with the 75 MM T21 slug. Care should be taken to impact the plates as near the exact center as possible.

(2) Obtain ballistic limits with the 37 MM projectile, also PTP tests.

d. Izod Impact Tests

Watertown Arsenal will conduct these tests. .

3. The above program should be completed before the stress relieving of welded armor assemblies is approved.

For the Commanding Officer:

G. L. COX,
Lt. Col., Ord. Dept.,
Assistant.

1 Incl. n/c
Tabulation(not included
in this rpt.)

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WAR DEPARTMENT
TANK—AUTOMOTIVE CENTER
UNION GUARDIAN BUILDING
DETROIT, MICH.

Handova/mjk

December 3, 1942

Wtn 470.5/5579
O.O.M. 470.5/665
Attn: SPOW-T-UG-19.5

Subject: Temper Brittleness Research Program

To: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

1. Reference:

O.O. 470.5/3423(R)
W.A. 470.5/5132(r)

2. In accordance with the above communication from Watertown Arsenal, this office is initiating the subject program. Armor is being obtained from the manufacturers and heat treated as recommended by the Ferrous Metallurgical Advisory Board.

3. The armor plates are to be shipped to Aberdeen Proving Ground for ballistic testing. Similarly heat treated coupons for Izod tests at your station are being obtained for all cast plates. Aberdeen Proving Ground will be instructed to provide Watertown Arsenal with material from the rolled plates after ballistic testing for Izod specimens.

4. Inclosed are copies of General Instructions sent to Districts and facilities and a copy of a letter sent to Aberdeen Proving Ground. Also inclosed is a copy of the reference file.

By Order of the Deputy Chief of Ordnance:

(S/T) D. J. PIPPEL,
Major, Ord. Dept.,
Assistant.

3 Incl.
Gen. Inst. (not incl. in this rpt.)
cpy Ltr. sent to A.P.G.
file fm. W.A. (See pages 1-5 of
Appendix A)

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WAR DEPARTMENT
ORDNANCE DEPARTMENT
TANK—AUTOMOTIVE CENTER
UNION GUARDIAN BUILDING
DETROIT, MICH.

Handova/mjk

December 3, 1942

O.O.M. 470.5/686
Attn: SPOMT-UG-19.5

Subject: Temper Brittleness Research Program

To: Commanding Officer
The Proving Center
Aberdeen Proving Ground, Maryland

1. In accordance with the recommendation of the Ferrous Metallurgical Advisory Board this office is initiating a program to determine the effect of temper brittleness on current compositions of armor.
2. The companies outlined by the Ferrous Metallurgical Advisory Board are being requested to supply material for this program. This office will instruct the facilities to send the plates to Aberdeen Proving Ground for ballistic testing. Watertown Arsenal will be provided directly with coupons for all cast material submitted. It is requested that sufficient material be cut from each rolled plate submitted to your station to provide at least six longitudinal and transverse Izod impact specimens and sent to Watertown Arsenal.
3. It is desired to obtain a direct comparison between these various plates to see whether any embrittling effect has resulted from slow cooling.
4. Inclosed are copies of General Instructions issued to the facilities and the Ordnance Districts concerned and a copy of the correspondence between this office and Watertown Arsenal.
5. It is requested that Aberdeen Proving Ground forward to this office by indorsement their recommendations regarding the ballistic testing of these plates.

By Order of the Deputy Chief of Ordnance:

3 Incls.
cpys Insts.
file fm. W.A.
ltr to W.A.

S/T D. O. Poppel
Major, Ord. Dept.
Assistant

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WAR DEPARTMENT

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ORDNANCE DEPARTMENT

TANK—AUTOMOTIVE CENTER

UNION GUARDIAN BUILDING

Handova/mjk

DETROIT, MICH.

December 30, 1942

O.O.M. 451.25/2-249
SPOMT-F-20

Subject: Temper Brittleness Research Program.

To: Commanding Officer
The Proving Center
Aberdeen Proving Ground, Maryland

1. Reference: Letter to Aberdeen 12-3-42 O.O.M. 470.5/686

2. This office has made arrangements for three temper brittleness armor plates to be shipped to Aberdeen from Carnegie Illinois Steel Corporation and three from Henry Disston. The plates from Henry Disston should arrive within two weeks, while the plates from Carnegie Illinois should arrive in about three weeks. Three cast homogeneous plates will also arrive in approximately four weeks from General Steel Castings, Eddystone, Pennsylvania.

3. It is requested that after ballistic testing, specimens be cut from three plates and appropriately marked for identification purposes, and sent to Watertown Arsenal. These samples should be so removed from the plates that the ballistic firing will have had no effect upon them. They should be approximately six inches by nine inches in size in order that transverse and longitudinal and Izod specimens can be cut from them. These samples are to be forwarded for each rolled homogeneous plate submitted for this purpose.

4. Separate cast coupons are being obtained for all cast plates submitted, therefore, cast samples will not be required from Aberdeen.

5. Firing reports should carry the notation, "Temper Brittleness Research Program".

For the Deputy Chief of Ordnance:

E. L. CUMMINGS,
Colonel, Ord. Dept.,
Assistant.

BY

J. V. COOLBE, MAJOR

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Wtn 470.5/6930

DDM 470.5/252

Attn: SPOME-E-22.1, Project #1040 1st Ind.

Reed/NAM/dmj

C.O., Watertown Arsenal, Watertown 72, Mass., 30 September 1943

To: Chief, Tank-Automotive Center, Fisher Bldg., Detroit 2, Michigan.
Attn: SPOME-E-22.1, Project #1040.

1. The results of this investigation indicated that the samples of cast and rolled armor slowly cooled from the draw temperature were relatively more brittle (as measured by the V-notch Charpy Test) than the samples quickly cooled from the draw. It is noted that there is a considerable variation in the V-notch Charpy value of each type analysis. This is due to the fact that the samples as received were incompletely quench-hardened to various degrees - resulting in fractures which were from 100% crystalline to fractures which were nearly all fibrous. Furthermore, the relatively low Charpy values obtained at sub-zero temperatures are correlated with heterogeneous microstructures which are the result of incomplete quench-hardening.

2. Generally speaking, molybdenum was not effective in eliminating embrittlement noted in samples slowly cooled from the draw.

3. The embrittling effect noted on the rolled armor plates (ref. APG Report No. AD-379) which were slowly cooled from the draw may have been due to the fact that these rolled plates were subjected to a more severe ballistic test as compared to the cast plates which also were slowly cooled from the draw.

4. A complete report on this investigation is in preparation and will be forwarded to his office as soon as available.

For the Commanding Officer:

G. L. COX,
Lt. Col., Ord. Dept.
Assistant.

2 Incls.

Incl. 1 n/c)not incl.

Added 1 Incl.)in this

Incl. 2 Data Sheet)report

~~RESTRICTED~~

TABLE III

Summary of V-Notch Charpy Impact Test
Cast and Rolled Armor Cooled Quickly

Manufacturer	Sample No.	Chemical Composition								Draw Temp Subseq Cooling
		C	Mn	Si	Cr	Ni	Mo	Cu	Zr	
CAST ARMOR American Steel Foundries (Basic OH)	C-371A	.29	1.57	.52	.30	-	.09	-	-	1150°F, quenched
	C-371B	.29	1.57	.52	.30	-	.09	-	-	1150°F, cooled to
Continental Roll & Steel Foundry Co. (Acid OH)	5315A1	.31	1.21	.37	.46	.36	.50	-	-	1220°F, quenched
	5315A3	.31	1.21	.37	.46	.36	.50	-	-	1220°F, cooled to 39° per
McConway & Torley (Acid Electric)	494-1	.29	1.50	.48	-	-	.47	-	-	1180°F, quenched
	494-2	.29	1.50	.48	-	-	.47	-	-	1180°F, cooled to over a p of 30 ho
General Steel Castings Co. (Basic OH)	7110-2	.29	1.56	.39	.50	-	.31	-	-	1125°F,
	7110-3	.29	1.56	.39	.50	-	.31	-	-	1125°F, f

*Porosity at center of section associated with crystallinity. None on end and surface.

Numbers in parentheses indicate difference between Charpy value of s

TABLE III

V-Notch Charpy Impact Tests and Other Metallurgical Properties of
Armor Cooled Quickly and Slowly from the Drawing Temperature

Composition			Draw Temp. and Subsequent Cooling Rates	Ave. BHN Hardness Tests Made at W.A.	V-Notch Charpy Impact Values			Fracture Tests Made on Coupons at Room Temp.
Mo	Cu	Zr			Room Temp. +70°F.	0°F.	-40°F.	
.09	-	-	1150°F, water quenched	200	70	51.4	30.5	40% fibre, 60% crystalline
.09	-	-	1150°F, furnace cooled to 300°F	198	51.8 (18.2)	30.3 (21.1)	17.1 (13.4)	"
.50	-	-	1220°F, water quenched	235	54.8	52.6	42.0	70% fibre, 30% crystalline
.50	-	-	1220°F, furnace cooled to 300°F 39° per hour	231	48.5 (6.3)	35.2 (17.4)	22.8 (19.2)	"
.47	-	-	1180°F, water quenched	251	33.1	33.9	32.4	*50% fibre, 50% crystalline
.47	-	-	1180°F, slowly cooled to 300°F over a period of 30 hours	245	25.6 (7.5)	22.8 (11.1)	20.6 (11.8)	"
.31	-	-	1125°F, air cooled	269	64.0	60.3	38.3	Fibrous, trace of crystalline
.31	-	-	1125°F, furnace cooled	241	51.4 (12.6)	51.4 (8.9)	36.9 (1.4)	"

crystallinity. More evidence of fibre halfway between center

seen Charpy value of samples quickly and slowly cooled from the draw.

TABLE III

Metallurgical Properties of
Iron and Steel as a Function of
the Drawing Temperature

V-Notch Charpy Impact Values			Fracture Tests Made on Coupons at Room Temp.	Typical Microstructure at Midwall of Coupon
Room Temp. +70°F.	C°F.	-40°F.		
70	51.4	30.5	40% fibre, 60% crystalline	Sorbite and ferrite
51.8 (18.2)	30.3 (21.1)	17.1 (13.4)	"	"
54.8	52.6	42.0	70% fibre, 30% crystalline	Sorbite, trace of ferrite
48.5 (6.3)	35.2 (17.4)	22.8 (19.2)	"	Sorbite, grain boundary carbides
33.1	33.9	32.4	*50% fibre, 50% crystalline	Sorbite, some ferrite
25.6 (7.5)	22.8 (11.1)	20.6 (11.8)	"	Tempered martensite
64.0	60.3	38.3	Fibrous, trace of crystalline	Segregated fine carbide
51.4 (12.6)	51.4 (8.9)	36.9 (1.4)	"	Sorbite

halfway between center

and slowly cooled from the draw.

TABLE III (CONT'D)

Manufacturer	Sample No.	Chemical Composition								Drawn Su Cool
		C	Mn	Si	Cr	Ni	Mo	Cu	Zr	
Pacific Car & Foundry Co. (Basic Electric)	1	.22	1.18	.54	-	-	.40	1.28	-	1200
	2	.22	1.18	.54	-	-	.40	1.28	-	1200 cool
Wehr Steel Co. (Acid Electric)	TBR-1-584	.27	.60	.50	.66	.62	.31	-	-	1150
	TBR-1-583	.27	.60	.50	.66	.62	.31	-	-	1150 cool
Union Steel Castings Co. (Acid OH)	829	.29	1.70	.40	-	-	.55	-	-	1225
	830	.29	1.70	.40	-	-	.55	-	-	1225
<u>ROLLED ARMOR</u>										
Henry Disston & Sons, Inc. (Basic OH)	AR1990-1	.22	.81	.23	.53	1.09	.31	.08	-	1150
	AR1990-2	.22	.81	.23	.53	1.09	.31	.08	-	1150 cool in 2
Great Lakes Steel Corp. (Basic OH)	1	.29	1.10	.81	.61	-	.25	-	.08	1230
	2	.29	1.10	.81	.61	-	.25	-	.08	1230

**Some crystallinity at center of section. More evidence of fibr

Numbers in parentheses indicate difference between Charpy value

TABLE III (Cont'd)

Composition					Draw Temp. and Subsequent Cooling Rates	Ave. BHN Hardness Tests Made at W.A.	V-Notch Charpy Impact Values			Fracture Made at at Room
Cr	Ni	Mo	Cu	Zr			Room Temp. +70°F.	0°F.	-40°F.	
-	-	.40	1.28	-	1200°F, air cooled	190	52.5	12.0	7.4	100% fracture
-	-	.40	1.28	-	1200°F, furnace cooled to 240°F	198	43.4 (9.1)	34.1 (-22.1)	8.1 (-.7)	
.66	.62	.31	-	-	1150°F, air cooled	246	39.5	31.3	21.5	80% fracture
.66	.62	.31	-	-	1150°F, furnace cooled to 300°F	243	32.8 (6.7)	24.5 (6.8)	14.1 (7.4)	
-	-	.55	-	-	1225°F, water quenched	241	39.2	28.8	24.7	**80% fracture
-	-	.55	-	-	1225°F, air cooled	229	19.8 (19.4)	12.9 (15.9)	10.6 (14.1)	
.53	1.09	.31	.08	-	1150°F, air cooled	248	72.7	74.6	81.3	100% fracture
.53	1.09	.31	.08	-	1150°F, furnace cooled to 300°F in 21 hours	233	63.2 (9.5)	67.1 (7.5)	73.1 (8.2)	
.61	-	.25	-	.08	1230°F, air cooled	260	57.2	54.8	23.1	100% fracture
.61	-	.25	-	.08	1230°F, furnace cooled	257	30.4 (26.8)	29.6 (25.2)	11.0 (12.1)	

n. More evidence of fibre halfway between center and surface.

rence between Charpy value of samples quickly and slowly cooled from draw.

24/3

TABLE 3 CONT'D

cont'd)

Ave. BHN Hardness	V-Notch Charpy Impact Values			Fracture Tests Made on Coupons at Room Temp.	Typical Microstructure at Midwall of Coupon
	Room Temp.	0°F.	-40°F.		
Tests Made at W.A.	+70°F.	0°F.	-40°F.		
190	52.5	12.0	7.4	100% crystalline	Spheroidized carbide and ferrite
198	43.4 (9.1)	34.1 (-22.1)	8.1 (-.7)	"	"
246	39.5	31.3	21.5	80% fibre, 20% crystalline	Sorbite and ferrite
243	32.8 (6.7)	24.5 (6.8)	14.1 (7.4)	"	"
241	39.2	28.8	24.7	**80% fibre, 20% crystalline	Sorbite and some ferrite
229	19.8 (19.4)	12.9 (15.9)	10.6 (14.1)	"	"
248	72.7	74.6	81.3	100% fibre	Sorbite and ferrite
233	63.2 (9.5)	67.1 (7.5)	73.1 (8.2)	"	Sorbite trace of ferrite
260	57.2	54.8	23.1	100% fibre	Sorbite
257	30.4 (26.8)	29.6 (25.2)	11.0 (12.1)	"	"

ween center and surface.

quickly and slowly cooled from draw.

3 of 3

(2)

TABLE III (CONT'D)

TABLE

Manufacturer	Sample No.	Chemical Composition								Draw Temp Subsequ Cooling
		C	Mn	Si	Cr	Ni	Mo	Cu	Zr	
Standard Steel Spring Co. (Basic Oxi)	1728	.26	1.68	.25	-	-	.27	-	-	B added 1190°F, w que
	1729	.26	1.68	.25	-	-	.27	-	-	B added 1190°F, fu c

NOTE: V-notch Charpy bars cut from rolled plates in the longitudinal
V-notch Charpy values shown above are an average of two tests.

Numbers in parentheses indicate difference between Charpy value

TABLE III (Cont'd)

Condition	Mo	Cu	Zr	Draw Temp. and Subsequent Cooling Rates	Ave. BHN Hardness Tests Made at W.A.	V-Notch Charpy Impact Values			Fracture Tests Made on Coupons at Room Temp.
						Room Temp. +70°F.	0°F.	-40°F.	
27	-	-	-	1190°F, water quenched	262	60.5	57.5	39.4	100% fibre
27	-	-	-	1190°F, furnace cooled	250	56.2 (4.3)	36.9 (20.6)	25.4 (14.0)	"

in the longitudinal direction.
Average of two tests.

between Charpy value of samples quickly and slowly cooled from draw.

TABLE III (CONT'D)

V-Notch Charpy Impact Values			Fracture Tests Made on Coupons at Room Temp.	Typical Microstructure at Midwall of Coupon
Room Temp.	0°F.	-40°F.		
+70°F.	0°F.	-40°F.	100% fibre	Sorbite and ferrite
60.5	57.5	39.4	"	Sorbite and ferrite Acicular pattern
56.2 (4.3)	36.9 (20.6)	25.4 (14.0)		

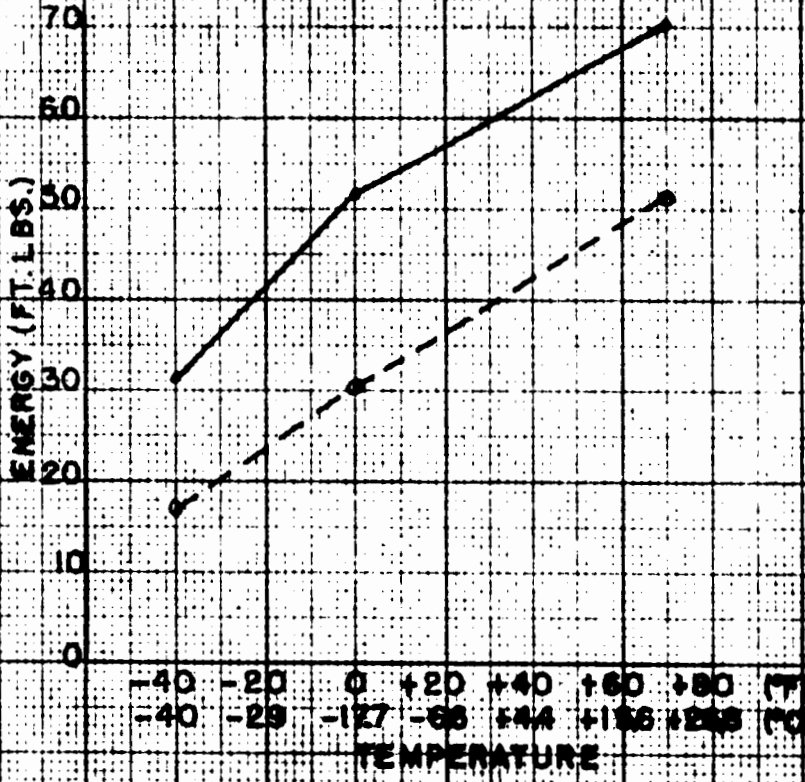
ickly and slowly cooled from draw.

3 of 3

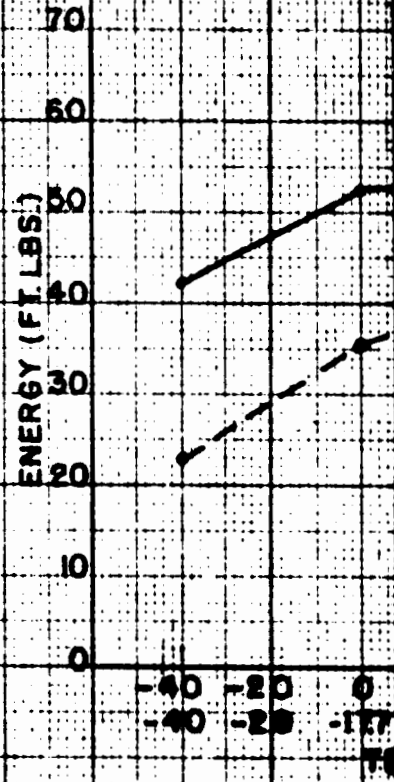
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TEMPER BRITTLENESS PROGRAM

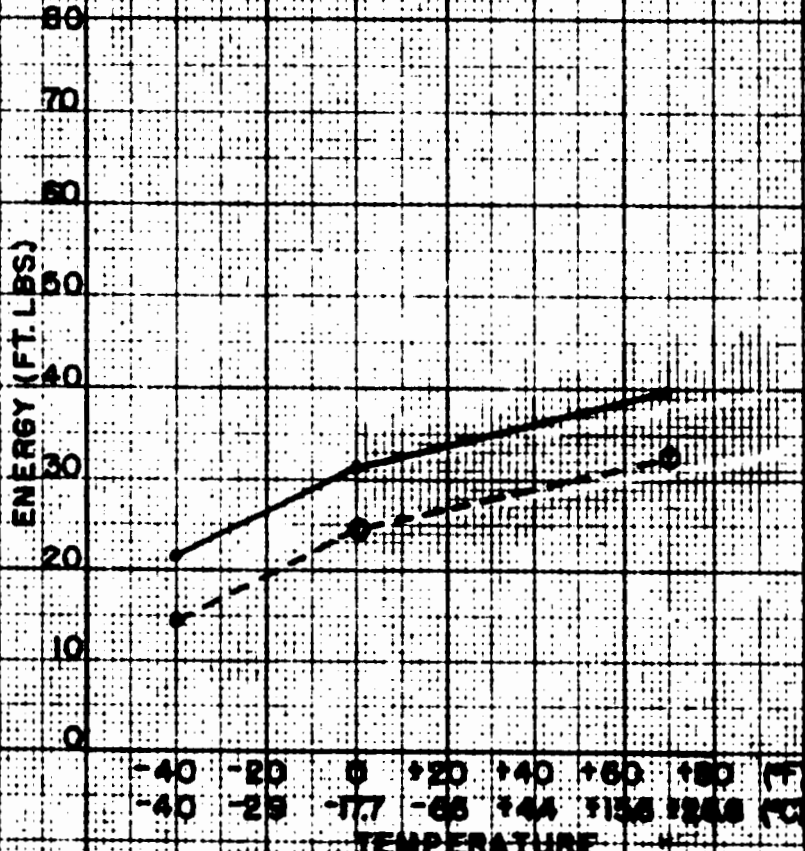
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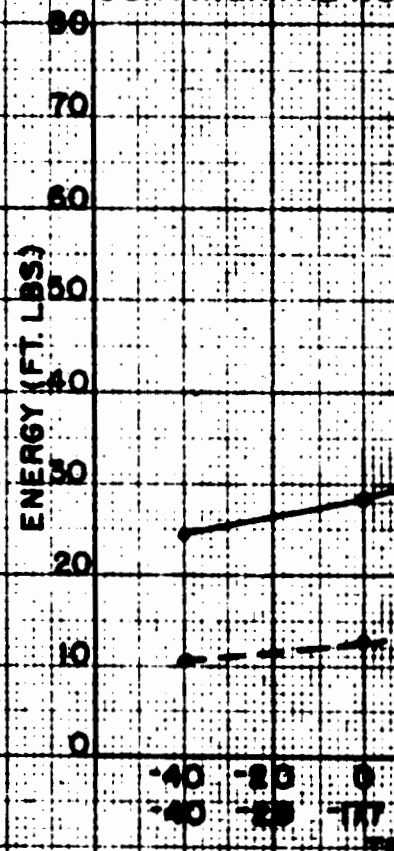
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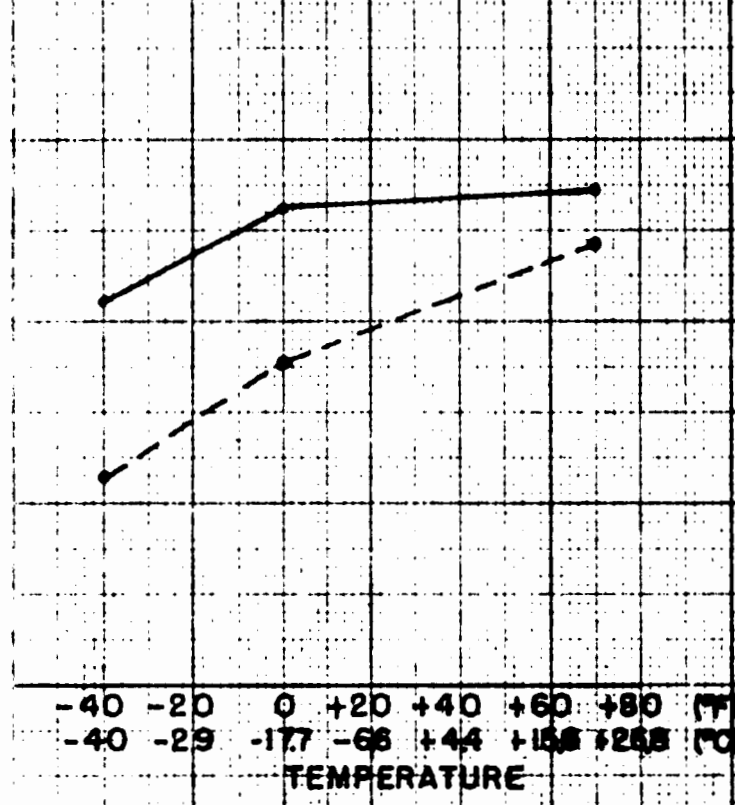


WEHR STEEL CO.

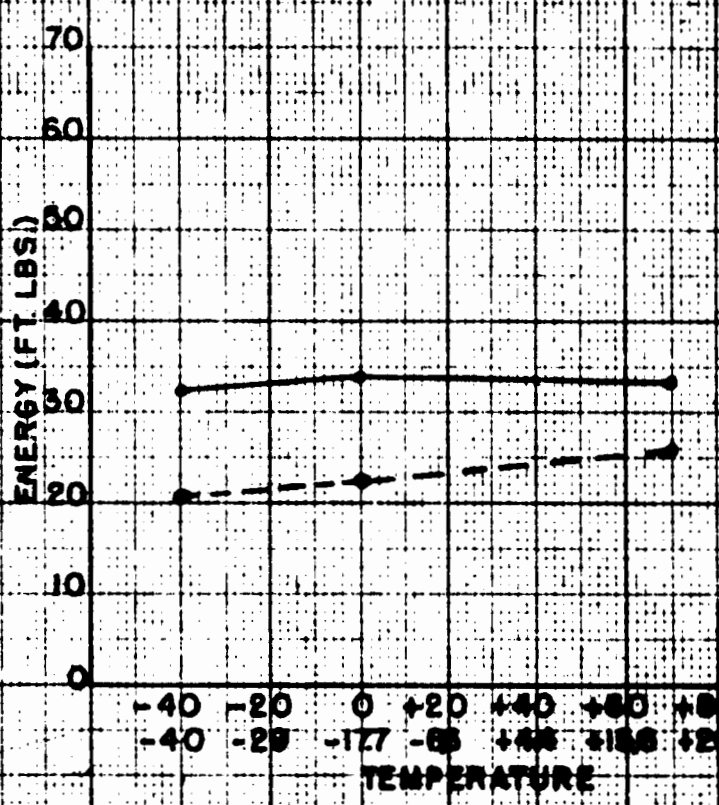


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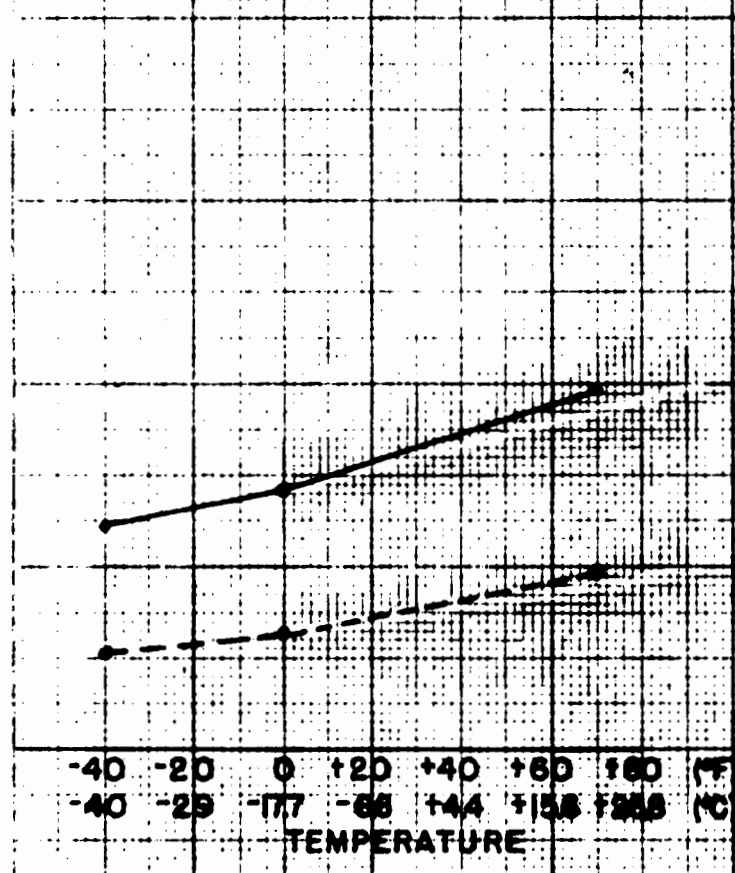
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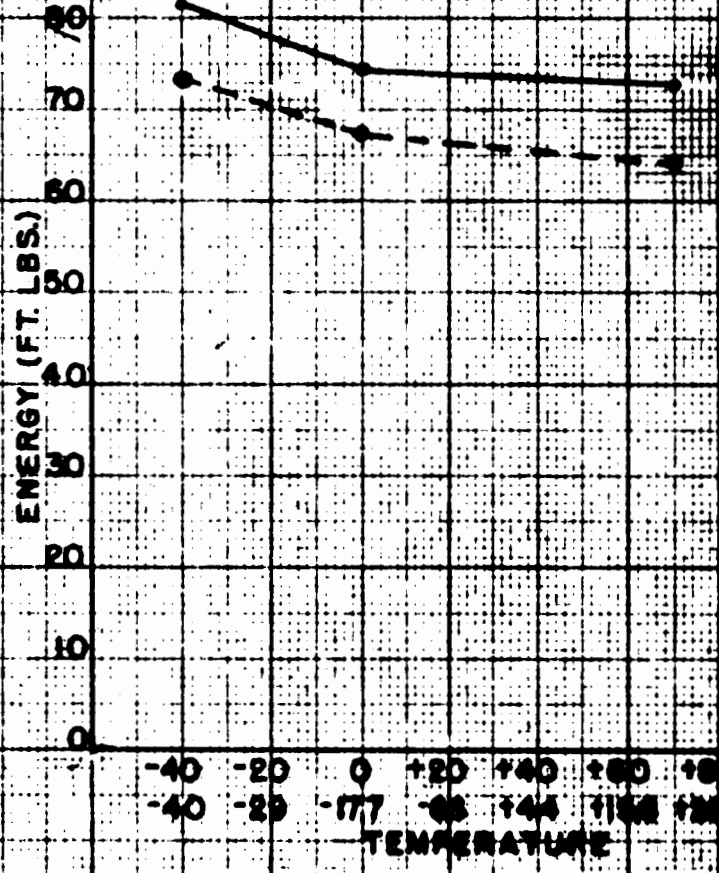
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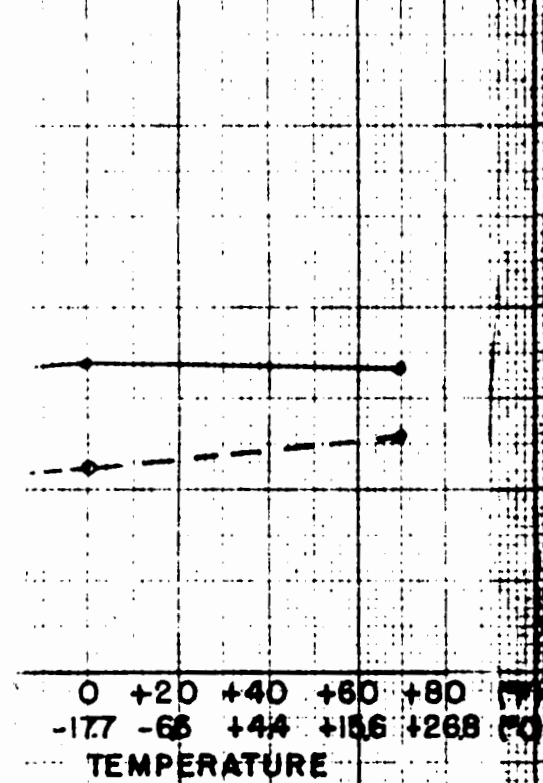


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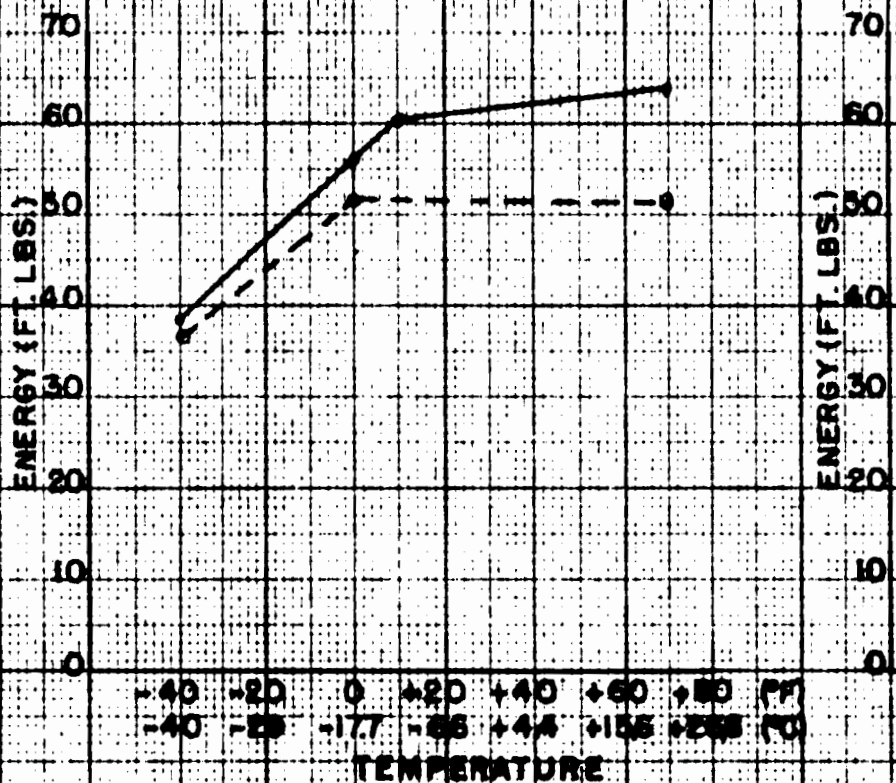


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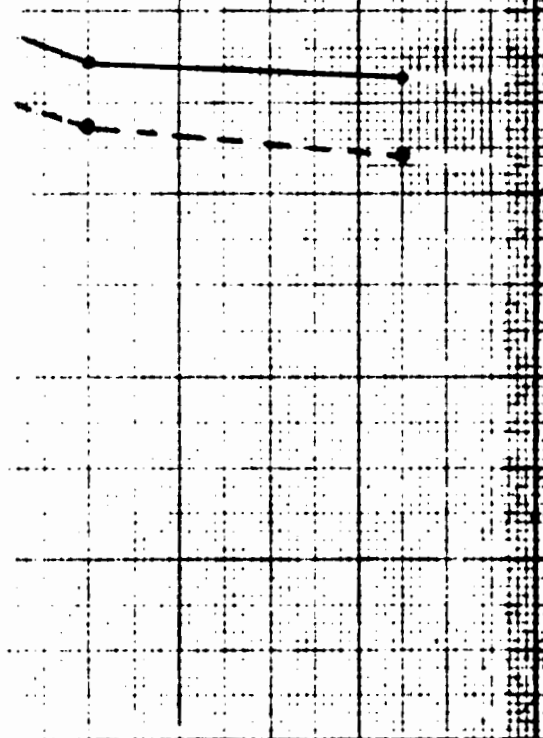
3 ROLLED ARMOR QUICKLY & SLOWLY COOLED FROM THE DRAW



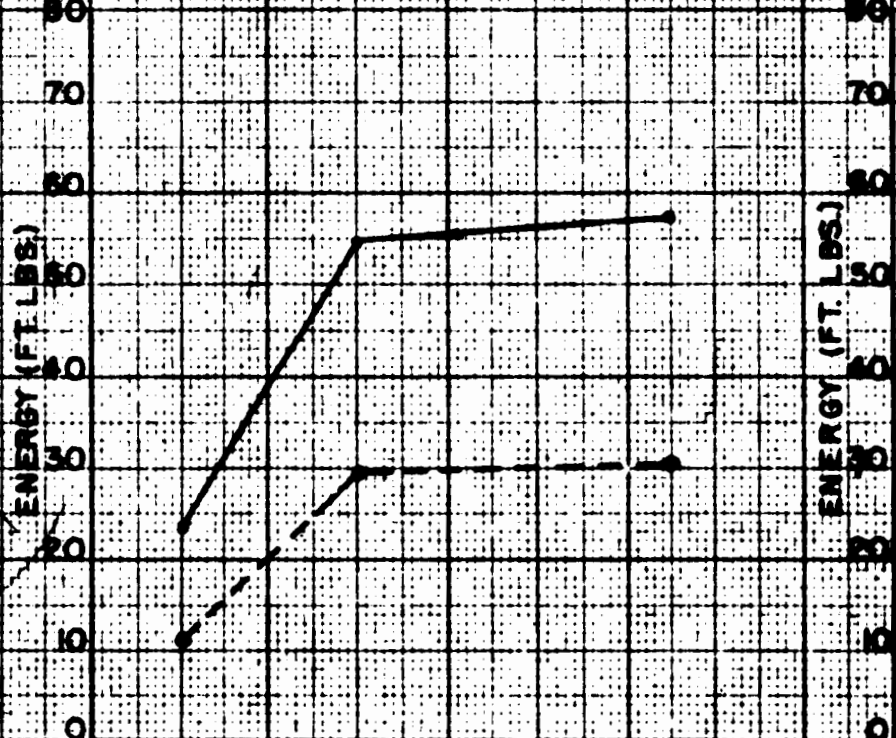
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GENERAL STEEL CASTINGS CO.



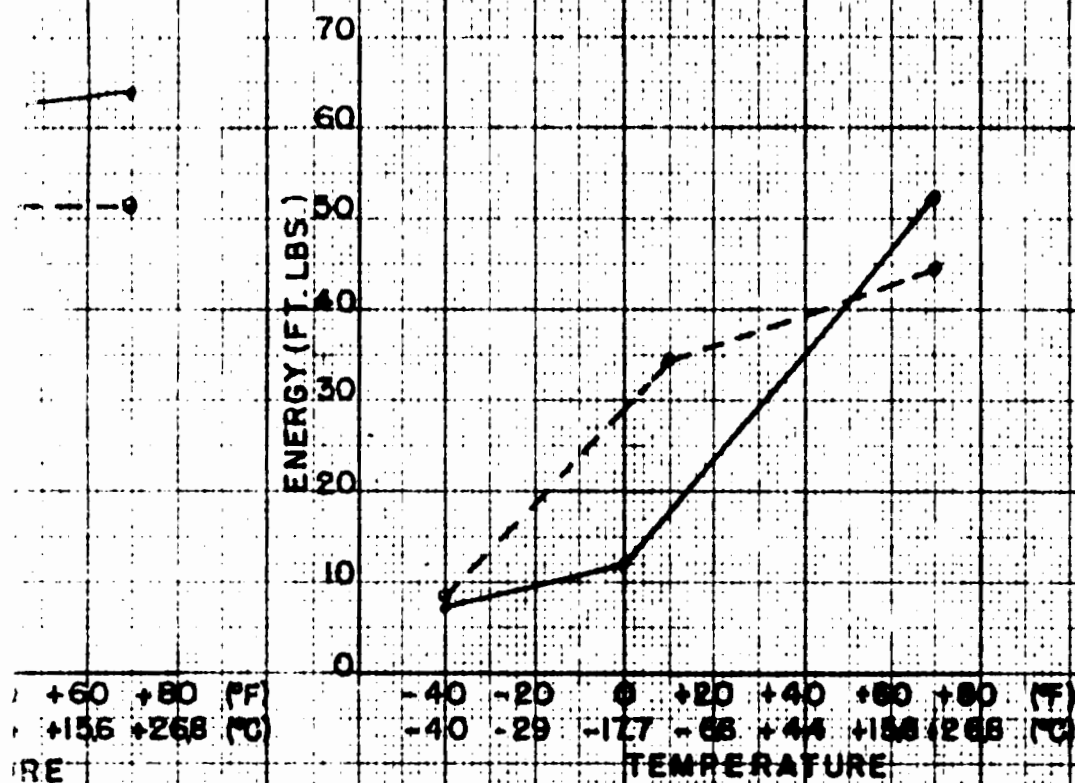
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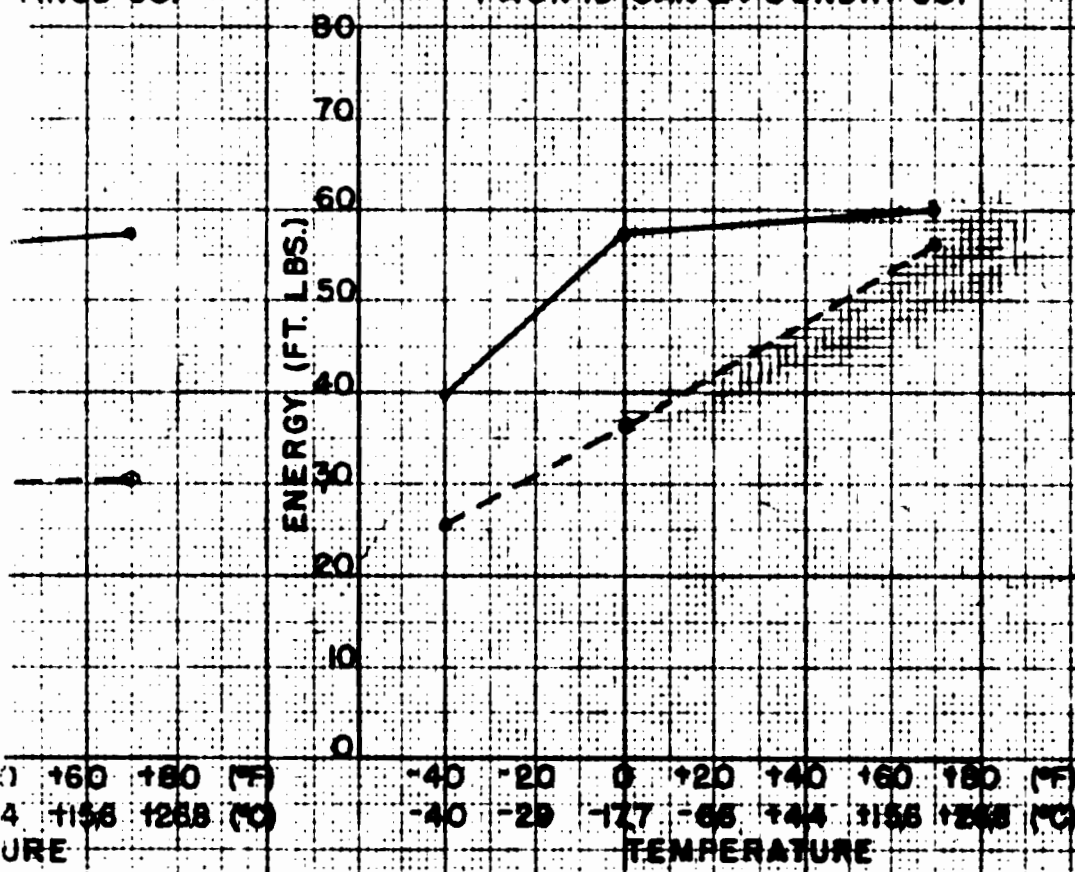
GREAT LAKES STEEL CORP.

FROM THE DRAWING

REPRODUCED AT GOVERNMENT EXPENSE
TEMPERATURE



PACIFIC CAR & FOUNDRY CO.



QUICKLY COOLED FROM DRAWING TEMPERATURE

SLOWLY COOLED FROM DRAWING TEMPERATURE

STANDARD STEEL SPRING CO.

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END