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WATERTOWN ARSENAL
LABORATORY

MEMORANDUM REPORT

NO. WAL 710/763

AD-A954 819

710/763

Resistance of Various Steels to Perforation by Fragment-

Simulating Projectiles

BY

J. F. Sullivan
Assoc. Ord. Eng.

UNCLASSIFIED

DATE 15 September 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/763

Partial Report on Problem B-8.2

15 September 1945

Resistance of Various Steels to Perforation by
Fragment-Simulating Projectiles

1. In response to requests of the Office, Chief of Ordnance¹⁻⁸, and in cooperation with various steel producers, tests have been conducted at this laboratory, over a period of several months, on various steels in varying conditions of treatment. While the results of these tests have been reported, as they have been completed in Watertown Arsenal reports, an attempt is made in this report to collate and integrate the results of the several tests.

2. In attempting to evaluate by means of a single ballistic limit test, the relative resistance of various materials with respect to service attack, there were developed at this laboratory several fragment-simulating projectiles⁹⁻¹¹. These projectiles, in addition to cal. .45 ball projectiles which have been used traditionally to evaluate ballistically helmet materials^{12,13}, have been used to test materials submitted to this laboratory for ballistic evaluation. The results of tests conducted on the various steels are recited in Tables I to XIX.

3. Although tests conducted at Aberdeen Proving Ground, in which 20 mm. H.E. shell are statically detonated, have shown such a disappointing lack of correlation with ballistic limit tests conducted here as to discourage sole reliance upon the latter, it is considered desirable to collect into a single report the results of tests upon similar materials and compare them.

4. Inasmuch as the samples tested have been of various thickness, some difficulty arises in attempting to compare them. In order to surmount this difficulty, there has been taken the liberty of assigning to each sample a figure of merit based upon the relation of its resistance to perforation by a given projectile to that which has been characteristic of average samples of Hadfield manganese steel of equivalent weight. Since this latter characteristic is reliably known only in the ranges .040" to .050", figures of merit have been assigned only to samples whose weight per unit area is equivalent to Hadfield manganese steel in this thickness range. The samples thus submitted appear in order of ascending weight per unit area in Table XX with respect to resistance to perforation by the .45 ball projectile and in Table XXI with respect to resistance to perforation by the .45 ball fragment-simulator, G-2 (237).

5. The results of the various tests may be summarized as follows:

a. Hadfield Manganese Steel

Since there was available a considerable store of knowledge concerning Hadfield manganese steel, as a result of its use in helmets, its most resistant condition, according to extent criteria, was rather well defined and, aside from a few corroborative studies of the effect of variation in hardness, microstructure and thickness¹⁴⁻¹⁵, the efforts of this laboratory were, for the most part, expended in the development of inspection tests which would tend to eliminate material of inferior quality.

The results of the various tests indicated that dead soft (Rockwell "B" about 90) Hadfield manganese steel, free of decarburization and free of undissolved carbides, represented the optimum condition of that material as regards resistance to perforation by fragment-simulating projectiles.

b. Stainless Steel

Stainless steel was tested in three conditions of hardness induced by cold working¹⁹. In the "1/4 hard" (27 Rockwell "C") condition it exhibited much better overall resistance characteristics than in the "1/2 hard" (33 Rockwell "C") or "full hard" (45 Rockwell "C") conditions (Table II). Later tests (Table XVa) corroborated these findings, although the differences were less distinct, and indicated that when the nickel content of an 18-8 stainless steel was increased from 7% to 9.5% a drop in elongation occurred which was reflected in a drop in resistance to perforation²⁰.

c. SAE 4330 Steel

This steel, as heat-treated to a hardness of Rockwell "C" 34 to 36, exhibited resistance characteristics which were inferior to other ferritic steels (Table II)²¹.

d. SAE 4340 steel (Modified)

Samples of a modified SAE 4340 steel as normalized, oil quenched and tempered to 30, 40 and 50 Rockwell "C" were tested (Table VII). No appreciable difference in the perforation resistance of this steel at 30 Rockwell "C" and at 50 Rockwell "C" was observed²². The steel of intermediate hardness was somewhat inferior to these and all were substantially inferior to Hadfield manganese steel of equivalent weight. The quality of these samples was very poor, however, and directional failing due to non-metallic stringers was frequent.

e. Mn-Mo Steel

Several samples of manganese-molybdenum steels have been tested (Tables III, X, XI and XIII). The manganese content of these steels varied from 1.19% to 1.80% and the molybdenum content from .31% to .51%

while the carbon content hovered about .25%. Various heat treatments were employed: water quench; water quench, followed by tempering; oil quench; oil quench, followed by tempering; and austemper, with and without agitation. While no clean-cut decisions could be made because of the variability of samples, it appeared that samples as-quenched, with a stress-relief treatment at 300°F, were superior to samples in any other condition²⁵⁻²⁶. Samples at the lower end of the .040" to .050" thickness range were substantially inferior to Hadfield manganese steel, but as the gauge approached the .050" mark samples of this steel showed equivalence to, or even slight superiority over, the austenitic steel of equivalent weight.

f. 0.70% Carbon Anala Steel

The resistance of a normalized, oil quenched sample of this material, tempered to 41/42 Rockwell "C" was inferior to that of a normalized, oil quenched sample tempered to 49/51 Rockwell "C" under impact of cal. .22 fragment simulating projectiles and samples austempered to 49/50 Rockwell "C" and 53/54 Rockwell "C" were substantially superior to both although inferior to Hadfield manganese steel (Table IV). Under impact of cal. .45 ball projectiles, very little difference in resistance was demonstrated among the samples tested²⁷.

g. Silico-Manganese Spring Steel

A .042" sample of this steel, tempered to 49 Rockwell "C" exhibited resistance to perforation by cal. .22 fragment-simulating projectiles, G-2, superior to that of an equivalent weight of Hadfield manganese steel, but under impact of the cal. .45 steel-jacketed ball projectile, the resistance of a similar sample was greatly inferior (Table XII). The resistance of samples tempered to 40/43 Rockwell "C" was considerably inferior under both types of attack²⁸.

h. Si-Mn-Cr-Mo and Cr-Mo-V Steels

Samples of steels of these two types were given three different heat treatments: oil quench and temper; austemper; and normalize. The normalized samples (Rockwell "C" 49 and 51, respectively) afforded greatest resistance to perforation by both types of projectiles and both types appeared to offer equal protection (Table VIII)²⁹. The quenched and tempered samples (Rockwell "C" 23 and 37, respectively) gave poorest results with little to choose between types. The austempered samples (both 46 Rockwell "C") produced intermediate results, with the Si-Mn-Cr-Mo steel exhibiting slightly superior resistance characteristics. All samples, however, were considerably inferior to the Hadfield types.

i. An Austenitic Steel

Samples of an austenitic steel of special analysis were tested "as annealed", and as "1/4 Hard", "1/2 Hard", and "Full Hard"³⁰. The "as-annealed" sample was superior to that of the hardened samples. Under impact of the cal. .22 fragment-simulator, the "1/4 Hard" sample appeared to be best. Neither approached the performance of Hadfield steel under similar conditions of attack (Table IX).

j. SAE X4130 Steel

Samples of this steel were tested "as-rolled" and after an "oil quench and stress relief" treatment. "As-rolled" the resistance of this steel was very poor (Table XIV). Heat treatment of a sample which was .048" thick increased its resistance to both types of projectile impact to the point that its performance duplicated that of Hadfield manganese steel of equivalent gauge³¹.

k. AE-8630 Steel

Samples of this steel were tested "as-rolled" and after the same heat treatment as was the SAE X4130 steel above (j). These samples were .042"/.043" thick and, although heat-treatment increased the resistance of one sample to perforation by both projectiles, only its resistance to cal. .45 projectile perforation approached that of Hadfield steel (Table XIV)³².

l. AE-8620 Steel

Samples of AE-8620 steel "as-quenched" and "as-tempered" at various temperatures were tested (Table XVI). The "as-quenched" samples again exhibited the best resistance characteristics. However, even "as-quenched", these samples did not compare with the AE-8630 samples above (k), which were heat treated here³³.

m. Ni-Mo Steel

Samples of a nickel-molybdenum steel in several conditions of heat treatment were tested (Table XVII)³⁴. Under impact of the cal. .45 ball projectiles a normalized sample provided superior resistance. Under impact of cal. .22 fragment-simulating projectiles, the normalized sample and a sample stress relieved at 300°F. after quenching in oil were superior to samples which had received other heat treatment. None approached the performance of Hadfield manganese steel, however.

n. Si-Cr-Mo-Zr Steels

Samples of a Si-Cr-Mo-Zr steel in several conditions of heat treatment were tested (Table XVII). Under impact of cal. .45 ball projectiles, samples "as-quenched", "normalized", and "austempered at 675°F." were superior to others, and under impact of the cal. .22 fragment-simulator a sample stress-relieved at 300°F. after quenching and a sample "as-quenched" were greatly superior to other samples and equivalent to Hadfield manganese steel³⁵. All these samples were in the upper end of the thickness range, .040" to .050".

6. Since the resistance of steels other than the Hadfield manganese type to perforation by actual fragments of high-explosive shell has not been definitely established, no authoritative estimate of their relative merits can be made.

7. However, if resistance to perforation by the cal. .22 fragment-simulating projectiles, G-2, may be considered a criterion of a steel's

resistance to perforation by actual fragments, the following observations are permissible:

a. For consistent high resistance to perforation, in thicknesses of .040" to .045", Hadfield manganese steel, free of decarburization and free of undissolved carbides, is outstanding;

b. Silico-manganese steel, tempered to a hardness of about 50 Rockwell "C" merits additional investigation and should be given an actual fragmentation test;

c. As the thickness nears the .050" gauge, ferritic steels appear to be able to match and sometimes better the performance of Hadfield manganese steel;

d. Among ferritic steels, greater resistance tends to attend higher hardness, unless inordinate brittleness accompanies the hardness;

e. Thus, "as-quenched" samples tend to be better than samples tempered to a lower hardness, but if the same hardness can be achieved by normalizing, or after a stress-relief treatment at about 300°F., the resulting product, with reduced brittleness, seems to afford slightly better protection.

f. Austenitic steels, in general, tend to offer greatest resistance in the "dead-soft" condition, as-annealed; this is not inconsistent with the observations made on ferritic steels, since in the case of the austenitic steels, increases in hardness above the "dead-soft" level must be induced by work-hardening which apparently introduces brittleness, even when only slightly applied.

J. F. Sullivan

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APPROVED:

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APPENDIX A

TABLE I

(Reference - Report No. WAL 110/568)

Ballistic Limits of Various Samples of Steels with Different Projectiles
and at Different Temperatures - Fired at Watertown Arsenal, 1 to 6 December 1943

Identifi- fication	Dimensions (Inches)	Gauge (Inches)	Hardness	Type	Ballistic Limits		
					(Projectile or Piece Thereof T.R.)	Cal. .45 (+30°F.)	Cal. .45 (-6°F.)
C	12x12	.048	75 Rb	Ferritic Steel	< 745	< 890	425
D	-	.048	23 Rc	Ferritic Steel	820	< 870	463
B	-	.043	35 Rc	Ferritic Steel	940	< 880	413
F	-	.043	88 Rb	Hadfield Steel	1117	955	545
E	-	.043	30 Rc	Hadfield Steel	948	943	418
A	-	.046	40 Rc	Hadfield Steel	928	Cracked	< 415
A-62	-	.044	92 Rb	Hadfield Steel	1151	1175	501
G-5	Helmet	.040	50 Rc	Hadfield Steel	-	< 920	-
G-2	-	.040	90 Rb	Hadfield Steel	-	925	-
K-5	-	.040	50 Rc	Hadfield Steel	-	< 920	-
H-2	-	.040	90 Rb	Hadfield Steel	-	1010	-

APPENDIX A

TABLE II

(Reference - Report No. WAL 710/615)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Four Types of Steels Submitted by Republic Steel Corporation

Sample	Gauge	Ballistic Limit (V/S)	
		0-2 (Cal. .22, 17 Grains)	Standard Cal. .45 Ball
1/4 Hard Stainless (Rockwell C-27)	.0512	1675	912
1/2 Hard Stainless (Rockwell C-33)	.0468	1173	646
Full Hard Stainless (Rockwell C-45)	.0448	1118	658
S&S 4330 (Rockwell C-36)	.0488	1553	698
S&S 4330 (Rockwell C-34)	.0508	1545	655
Hadfield Manganese (Average)	.0508	1750	1000

*Steel-jacketed.

APPENDIX A

TABLE III

(Reference - Report No. WAL 710/617)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of a Mn-Ni Type Steel Submitted by

Jones and Laughlin Steel Corporation and Breese Corporations, Inc.

Sample	Gauge	Chemical Composition					Tempering Temp. (°F.) 1 hour	Hardness Rockwell "C"	Ballistic Limit F/S		
		C	Mn	Si	S	P				0-21 Cal.	0-21 Cal.
GU-1	.023*	.23	1.19	.19	.020	.017	.33	As quenched	35	880	—
GU-2	.031*	.23	1.19	.19	.020	.017	.33	600*	29	775	—
GU-3	.030*	.23	1.19	.19	.020	.017	.33	700*	26	785	—
GU-4	.030*	.23	1.19	.19	.020	.017	.33	800*	18	750	333
GT-9	.039*	.24	1.50	.20	.016	.018	.31	As quenched	41	1375	699
GT-10	.040*	.24	1.50	.20	.016	.018	.31	600*	35	1105	494
GT-11	.038*	.24	1.50	.20	.016	.018	.31	700*	34	1050	less than 409
GT-12	.038*	.24	1.50	.20	.016	.018	.31	800*	33	1055	459
GT-1	.049*	.24	1.50	.20	.016	.018	.31	As quenched	35	1913	1027
GT-2	.048*	.24	1.50	.20	.016	.018	.31	600*(F)	29	1775	874
GT-3	.050*	.24	1.50	.20	.016	.018	.31	700*(F)	37	1920	1042
GT-4	.054*	.24	1.50	.20	.016	.018	.31	800*(F)	31	1833	617

All plates above were quenched in oil at 1250°F. from twenty minute re-heat at 1600°F.

Hadfield

NonQuenched

Steel (Average) .040*

— — — — — 1600 900

Hadfield

NonQuenched

Steel (Average) .050*

— — — — — 1750 1000

1. Cal. .22 (17 grains)

2. Standard cal. .45 ball ammunition (steel jacketed) 230 grains.

APPENDIX A

TABLE IV

(Reference - Report No. WAL 710/619)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Light Gauge (.041" to .046") Samples of 0.70% Carbon Armco Steel

Submitted by Carnegie-Illinois Steel Corporation

Nominal Chemical Composition

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Mo</u>
.60/.70	.70/.90	.040 max.	.040 max.	.20/.35	.20/.30

<u>Sample</u>	<u>Gauge</u>	<u>Hardness</u>	<u>Ballistic Limit (ft/s)</u>	
			<u>0-21</u>	<u>Cal. .45²</u>
<u>Item 9</u>				
Normalized, oil	.039"	41 Rc	1053	—
quenched and tempered.	.039"	42 Rc	—	514
<u>Item 10</u>				
Normalized, oil	.040"	49 Rc	1057	—
quenched and tempered.	.039"	51 Rc	—	615
<u>Item 11-A</u>				
Austempered	.044"	50 Rc	—	830
	.046"	49 Rc	1185	—
<u>Item 11-B</u>				
Austempered	.041"	53 Rc	1020	—
	.041"	54 Rc	—	827
<u>For Comparison:</u>				
Radfield	.040"	88 Eb	1600	900
Manganese Steel	.045"	88 Eb	1675	950

1. Cal. .22 (17 grains)

2. Standard cal. .45 ball ammunition (steel jacketed) 230 grains.

APPENDIX A

TABLE V

(Reference - Report No. WAL 710/630)

Summary of Comparative Ballistic Tests of Single Thin Gauge (.050") Steel
Sheets and Multi-Layered Assemblies of the Same Aggregate Weight

<u>Sample</u>	<u>Ballistic Limit (F/S)</u>	
	<u>Caliber .45¹</u>	<u>0-2²</u>
one .050" sheet	867 (partial penetration)	1574
two .025" sheets	-	1230
five .010" sheets	849 (complete penetration)	935

1. Standard caliber .45 ball ammunition (230 grains - steel jacketed).
2. Caliber .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE VI

(Reference - Report No. WAL 710/632)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Radfield Manganese Steel, As Annealed and After Hardening by Cold Reduction

Sample	Gauge	Hardness	Ballistic Limit (F/s)		
			G-1-A ¹	G-1-S ²	G-2 ³ Cal. .45 ⁴
As Annealed	.044 ⁵	89 Rb 88 Rb 87 Rb	-- -- 485	-- 1144 1033	949 -- 1570
Half-Hard (Nominal)	.040 ⁵	38 Rc 39 Rc	-- 345	614 --	-- 1232 613
3/4 Hard (Nominal)	.040 ⁵	37 Rc 36 Rc	-- --	-- --	-- 1184 625
Corrected for thickness difference ⁶					
As Annealed	.040 ⁵	--	--	(factor undetermined)	1325 ⁶ 909 ⁶

1. caliber .30 fragment-simulating projectile (150 grains)
2. caliber .30 fragment-simulating projectile (34 grains)
3. caliber .22 fragment-simulating projectile (17 grains)
4. caliber .45 ball ammunition (230 grains - steel jacketed)
5. 1570 - (4x15) = 1510
6. 949 - (4x10) = 909

APPENDIX A

TABLE VII

(Reference - Report No. WAL 710/633)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Thin-Gauge Samples of a Modified SAE 4340 Steel

in Three Conditions of Hardness

C	Mn	P	S	Si	Mn	C	Mo	V
.30/.40	.50/.80	.025 max.	.025 max.	.20/.35	1.50/2.00	.70/.90	.25/.50	.15 min.

Sample	Hardness	Gauge	Ballistic Limit (F/E)			
			G-1-A ¹	G-1-S ²	G-2 ³	Cal. .45 ⁴
Item 4	25 Rc	.042"	405	--	--	--
Normalized, oil quenched & tempered	29 Rc	.040"	--	820	1104	--
	31 Rc	.041"	--	--	--	592
Item 5	38 Rc	.040"	342	--	--	--
Normalized, oil quenched & tempered	39 Rc	.040"	--	817	1043	--
	40 Rc	.039"	--	--	--	493 P ⁵
Item 6	47 Rc	.039"	325	--	--	626
Normalized, oil quenched & tempered	52 Rc	.039"	--	810	1129	646

For Comparison:

Hardfield Manganese Steel

88 Eb .040" -- 900 1600 900

1. Caliber .30 fragment-simulating projectile - 150 grains.
2. Caliber .30 fragment-simulating projectile - 34 grains.
3. Caliber .22 fragment-simulating projectile - 17 grains.
4. Caliber .45 steel jacketed ball projectile - 230 grains.

APPENDIX A

TABLE VIII

(Reference - Report No. WAL 710/634)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Light-Gauge Samples of Si-Mn-Cr-Mo Steel and Cr-Mo-V Steel

Heat Treatment	Chemical Composition						Ballistic Limit (F/S)	
	C	Mn	Si	Cr	Mn	V	G-21	Cal. .452
Oil Quench: 1600°F. - 10 min. Oil quench	.44	.57	.22	1.08	.90	.21	1132	510
1050°F. - 1 hour Air Cool	.35	.81	.96	.75	.66	.25	1088	532
Austemper: 1500°F. - 10 min. Quench in salt at 600°F. Hold 1 hour Water quench		.041*					46 Rc	560
		.041*					46 Rc	613
Normalizer: 1600°F. - 10 min. Air Cool		.041*					51 Rc	777
		.040*					49 Rc	783
For Comparison: Heatfield Manganese Steel		.040*					83 Rc	900

1. Caliber .22 fragment-simulating projectile - 17 grains.
2. Caliber .45 steel-jacketed ball projectiles - 230 grains.

APPENDIX A

TABLE IX

(Reference - Report No. WAL 710/638)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Samples of an Austenitic Steel Submitted by Jessop Steel Co.

Sample	Gauge	Hardness	Ballistic Limit (F/s)	
			Cal. .451	C-22
Ac Annealed	.042"	255 BHN	728	1171
	.042"	255 BHN		
1/4 Hard	.045"	270 BHN	689	1203
	.045"	270 BHN		
1/2 Hard	.042"	282 BHN	625	1155
	.044"	282 BHN		
Full Hard	.045"	301 BHN	685	1237
	.046"	295 BHN		

For Comparison:

Hardfield

Manganese Steel

88 Rb

920

88 Rb

920

1630

1. Cal. .45 (steel-jacketed) ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectiles - 17 grains.

APPENDIX A

TABLE X

(Reference - Report No. WAL 710/648)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Light-Gauge Mn-Mo Steel As-Quenched and As-Tempered

at 300°F., 400°F., and 500°F.

Chemical Composition

C	Mn	Si	S	P	Mo	Hardening Treatment
.27	1.80	.21	.018	.015	.51	1575°F. - Water Quench

Sample	Gauge	Tempering		Hardness (Rc)		Ballistic Limit (F/S)
		Pre-Temper	Post Temper	Pre-Temper	Post Temper	
A-1	.041"	1 hr. - 500°F.	42-47	41-43	1004	less than 421
A-2	.041"	1½ hr. - 400°F.	38-44	40-42	1072	378
A-3	.041"	2 hrs. - 300°F.	50-53	47-50	1327	567
A-4	.039"	none	51-53	51-53	1163	651
B-1	.051"	1 hr. - 500°F.	44-48	39-41	1755	970
B-2	.051"	1½ hr. - 400°F.	49-51	45-46	1715	963
B-3	.051"	2 hrs. - 300°F.	50-52	47-49	1741	962
B-4	.051"	none	50-52	50-52	1750	plate split
For Comparison:						
Hadfield	.040"					
Manganese Steel	.050"				1600	900
					1750	1000

1. Cal. .22 fragment-simulating projectiles - 17 grains.
2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

APPENDIX A

TABLE XI

(Reference - Report No. WAL 710/554)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Samples of Mn-No Steel Made by Jones and Laughlin Steel Corporation
and Heat Treated by Breeze Corporations, Inc.

Chemical Composition

	C	Mn	Si	S	P	Mo
	.25	1.61	.22	.017	.020	.50

Hardening Treatment

All Plates Quenched in Oil from 1600°F.

Sample	Gauge	Heat Treatment After Quenching	Hardness	Ballistic Limit (F/S)	
				Cal. .45	0-2
HP-1	.042*	As Quenched	47 Rc	544	1092
HP-2	.041*	2 hrs. - 300°F.	45 Rc	546	1234
HP-3	.042*	1 1/2 hrs. - 450°F.	44 Rc	420	1215
HP-4	.040*	1 hr. - 600°F.	40 Rc	436	1270
HP-5	.040*	Austemper - 300°F.	45 Rc	592	1086

For Comparison:

Average Halffield Manganese steel	.040*	-	53 Rc	900	1600
--------------------------------------	-------	---	-------	-----	------

1. Cal. .45 (steel-jacketed) ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE XII

(Reference - Report No. WAL 710/667)

Summary of Penetration Tests Conducted at Watertown Arsenal on

Samples of Silico-Manganese Spring Steel

Chemical Composition

C Mn P S Si
 .55/.65 .70/1.00 .040 max. .040 max. 1.80/2.20

All plates normalized, oil quenched and tempered.

Sample	Gauge	Hardness	Ballistic Limit (F/S)	
			G-21	Cal..452
7-1	.042*	40 Rc	--	682
7-1	.043*	43 Rc	1170	-
8-1	.039*	51 Rc	--	679
8-5	.042*	49 Rc	1760	-
For Comparison:				
Hadfield Manganese				
Steel (Average)				
	.042*	88 Hb	1630	920

1. Cal. .22 fragment-simulating projectile - 17 grains.
2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

APPENDIX A

TABLE XIII

(Reference - Report No. WAL 710/563)

Summary of Results of Tests Conducted at Watertown Arsenal on:

Samples of Austempered Mn-No Steel

Chemical Analysis

C	Mn	Si	S	P	Mo
.25	1.61	.22	.017	.020	.50

Sample	Actual Gauge	Hardness Rockwell "C"	Austempering Temperature (In salt Bath)	Ballistic Limit (F/s)	
				Cal.	51
HF-6	.040"	46	450° F.	553	
HF-7	.042"	44	500° F.	580	
HF-8	.043"	42	600° F.	489	
HF-9	.042"	38	700° F.	536	
HF-10	.043"	45	500° F. (with agitation)	532	
<u>For Comparison:</u>					
Average Hadfield					
Manganese Steel	.043"	--	--	930	
Ne-8530 Steel ²	.042"	49	--	830	

1. Cal. .45 steel-jacketed ball projectile - 230 grains.
 2. WAL 710/672. NE-8530 steel heat treated at Watertown Arsenal.

APPENDIX A

TABLE XIV

(Reference - Report No. WAL 710/672)

Summary of Results of Tests Conducted at Watertown Arsenal on
Samples of X4130 Steel and 8630 Steel

Sample No.	Condition	C	Mn	P	S	Si	Ni	Cr	Mo	Actual Gauge	Hardness Rockwell "C"	Ballistic Limit (F/S)		
												Cal. .45	Cal. .22	
09-1	Heat Treated	.29	.47	.017	.025	.28	-	.98	.20	.043*	51	917	1633	
09-2	As Rolled	.29	.47	.017	.025	.28	-	.98	.20	.043*	22	916	--	
010-1	Heat Treated	.29	.73	.018	.028	.25	.46	.52	.17	.042*	49	980	1390	
010-2	As Rolled	.29	.73	.018	.028	.25	.46	.52	.17	.043*	24	375	--	
For Comparison:														
Average Hadfield														
Manganese Steel														
										.042*	--	920	1530	
										.043*	--	980	1720	

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE XVa

(Reference - Report No. WAL 710/693)

Summary of Results of Tests on 18-8 Stainless Steel

Sample No.	Actual Gauge	Hardness (Rockwell "C")	% Nickel	Condition	Ballistic Limit (F/S)	
					Gal. .45	Gal. .50
O-1	.042"	27	7.07	1/4 Hard	638	-
O-2	.042"	27	7.07	1/4 Hard	-	1055
O-4	.042"	27	7.07	1/4 Hard	616	-
O-5	.042"	27	7.07	1/4 Hard	-	1175
A-1	.042"	35	7.07	1/2 Hard	624	-
A-2	.042"	35	7.07	1/2 Hard	-	1052
B-1	.042"	42	7.07	Full Hard	656	-
B-2	.042"	42	7.07	Full Hard	-	1095
B-3	.042"	41	7.07	Full Hard	520	-
B-4	.041"	42	7.07	Full Hard	575	-
C-1	.041"	31	8.75	1/4 Hard	495	-
C-2	.042"	31	8.75	1/4 Hard	-	985
D-1	.042"	34	8.75	1/2 Hard	445	-
D-2	.042"	34	8.75	1/2 Hard	-	1035
E-1	.041"	39	8.75	Full Hard	462	-
E-2	.042"	39	8.75	Full Hard	-	900
F-1	.042"	30	9.53	1/4 Hard	433	-
F-2	.042"	29	9.53	1/4 Hard	-	1038
G-1	.041"	34	9.53	1/2 Hard	390	-
G-2	.042"	34	9.53	1/2 Hard	-	975
H-1	.040"	37	9.53	Full Hard	377	-
H-2	.042"	38	9.53	Full Hard	-	915
For Comparison:						
Hadfield Manganese Steel (Average)	.042"	-	-	-	920	1670

1. Cal. .45 steel-jacketed ball projectile--250 grains.
2. Cal. .22 flat-simulating projectile - 17 grains.

APPENDIX A

TABLE XVb

(Reference - Report No. WAL 710/593)

Chemical Composition and Physical Properties of Samples of 18-8 Stainless Steel
as Reported by Republic Steel Corporation

Sample No.	Chemical Composition								Yield Strength	Tensile Strength	Elongation (2%)
	C	Mn	P	S	Si	Ni	Cr	Temper			
O-1 to O-5	.12	1.18	.023	.010	.44	7.07	17.90	1/4 Hard	101,620	140,320	20.5
A-1, A-2	.10	1.25	.035	.014	.45	7.07	18.14	1/2 Hard	117,970	164,440	17.5
B-1 to B-4	.10	1.25	.035	.014	.45	7.07	18.14	Full Hard	147,700	195,120	12.0
C-1, C-2	.08	1.12	.021	.015	.54	8.75	17.02	1/4 Hard	115,250	137,800	19.5
D-1, D-2	.08	1.12	.021	.015	.54	8.75	17.02	1/2 Hard	129,220	155,900	12.5
E-1, E-2	.08	1.12	.021	.015	.54	8.75	17.02	Full Hard	156,700	181,200	9.5
F-1, F-2	.11	1.07	.023	.010	.35	9.53	17.96	1/4 Hard	110,200	138,800	16.0
G-1, G-2	.11	1.07	.023	.010	.35	9.53	17.96	1/2 Hard	140,570	166,680	10.0
H-1, H-2	.11	1.07	.023	.010	.35	9.53	17.96	Full Hard	164,750	189,100	7.5

APPENDIX A

TABLE XVI

(Reference - Report No. WAL 710/697)

Summary of Tests Conducted at Watertown Arsenal on Samples of

F.B. 8620 Steel Supplied by Republic Steel Corporation

Chemical Composition

C	Mn	P	S	Si	Ni	Cr	Mo
.18	.89	.019	.020	.30	.55	.50	.15

Sample No.	Actual Grains	Hardness Rockwell "C"	Tempering Temperature	Ballistic Limit (F/S)	
				Cal. .451	G-22
A	.045"	31	900°F.	486	--
B	.044"	29	1000°F.	426	--
C	.044"	25	1100°F.	439	--
D	.045"	19	1200°F.	453	--
E	.044"	43	As Quenched	548	--
F	.044"	43	As Quenched	526	--
G	.044"	42	As Quenched	-	1307
H	.044"	39	As Quenched	-	1155

For Comparison:
Average Hadfield
Manganese Steel

940

1660

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 flak-simulating projectiles - 17 grains.

APPENDIX A

TABLE XVII (Cont'd)

Sample No.	Heat Treatment	Chemical Composition										Actual Gauge	Ballistic Limit (F/S)		
		C	Mn	Si	P	S	Mi	Cr	Mo	Zr	Cu		0-2	0-1-A	0-1-B
21-1	As quenched in oil from 1650°F.	.25	.88	.81	.019	.021	—	.82	.14	.14	.084	689	—	—	—
21-2	As quenched in oil from 1650°F.							45				—	1660	480	1050
22-1	Oil quenched from 1650°F. Drawn at 300°F.							44				537	—	423	975
22-2	Oil quenched from 1650°F. Drawn at 300°F.							44				—	1685	—	—
23-1	Oil quenched from 1650°F. Drawn at 600°F.							43				579	—	500	948
23-2	Oil quenched from 1650°F. Drawn at 600°F.							41				—	1305	—	—
24-1	Oil quenched from 1650°F. Drawn at 900°F.							36				489	—	—	—
24-2	Oil quenched from 1650°F. Drawn at 900°F.							35				—	1097	470	828
25-1	Oil quenched from 1650°F. Drawn at 1200°F.							20				539	—	—	—
25-2	Oil quenched from 1650°F. Drawn at 1200°F.							23				—	1055	378	830
26-1	Normalized from 1650°F.							29				634	—	—	—
26-2	Normalized from 1650°F.							28				—	1370	430	940
27-1	Quenched from 1600°F. into salt bath at 675°F. for 10 minutes.							38				684	—	—	—
27-2	"							43				—	1195	426	940
27-3	"							33				615	—	—	—
For Comparison:															
Heat-treated Manganese Steel															
The ladle carbon of this heat was 0.20 but apparently decarburization occurred during re-rolling.															
1.	Cal. .45 steel-jacketed ball projectiles - 230 grains.														
2.	Cal. .22 fragment-simulating projectile - 17 grains.														
3.	Cal. .30 fragment-simulating projectile - 150 grains.														
4.	Cal. .30 fragment-simulating projectile - 34 grains.														

APPENDIX A

TABLE XVIII

(Reference - Report No. WAL 710/712)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of Hadfield Manganese Steel Submitted by Carnegie-Illinois Steel Corporation

Sample No.	Actual Gauge	Hardness	Ballistic Limits (f/s)						
			0-1-S ¹	0-1-A ²	0-2 ³	.45 ⁴	.30 Ball ⁵	.30 Carb. ⁶	
12-1	.032"	83 Rb	815	--	1215	--	--	--	--
12-2	.032"	85 Rb	--	--	--	704	--	--	--
12A-1	.041"	85 Rb	--	--	1600	--	--	--	--
12A-2	.041"	83 Rb	--	--	--	946	--	--	--
12A-3	.041"	82 Rb	--	--	--	--	1040	--	1248
12B-1	.053"	90 Rb	--	--	--	1096	--	--	--
12B-2	.053"	91 Rb	--	--	--	--	1229	--	1375
12B-3	.052"	91 Rb	--	--	--	--	1261	--	1410
12B-4	.052"	90 Rb	--	--	--	1100	--	--	--
12B-5	.053"	91 Rb	1425	--	--	--	--	--	--
12B-6	.052"	90 Rb	--	550	1780	--	--	--	--
12C-1	.063"	89 Rb	--	--	--	1266	1270	--	1443
12C-2	.063"	87 Rb	--	--	--	--	1265	--	1476
12D-1	.069"	90 Rb	--	--	--	--	1344	--	1618
12D-2	.069"	90 Rb	--	--	--	--	--	--	1433
12E-1	.079"	89 Rb	--	--	--	--	1498	--	1544
12E-2	.080"	89 Rb	--	--	--	--	--	--	1503

1. Cal. .30 fragment-simulating projectile - 34 grains.
2. Cal. .30 fragment-simulating projectile - 150 grains.
3. Cal. .22 fragment-simulating projectile - 17 grains.
4. Cal. .45 steel-jacketed ball projectile - 230 grains.
5. Cal. .30 ball M2 projectile.
6. Cal. .30 carbine ball projectile.

APPENDIX A

TABLE XIX

(Reference - Report No. WAL 710/733)

Resistance of Hadfield Manganese Steel in Form of a Helmet, M1,
to Perforation by the Fragment-Simulator, G-2

<u>Thickness of Helmet at Point of Impact</u>	<u>Apparent Ballistic Limit (A)</u>
.036*	965 f/s
.037*	985
.038*	1000
.039*	1015
.040*	1040
.041*	1070
.042*	1110
.043*	1155
.044*	1210
.045*	1275

APPENDIX A

TABLE XX

Comparative Resistance of Various Samples of Steels to Perforation
by Cal. .45 Ball Projectiles

<u>Description of Material</u>	<u>Actual Thick- ness</u>	<u>Ballistic Limit</u>	<u>Figure of Merit*</u>	<u>Reference</u>
C10-2 8630 steel as rolled	.043"	378	.41	Table XIV
A-2 Mn-Mo Steel	.042"	378	.42	Table X
H-1 18-8 Stainless	.040"	377	.42	Table IVa
G-1 18-8 Stainless	.041"	390	.43	Table XVa
13-1 Ni-Mo Steel	.050"	438	.44	Table XVII
B 8386 Steel	.044"	426	.45	Table XVI
14-1 Ni-Mo Steel	.048"	446	.46	Table XVIII
HF-3 Mn-Mo Steel	.042"	420	.46	Table XI
A-1 Mn-Mo Steel	.041"	421	.46	Table I
F-1 18-8 Stainless	.042"	433	.47	Table IVa
C 86 8620	.044"	439	.47	Table XVI
HF-4 Mn-Mo	.040"	436	.48	Table XI
D-1 18-8 Stainless	.042"	445	.48	Table IVa
D 86 8620 Steel	.045"	453	.48	Table XVI
17-1 Ni-Mo Steel	.049"	487	.49	Table XVII
24-1 Si-Cr-Mo-Zr Steel	.049"	487	.49	Table XVII
12-1 Ni-Mo Steel	.048"	488	.50	Table XVII
15-1 Ni-Mo Steel	.049"	500	.50	Table XVII
A 86 8620 Steel	.045"	486	.51	Table XVI
E-1 18-8 Stainless Steel	.041"	462	.51	Table IVb
11-1 Ni-Mo Steel	.049"	514	.52	Table XVII
HF-8 Mn-Mo Steel	.043"	489	.53	Table XIII
C-1 18-8 Stainless	.041"	495	.54	Table XVa
25-1 Si-Cr-Mo-Zr Steel	.049"	539	.54	Table XVII
22-1 Si-Cr-Mo-Zr Steel	.048"	537	.55	Table XVII
GT-10 Mn-Mo Steel	.040"	494	.55	Table III
843-3 Cr-Mo-V Steel	.041"	510	.56	Table VIII
F 86 8620 Steel	.044"	526	.56	Table XVI
16-1 Ni-Mo Steel	.048"	568	.58	Table XVII
EF-9 Mn-Mo Steel	.042"	536	.58	Table XIII

APPENDIX A

TABLE IX (Cont'd)

Description of Material	Actual Thickness	Ballistic Limit	Figure of Merit*	Reference
9 .70 ⁿ carbon Amola steel	.039 ⁿ	514	.58	Table IV
23-1 Si-Cr-Mo-Zr Steel	.049 ⁿ	579	.58	Table XVII
HF-1 Mn-Mo Steel	.042 ⁿ	544	.58	Table XI
1739-3 Si-Mn-Cr-Mo Steel	.041 ⁿ	532	.58	Table VIII
E ME 8620 Steel	.044 ⁿ	548	.59	Table XVI
HF-2 Mn-Mo Steel	.041 ⁿ	546	.60	Table XI
HF-6 Mn-Mo Steel	.040 ⁿ	553	.61	Table XIII
843-1 Cr-Mo-V Steel	.042 ⁿ	560	.61	Table VIII
HF-7 Mn-Mo Steel	.042 ⁿ	580	.62	Table XIII
27-3 Si-Cr-Mo-Zr Steel	.050 ⁿ	615	.62	Table XVII
A-3 Mn-Mo Steel	.041 ⁿ	567	.62	Table X
B-4 18-8 Stainless	.041 ⁿ	575	.63	Table XVa
31 Rc Modified SAE 4340	.041 ⁿ	592	.65	Table VII
1/2 ⁿ Hard Stainless (Rockwell C-33)	.048 ⁿ	646	.66	Table II
HF Mn-Mo Steel	.040 ⁿ	592	.66	Table XI
C9-2 X-4130 As-Rolled	.048 ⁿ	616	.67	Table XIV
O-4 18-8 Stainless Steel	.042 ⁿ	616	.67	Table XVa
B-3 18-8 Stainless Steel	.042 ⁿ	620	.67	Table XVa
SAE 4330 (Rockwell C-34)	.050 ⁿ	665	.67	Table II
1739-1 (Si-Cr-Mn-Mo Steel)	.042 ⁿ	613	.67	Table VIII
27-1 (Si-Cr-Mo-Zr Steel)	.050 ⁿ	684	.68	Table XVII
26-1 Si-Cr-Mo-Zr Steel	.050 ⁿ	684	.68	Table XVII
A-1 18-8 Stainless Steel	.042 ⁿ	624	.68	Table XVa
Half-hard Hadfield Manganese	.040 ⁿ	613	.68	Table VI
HF-10 Mn-Mo Steel	.043 ⁿ	632	.68	Table XIII
1/2 Hard Austenitic Steel	.042 ⁿ	625	.68	Table IX
O-1 18-8 Stainless Steel	.042 ⁿ	638	.69	Table XVa
3/4 Hard (Hadfield Manganese)	.040 ⁿ	625	.69	Table VI
Item 10 (.70% Carbon Amola Steel)	.039 ⁿ	615	.69	Table IV
Full Hard Stainless (Rockwell C-45)	.044 ⁿ	658	.70	Table II
47 Rc (Modified SAE 4340 Steel)	.039 ⁿ	626	.70	Table VII
21-1 Si-Cr-Mo-Zr Steel	.049 ⁿ	689	.70	Table XVII
B-1 18-8 Stainless Steel	.042 ⁿ	656	.71	Table XVa

APPENDIX A

TABLE IX (Cont'd)

Description of Material	Actual Thickness	Ballistic Limit	Figure of Merit*	Reference
SAE 4330 Rockwell C-36	.048"	698	.71	Table II
A-4 Mn-Mo Steel	.039"	651	.72	Table X
Full Hard (Austenitic Steel)	.045"	685	.72	Table IX
52 Rc (Modified SAE Steel)	.039"	646	.73	Table VII
1/4" Hard (Austenitic Steel)	.045"	689	.73	Table IX
7-1 Silico-Manganese	.042"	682	.74	Table XII
8-1 Silico-Manganese	.039"	679	.76	Table XII
C (Ferritic Steel)	.048"	745	.76	Table I
Austenitic Steel	.042"	728	.79	Table IX
GT-9 Mn-Mo	.039"	699	.79	Table III
I (Ferritic Steel)	.048"	822	.84	Table I
843-2 Cr-Mo-V Steel	.041"	777	.85	Table VIII
1739-2 Si-Ni-Cr-Mo Steel	.040"	783	.87	Table VIII
11-a .70% Carbon Anala Steel	.044"	830	.88	Table IV
GT-2 Mn-Mo Type	.048"	874	.89	Table III
1/4 Rockwell Stainless (Rockwell C-27)	.051"	912	.90	Table II
E (Hadfield Steel)	.043"	848	.91	Table I
11-B (70% Carbon Anala Steel)	.041"	827	.91	Table IV
A Hadfield Steel	.046"	898	.94	Table I
B-3 Mn-Mo Steel	.051"	962	.95	Table X
B-2 Mn-Mo Steel	.051"	963	.95	Table X
B (Ferritic Steel)	.048"	940	.96	Table I
C-10-1 8630 Steel (Heat Treated)	.042"	880	.96	Table XIV
NE 8630 Hadfield Manganese	.042"	880	.96	Table XIII
B-1 (Light Weight Mn-Mo Steel)	.051"	970	.96	Table X
Hadfield Manganese (Average)	.050"	1000	1.00	Table II
C-9-1 X 4130 Heat Treated	.048"	917	1.00	Table XIV
Hadfield Manganese, As Annealed	.044"	949	1.01	Table VI
12A-2 Hadfield Manganese	.041"	946	1.04	Table XVIII
GT-3 Mn-Mo Steel	.050"	1042	1.04	Table III
GT-1 Mn-Mo Type Steel	.049"	1027	1.04	Table III
A-62 Hadfield Steel	.044"	1131	1.20	Table I
F Hadfield Steel	.043"	1117	1.20	Table I

APPENDIX A

TABLE XI (Cont'd)

*Figure of merit determined from the formula:

$\frac{V_{SUB} \times 100}{V_{HAD}}$ where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

APPENDIX A

TABLE XVI

Comparative Resistance of Various Samples of Steels to Perforation
by Cal. .22 Fragment-Simulating Projectile, G-2

Description of Material	Actual Thick- ness	Ballistic Limit	Figure of Merit*	Reference
15-2 Ni-Mo Steel	.049"	893	.51	Table XVII
17-2 Ni-Mo Steel	.049"	935	.54	Table XVII
14-2 Ni-Mo Steel	.048"	950	.55	Table XVII
E-2 18-8 Stainless Steel	.042"	900	.55	Table IXa
H-2 18-8 Stainless Steel	.042"	915	.56	Table IXa
C-2 18-8 Stainless Steel	.042"	985	.60	Table IXa
11-2 Ni-Mo Steel	.047"	1030	.60	Table XVII
G-2 18-18 Stainless Steel	.042"	975	.60	Table IXa
13-2 Ni-Mo Steel	.047"	1045	.61	Table XVII
A-1 Mn-Mo Steel	.041"	1004	.62	Table I
25-2 Si-Cr-Mo-Zr Steel	.047"	1055	.62	Table XVII
11-B (.70 Carbon Anala Steel)	.041"	1020	.63	Table IV
D-2 18-8 Stainless Steel	.042"	1033	.63	Table IXa
16-2 Ni-Mo Steel	.048"	1085	.63	Table XVII
F-2 18-8 Stainless Steel	.042"	1038	.64	Table IXa
24-2 Si-Cr-Mo-Zr Steel	.046"	1097	.65	Table XVII
A-2 18-8 Stainless Steel	.042"	1052	.65	Table IXa
O-2 18-8 Stainless Steel	.042"	1055	.65	Table IXa
39 Bc Modified SAE Steel	.040"	1043	.65	Table VII
A-2 Mn-Mo Steel	.041"	1072	.66	Table I
9 (.70% Carbon Anala Steel)	.039"	1053	.66	Table IV
10 (.70% Carbon Anala Steel)	.040"	1051	.66	Table IV
1739-3 (Si-Ni-Cr-Mo Steel)	.041"	1089	.67	Table VIII
B-2 18-8 Stainless Steel	.042"	1095	.67	Table IXa
HF-1 Mn-Mo Steel	.042"	1092	.67	Table XI
Full Hard Stainless (Rockwell C-45)	.044"	1118	.67	Table II
12-2 Ni-Mo Steel	.047"	1155	.68	Table XVII
1/2" Hard Stainless (Rockwell C-33)	.048"	1173	.68	Table II
HF-5 Mn-Mo Steel	.040"	1086	.68	Table XI
29 Bc (Modified SAE 4340 Steel)	.040"	1104	.69	Table VII

APPENDIX A

TABLE XII (Cont'd)

Description of Material	Actual Thick- ness	Ballistic Limit	Figure of Merit*	Reference
11-9 (.70% Carbon Armco Steel)	.046"	1165	.69	Table III
GT-10 Mn-Mo Type Steel	.040"	1105	.69	Table III
1/2 Hard (Austenitic Steel)	.044"	1255	.70	Table IX
843-3 (Cr-Mo-V Steel)	.041"	1132	.70	Table VIII
H NE 8620 Steel	.044"	1155	.70	Table XVI
52 Rc (Modified SAE 4340 Steel)	.039"	1129	.71	Table VII
6-1 Silico Manganese	.043"	1170	.71	Table XII
0-5 18-8 Stainless Steel	.042"	1175	.72	Table IVa
Austenitic Steel	.042"	1171	.72	Table IX
843-1 Cr-Mo-V Steel	.042"	1166	.72	Table VIII
Full Hard (Austenitic Steel)	.046"	1237	.73	Table IX
A-4 Mn-Mo Steel	.039"	1163	.73	Table X
1739-1 Si-Ni-Cr-Mo Steel	.042"	1212	.74	Table VIII
3/4 Hard (Hadfield Manganese Steel)	.040"	1184	.74	Table VI
HF-3 Mn-Mo Steel	.042"	1215	.75	Table XI
HF-2 Mn-Mo Steel	.041"	1234	.76	Table XI
1/4 Hard (Austenitic Steel)	.045"	1283	.77	Table IX
Half Hard (Hadfield Manganese)	.040"	1232	.77	Table VI
23-2 Si-Cr-Mo-Zr Steel	.047"	1305	.77	Table XVII
G NE 8620 Steel	.044"	1307	.79	Table XVI
HF-4 Mn-Mo Steel	.040"	1270	.79	Table XI
26-6 Si-Cr-Mo-Zr Steel	.048"	1370	.80	Table XVII
843-2 Cr-Mo-V Steel	.041"	1322	.82	Table VIII
G10-1 8630 Steel - Heat Treated	.042"	1390	.85	Table XIV
GT-9 Mn-Mo Type Steel	.039"	1375	.87	Table III
A-3 Mn-Mo Type Steel	.041"	1327	.88	Table X
SAE 4330 (Rockwell C-34)	.050"	1545	.88	Table II
.050" Steel Sheets & Multi-Layered Assemblies	.050"	1574	.90	Table V
SAE 4330 (Rockwell C-36)	.048"	1553	.90	Table II

APPENDIX A

TABLE XXI (Cont'd)

Description of Material	Actual Thickness	Ballistic Limit	Figure of Merit*	Reference
Hadfield Manganese, As Annealed	.040"	1510	.94	Table VI
Hadfield Manganese, As Annealed	.044"	1570	.94	Table VI
1/4" Hard Stainless (Rockwell C-27)	.051"	1675	.95	Table II
B-2 Mn-Mo Steel	.051"	1715	.97	Table X
C9-1 K4130 Heat Treated	.048"	1683	.98	Table XIV
12A-1 Hadfield Manganese	.041"	1600	.99	Table XVIII
B-4 Mn-Mo Steel	.051"	1750	.99	Table X
B-3 Mn-Mo Steel	.051"	1741	.99	Table Z
B-1 Mn-Mo Steel	.051"	1755	.99	Table X
Hadfield Manganese (Average)	.050"	1750	1.00	Table II
21-2 Si-Cr-Mo-Zr Steel	.047"	1660	1.00	Table XVII
22-2 Si-Cr-Mo-Zr	.045"	1685	1.01	Table XVII
GT-2 Mn-Mo Type Steel	.048"	1775	1.03	Table III
8-5 Silico Manganese	.042"	1760	1.05	Table XII
GT-3 Mn-Mo Type Steel	.050"	1920	1.10	Table III
GT-1 Mn-Mo Type Steel	.049"	1913	1.10	Table III

*Figure of merit determined from the formula:

$\frac{V_{SUB}}{V_{HAD}} \times 100$ where V_{SUB} is the ballistic limit of the subject sample and

V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.