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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/635

Ballistic Tests of .040 - .050" Hadfield Steel Sheet With Caliber .45 Ball Projectiles for Development of Specification Requirements

[redacted]

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BY

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Assoc. Metallurgist

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Major, Ordnance Dept.

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WATERTOWN ARSENAL LABORATORY

Memorandum Report No. WAL 710/635

Partial Report on Project B-9

18 May 1944

Ballistic Tests of .040 - .050" Hadfield Steel Sheet With Caliber .45 Ball Projectiles for Development of Specification Requirements

ABSTRACT

Report covers the results of ballistic tests of Hadfield manganese steel sheet (as presently procured for helmets and flyer's protective armor) in the thickness range of .040 to .050 inches. Test results are given on 106 sheets of satisfactory metallurgical quality. Specification requirements are suggested over the range .040 to .050 inches using the caliber .45 - 230 grain (steel jacketed) Ball projectile.

1. At the request of the Office, Chief of Ordnance, Industrial Division, Small Arms Branch, numerous samples of Hadfield manganese steel sheet produced by the two manufacturers of this material, Carnegie-Illinois Steel Corporation and Sharon Steel Corporation, were forwarded to this arsenal for ballistic tests. Ballistic tests were conducted with the caliber .45 Ball, 230 grain projectile for the purpose of developing the ballistic test requirements for this material over the thickness range .040 to .050 inches.

2. At the present time the requirements of Specification AXS-1170, "Steel, Non-magnetic Sheet and Strip (For Body Armor)", call for ballistic tests with the caliber .45 Ball, 230 grain projectile. These requirements were based upon an adequate amount of data over the thickness range (.042" - .046") in which body protection armor is now being procured. However, it was soon discovered that armor in this thickness range having satisfactory metallurgical characteristics was failing these test requirements by a considerable margin. The reason for this discrepancy has now been ascertained to be a change in the characteristics of the projectile. The original firings were conducted with copper-alloy jacketed projectiles. However, a later shipment of projectiles,

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representing the type now most available and in quantity production, were of a steel-jacketed type provided with a superficial copper coating. It seems desirable to revise the specification requirements in accordance with the results of tests utilizing the now-standard steel-jacketed projectile.

3. The ballistic tests which are reported herein were all conducted in a standard manner. The helmet circles (16 inch diameter) or square specimens (12"x12") were clamped securely to a wooden framework. Hand loaded rounds containing various powder charges were loaded into a special weapon which allows the attainment of velocities up to 1250 feet-per-second. The gun consists of the barrel for a Thompson Sub-Machine Gun (10" in length) which is fitted to the receiver of a Caliber .30 Model 1903 Springfield type action. Instrumental velocities were recorded by an Aberdeen type chronograph and striking velocities were calculated from instrumental velocities so determined. The results of all impacts which struck too close to previous impacts (less than approximately 3 inches) were discarded. Ballistic limits were obtained which are the average of two rounds, one of which does not perforate the sheet and the second of which passes completely through the sheet. In all cases the difference in velocity between the two rounds upon which the limit is based is less than 50 feet-per-second, and, in the great majority of cases, is less than 30 feet-per-second.

4. Ballistic tests were conducted on four groups of material, as follows:

a. Group 1. Five helmet circles in each thousandth of an inch thickness increment over the range .046 to .050 inches were received from the Carnegie-Illinois Steel Corporation. The three most satisfactory sheets in each thickness on the basis of the magnetic deflection test prescribed in Specification AXS-1170 were selected for test. Rockwell C hardness determinations and microscopic examinations were conducted on each selected sheet. The sheets were then tested ballistically. The results appear in Table I. The results of tests are recorded only on sheets which passed the magnetic deflection test (magnetic deflection of not over six inches).

b. Group 2. A similar group of helmet circles were received from the Sharon Steel Corporation. Similar ballistic tests were conducted on these sheets. Only data on sheets with satisfactory magnetic deflection characteristics are included. No hardness or microscopic tests were conducted on this material. These results are shown in Table II.

c. Group 3. During March 1944 Carnegie-Illinois Steel Corporation submitted samples 12"x12" in size from numerous production lots then being processed which covered the thickness range .042 to .046 inches. Bend tests and magnetic deflection tests were conducted on this material in accordance with Specification AXS-1170. Ballistic tests results are reported only on sheets which were satisfactory in these two tests. Bend tests were conducted on the sheet with both faces in tension. The sheets were bent back flat upon themselves. Bend test results were considered satisfactory if rating number 3 or lower of the Quality Control Standards was maintained. Approximately 4% of the sheets tested failed the bend test in one or more directions, whereas approximately 60% of the sheets failed the magnetic deflection test as applied to one or both faces of the sheet. In general, when the magnetic deflection exceeded 10 inches the bend test was also poor. However, many 1 and 2 standard bends were obtained on sheet giving magnetic deflections up to 10 inches. The results on satisfactory sheets which were tested ballistically appear in Table III.

d. Group 4. Similar sheet samples from production lots were furnished by Sharon Steel Corporation during March 1944. Similar tests were performed and the results on satisfactory sheets in accordance with the magnetic deflection and bend tests and, which were ballistically tested, are recorded in Table IV. Two and a half percent (2.5%) of the sheets tested failed either the magnetic deflection or bend tests.

5. The ballistic results contained in Tables I and III on sheet samples supplied by Carnegie-Illinois Steel Corporation have been plotted as Figure 1. Also shown on the plot are the present specification requirements of Specification AXS-1170, based upon copper-alloy jacketed projectiles, and proposed new values for the steel-jacketed projectiles based upon these firings. A similar plot has been drawn for the sheet supplied by Sharon Steel Corporation from the ballistic data contained in Tables II and IV.

6. The proposed new requirements may appear conservative. However, it will be recalled that these tests represent the best quality Hadfield manganese steel that is presently being produced. Furthermore, there are numerous indications that, of the heat treated steels tested to date, none consistently compares favorably with the average values of Hadfield manganese steel. It will also be noted that there is a considerable variability in the ballistic values obtained on a constant thickness of Hadfield sheet which is not explainable by the metallurgical tests which have been applied to date. This is, perhaps, understandable when one considers that the test involves an extremely heavy, deforming projectile against a thin sheet. Under these conditions slight variations in the behavior of the steel, as affecting projectile deformation, will cause a variation in ballistic efficiency. By the same reasoning, variations in projectile characteristics with respect to resistance to deformation would also be expected to affect the ballistic efficiency obtained. This is strikingly indicated by the differences in the proposed specification requirements for the copper alloy-jacketed and steel-jacketed projectiles. It will be observed that the slope of the proposed specification line for the steel-jacketed projectiles is considerably less than for the copper alloy-jacketed projectiles. This is a reflection of the differences in deformation characteristics of the two types of projectiles as affected by changes in gauge.

7. The use of a non-deforming type of projectile would be more satisfactory for an acceptance test. The fragment-simulating projectiles developed at this arsenal approach the desired characteristics, but it is doubtful that these are, at present, in sufficiently advanced stages to turn over to the proving agencies for acceptance testing. It is, therefore, suggested that the proposed ballistic values be considered to apply to all steel procured for helmets, body armor, and "flak curtain" armor pending the standardization of improved projectiles. The ballistic tables over the range .040 to .050 inches would be as follows:

Gauge (Ave.)	Required Striking Velocity, f/s. Cal. .45, 230 grain Ball (Steel Jacketed) Projectile.
.040"	850
.041"	860
.042"	870
.043"	880
.044"	890
.045"	900
.046"	910
.047"	920
.048"	930
.049"	940
.050"	950

Other requirements, pertaining to the extent of allowable cracking, should be the same as those now required in Specification AXS-1170. It is mandatory that care be exercised to insure that only the steel-jacketed (copper coated) projectiles be used in conjunction with these ballistic values.

Acknowledgement is hereby paid to Miss Barbara Phelps, who accumulated much of the data contained in this report.

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N. A. Matthews

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Major, Ordnance Dept.
Chief, Armor Section

nota 1817

Table I

Carnegie-Illinois Steel Corporation

Helmet Circles of Various Gauges

Sample No.	Thickness, Inches	Rockwell B Hardness	Magnetic Traverse Inches	Ballistic Limit Cal. .45 Ball F/S	Microstructure Amount of Decarburization
103	.040	90.0	6.0	863	Discontinuous to .0004"
104	.0405	88.5	3.5	1013	None
105	.040	90.0	3.0	957	None
91	.041	88.5	5.5	937	Discontinuous to .0004"
92	.041	88.0	4.5	946	"
100	.041	90.0	3.0	1036	None
74	.042	87.5	3.0	1010	None
82	.042	87.0	5.0	993	None
83	.042	87.5	5.0	960	None
73	.043	87.0	3.0	979	None
80	.043	88.0	4.0	1021	None
53	.044	88.5	5.5	1044	None
57	.044	89.5	5.0	1006	None
58	.044	88.5	3.5	999	Discontinuous on one side to .0008"
46	.0455	88.0	4.0	970	None
49	.045	87.5	5.5	1016	None
50	.045	88.5	4.5	940	None
36	.046	89.0	3.0	943	Discontinuous on one side to .0006"
34	.0465	87.5	4.0	1039	"
35	.047	86.5	5.0	1009	None
37	.047	88.5	3.5	1062	Discontinuous on one side to .0014"
14	.0485	90.0	5.0	1023	None
17	.049	89.5	5.0	1050	Discontinuous on one side to .0006"

All sheets were free from undissolved carbides and showed normal austenitic structure.

Table II

Sharon Steel Corporation

Helmet Circles of Various Gauges

Sample No.	Thickness Inches	Magnetic Deflection Inches	Cal. .45 Ball 230 grain Steel Jacketed B.L. F/S
A-1	.041	3.0	898
A-2	.0405	4.0	908
A-3	.040	4.5	934
B-1	.0415	4.5	988
B-2	.0415	5.0	1009
B-3	.041	4.5	1012
C-1	.0425	3.5	997
C-2	.0425	6.0	1041
C-3	.0425	4.5	969
D-1	.043	4.0	1005
D-2	.0435	5.0	983
D-3	.0435	5.0	1025
E-1	.0445	6.0	1030
E-2	.045	3.0	1031
E-3	.045	2.5	1065
F-1	.046	4.0	1043
F-2	.046	5.0	1050
F-3	.046	3.0	1042
G-1	.047	2.5	1072
G-2	.047	5.5	1013
G-3	.047	4.5	990
H-1	.0485	2.5	1050
H-2	.048	3.5	1077
H-3	.0475	3.5	1031
I-1	.0485	2.0	1070
I-2	.0485	2.0	1105
I-3	.0485	2.0	1084
J-1	.049	1.0	1122
J-2	.050	2.0	1113

Table III

Carnegie-Illinois Steel Corporation

Samples of Production Sheet

Sample Size 12"x12"

No.	Heat Number	Lift No.	Thickness	Cal. .45 Ball B.L. F/S	Bend Test: One face in Tension 1	Bend Test: Opposite face in Tension 2	Magnetic Test Deflection in Inches	
C2	220103	53592	.0445	1016	2	2	2	5
C4	220103	53596	.046	974	1	2	4	2
C6	220103	53597	.046	1031	1	1	0	0
C8	220103	53598	.043	978	2	3	2	4½
C10	220103	53599	.043	1043	1	2	½	½
C14	180109	53602	.044	1010	1	2	5½	5½
C16	180109	53603	.045	1027	1	3	3½	3½
C18	180109	53604	.043	985	1	1	4½	4
C20	180109	53607	.043	965	2	2	5½	4
C30	220105	53617	.044	986	2	2	4	3½
C31	220105	53632	.043	1011	1	2	3½	2½
C32	220105	53636	.043	1025	1	1	2	2½
C40	220105	53617	.044	1000	1	1	1	2
C46	220105	53634	.043	1000	1	1	3½	3
C50	220105	53637	.043	996	[illegible]	2	4½	4½
C53	220105	53638	.045	1016	1	1	5	6

Table III (Cont'd)

No.	Heat Number	Lift No.	Thickness	Cal. .45 Ball B.L. F/S	Bend Test: One face in Tension 1	Bend Test: Opposite face in Tension 2	Magnetic Test Deflection in Inches	
C55	220105	53639	.045	1018	2	1	5½	2½
C64	220105	53644	.043	1017	2	1	5½	4½
C74	190101	53652	.043	993	1	2	3½	3½
C80	190101	53655	.044	999	1	2	3	1½
C86	210091	53573	.041	1006	2	2	4	2
C90	210091	53578	.044	1011	2	2	4	3½
C93	201191	53584	.042	1006	2	3	5	2½
C95	220105	53615	.043	1011	1	2	3	3
C101	190101	53659	.0415	1034	1	2	3	1½
C105	190101	53661	.043	1017	2	1	5	4
C113	210097	53668	.044	1031	2	1	6	5
C120	210097	53672	.044	1032	1	2	2½	3
C124	180113	53699	.045	1055	1	2	5½	4½
C130	180113	53696	.044	1030	1	2	4½	5½
C146	210095	53730	.043	990	1	2	2½	2½
C156	210095	53719	.043	1045	2	1	5½	6
C163	180113	53711	.044	1007	2	2	3	4

Table IV

Sharon Steel Corporation

Samples of Production Heat

Sample Size 12"x12"

Sample Number	Heat Number	Lot No.	Thickness	B.L. F/S	Bent Test: One face in Tension 1	Bent Test: Opposite face in Tension 2	Magnetic Test Deflection in Inches	
S1	73328	46	.047	921	2	1	2	1½
S5	73329	44	.044	948	2	1	1	1½
S7	73345	43	.045	932	2	2	1	1
S8	73332	47	.045	1003	3	2	3	2
S12	73345	40	.043	915	2	3	3½	2
S14	73327	48	.0455	981	2	2	6	5
S15	73268	45	.046	923	2	2	2	2
S16	73339	49	.0445	958	2	1	3	2½
S17	73345	41	.044	936	2	2	2½	2
S24	73347	51D	.045	969	1	2	2	3
S25	73347	51C	.045	940	2	2	2½	2
S26	73347	50A	.0455	950	2	1	2	3
S27	73323	39	.041	817	2	2	2	2½
S28	73323	35	.044	910	2	2	2	2½
S29	73347	50B	.046	976	2	2	1½	1
S31	73323	37	.044	905	2	3	1	1½
S38	73323	38	.047	934	2	2	2	1
S40	73323	36	.045	886	2	1	1½	1
S41	73323	34	.045	940	2	3	1½	1

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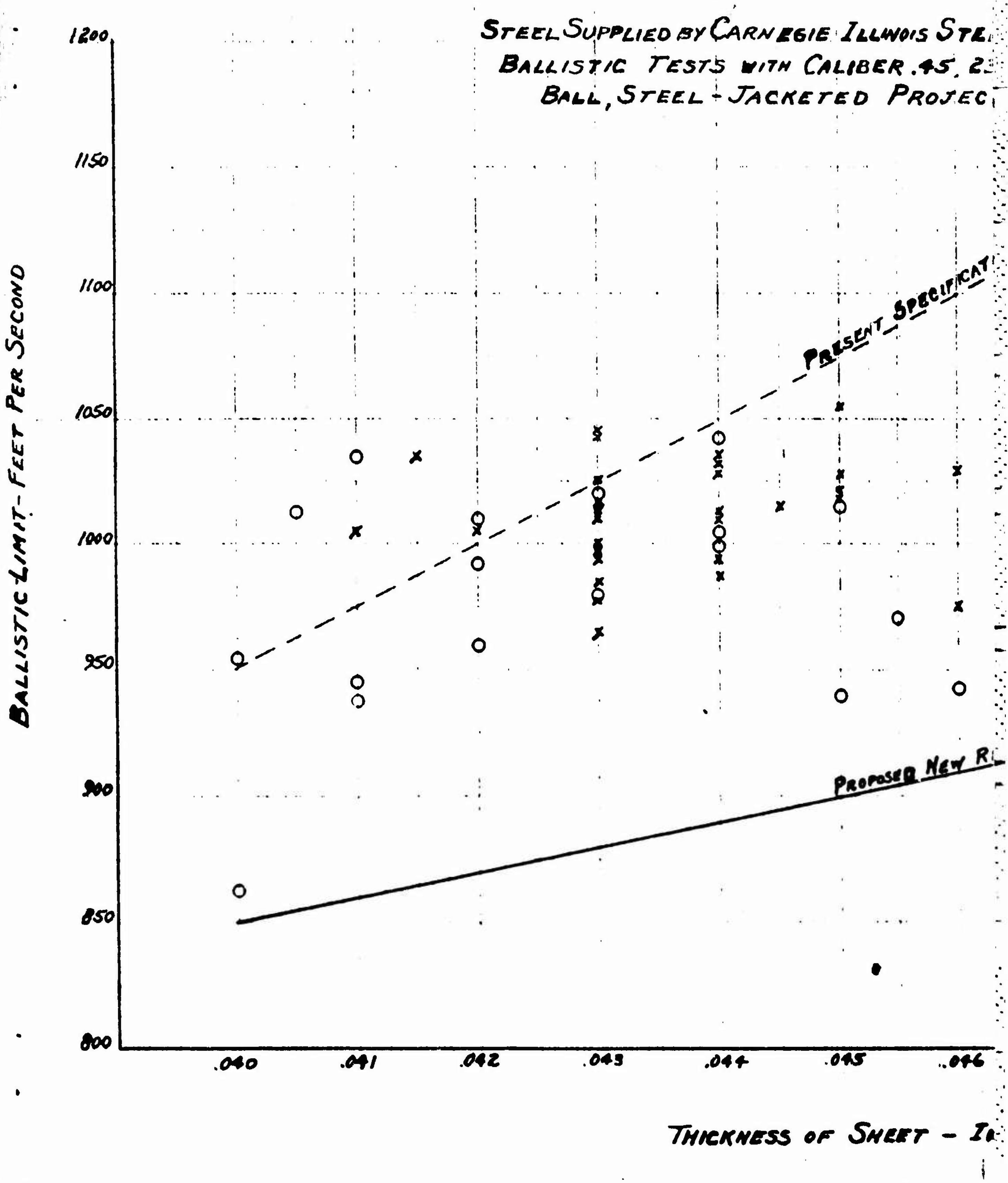

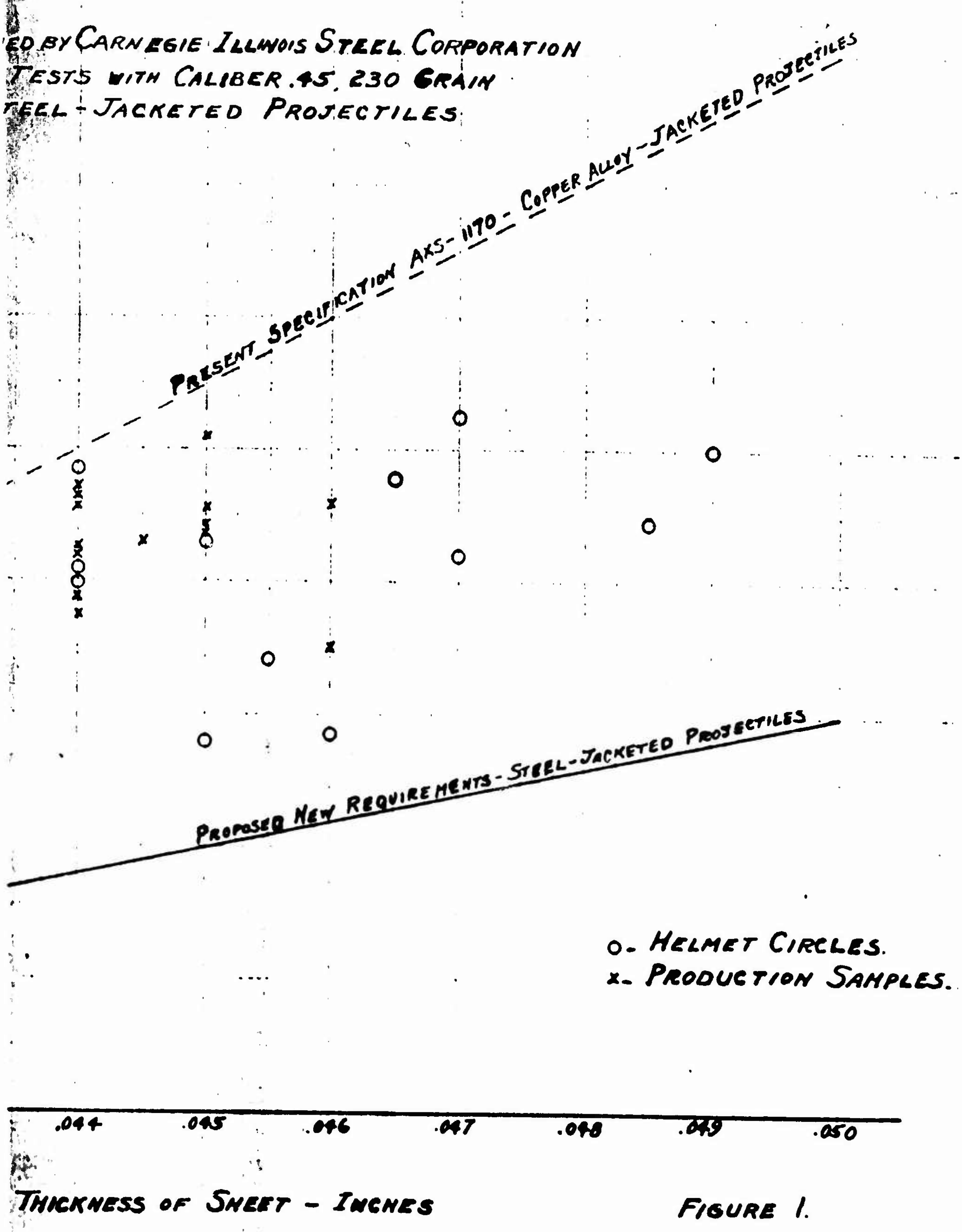
ED BY CARNEGIE ILLINOIS STEEL CORPORATION
TESTS WITH CALIBER .45, 230 GRAIN
TEEL-JACKETED PROJECTILES
PRESENT SPECIFICATION AXS-1170 - COPPER ALLOY-JACKETED PROJECTILES
PROPOSED NEW REQUIREMENTS - STEEL-JACKETED PROJECTILES
O- HELMET CIRCLES.
X- PRODUCTION SAMPLES.
.044
.045
.046
.047
.048
.049
.050
THICKNESS OF SHEET - INCHES

FIGURE 1.

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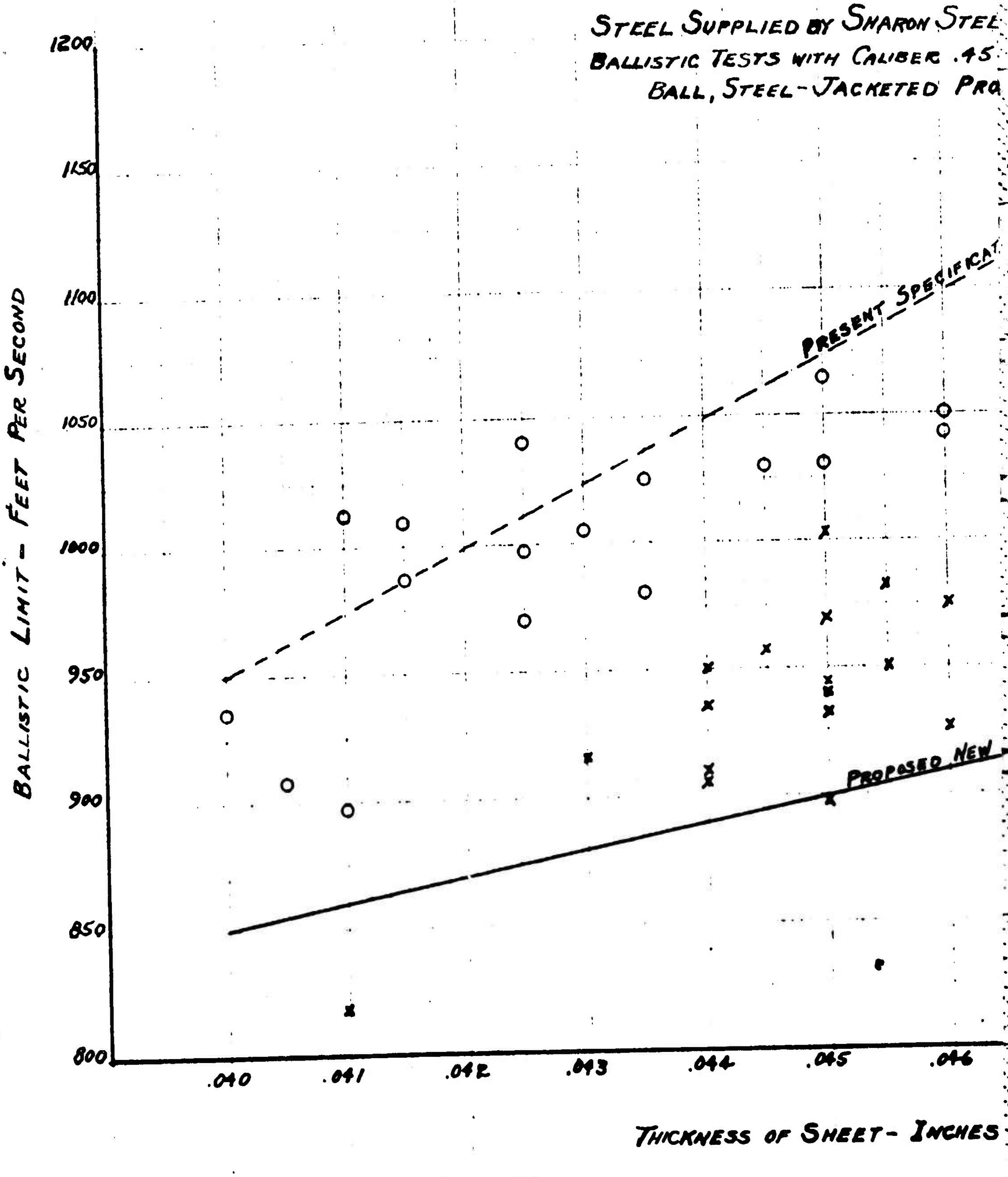

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ALLISTIC TESTS WITH CALIBER .45, 230 GRAIN
BALL, STEEL-JACKETED PROJECTILES

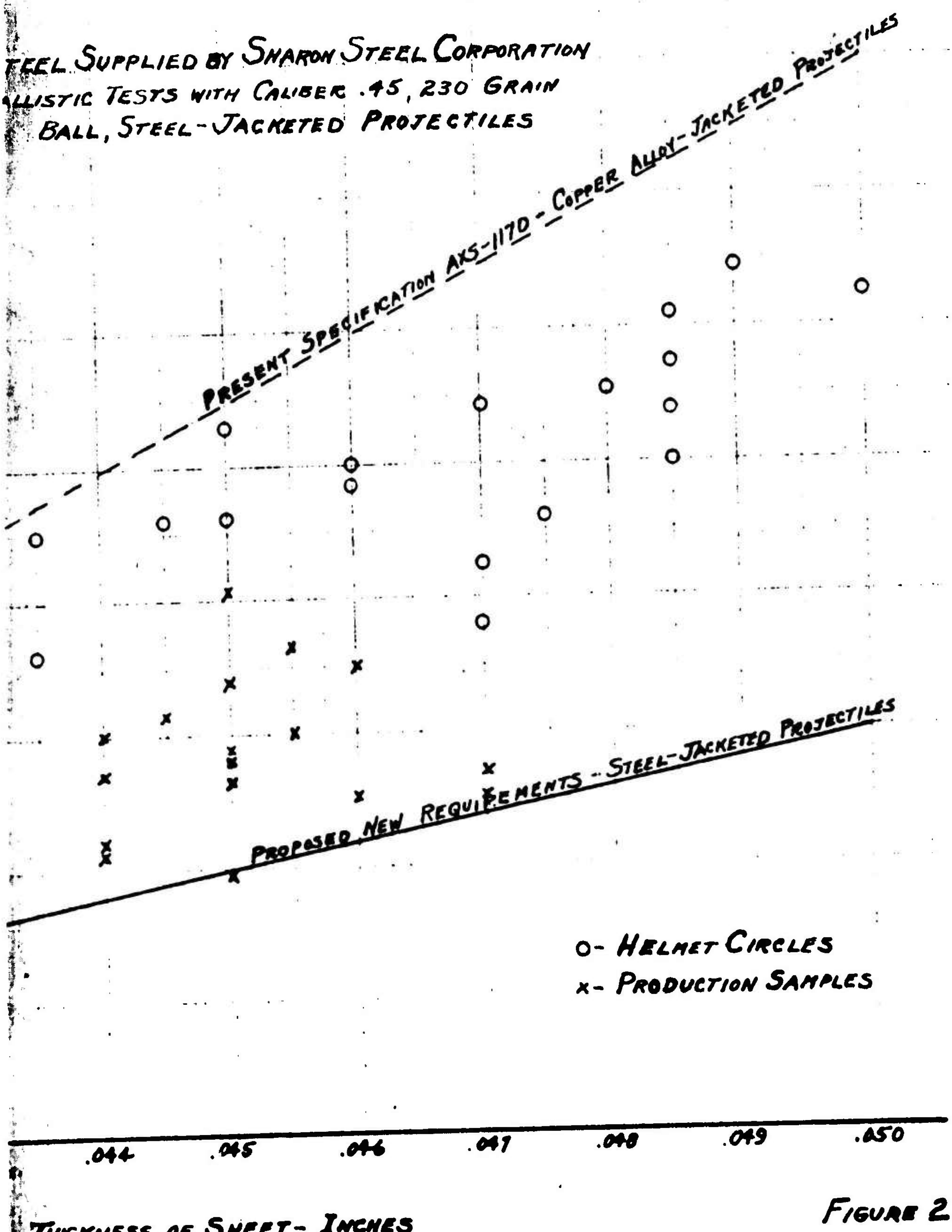

FIGURE 2.