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MEMORANDUM REPORT

NO. WAL 710/635

Ballistic Tests of .040 - .050" Hadfield Steel Sheet

With Caliber .45 Ball Projectiles for Development

of Specification Requirements

BY

A. KÜHLICH
Assoc. Metallurgist

K. A. MATTHEWS
Major, Ordnance Dept.

DATE 18 May 1944

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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 tests were conducted with copper-alloy jacketed projectiles. However, a later shipment of projectiles,
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 (1" 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 action. Instrumental velocities were recorded by an Aberdeen type chronograph and striking velocities were calculated from instrumental velocities as determined. The results of all impacts which strick too close to previus 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 interval over the range .040 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 are seen 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 12 sheets 12"x12" in size from numerous production lots then being processed which covered the thickness range .042 to .060 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 those 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 1 or lower of the Quality Control Standards was maintained. Approximately 40% of the sheets tested failed the bend test in one or more directions, whereas approximately 30% of the sheets failed the magnetic deflection test. 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 XXX.

**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 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 are not 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" armament, ending the standardization of improved projectiles. The ballistic tables over the range .040 to .050 inches would be as follows:

<table>
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<tr>
<th>Gauge (Ave.)</th>
<th>Required Striking Velocity, f/s.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.040&quot;</td>
<td>850</td>
</tr>
<tr>
<td>.041&quot;</td>
<td>860</td>
</tr>
<tr>
<td>.042&quot;</td>
<td>870</td>
</tr>
<tr>
<td>.043&quot;</td>
<td>880</td>
</tr>
<tr>
<td>.044&quot;</td>
<td>890</td>
</tr>
<tr>
<td>.045&quot;</td>
<td>900</td>
</tr>
<tr>
<td>.046&quot;</td>
<td>910</td>
</tr>
<tr>
<td>.047&quot;</td>
<td>920</td>
</tr>
<tr>
<td>.048&quot;</td>
<td>930</td>
</tr>
<tr>
<td>.049&quot;</td>
<td>940</td>
</tr>
<tr>
<td>.050&quot;</td>
<td>950</td>
</tr>
</tbody>
</table>

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 Helms, who accumulated much of the data contained in this report.

A. Hrubich
A. MURCH
Assoc. Metallurgist

M. C. Wallis
N. A. MATTHEWS
Major, Ordnance Dept.
Chief, Armor Section
Table I

Carnegie-Illinois Steel Corporation

Helmet Circles of Various Gauges

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness</th>
<th>Rockwell B</th>
<th>Traverse</th>
<th>Cal. .45 Ball</th>
<th>Microstructure</th>
<th>Amount of Carburetation</th>
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</thead>
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<tr>
<td>No.</td>
<td>Inches</td>
<td>Hardness</td>
<td>Inches</td>
<td>F/S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>.040</td>
<td>90.0</td>
<td>6.0</td>
<td>863</td>
<td>Discontinuous</td>
<td>.0004&quot;</td>
</tr>
<tr>
<td>104</td>
<td>.0405</td>
<td>88.5</td>
<td>3.5</td>
<td>1013</td>
<td>None</td>
<td></td>
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<tr>
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<td>.040</td>
<td>90.0</td>
<td>3.0</td>
<td>957</td>
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<td></td>
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<tr>
<td>91</td>
<td>.041</td>
<td>88.5</td>
<td>5.5</td>
<td>937</td>
<td>Discontinuous</td>
<td>.0004&quot;</td>
</tr>
<tr>
<td>92</td>
<td>.041</td>
<td>78.0</td>
<td>4.5</td>
<td>946</td>
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<td>90.0</td>
<td>3.0</td>
<td>1036</td>
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<tr>
<td>74</td>
<td>.042</td>
<td>87.5</td>
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<td>1010</td>
<td>None</td>
<td></td>
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<tr>
<td>82</td>
<td>.042</td>
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<td>5.0</td>
<td>993</td>
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<td>970</td>
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<td>940</td>
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All sheets were free from undissolved carbides and showed normal austenitic structure.
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<tr>
<th>Sample No.</th>
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<th>Magnetic Deflection Inches</th>
<th>Cal. .45 Ball .230 grain Steel Jacketed B.L. F/S</th>
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<td>998</td>
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<td>.041</td>
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<td>3.5</td>
<td>997</td>
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<td>969</td>
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Table III
Carnegie-Illinois Steel Corporation

Samples of reduction Sheet

<table>
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<tr>
<th>No.</th>
<th>Heat Number</th>
<th>Lift No.</th>
<th>Thickness</th>
<th>Cal. .15 Ball</th>
<th>One face in Tension</th>
<th>Opposite face in Tension</th>
<th>Magnetic Test Deflection in Inches</th>
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<tbody>
<tr>
<td>C2</td>
<td>220103</td>
<td>53592</td>
<td>.0415</td>
<td>1016</td>
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<td>2</td>
<td>2, 5</td>
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<tr>
<td>C4</td>
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<td>53596</td>
<td>.046</td>
<td>974</td>
<td>1</td>
<td>2</td>
<td>2, 4</td>
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<td>C6</td>
<td>220103</td>
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<td>.046</td>
<td>1031</td>
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<td>0, 0</td>
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<td>53598</td>
<td>.043</td>
<td>978</td>
<td>2</td>
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<td>2, 4/2</td>
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<td>53599</td>
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<td>1043</td>
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<td>53617</td>
<td>.044</td>
<td>986</td>
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<td>2</td>
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<td>2</td>
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Table IV
Sharon Steel Corporation

Samples of Production Test

Sample Size 12" x 12"

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Steel Supplied by Carnegie Illinois Ste.
Ballistic Tests with Caliber .45, 2. Ball, Steel + Jacketed Projec.

Ballistic Limit - Feet Per Second

Thickness of Sheet - In.
ED BY CARNEGIE ILLINOIS STEEL CORPORATION
TESTS WITH CALIBER .45, 230 GRAIN
STEEL - JACKETED PROJECTILES

PRESENT SPECIFICATION A45 - 170 - COPPER ALLOY - JACKETED PROJECTILES

PROPOSED NEW REQUIREMENTS - STEEL - JACKETED PROJECTILES

O - HELMET CIRCLES.
X - PRODUCTION SAMPLES.

THICKNESS OF SHEET - INCHES

Figure 1.
Steel Supplied by Sharon Steel
Ballistic Tests with Caliber .45
Ball, Steel-Jacketed Pro

Ballistic Limit - Feet Per Second

Thickness of Sheet - Inches
Steel supplied by Sharon Steel Corporation

Ballistic tests with caliber .45, 230 grain ball, steel-jacketed projectiles

Present specification AISI-1170 - Copper alloy-jacketed projectiles

Proposed new requirements - steel-jacketed projectiles

- Helmet circles
- Production samples

Thickness of sheet - inches

Figure 2