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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/609

Metallurgical and Ballistic Investigation of a

3½% Nickel Modified Hadfield Manganese Steel

Proposed for Use in the M1 Helmet

BY

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DATE 12 April 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Partial Report on Problem B-7.3

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ABSTRACT

Helmets fabricated from an experimental heat of a 3½% nickel manganese steel are ballistically comparable to regular production helmets. In the annealed flat sheet form, the nickel modified steel is approximately 8% inferior to normal manganese steel in ballistic properties when tested with caliber .45 ball ammunition. Hardness surveys show that nickel manganese steel helmets are from 3-6 points Rockwell C softer than manganese steel helmets in identical areas, and consequently have lower residual stresses. Bend tests performed on sections cut from the visors of helmets demonstrate the superior ductility of nickel manganese steel over manganese steel in an equally cold-worked condition. High magnetic properties of some nickel manganese steel discs were traced to a harmless oxide layer containing either a magnetic oxide or other phase of iron. This oxide layer can be readily removed by immersion in warm dilute hydrochloric acid. The harmless magnetic oxide layer makes the magnetic test specified in Specification AXS-1170 inapplicable for nickel manganese steel. The bend test remains the best criterion of quality of helmet steel. Nickel, as an austenite stabilizer, is apparently capable of preventing or reducing the amount of transformation to martensite which occurs when Hadfield steel is cold worked.

1. At the request of the Office, Chief of Ordnance[1], six helmets and six helmet discs fabricated from an experimental heat of a 3½% nickel modified Hadfield manganese steel were forwarded to this arsenal for metallurgical and ballistic investigation to determine comparability with normal production helmets and helmet steel. This heat was produced by the Carnegie-Illinois Steel Corporation in an attempt to determine if the addition of an austenite stabilizing element to normal Hadfield steel would improve the drawability and decrease the tendency to form brittle surface layers of austenite decomposition products resulting from surface decarburization during processing of the helmet sheet.

2. Approximately 12,000 discs of the 3½% nickel manganese steel were processed into helmets at the McCord Radiator and Manufacturing Company. The entire fabrication breakage amounted to only 0.16%, significantly lower than the normal breakage encountered with regular manganese steel. According to data supplied by the McCord Radiator and Manufacturing Company covering 26 heats of regular Hadfield steel processed into helmets at that plant, the draw breakage averaged 4.25%. The 26 heats of steel were included in McCord Lots 516 to 619. It is also significant that the trimmed edge of the helmet, particularly along the visor, was very smooth and notch-free in the case of the nickel manganese steel. Normal production helmets are found to have very jagged edges, giving the appearance of having been broken rather than sheared in the trimming dies. This condition apparently indicates superior ductility in the nickel manganese steel which is associated with lower hardnesses in the region where the trimming operation takes place.

3. According to data published by the International Nickel Company, Inc.[2], Hadfield steel to which 3-5% nickel is added has more ductility and better drawability than the normal austenitic manganese steel. Prolonged heating at temperatures up to 800°F causes no carbide precipitation in the nickel manganese steel, while manganese steel is subject to carbide precipitation at temperatures as low as 550°F. Cold working tests consisting of dropping weights upon conical specimens showed that although the same impact energy produces approximately the same deformation in both nickel manganese and manganese steel, the nickel manganese steel is cold worked to a lower hardness than the manganese steel and exhibits superior ductility in the cold worked condition.

4. With the factors described in the preceding paragraph in mind, it would be expected that the nickel manganese steel might be particularly useful for the helmet application. The superior drawability and cold working characteristics of nickel manganese steel may eliminate or greatly reduce the production difficulties being presently encountered with normal manganese steel. These difficulties consist of draw breakage, visor cracking, and delayed cracking occurring either in storage or during the service life of the helmet.

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1. Teletype dated 22 March 1944, see Appendix C.

2. "A New Nickel Manganese Steel" John Howe Hall, Booklet Published by the International Nickel Company, Inc., 67 Wall Street, New York City.

5. Metallurgical and ballistic investigation disclosed the following:

a. The ballistic properties of helmets fabricated from nickel manganese steel are deemed comparable to those of normal production helmets. Three 3½% nickel manganese steel helmets had an average ballistic limit of 900 ft./sec. with caliber .45 ball ammunition compared to an average of 913 ft./sec. for seven regular production helmets.

b. In the annealed sheet form, 3½% nickel manganese steel has a ballistic limit of approximately 920 ft./sec. for a thickness of 0.044" and normal manganese steel 1005 ft./sec. for the same thickness. The difference is believed attributable to differences in work hardening properties.

c. 90° bend tests conducted upon vertical sections cut from the visors of helmets indicate superior ductility of 3½% nickel manganese steel over normal manganese steel after an equal amount of plastic deformation.

d. The maximum hardness in the region of the visor resulting from cold working averages Rockwell C 45-47 in the 3½% nickel manganese steel and Rockwell C 50-53 in normal Hadfield steel helmets. The maximum hardness in the vertical areas to the right and left of the backs[3] of the helmets lies in the range of Rockwell C 48-51 in nickel manganese steel and Rockwell C 50-54 in normal Hadfield steel helmets. Since lower residual stresses accompany lower hardnesses, draw breakage and service cracking should show a marked reduction in the case of nickel manganese steel.

e. Nickel manganese steel is softer in the water toughened condition than normal manganese steel, averaging Rockwell B 86.5 against Rockwell B 91.5 for the latter.

f. Increased magnetic properties noted in some of the submitted 3½% nickel manganese steel discs are due to the presence of a complex oxide layer on the surfaces of the discs resulting from a combination of decarburization and oxidation during processing. The oxide layer, unlike the martensite layer occurring on decarburized manganese steel, does not embrittle the material and apparently does not introduce difficulties in the drawing operation. Steels with a high degree of magnetism resulting from the presence of the oxide layer show excellent bend tests.

g. Because of the nature of the magnetic oxide layer on 3½% nickel manganese steel, the magnetic test incorporated in Specification AXS-1170 cannot be applicable if the oxide layer is found to be peculiar to this steel.

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3. The two areas at 140-170° and 190-240° have been found to be zones of maximum hardness and maximum residual stress. Service cracking is generally confined to these zones and the visors of helmets.

h. The complex oxide layer is readily dissolved upon immersion in warm dilute hydrochloric acid, resulting in the complete elimination of the magnetic properties.

6. Materials and Test Procedure

The submitted material consisted of 6 drawn, spanked, and trimmed helmets, and 6 helmet discs forwarded from the McCord Radiator and Manufacturing Company, McCord Lot 808A, Carnegie-Illinois Heat No. 110077. Identification numbers are listed in Table I.

Table I

Helmet Discs No.	Helmet Bodies No.
11	21
12	22
13	23
15	24
17	25
19	26

The test procedure consisted of the following:

a. Chemical analysis.

b. Ballistic tests of helmets and discs.

c. 90° bend tests on sections cut from helmets.

d. 180° bend tests on sections cut from discs.

e. Hardness surveys of helmets and discs.

f. Magnetic tests of discs.

g. Microscopic examination.

7. Details of the ballistic and metallurgical tests are as follows:

a. Chemical Analysis. A chemical analysis was made of millings cut from disc #15 with the following result:

	C	Mn	Si	S	P	Ni	Cr
Watertown Analysis	1.12	12.53	.315	.020	.039	3.54	.06
Ladle Analysis (C.I.)	1.27	13.00	.32	.009	.052	3.48	—

b. **Ballistic Tests.** Ballistic tests were performed upon three helmets and six discs selected from the submitted samples using preloaded caliber .45 ball ammunition at a range of 25 feet. An Aberdeen chronograph was used to record the striking velocities. The results obtained were compared to firings conducted during the last two months against normal production helmets and helmet discs. Detailed results of the firing tests are contained in Appendix A and are summarized in Table II.

Table II

Ballistic Tests of Helmets and Helmet Discs

3½% Nickel Manganese Steel Helmets

Helmet No.	McCord Lot No.	Ballistic Limit ft./sec.
21	808A	907
25	808A	913
26	808A	880
		Average - 900 ft./sec.

Normal Production Manganese Steel Helmets

Helmet No.	McCord Lot No.	Ballistic Limit ft./sec.
I-1	584C	835
I-2	589A	905
I-3	594A	921
I-4	594B	927
I-5	595B	948
I-6	595A	952
G-7	621A	907
		Average - 913 ft./sec.

Table II (Cont'd)

3½% Nickel Manganese Steel Discs

Disc No.	Average Thickness	Carnegie-Illinois Heat No.	Ballistic Limit ft./sec.
11	.044	110077	943
12	.044	110077	924
13	.044	110077	904
15	.044	110077	911
17	.044	110077	948
19	.044	110077	899
			Average - 921 ft./sec.

Normal Production Manganese Steel Discs

No. of Discs	Thickness of each Disc	Carnegie-Illinois Heat Nos.	Average Ballistic Limit - ft./sec.
20	.044"	See Appendix A	1005

As a result of the above tests, the ballistic properties of 3½% nickel manganese steel helmets are considered comparable to those of regular production helmets. In tha annealed flat sheet form, however, the ballistic limit of the nickel manganese steel is 8% lower than that of normal manganese steel. This is believed attributable, as will be more fully discussed later in the report, to differences in the work hardening properties of the two steels.

c. Bend Tests on Helmets and Discs. Vertical sections approximately 2" wide and 3" long were cut from the middle of the visors of three 3½% nickel manganese steel helmets, Nos. 21, 25, and 26, and from three regular production manganese steel helmets which were on hand at this arsenal. The three regular production helmets were from McCord Lots 35C2, 37C2, and 40A2. The sections were cut from the portions of the visors lying between 340° and 20°. The longer sides of the sections were clamped in the jaws of a vise and a 90° bend produced by hammering the projection down. The bends were made in the same direction as the original curvature produced by the cold forming of the helmets.

A photograph of the 90° bends are shown in Figure 1. The three 3½% nickel manganese steel specimens show very minute cracks on the bends, while the manganese steel specimens are completely broken through the thickness of the section for a length of approximately one inch. After two days time, the breaks in the sections from helmets 35C2 and 37C2 extended down to the rim and the ends sprang apart. More recently, similar 90° bend tests were made on regular production helmets from Schlueter Lots 213B2 and 213B3 which resulted in the complete breaking of the vertical sections cut from the visors. The 90° bend tests demonstrate that, in equally plastically deformed conditions, the nickel manganese steel is more ductile than the manganese steel. This is in agreement with tests made by the International Nickel Company.[2]

180° bend tests were made in both directions on sections cut from the six nickel-manganese steel discs in accordance with the requirements of Specification AXS-1170. Both bends from discs Nos. 11, 13, 15, and 17 were completely free from even the most minute cracks. Both bends from discs Nos. 12 and 19 showed some very minute cracking and would be rated as lying between #1 and #2 on the basis of the Carnegie-Illinois Steel Corporation photographic standard for the bend test. All six discs are considered to have very satisfactory bends.

d. <u>Hardness Surveys of Sections Cut From Helmets and Discs</u>.

Vertical sections approximately two inches wide and three inches long were cut from the visors of helmets, Nos. 21, 25, and 26 in the region lying between 330° and 30°, and from regions lying to the right and left of the backs of helmets, Nos. 21 and 26, from 130° to 175° and from 190° to 240° respectively.[3]

Rockwell C hardness surveys were made on the visor sections approximately ½ inch up from the rim and also approximately 2 inches above the rim, and on the sections from the rear of the helmets approximately 1 inch and also 2 inches up from the rim. Similar hardness surveys have been made on numerous production helmets fabricated from normal manganese steel.

The detailed results of the hardness surveys are contained in Appendix B and are summarized in Table III.

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2. See footnote on page 2.

3. See footnote on page 3.

Table III

Rockwell C Hardness Surveys of Nickel Manganese and Manganese Steel Helmets

Type of Steel	Location of Zone-Degrees	Distance Up From Rim	Maximum Hardness Range Rockwell C
Nickel Manganese	330-350(visor)	0.5	45 - 47
Manganese	330-350(visor)	0.5	49 - 54
Nickel Manganese	330-350(visor)	2.0	44 - 48
Manganese	330-350(visor)	2.0	45 - 50
Nickel Manganese	350-10 (visor)	0.5	44 - 47
Manganese	350-10 (visor)	0.5	50 - 53
Nickel Manganese	350-10 (visor)	2.0	44 - 48
Manganese	350-10 (visor)	2.0	45 - 50
Nickel Manganese	10-30 (visor)	0.5	44 - 46
Manganese	10-30 (visor)	0.5	48 - 53
Nickel Manganese	10-30 (visor)	2.0	45 - 48
Manganese	10-30 (visor)	2.0	46 - 50
Nickel Manganese	130-175 (right) (rear)	1.0	45 - 47.5
Manganese	130-175 (right) (rear)	1.0	50 - 54
Nickel Manganese	130-175 (right) (rear)	2.0	40 - 45
Manganese	130-175 (right) (rear)	2.0	42 - 47
Nickel Manganese	190-240 (left) (rear).	1.0	48 - 51
Manganese	190-240 (left) (rear)	1.0	50 - 53
Nickel Manganese	190-240 (left) (rear)	2.0	45 - 48
Manganese	190-240 (left) (rear)	2.0	46 - 50

From the data in Table III it is evident that manganese steel helmets average 3 to 6 points Rockwell C harder than identical regions on nickel manganese steel helmets. This demonstrates that the same degree of plastic deformation produces greater hardnesses in manganese steel than in the modified alloy. According to Hall[4] some transformation to martensite occurs when Hadfield steel is cold worked, consequently some of the hardening which occurs upon cold working is attributable to this martensitization. The addition of nickel to Hadfield steel, resulting in an increase of the stability of the austenite, must necessarily decrease the tendency of the austenite to transform to martensite upon cold deformation. Thus, equal degrees of cold deformation would be expected to result in a lesser increase in the hardness of nickel manganese steel than of manganese steel.

Previous work at this arsenal has established that the hardness of variously cold worked regions of the helmets are proportional to the residual stresses; the zones of maximum hardness coinciding with the zones of maximum residual stress. It therefore follows that nickel manganese steel helmets, having generally lower hardnesses than manganese steel helmets, would also have lower residual stresses and would consequently be less liable to crack both during the drawing operation and in service.

The increased ductility of nickel manganese steel as shown by the 90° bend tests of sections cut from the visors of helmets is consistent with a lower hardness level. It is believed that the somewhat lower ballistic properties of annealed flat sheets of the nickel manganese steel are due to the difference in cold working properties between that steel and normal manganese steel. The nickel steel, being less resistant to deformation, work hardens to a lesser extent and offers less resistance to the passage of the projectile. When the steel has been cold worked into helmets, however, the difference becomes negligible from the viewpoint of ballistic performance, but is extremely significant from the viewpoint of cracking because of lower residual stresses and increased ductility.

Hardness surveys made on the flat discs, see Appendix B, showed them to have an average hardness of Rockwell B 86.5 whereas normal Hadfield steel has an average hardness of approximately Rockwell B 91.5. The slightly lower hardness of the nickel manganese steel is advantageous for the deep drawing operation involved in helmet production.

e. <u>Magnetic Tests of Nickel Manganese Steel</u>. Two inch by three inch sections were cut from the six submitted helmet discs and were subjected to the magnetic test previously described.[5] The results are given in Table IV.

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4. John Howe Hall "Studies of Hadfield's Manganese Steel with the High Power Microscope", Henry Marion Howe Memorial Lecture. Transactions of the Iron and Steel Division of the A.I.M.M.E. (1929) 84, 382-427.

5. Report No. WAL 710/571, "Defective Helmet Steel", A. Hurlich, 28 August 1943.

Table IV

Results of Magnetic Tests of

Nickel Manganese Steel Discs

Disc No.	Bend Test	Magnetic Traverse - Inches Surface 1	Surface 2
11	OK - No cracking	1.5	3.5
12	OK - Very minute cracking	13	13.5
13	OK - No cracking	3.5	4.5
15	OK - No cracking	4.5	2.5
17	OK - No cracking	6	2.5
19	OK - Very minute cracking	9	11

In previous work on normal manganese steel it was found that a magnetic traverse of 10 inches and over was associated with poor bend tests. The fact that one of the nickel manganese steel discs having a magnetic traverse of 13.5 inches showed up well on the bend test suggests a significant deviation from the properties of normal manganese steel.

f. Microscopic Examination. Specimens from microscopic examination were cut from the six helmet discs of nickel manganese steel. The microstructure of all six specimens consists of undeformed austenite grains free from undissolved or precipitated carbides. The surfaces of discs, Nos. 11, 13, 15, and 17 are free from any decarburization products, see Figure 1A. Discs, Nos. 12 and 19 have surface layers varying from 0.001 to 0.0015" in thickness, see Figures 1A, B, and C. These surface layers consist of a three phase oxide layer, which under a light nital etch shows up as dark gray, light gray, and white areas. Surface layers of this type have not been previously observed on normal Hadfield steel.

The surface layer is powdery and brittle in nature but does not embrittle the steel as does the martensite layer observed on decarburized Hadfield steel. The martensite layer on normal manganese steel embrittles it because the layer is integral with the body of the metal, and cracks which form in the martensite layer when the steel is deformed act as notches which enable the cracks to progress through the otherwise ductile austenitic body of the metal. On the other hand, the oxide layer is not integral with the base metal and any cracks forming in this brittle layer are not transmittable to the metal beneath the oxide coating.

Since the oxide layers were found only upon the two discs with high magnetic traverses it proved necessary to check if the magnetism was traceable to a magnetic oxide or magnetic phase of iron present in the oxide layer. A two inch square section of disc #12, having a magnetic traverse of approximately 13 inches on both surfaces, was immersed in a warm solution of 5% hydrochloric acid in water for a period of five minutes. It was noted that the surface of the steel was readily attacked by the acid. The specimen was washed and dried, then subjected to the magnetic test. No measurable deflection of the suspended magnet was observed. This establishes that the high magnetic attraction observed on nickel manganese steel discs results from a harmless oxide layer containing either a magnetic oxide or phase of iron. Practically no martensite was found on any of the specimens examined, whether or not the oxide layer was present.

If experience shows that this type of oxide layer is peculiar to nickel manganese steel, the magnetic test required by Specification AXS-1170 should not be considered applicable. The bend test appears to be a most satisfactory criterion of acceptability of both normal manganese and nickel manganese steel.

8. General Considerations

As a result of the tests performed on the 3½% nickel manganese steel it is believed that adoption of this material would greatly alleviate the difficulties being encountered both by the steel producers and helmet fabricators. The severity of the present steel specification requirements could probably be considerably relaxed because of the superior ductility, cold working properties, and reduced tendency to form martensitic surface layers possessed by the nickel manganese steel.

The results of the 90° bend test applied to sections cut from the helmet visors indicate the nickel manganese steel to be particularly desirable from the viewpoint of the problems of residual stresses and service cracking.

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APPROVED:

N. A. MATTHEWS
Major, Ord. Dept.
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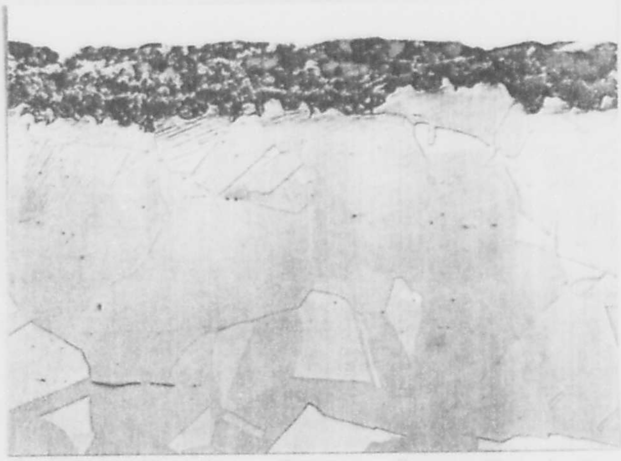
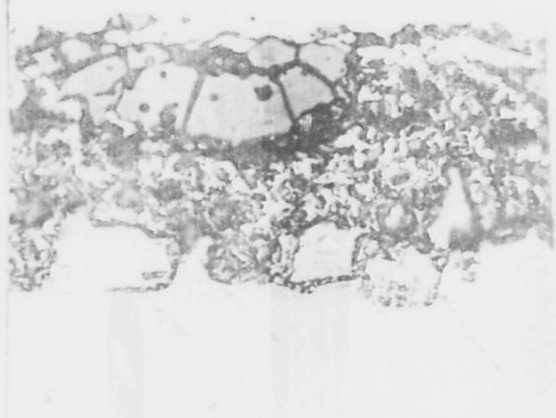
Microstructure of 3½% Nickel Hadfield Steel

A Disc No. 11 X100 Nital Etch
Normal austenitic structure. Complete freedom from visible surface decarburization.

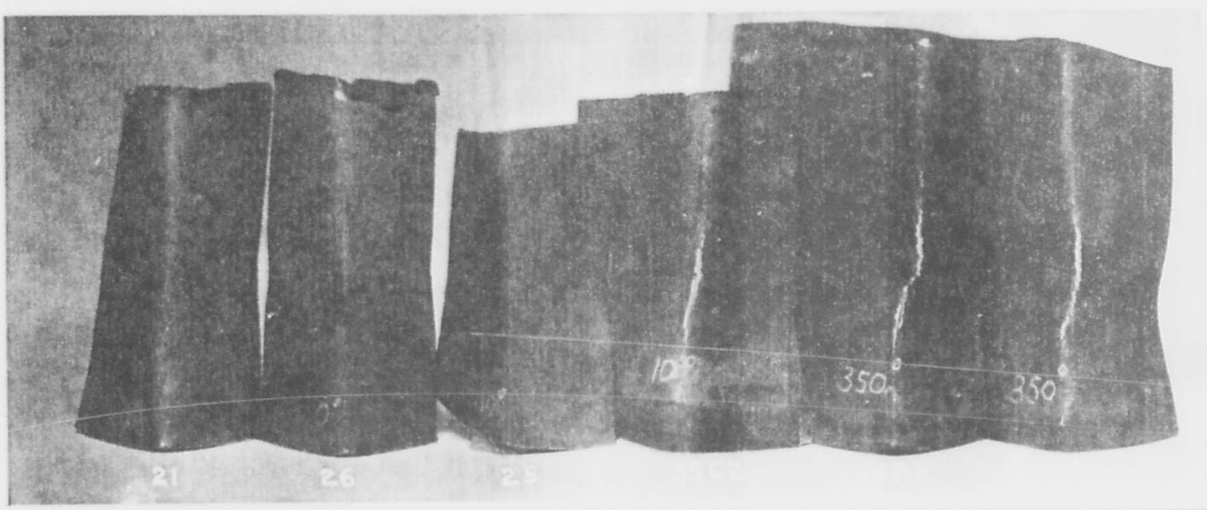
B Disc No. 12 X100 Light Nital
Oxide layer on surface of steel ha
high magnetism. No martensite lay



C Disc No. 12 X250 Light Nital Etch
Oxide layer at higher magnification. Layer is powdery, does not embrittle steel.



D Disc No. 12 X1000 Light Nital
Three phase oxide layer. This layer responsible for magnetic properties.



90° bend tests made on sections cut from visors of helmets. #21, 26, 25 are from 3½% Nickel Hadfield steel, remainder from normal steel. This demonstrates improved ductility of nickel steel.

FIGURE 1

APPENDIX A

Ballistic Test Data

Gun:	Cal. .45 Thompson Sub-machine Gun Barrel Fitted with Springfield Mod. 1903 Bolt Action #1534454
Projectile:	Cal. .45 M1911 Pistol Ball F.A. Lot 1349
Powder:	Lot 137
Range:	25 feet
Velocity Recorder:	Aberdeen Chronograph

The helmets were impacted on the vertical zone around the circumference lying between 3" and 1" up from the rim.

Helmet #21 (Nickel Manganese) McCord Lot 808A

Round No.	Striking Velocity	Result
1	909	PTP
2	904	PP

Ballistic Limit - 907 ft./sec.

Helmet #25 (Nickel Manganese) McCord Lot 808A

Round No.	Striking Velocity	Result
1	904	PP
2	962	PTP
3	922	PTP

Ballistic Limit - 913 ft./sec.

Helmet #26 (Nickel Manganese) McCord Lot 808A

Round No.	Striking Velocity	Result
1	871	PP
2	927	PTP
3	889	PTP

Ballistic Limit - 880 ft./sec.

Helmet I-1 (Manganese) McCord Lot 584C

Round No.	Striking Velocity	Result
1	893	PTP
2	847	PTP
3	822	PP

Ballistic Limit - 835 ft./sec.

Helmet I-2 (Manganese) McCord Lot 589A

Round No.	Striking Velocity	Result
1	893	PP
2	916	PTP

Ballistic Limit - 905 ft./sec.

Helmet I-3 (Manganese) McCord Lot 594A

Round No.	Striking Velocity	Result
1	949	PTP
2	893	PP

Ballistic Limit - 921 ft./sec.

Helmet I-4 (Manganese) McCord Lot 594B

Round No.	Striking Velocity	Result
1	904	PP
2	976	PTP
3	950	PP

Ballistic Limit - 927 ft./sec.

Helmet I-5 (Manganese) McCord Lot 535E

Round No.	Striking Velocity	Result
1	969	PTP
2	927	PP

Ballistic Limit - 948 ft./sec.

Helmet I-6 (Manganese) McCord Lot 595A

Round No.	Striking Velocity	Result
1	939	PP
2	964	PTP

Ballistic Limit - 952 ft./sec.

Helmet #G7 (Manganese) McCord Lot 621A

Round No.	Striking Velocity	Result
1	893	PP
2	920	PTP

Ballistic Limit - 907 ft./sec.

Ballistic Tests of Annealed Helmet Discs:

20 plates, each 0.044" thick, of manganese steel manufactured by the Carnegie-Illinois Steel Corporation tested for comparison with annealed nickel-manganese steel helmet discs.

Manganese Steel

Disc No.	Carnegie-Illinois Heat No.	Ballistic Limit ft./sec.
C2	220103	1016
C11	220103	973
C14	180109	1010
C28	180109	1046
C30	220105	986
C39	220105	1008
C48	220105	971
C66	220105	999
C68	220105	1012
C70	190101	1024
C76	190101	1015
C78	190101	1003
C80	190101	999
C82	190101	979
C90	210091	1011
C103	190101	1009
C107	210097	1011
C123	190101	972
C120	210097	1032
C118	210097	1024

Average - 1005 ft./sec.

APPENDIX B

Hardness Surveys of

Helmets and Helmet Discs

Hardness readings were made on the inside surface of sections cut from the helmets and spaced 1/2 inch apart on a line parallel to the rims of the helmets.

Helmet No.	Location of Section-Degrees*	Distance up from rim inches	Hardness Readings - Rockwell C
21	332-357 (visor)	0.5	47.0, 43.5, 45.0, 42.0, 42.5
(Nickel manganese steel)	"	2.0	46.0, 44.5, 43.5, 41.5
	358-16 (visor)	0.5	41.0, 39.5, 41.0, 43.5, 44.0
	"	2.0	41.5, 42.0, 42.0, 42.5
	17-35 (visor)	0.5	42.5, 44.0, 44.0, 43.0, 43.0
	"	2.0	44.5, 46.5, 47.0, 48.5
	130-155 (right rear)	1.0	45.5, 45.5, 46.5
	"	2.0	45.5, 45.5, 42.5
	155-175 (right rear)	1.0	43.5, 43.5, 43.5
	"	2.0	38.5, 39.5, 37.5
	190-215 (left rear)	1.0	45.5, 48.5, 50.5
	"	2.0	46.5, 47.5, 48.5
	215-240 (left rear)	1.0	45.5, 47.0, 44.5
	"	2.0	43.0, 42.5, 43.0

*Starting with the middle of the visor as 0° and rotating clockwise around the circumference of the rim.

Helmet No.	Location of Section-Degrees	Distance Up from rim inches	Hardness Readings-Rockwell C
25	338-0 (visor)	0.5	44.5, 47.0, 43.5, 47.0, 46.5
(Nickel manganese steel)	"	2.0	43.5, 45.0, 42.5, 42.0
	1-22 (visor)	0.5	42.0, 44.0, 44.5, 44.0, 43.0
	"	2.0	43.5, 42.0, 40.5, 40.0
26	330-353(visor)	0.5	47.5, 45.0, 45.0, 43.0, 40.0
(Nickel manganese steel)	"	2.0	48.5, 43.0, 44.0, 43.5
	354-12 (visor)	0.5	47.0, 43.5, 44.0, 44.5, 46.0
	"	2.0	40.0, 36.0, 41.0, 39.0
	13-30 (visor)	0.5	44.5, 42.5, 45.0, 46.0, 44.0
	"	2.0	45.5, 43.5, 44.0, 44.0
	130-155 (right) (rear)	1.0	47.5, 47.5, 45.5
	"	2.0	45.0, 45.0, 45.0
	155-175 (right) (rear)	1.0	50.0, 47.5
	"	2.0	44.5, 43.0
	190-215 (left) (rear)	1.0	50.5, 50.5, 51.0
	"	2.0	47.0, 47.5, 46.5
	215-240 (left) (rear)	1.0	46.5, 46.0, 45.0
	"	2.0	43.5, 43.0, 42.5

The hardness values contained in Table III covering the hardness of regular production manganese steel helmets represent the average of surveys made on five helmets. The typical results obtained on one helmet are given below:

Helmet No.	Location of Section-Degrees	Distance Up from rim inches	Hardness Readings - Rockwell C
4	342-20 (visor)	0.5	49.5, 50.5, 50.5, 52.5, 53.0, 52.5
(Manganese steel) McCord Lot 35C2	"	2.0	47.5, 50.0, 47.5, 49.5, 49.0, 48.0
	140-180 (right) (rear)	1.0	52.5, 53.5, 50.5, 51.5, 48.5
	"	2.0	45.5, 45.5, 45.5, 46.0, 46.0
	180-220 (left) (rear)	1.0	50.5, 54.5, 53.5, 49.0, 50.5
	"	2.0	45.0, 47.5, 48.5, 47.5, 46.5

Hardness Survey of Annealed Helmet Discs:

Helmet Disc	Type Steel	Rockwell B Hardness 1	2	3	Average
11	Nickel Manganese	87.5	86.5	90.5	88.0
12	"	85.5	85.0	85.5	85.5
13	"	85.5	86.5	86.5	86.0
15	"	84.0	85.5	86.5	85.5
17	"	88.5	90.0	88.5	88.5
19	"	86.5	86.5	85.5	86.0
				Average -	86.5

Helmet Disc	Type Steel	Mfr.	Heat No.	Rockwell B Hardness 1	2	3	Average
E1	Manganese	Sharon	72195	93.0	92.5	93.5	93.0
A1	"	"	72312	91.0	89.5	90.0	90.0
C1	"	"	72044	90.0	90.5	91.0	90.5
C2	"	"	72044	92.5	92.5	92.0	92.5
2	"	"	72257	93.5	93.5	92.5	93.0
4	"	"	72202	89.5	89.5	90.5	90.0
						Average -	91.5

APPENDIX C

Correspondence

COPY

B15

WA98

BWA V WAOC 49 WD

FROM KIRK C OF ASF WASHINGTON DC 222353Z MAR 44

TO WATERTOWN ARS WATERTOWN, MASS

GR NC

ATTN MR HURLICH

ON 21 MARCH MCCORD RADIATOR CO SHIPPED TO YOUR ARSENAL BY AIR EXPRESS SIX HELMETS AND SIX DISCS MADE OF SPECIAL HADFIELD MANGANESE STEEL CONTAINING 3½ PERCENT NICKEL. REQUEST YOUR ARSENAL RUN BALLISTIC LIMIT AND ANY OTHER TESTS DEEMED NECESSARY TO PROVE COMPARABILITY WITH REGULAR HELMETS. REQUEST SOME TEST TO DETERMINE IF THERE IS ANY SIGNIFICANT INCREASE IN MAGNETIC PERMEABILITY OF 3½ PERCENT NICKEL STEEL. END CITE SPOIS VOLBERG

230155Z

COPY

COPY

X LABORATORY

29 MARCH 1944 NAM/anv

CHIEF OF ORDNANCE

ARMY SERVICE FORCES, PENTAGON BUILDING, WASHINGTON 25, D. C.

SPOIS - MAJOR F. M. VOLBERG

REURTT 222353Z MARCH 1944, SPOIS VOLBERG, PRELIMINARY EXAMINATION INDICATES 3½ NICKEL HADFIELD STEEL LESS LIABLE TO AGE CRACKING AND HAS LOWER RESIDUAL STRESSES THAN NORMAL HADFIELD HELMETS. MAXIMUM HARDNESS RESULTING FROM COLD FORMING AVERAGES 45-47 ROCKWELL C IN 3½ NICKEL STEEL AND 50-53 ROCKWELL C IN NORMAL HADFIELD HELMETS. LOWER MAXIMUM HARDNESS OF 3½ NICKEL STEEL BELIEVED RESPONSIBLE FOR SMOOTH NOTCH-FREE EDGES AFTER TRIMMING. BALLISTIC LIMIT OF 3½ NICKEL HELMETS AVERAGES 900 FT.PER SEC. RECENT PRODUCTION HELMETS AVERAGE 915 FT. PER SEC. BALLISTIC PROPERTIES DEEMED COMPARABLE TO REGULAR HELMETS. POSSIBILITY EXISTS THAT 3½ NICKEL STEEL MAY ALLOW LESS STRINGENT STEEL QUALITY REQUIREMENTS. NO THEORETICAL BASIS TO BELIEVE THAT NICKEL ADDITION CAN INCREASE MAGNETIC PERMEABILITY OF HADFIELD STEEL. THE REVERSE IS MORE PROBABLE. REPORT TO FOLLOW. END CITE LABORATORY MATTHEWS.

MATHER, WATERTOWN ARSENAL

H. H. ZORNIG
COLONEL, ORD. DEPT.
ASSISTANT

COPY