~~RESTRICTED~~

REPORT NO. 710/439

HELMETS

COMPARISON OF HELMETS MADE FROM MAX AND HADFIELD MANGANESE STEEL

by

J. F. Sullivan
Statistical Clerk

A. Hurlich
Jr. Metallurgist

June 20, 1942

WATERTOWN ARSENAL
WATERTOWN, MASS.

 (1)

Report No. 710/439
Watertown Arsenal
Ex.O. 51A28

June 20, 1942

HELMETS

Comparison of Helmets Made from NAX and Hadfield Manganese Steels.

OBJECT

To compare the ballistic and metallurgical characteristics of helmets made from NAX 9120 and Hadfield manganese steels.

REFERENCES

O.O. 421/680			
O.O. 121.2/12128,	W.A.	421/224	1st Ind.
O.O. 121.2/12128,	W.A.	421/224	2nd Ind.
O.O. 421/1044,	W.A.	421/289	1st Ind.

CONCLUSIONS

1. Of the helmets submitted for test, those made from Hadfield manganese steel have a higher resistance to penetration of .45 caliber lead ball ammunition than those made from NAX 9120 steel.

a. Average ballistic limit of Hadfield helmets is 1016 f/s at an average thickness of .043".

b. Average ballistic limit of NAX helmets is 893 f/s at an average thickness of .042".

2. Although the Hadfield helmets resisted complete penetrations at higher velocities than the NAX helmets, nevertheless, the NAX helmets had shallower indentations on partial penetrations. If minimum indentation is a desirable feature of helmet shells; it is believed as a result of these considerations that the NAX steel at a quality level comparable with the material in these helmets would provide a satisfactory substitute steel for the helmet application.

3. Deep drawing a ferritic steel such as NAX in dies designed for Hadfield austenitic steel does not develop the optimum properties of the ferritic steel:

a. The NAX helmets drawn in the same dies as the Hadfield steel average 0.006" less in thickness in the crown area than the Hadfield helmets, see Figure 6.

b. The abrupt variations in wall thickness of the NAX helmets resulting from an improper drawing technique tend to produce irregular ballistic results.

4. The weld between the stainless steel strip and the rim of the NAX helmet was unsatisfactory, separation occurring when the metal in the vicinity of the weld deformed under impact, see Figure 7, NAX helmet No. 2.

5. The weld between the chin strap clip and the NAX helmet shell was unsatisfactory; the chin strap clips frequently broke off during the ballistic test, see Figure 7, NAX helmet No. 3.

6. Metallographic examination reveals porosity and interdendritic cracks in the weld between the stainless steel chin strap clip and the NAX helmet shell.

7. Welding the chin strap clips and the rim to the helmet shell prior to heat treatment should greatly increase the quality and tenacity of the weld.

J. F. Sullivan
J. F. Sullivan
Statistical Clerk

A. Hurlich
A. Hurlich
Jr. Metallurgist

Approved:

H. H. Zornig,
Colonel, Ordnance Dept.,
Director of Laboratory.

INTRODUCTION

Ninety (90) helmets made from Great Lakes Steel Corporation NAX 9120 steel and fifty (50) helmets of the production variety made from Hadfield steel by the McCord Radiator Company were sent to this arsenal as a result of the contract placed to investigate the possibilities of the NAX steel for helmets. The helmets were completely finished with rims and straps applied and painted but without the liners.

The NAX helmets had been heat treated as follows: Water quenched from 1600°F, and drawn at 300-400°F. The Hadfield helmets were in the cold worked condition resulting from the drawing operations.

TEST PROCEDURE

Ten helmets of each variety were selected at random for ballistic test. Transverse and longitudinal cross-sectional strips were taken from two additional helmets of each type selected at random for hardness and thickness surveys. Chips for chemical analysis were taken from the latter helmets. Transverse and longitudinal microspecimens were taken from two helmets of each type which, on the basis of the ballistic tests, were considered the best and the poorest of each type.

On the basis of the thickness surveys, the thickness at the point of each impact was estimated taking into consideration the position of the impact and the position where an actual thickness measurement had been made on each helmet.

RESULTS

1. Chemical Analysis

Chemical analyses of typical helmets of each type are as follows:

Helmet Steel	C	Mn	Si	S	P	Ni	Cr	Mo	Zr
Hadfield	1.27	14.50	.38	.017	.031	nil	--	.24	--
NAX	.24	.81	.92	.035	.034	nil	.84	.16	.14

2. Microscopic Examination

a. Hadfield Manganese Steel Helmets

The size, shape, and distribution of the nonmetallic inclusions are similar in both Hadfield helmets No. 3 and No. 9, consisting of fairly well distributed stringers ranging up to 0.003" in length. Hadfield helmet No. 3 was selected as the best, and No. 9 as the poorest helmet on the basis of the ballistic tests. The steel of both helmets is moderately clean. (See Figure 1B, X100.)

The microstructure consists of deformed austenitic grains, with the deformation being somewhat more severe in the transverse direction than in the longitudinal. No free carbides are present in the microstructure. Extensive cold working is revealed by the large number of slip lines present. (See Figures 2C and 2D, X100.) Helmet No. 3 has a grain size of A.S.T.M. No. 4-5 and helmet No. 9 a grain size of A.S.T.M. No. 3-4. The specimens for microscopic examination were cut from the sides of the crown approximately four inches up from the rim.

A section through the weld between a chin strap clip and the shell of a Hadfield helmet is shown unetched in Figure 3A, X5, and etched with Vilella's reagent in Figure 3B, X5, to show the relatively small nugget formed in the spot welding operation and the resulting low strength. A view at higher magnification of the weld nugget, Figure 4A, X100, shows the extreme heterogeneity of the spot weld between Hadfield manganese steel and stainless steel.

b. NAX STEEL HELMETS

The steel of both NAX helmets No. 9 and No. 10 is moderately clean, containing well distributed nonmetallics with but a slight tendency towards elongation in the direction of rolling. (See Figure 1A, X100.) Helmet No. 10 was the best and helmet No. 9 the poorest NAX helmet on the basis of the ballistic tests. Both helmets were decarburized on both surfaces, with ferrite grains extending down approximately 0.0015" from the surfaces. (See Figure 1C, X1000.)

The microstructure of both helmets consists of martensite that was tempered at a relatively low temperature. (See Figures 2A and 2B, X1000.) Helmet No. 9 has a grain size of A.S.T.M. No. 7 and helmet No. 10 a grain size of A.S.T.M. No. 6.

A section through a weld between a chin strap clip and the helmet shell of an NAX helmet is shown unetched in Figure 3C, X5, and etched in Vilella's reagent in Figure 3D, X5. Porosity and cracking are evident. A view at higher magnification of the weld nugget is shown in Figure 4B, X100. The cracking occurs along the interdendritic network in the weld nugget.

3. HARDNESS SURVEYS

Hardness Surveys were made along strips cut through both longitudinal and transverse midsections of Hadfield and NAX helmets. The results are shown in tabular form in Figure 5. The ranges of hardness obtained on both types of helmets are as follows:

HELMET STEEL	HARDNESS RANGE ROCKWELL C	EQUIVALENT BRINELL
Hadfield(Transverse section)	28-43.5	275-420
Hadfield(Longitudinal section)	31-50	300-495
NAX(Transverse section)	34.5-44	325-430
NAX(Longitudinal section)	38-42.5	360-400

4. THICKNESS MEASUREMENTS

The thicknesses of the shells of Hadfield and NAX helmets were measured every half-inch along the strips used for the hardness surveys, and the results are plotted in Figure 6.

5. BALLISTIC TESTS

Ballistic tests were conducted on 10 helmets of each type using specially loaded caliber .45 lead ball ammunition fired from a caliber .45 revolver at a range of 25 feet. Striking velocities were recorded by means of an Aberdeen Chronograph. Photographs of typical results of firing at both types of helmets are shown in Figure 7.

During the ballistic tests, shots were fired at corresponding areas on the two types of helmets to obtain comparable results.

Detailed reports of the ballistic tests are as follows:

TABLE I

HELMET NO.	GAUGE IN.	GAUGE POSITION	RD. NO.	STR. VEL.	PEN. DEPTH	IMPACT POSITION	EST. GAUGE AT IMPACT	EFFECT ON WELDING: RIM	EFFECT ON WELDING: CHIN STRAP CLIP	RESULT
HAD 1	.048	.7 F	1	Lost	.99	3.1 S	.044	None	None	PP
			2	913	1.01	2.8 S	.043	None	None	PP
			3	990	1.09	2.1 B	.041	None	None	PP
			4	1025	CP	2.2 S	.043	None	None	CP-1.4"x1.3" Tear
			5	Service	PP	7.5 B	.037	None	None	PP
HAD 2	.048	.7 FS	1	Lost	1.13	2.5 S	.043	None	None	PP
			2	1023	CP	1.3 B	.040	Failed	None	CP-2.2"x1.6" Piece broken out upon impact near rim; rim parted and pushed aside.
			3	1071	1.42	2.7 B	.038	None	None	PP
			4	1092	1.54	3.3 S	.041	None	None	PP
			5	1139	CP	3.3 F	.042	None	None	CP-1.6"x1.3" Tear
			6	Service	1.31	7.7 S	.038	None	None	PP
HAD 3	.047	.9 S	1	Lost	1.09	2.4 S	.042	None	None	PP
			2	1084	1.08	2.9 B	.041	None	None	PP
			3	1134	CP	2.8 B	.041	None	None	CP-2.6"x1.5" Tear
			4	Service	1.34	8.8 S	.039	None	None	PP
HAD 4	.044	1.1 BS	1	1077	CP	2.6 S	.044	None	None	CP-1.1"x.7" Piece broken out.
			2	883	.87	2.5 S	.044	None	None	PP
			3	909	1.18	3.2 F	.044	None	None	PP
			4	1009	1.10	2.8 S	.042	None	None	PP
			5	1024	.97	2.5 B	.041	None	None	PP
			6	1061	.99	2.5 B	.041	None	None	PP
			7	Service	1.32	8.6 S	.039	None	None	PP

TABLE I Cont.

HELMET NO.	GAUGE IN.	GAUGE POSITION	RD. NO.	STR. VEL.	PEN. DEPTH	IMPACT POSITION	EST. GAUGE AT IMPACT	EFFECT ON WELDING RIM	EFFECT ON WELDING CHIN STRAP CLIP	RESULT
HAD 5	.046	.6 S	1	1008	1.42	3.4 S	.041	None	None	PP
			2	1009	1.03	2.0 B	.040	None	None	PP
			3	1091	CP	2.9 S	.042	None	None	CP-2.0"x1.4" Tear
			4	1041	CP	2.3 BS	.041	None	None	PP
			5	Service	1.32	8.7 S	.038	None	None	PP
HAD 6	.046	.9 S	1	1051	CP	3.1 S	.043	None	None	CP-1.5"x1.3" Tear
			2	1009	1.32	2.2 B	.041	Loosened	None	PP
			3	Service	1.25	8.5 F	.037	None	None	PP
HAD 7	.048	.9 S	1	1050	CP	2.1 S	.045	None	None	CP-1"x.85" Tear
			2	1022	CP	2.6 FS	.044	None	None	CP-1.4"x1.25" Tear
			3	1038	CP	3.2 F	.044	None	None	CP-1.2"x1.1" Tear
			4	1009	CP	2.4 FS	.044	None	None	CP-1.85"x1.4" Tear
			5	963	1.27	2.9 S	.043	None	None	PP
			6	Service	1.30	8.2 S	.038	None	None	PP
HAD 8	.048	1.0 FS	1	982	CP	2.6 S	.044	None	None	CP-1.1"x1.0" Tear
			2	976	CP	1.5 S	.046	Loosened	None	CP-1.8"x1.7" Tear Extending at one extremity to rim.
			3	927	.85	1.9 FS	.045	None	None	PP
			4	Service	1.29	8.4 F	.038	None	None	PP
HAD 9	.047	.7 S	1	967	CP	1.7 S	.045	None	None	CP-1.4"x1.2" Tear
			2	925	1.23	2.8 S	.043	None	None	PP
			3	Service	1.32	8.5 S	.038	None	None	PP
HAD 10	.047	1.3 S	1	936	CP	2.7 S	.045	None	None	CP-1.2"x1.1" Tear
			2	876	1.10	2.7 S	.045	None	None	PP
			3	896	1.16	3.3 F	.044	None	None	PP
			4	Service	1.24	9.2 S	.039	None	None	PP

TABLE II

HELMET NO.	GAUGE IN.	GAUGE POSI-TION	RD. NO.	STR. VEL.	PEN. DEPTH	* IMPACT POSI-TION	EST. GAUGE AT IMPACT	EFFECT ON WELDING RIM	EFFECT ON WELDING CHIN STRAP CLIP	RESULT
NAX 1	.047	.8 FS	1	Lost	*	2.45	.044	None	None	PP*Depth of penetration affected by impact on inside with spent bullet of Rd. No. 4.
			2	832	.79	2.6 BS	.043	None	None	PP
			3	942	.84	2.2 BS	.043	None	None	PP
			4	986	CP	2.3 S	.044	Loosened	1 Failed	CP-1.4"x1.15" Tear
			5	Service	CP	8.8 S	.032	None	None	CP-1.7"x1.3" Tear
NAX 2	.046	.7 FS	1	942	CP	1.7 S	.044	None	None	CP-2.6"x1.7" Tear
			2	862	.92	2.5 FS	.042	None	None	PP
			3	951	CP	3.3 F	.041	Failed	None	CP-1.35"x1.3" Tear; Bullet exited at .9B, causing 1.9"x.6" Tear and influencing rim weld failure.
			4	887	1.05	2.9 S	.042	None	None	PP
			5	909	.89	2.4 BS	.043	None	None	PP
			6	Service	CP	8.5 S	.033	None	None	CP-1.4"x1.4" Tear
NAX 3	.046	.8 S	1	923	.87	2.9 S	.042	None	1 Failed	PP
			2	921	.98	3.0 F	.041	None	None	PP
			3	Lost	1.04	2.6 S	.043	None	1 Failed	PP
			4	Lost	CP	2.5 BS	.043	None	None	CP-1.6"x1.5" Tear
			5	936	CP	3.2 B	.042	Failed	None	CP-1.4"x1.2" Tear; Bullet exited at 1.5 F, causing 1.6"x.8" Tear and influencing rim weld failure.
			6	Service	CP	9.3 S	.032	None	None	CP-1.4"x1.3" Tear

TABLE II Cont.

HELMET NO.	GAUGE IN.	GAUGE POSITION	RD. NO.	STR. VEL.	PEN. DEPTH	IMPACT POSITION	EST. GAUGE AT IMPACT	EFFECT ON WELDING RIM	EFFECT ON WELDING CHIN STRAP CLIP	RESULT
NAX 4	.047	.9 FS	1	959	1.05	3.0 S	.044	Loosened	1 Failed	PP
			2	Lost	1.15	3.2 BS	.043	None	None	PP
			3	991	CP	2.4 B	.043	None	None	CP-1.6"x1.4"Piece broken out.
			4	Service	CP	9.1 S	.033	None	None	CP-1.55"x1.4" Tear
NAX 5	.046	.7 FS	1	935	CP	2.9 S	.043	None	1 Failed	CP-1.35"x1.2" Tear; spent bullet passed through to impact inside of helmet at 2.1S, influencing chin strap clip weld failure.
			2	909	CP	2.8 FS	.042	None	None	CP-1.7"x1.6"Piece broke out, .35" adjacent crack.
			3	904	1.05	3.4 FS	.041	None	None	PP
			4	Service	CP	8.4 S	.034	None	None	CP-1.4"x1.4" Tear
NAX 6	.045	.9 FS	1	Lost	CP	2.6 S	.043	None	None	CP-1.5"x1.4" Tear
			2	851	.95	2.9 S	.042	Failed	None	PP
			3	893	CP	3.1 F	.040	None	None	CP-2.5"x1.2" Tear
			4	Service	CP	9.2 S	.032	None	None	CP-1.35"x.4" Tear;.4" and .2" cracks.
NAX 7	.043	.7 FS	1	877	CP	2.8 S	.040	None	None	CP-1.45"x1.05" Tear
			2	890	CP	2.3 F	.040	None	None	CP-1.7"x1.45" Tear
			3	771	.77	2.7 F	.039	None	None	PP
			4	847	CP	3.1 S	.039	None	1 Failed	CP-1.65"x1.4" Tear; spent bullet passed through to impact inside of helmet at 2.4 S influencing chin strap clip weld failure.

TABLE II Cont.

HELMET NO.	GAUGE IN.	GAUGE POSITION	RD. NO.	STR. VEL.	PEN. DEPTH	IMPACT POSITION	EST. GAUGE AT IMPACT	EFFECT ON WELDING: RIM	EFFECT ON WELDING: CHIN STRAP CLIP	RESULT
NAX 7 cont.			5	828	1.02	2.7 BS	.040	None	None	PP
			6	Service	CP	9.0 B	.030	None	None	CP-1.3"x1.2" Tear
NAX 8	.044	.9 S	1	860	CP	2.4 S	.040	None	None	CP-1.9"x1.6" Tear
			2	773	.79	2.5 B	.040	None	None	PP
			3	862	CP	2.5 B	.040	None	None	CP-1.6"x1.4"Tear8" crack
			4	781	1.08	3.2 BS	.039	None	None	PP
			5	814	CP	2.2 S	.039	None	None	CP-1.8"x1.3" Tear
			6	Service	CP	8.1 S	.031	None	None	CP-1.3"x.4" Piece broken out.7" crack.
NAX 9	.048	.6 S	1	862	CP	1.9 S	.045	None	None	CP-2.0"x1.1" Tear
			2	769	.87	2.8 S	.044	Failed	None	PP
			3	847	.62	3.3 F	.043	None	None	PP
			4	Service	CP	8.8 S	.034	None	None	CP-1.35"x1.25" Tear .15" crack.
NAX 10	.045	.9 S	1	847	1.08	2.9 S	.040	None	Failed	PP
			2	866	CP	2.1 F	.039	None	None	CP-1.8"x1.25" Tear
			3	Service	CP	9.4 S	.030	None	None	CP-1.45"x1.2" Tear .25" crack.

*KEY

PP - partial penetration
CP - complete penetration
----Apply to ballistic results

The number preceding the group on the right indicates the distance in inches from the rim of the helmet.

F - front of helmet
S - side of helmet
B - back of helmet
FS - area between front and side of helmet
BS - area between back and side of helmet
---- Apply to position in which impact occurred or measurement was taken.

DISCUSSION

On the basis of ballistic limit alone, the NAX helmets tested did not equal the performance of those made from Hadfield manganese steel. The difference between the behavior of the NAX rim welds and chin strap clip welds under impact is the result of poor fabrication practice and no fault of the steel itself. In other respects NAX helmets compared favorably under impact with those of the Hadfield group,--the type of tearing and the character of the failures being similar.

On the basis of indentation, on the other hand, the NAX type was noticeably better, and inasmuch as helmets in service are often subject to attack by shrapnel, bomb fragments and other debris as well as from pistol or rifle fire, resistance to indentation may well be as important a consideration in helmets as resistance to penetration.

It should be noted that in spite of the fact that the NAX helmets tested were made under unfavorable conditions of fabrication, they exhibited many good features. It is believed, therefore, that NAX steel, formed into helmets in dies designed for this steel, with rims and chin strap clips welded prior to heat treatment, will prove a satisfactory substitute for the high manganese steel.

From the alloy conservation standpoint, the NAX steel is considered to be one of the best substitutes. The strategic alloy content is low, and the steel can be produced in large tonnages as an open-hearth product.

The weld between the stainless steel chin strap clips and the NAX helmets is unsatisfactory due to porosity and cracking in the weld nugget, see Figures 4C, 4D, and 5B.

It was noted that a sustained pull on the straps caused failure through the weld between the chin strap clips and the helmet shell of both the Hadfield and NAX helmets. This is attributed to the fact that a relatively small area of the contact surfaces between the metals is actually fused together, see Figures 4A to D. The contact surfaces which are not fused provide notch effects leading to regions of high stress concentration when load is applied to the chin strap clips. It is therefore believed that the use of a larger size spot welding machine electrode and a longer heating cycle to produce greater homogeneity in the nugget would produce a larger and stronger nugget and also a nugget having greater ductility.

Rockwell C surveys show both types of helmets to have the same range of hardness, thus precluding observations as to the effect of hardness on ballistic performance of the helmet steels in question.

The variation in gauge of the Hadfield helmet from rim to crown, see Figure 6, is normal for the cold forming process used. The excessive variation in gauge of the NAX helmets resulting from drawing them in dies designed to form austenitic steel can be eliminated by the use of suitably designed dies, and all variation in gauge can probably be eliminated by hot forming helmet bodies made of ferritic steels.

All the Hadfield helmets resisted complete penetrations in the crown when subjected to impact of a .45 caliber lead ball fired at service velocity (approximately 800 f/s); while in all cases complete penetrations resulted in the crowns of NAX helmets similarly tested. This is attributable in the main to the difference in thickness of the crown areas of the two types of helmets. The NAX helmets averaged 0.006" thinner in the crown than the Hadfield helmets, and in no case was this difference less than 0.003". The NAX helmet averaged 0.032" thick in the crown and the Hadfield 0.038".

The subject ferritic steel is representative of many similar low alloy high tensile steels on the market which are adaptable to deep forming operations. Although no complete tests have been carried out on these several steels, there is no reason to doubt but what similar results could be obtained with their use in the majority of cases.

In the fabrication of magnetic helmet shells it is believed that a low carbon strip steel could be used as the rim and fastener materials. This type of product has equivalent forming properties and would spot weld more easily. Furthermore, the stainless steel components should not be used from the conservation standpoint if avoidable.

FIGURE I

A. NAX Helmet No. 10

Average distribution of nonmetallic inclusions representative of both helmets.

Unetched X100 MA-4441

B. Hadfield Helmet No. 9

Average distribution of nonmetallic inclusions representative of both helmets.

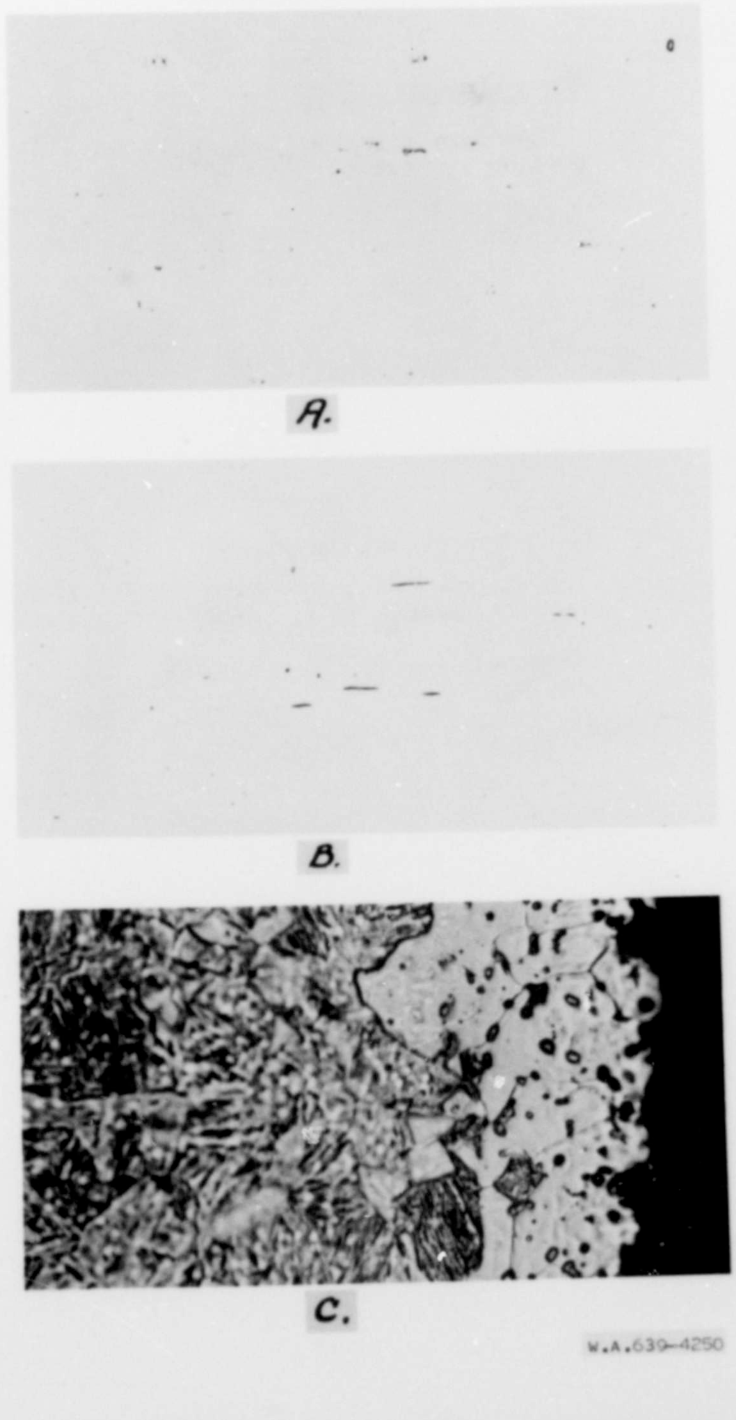
Unetched X100 MA-4442

C. NAX Helmet No. 10

Typical decarburization at both surfaces of the NAX helmets. Decarburization to ferrite averages 0.0015" in depth.

Nital and Picral etch X1000 MA-4445

FIGURE 1.



A.

B.

C.

W.A.639-4250

FIGURE 2

MICROSTRUCTURE OF HELMETS

A. NAX Helmet No. 10

Martensitic microstructure. A.S.T.M. grain size No. 6. Best NAX helmet on basis of ballistic tests.

Nital and Picral etch X1000 MA-4444

B. NAX Helmet No. 9

Martensitic microstructure. A.S.T.M. grain size No. 7. Poorest NAX helmet on basis of ballistic tests.

Nital and Picral etch X1000 MA-4443

C. Hadfield Helmet No. 3

Cold worked austenite grains. A.S.T.M. grain size No. 4-5. Best Hadfield helmet on basis of ballistic tests.

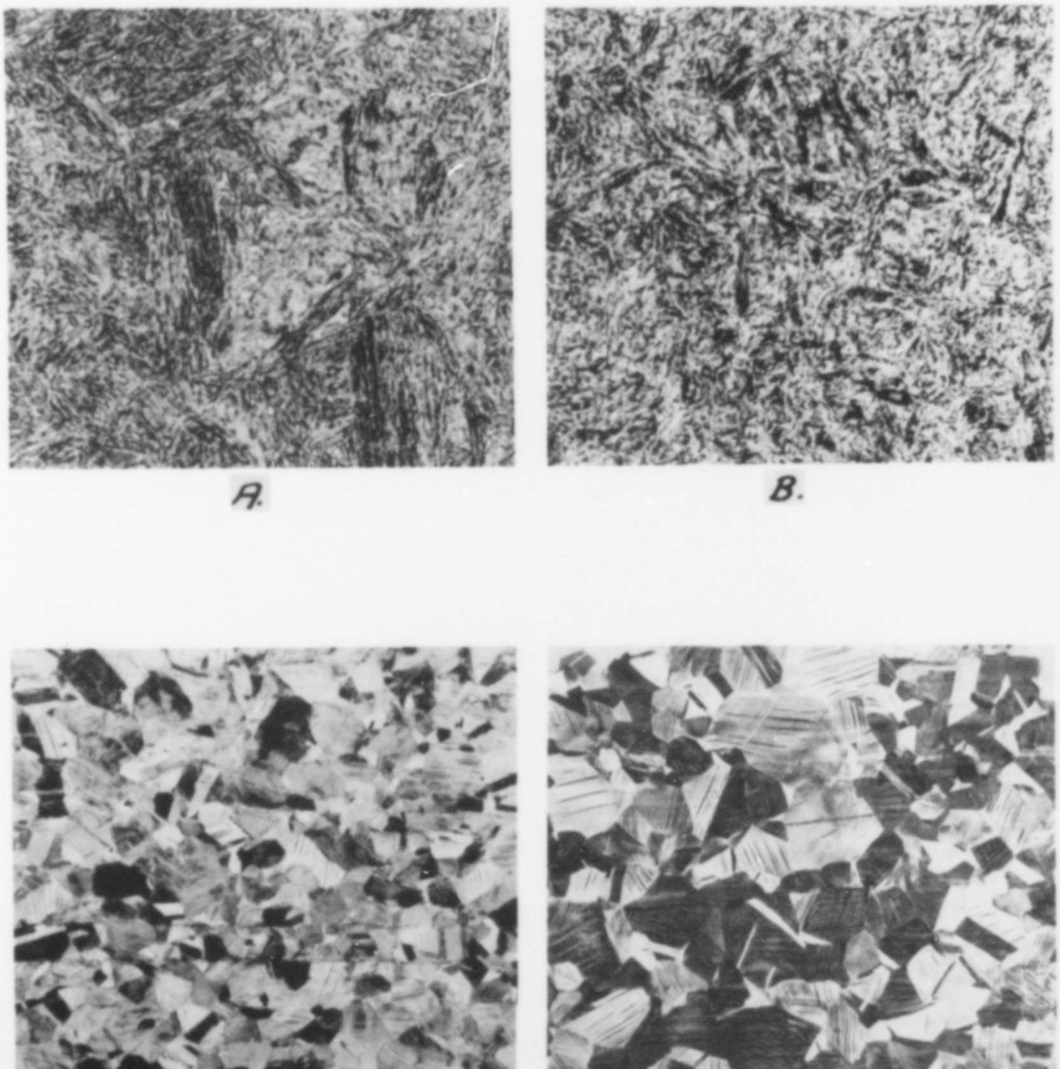
Nital and Vilella etch X100 MA-4454

D. Hadfield Helmet No. 9

Cold worked austenite grains. A.S.T.M. grain size No. 3-4. Poorest Hadfield helmet on basis of ballistic tests.

Nital and Vilella etch X100 MA-4452

FIGURE 2.



W.A.639-4251

FIGURE 3

CHIN STRAP CLIP WELDS

A. Hadfield Helmet

Section through chin strap clip weld showing relatively small area of contact surface fused together.

Unetched X5 MA-4447

B. Hadfield Helmet

Same as above. Note small weld nugget

Vilella etch X5 MA-4449

C. NAX Helmet

Section through chin strap clip weld showing small area of contact surface fused together. Note porosity and cracks in the weld.

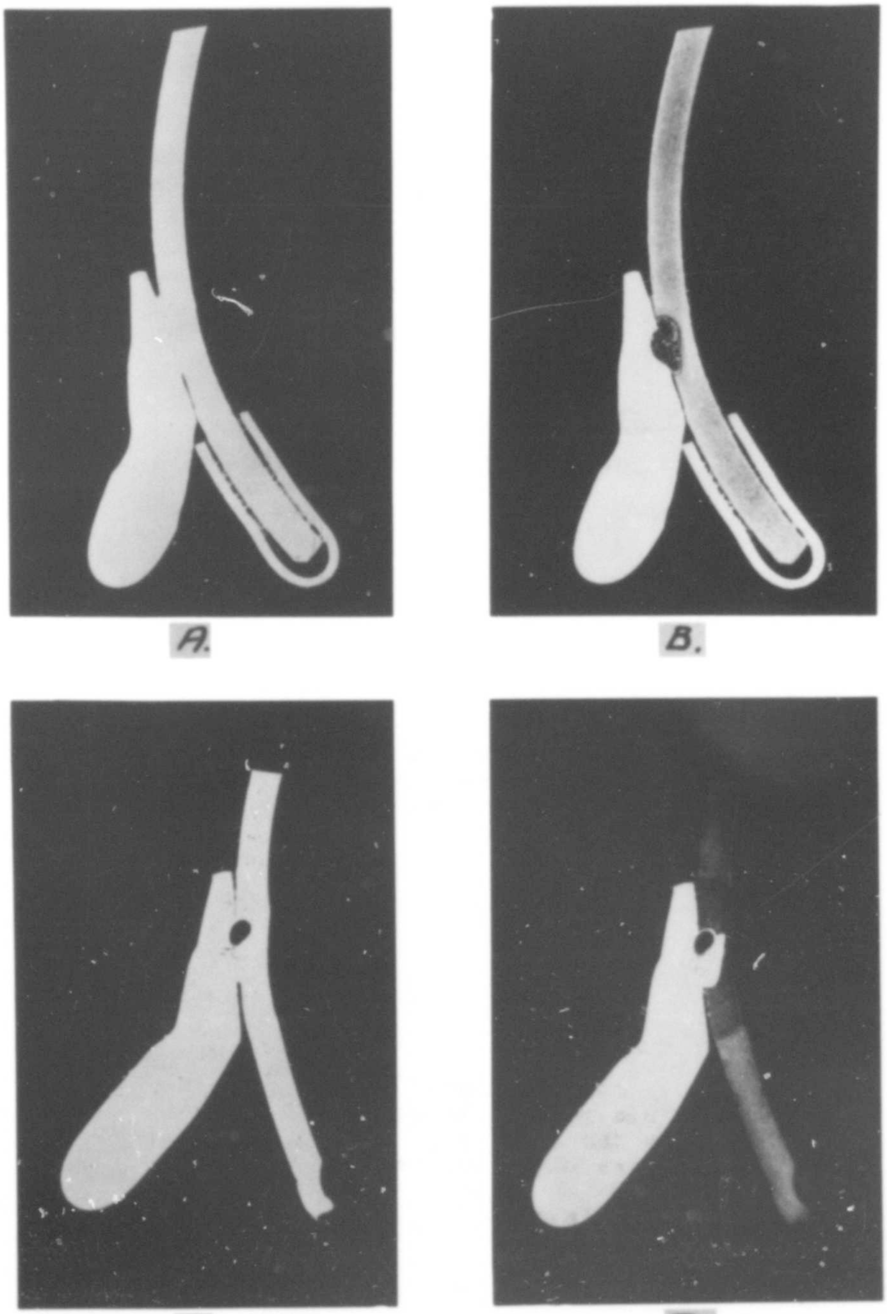
Unetched X5 MA-4446

D. NAX Helmet

Same as above. Note penetration of stainless steel into the NAX helmet shell, and the heat affected zone in the NAX steel, showing that welding was performed after heat treatment of the shell.

Vilella etch X5 MA-4448

FIGURE 3.



A. B.

C. D.

W.A.639-4252

FIGURE 4

CHIN STRAP CLIP WELDS

A. Hadfield Helmet

Spot weld nugget of chin strap clip weld between stainless steel and Hadfield helmet shell. Note extremely heterogeneous structure of weld.

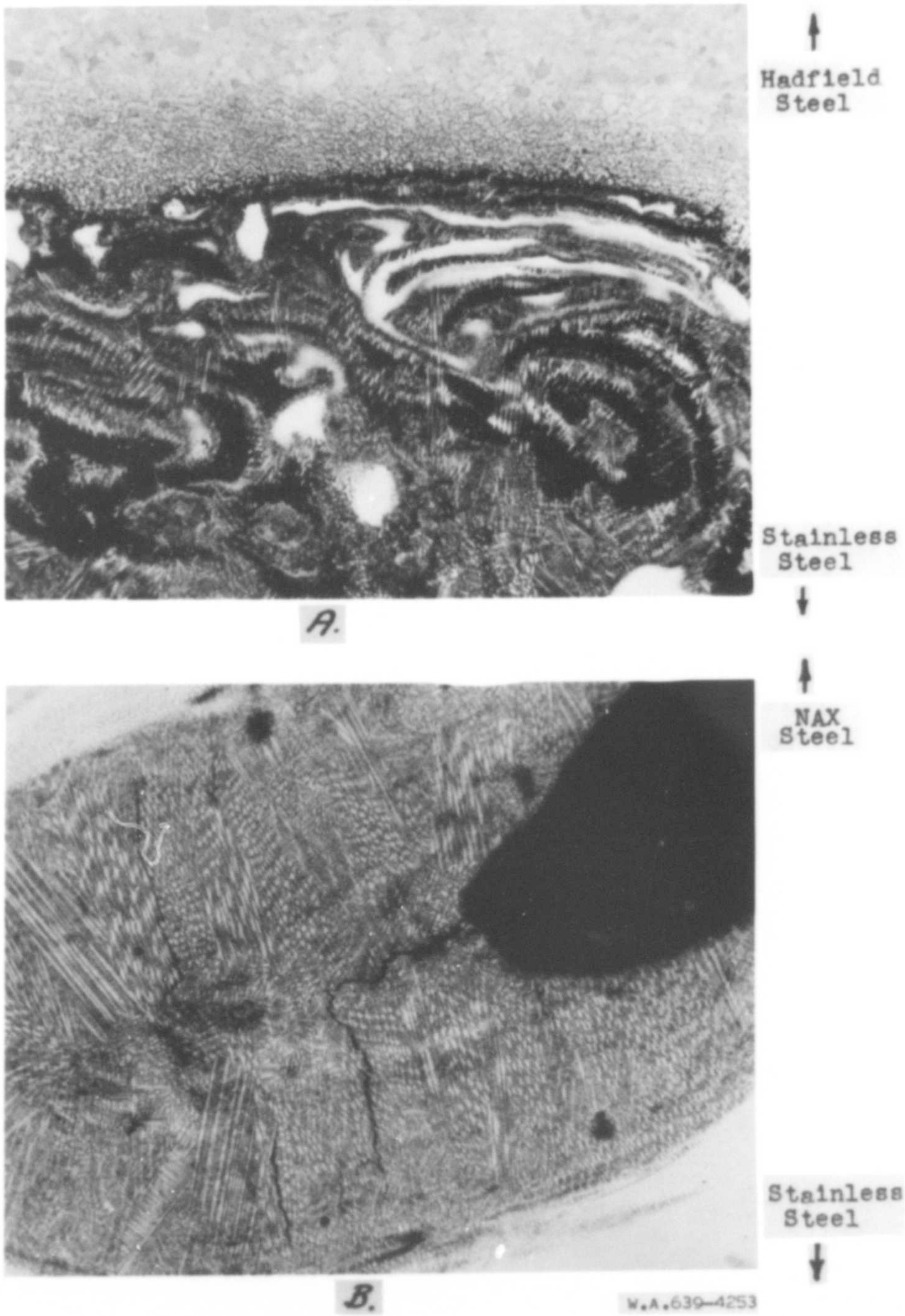
Vilella etch X100 MA-4450

B. NAX Helmet

Spot weld nugget of chin strap clip weld between stainless steel and NAX helmet shell. Note porosity and interdendritic cracks in weld nugget. This weld was made after the helmets were heat treated to a martensitic microstructure.

Vilella etch X100 MA-4451

FIGURE 4.



W.A.639-4253

FIGURE 5

Hadfield Manganese Steel

Longitudinal

Sta.	Rc	Sta.	Rc	Sta.	Rc
1	43.5	14	39.0	26	38.5
2	43.5	15	37.0	27	38.5
3	47.5	16	34.5	28	41.0
4	45.0	17	37.0	29	41.0
5	47.5	18	33.5	30	41.0
6	43.5	19	31.0	31	43.0
7	40.0	20	36.0	32	42.5
8	37.0	21	37.5	33	42.0
9	40.5	22	32.5	34	44.5
10	37.5	23	38.5	35	50.0
11	40.0	24	37.0	36	49.5
12	39.0	25	32.5	37	48.5
13	38.5			38	49.0

Transverse

Sta.	Rc	Sta.	Rc	Sta.	Rc
1	42.0	13	36.5	26	39.0
2	40.5	14	36.0	27	40.5
3	43.0	15	28.0	28	40.0
4	41.5	16	34.5	29	39.5
5	40.0	17	34.5	30	37.5
6	36.0	18	35.5	31	41.0
7	35.5	19	33.5	32	42.5
8	34.5	20	35.5	33	41.5
9	34.5	21	30.0	34	43.5
10	35.5	22	39.5	35	43.5
11	34.0	23	36.0	36	43.0
12	32.5	24	40.0	37	42.0
		25	41.0		

NAX Steel

Longitudinal

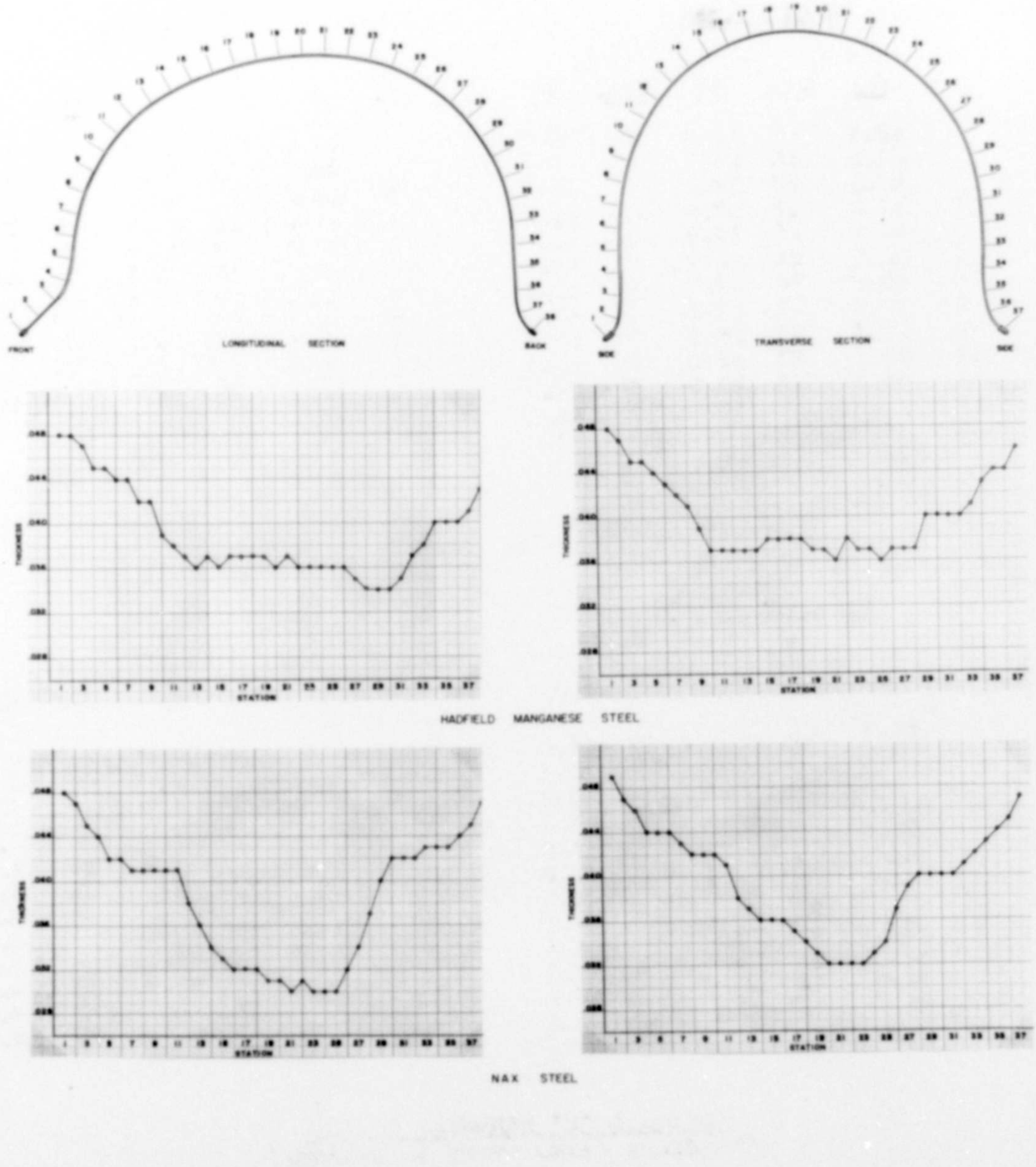
Sta.	Rc	Sta.	Rc	Sta.	Rc
1	41.0	14	41.0	26	40.0
2	42.5	15	40.5	27	40.5
3	41.5	16	40.5	28	40.0
4	41.5	17	39.5	29	40.0
5	42.0	18	41.5	30	39.5
6	41.0	19	40.0	31	40.5
7	40.0	20	39.5	32	40.0
8	41.0	21	39.5	33	39.5
9	41.5	22	39.5	34	40.5
10	42.5	23	38.0	35	40.5
11	41.0	24	38.5	36	40.5
12	41.5	25	39.5	37	40.5
13	42.0			38	42.0

Transverse

Sta.	Rc	Sta.	Rc	Sta.	Rc
1	44.0	13	42.0	26	41.5
2	43.0	14	43.0	27	41.0
3	43.5	15	43.0	28	42.0
4	42.5	16	42.0	29	42.0
5	41.5	17	42.5	30	41.5
6	42.5	18	40.5	31	38.5
7	42.0	19	43.5	32	36.0
8	42.5	20	42.0	33	36.5
9	42.5	21	42.5	34	36.0
10	42.0	22	41.5	35	37.5
11	44.0	23	41.0	36	34.5
12	41.5	24	41.5	37	36.0
		25	40.5		

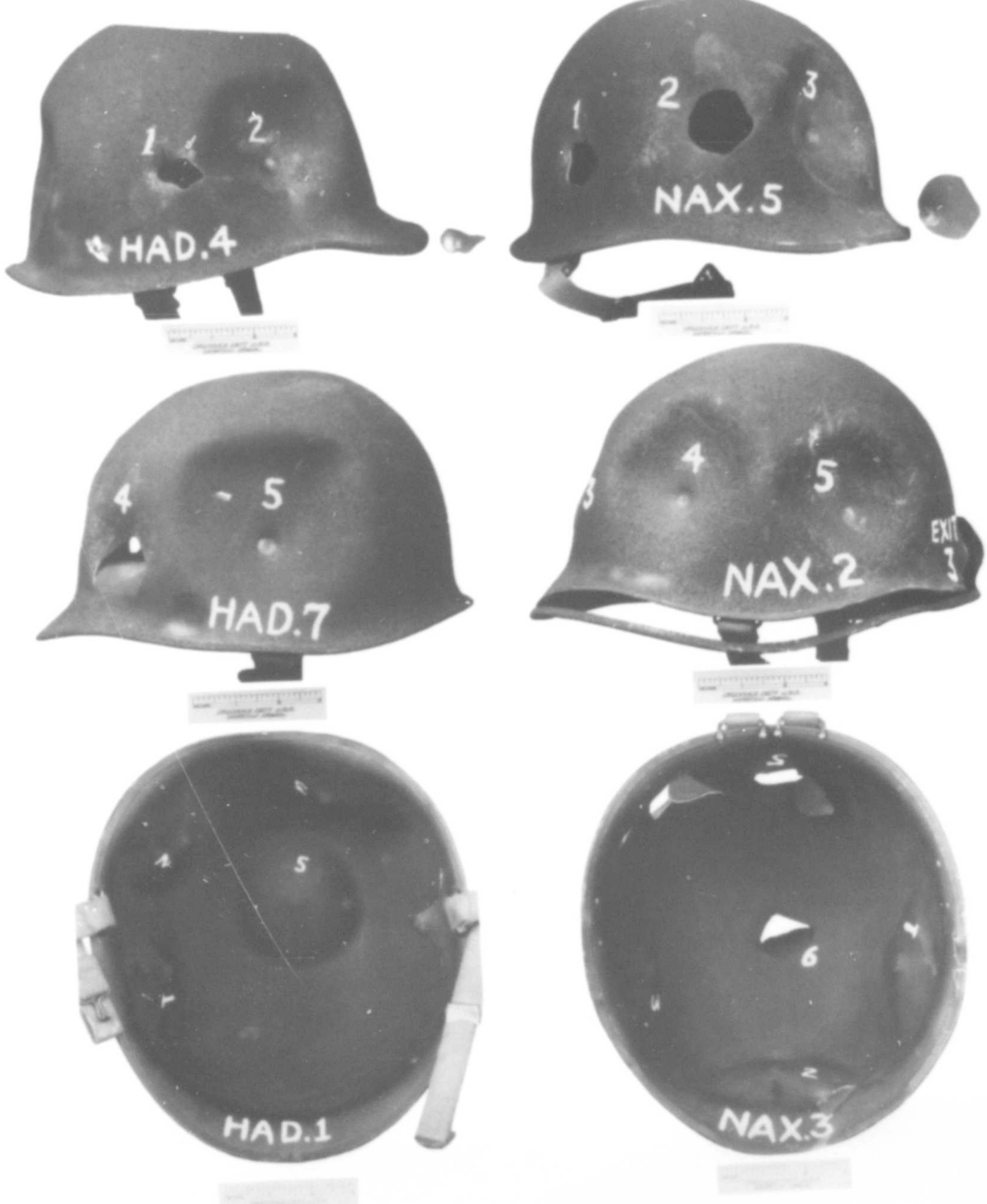
ROCKWELL "C" HARDNESS SURVEY
(Readings taken every half-inch.)

FIGURE 6



THICKNESS MEASUREMENTS ON CROSS SECTIONS OF HELMETS
JUNE 16 1942 W.A.639-4254

FIGURE 7



WATERTOWN ARSENAL

HELMET BALLISTIC TEST W.A.710-1877