RESTRICTED

ARMOR SECTION
WATERTOWN ARSENAL
WATERTOWN, MASS.

UNCLASSIFIED

Cy #3a

AD-A954 158

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/571

Defective Helmet Steel

UNCLASSIFIED

BY

A. Hurlich

Assistant Metallurgist

UNCLASSIFIED

DATE 28 August 1943

WATERTOWN ARSENAL
WATERTOWN, MASS.

RESTRICTED

1 10 23 10

WAL No. 710/571

RESTRICTED

ARMOR SECTION

Watertown Arsenal Laboratory

Memorandum Report

UNCLASSIFIED

Partial Report on Problem B-53

28 August 1943

DEFECTIVE HELMET STEEL

1. Reference letter from the Office, Chief of Ordnance, SPOIS, O.O. No. 421/2305, dated 7 June 1943, a preliminary metallurgical examination has been made on samples of defective unfinished helmets and helmet steel stock encountered at the Schlueter Manufacturing Company and forwarded to this Arsenal by the St. Louis Ordnance District Office, reference St. L.O.D. No. 421.1, 11 June 1943.

2. The following conclusions are evident at this stage of the investigation:

a. The cracking during the drawing operation occurring in the lots of steel submitted for study is traceable to either surface decarburization to the extent that thin layers of martensite exist at the surfaces of the sheets or to streaks of martensite below and parallel to the surfaces of the steel probably resulting from the rolling out of an ingot defect such as a pipe which had not been completely removed when the ingot was cropped.

b. When helmet sheet whose surfaces are decarburized to martensite is deformed by cold working, the thin, brittle martensite layers crack. Once cracking is initiated, it readily propagates through the otherwise tough and ductile austenitic body of the sheet.

c. The failure of five helmets from Schlueter Manufacturing Company's Lots 62A, 63A, and 64A to meet the requirements of the ballistic acceptance test resulted from surface decarburization indicated by the presence of martensite layers from 0.001" to 0.002" in thickness.

d. Surface decarburization of the austenitic manganese helmet stock in the annealed and not cold-worked condition lowers the ballistic limit as much as 200 ft/sec., using the caliber .45 ball ammunition.

e. Surface decarburization of helmet stock can be detected by the following means:

UNCLASSIFIED

RESTRICTED

1. Microscopic examination of cross-sections of the stock.
2. Magnetism capable of being detected by placing a piece of the annealed and not cold-worked helmet stock near a small suspended magnet.
3. Cupping tests such as the Olsen or Erichsen tests.

f. Surface decarburization to the extent found in the subject steels does not decrease the tensile strength and the percent elongation as determined by means of the tensile test piece described in Federal Specification QQ-M-151a, Figure 5; and cannot be detected by Rockwell B hardness surveys.

3. The material received from the St. Louis Ordnance District Office consisted of the items listed in Table I.

TABLE I

Item	Sharon Steel Corp. Heat No.	Schlueter Mfg. Co. Lot No.	Description
A	72312	48A	10 discs, defective, improperly annealed.
B	72193	61A	5 helmets broken in draw, improperly annealed.
C	72044	37B	10 discs, defective, laminations.
D	72314	51A	5 helmets broken in draw, laminations.
E	72195	62A	10 discs, o.k.
F	72195	62A	10 helmets, finished, unpainted, o.k.
G	72195	62A	5 helmets, drawn, o.k.
1,2,3,4,5	72257, 72202 (1,2) (3,4,5)	57A, 63A	5 discs from various lots of steels with which difficulties occurred in the drawing operation.
1,2,3,4,5	72195, 72202, 72110 (3,4) (1) (2,5)	62A, 63A, 64A	5 helmets which failed the ballistic acceptance test, having complete penetrations at velocities of 735-758 ft/sec.

Additional helmet stock in the form of 15" diameter discs supplied by Mr. H. E. Moser, Chief Metallurgist of the McCord Radiator and Manufacturing Company is listed in Table II.

TABLE III

Tensile Tests of Helmet Stock

Steel	Relation to Rolling Direction	Tensile Strength p.s.i.	% Elong.	Remarks
A-1	Longitudinal	111,400	38.5	-
A-1	Transverse	109,570	35.5	-
A-2	Longitudinal	119,560	35.0	-
A-2	Transverse	121,740	31.5	-
C-1	Longitudinal	81,740	-	Test piece split open along laminations.
C-1	Transverse	91,740	-	"
C-2	Longitudinal	84,350	-	"
C-2	Transverse	121,740	40.0	Test piece O.K.
E-1	Longitudinal	118,260	29.5	-
E-1	Transverse	119,130	27.5	-
E-2	Longitudinal	129,750	36.5	-
E-2	Transverse	132,170	32.5	-
1	Longitudinal	127,080	37.5	-
1	Transverse	127,080	35.0	-
2	Longitudinal	128,750	39.0	-
2	Transverse	129,180	34.5	-
4	Longitudinal	107,390	34.0	-
4	Transverse	113,910	33.5	-
5	Longitudinal	111,400	34.0	-
5	Transverse	110,000	33.0	-

Except for steel C in which case the tensile test pieces split open along laminations, no important differences exist between the tensile properties of the various steels. Since the tensile properties of steels which are both satisfactory and unsatisfactory for the helmet application overlap, the tensile test is not fully adequate as an aid in the selection of helmet stock.

b. Microscopic Examination

Specimens both longitudinal and transverse to the direction of rolling were selected for microscopic examination from the same discs from which the tensile test pieces were machined, as well as from two samples each from items B, D, G, and helmets 1, 2, 3, 4, and 5 from Sharon heats #72195, 72202, and 72110.

Steel A, which in the basic correspondence was declared defective due to improper annealing, was found to be decarburized on both surfaces to the extent that 0.0025" thick layers of martensite exist at both surfaces, see Figure 1A. In a previous investigation[1] of helmet stock, cracking during the deep drawing of helmets was attributed to undissolved carbides resulting either from incomplete solution of the carbides during heating of the steel, or from improper quenching practice. No undissolved carbides were found in any of the steels studied in this investigation.

Specimens from item B, which consists of helmets broken in the drawing operation, show surface decarburization similar to that found in item A. Cold working decarburized helmet stock causes cracking of the brittle martensite surface layers, Figure 1B, and this cracking, once initiated, evidently propagates readily through the otherwise ductile austenitic body of the sheet. Deep drawing of the helmet stock induces high stresses in the material, and small cracks, by their notch effect, are very dangerous stress raisers.

Steel C, which was described as defective due to laminations, contains a streak of fragmented grains of coarse martensite below and parallel to the surfaces of the sheet, see Figures 1C and D. This defect is probably the result of the rolling out of residual ingot piping that escaped being cropped. The surfaces of ingot pipes may be decarburized either by entrapped gases or by exposure to the air. A decrease in the normal carbon content of Hadfield manganese steel makes the austenite unstable and leads to the formation of martensite.

Specimens for microscopic examination cut from helmets from item D, which broke in the draw because of laminations, exhibit the same type of martensite streak that was observed in item C, see Figures 2A and B. In this heat of steel, the streak occurs approximately in the middle of the cross-section. The grains of martensite are fragmented

1. W.A. 470.14/11065, Nov. 18, 1941.

because it is the practice of the Sharon Steel Corporation to finish the sheet by cold rolling prior to the final anneal; and the martensite, being hard and brittle, cracks during the rolling.

Steel E is completely free from martensite resulting from surface decarburization and contains no martensite streaks, see Figures 3A and B. This steel was found to be satisfactory for the helmet application. In an attempt to reproduce the surface decarburization noted in other steels, a sample of steel E was reheat treated for 1 hour at 1850°F, followed by water quenching. The furnace atmosphere was not controlled; and some surface decarburization consequently occurred; compare Figures 3C and D with Figures 1A and B.

Microscopic examination of discs #1-5 and helmets #1-5 revealed greater or lesser amounts of surface decarburization on all sheets. Specimens from the helmets show precisely the same condition that was observed in item B, see Figure 1B, and it was concluded that the helmets failed the ballistic acceptance test because of the deleterious effect of the brittle martensitic skin which causes early failure by crack formation.

The discs supplied by Mr. H. E. Moser were described as having "smooth surfaces" and "rough surfaces". The discs having smooth surfaces give satisfactory performance in the drawing operation, while those having rough surfaces tend to crack and generally have a high percentage of breakage in the draw.

Microscopic examination of several of the above mentioned discs reveals that those having smooth surfaces are free from surface decarburization to martensite, while those having rough surfaces are decarburized to some extent. Martensite layers as much as 0.002" thick resulting from surface decarburization were found on both Sharon and Carnegie-Illinois steels, see Figures 3E and F. The Sharon steels are decarburized on both surfaces, while the Carnegie-Illinois steels are decarburized on only one surface. This is traceable to the fact thatthe Carnegie-Illinois steel is pack-rolled while hot, with one surface protected by contact with another sheet, while the Sharon steels are individually heated and rolled.

c. Ballistic Tests

The SharonSteel Corp. and Carnegie-Illinois Corp. discs having smooth and rough surfaces were tested ballistically with caliber .45 ball ammunition at a range of 25 feet. The Carnegie-Illinois discs, having rough surfaces on one side only, were fired with the rough surface as the back of the plate.

The results of the ballistic tests are listed in Table IV.

TABLE IV

Ballistic Tests of Helmet Discs

Manufacturer	Mfr's. Heat No.	McCord Lot No.	Surface Condition	Thickness Inches	Ballistic Limit Ft./Sec.
Carnegie-Illinois Steel Corp.	177055	612	Smooth	.043-.044	1074
"	177055	612	Smooth	.044	1152
"	246803	575	Rough	.044-.045	1064
"	-	-	Rough	.043	937
Sharon Steel Corp.	72372	603	Smooth	.043-.044	1171
"	72372	603	Smooth	.044-.045	1167
"	72403	587	Rough	.043-.044	1095
"	-	-	Rough	.043-.044	951

The data of Table IV indicate that the presence of a martensitic skin resulting from surface decarburization can lower the ballistic limit of helmet sheet by as much as 200 ft./sec. The hard, brittle surface layers crack readily and weaken the material considerably. Since upon cold forming into helmets, the martensite layers crack in many regions, see Figure 1B, it is conceivable that the ballistic limit of these helmets may be lowered even more than that of the annealed sheets having the same degree of decarburization.

d. Magnetic Tests

Previous work[2] at this Arsenal indicated that a sensitive magnet placed near helmet steel can pick out those which are badly decarburized.

A small "Alnico" magnet, obtainable from the Crucible Steel Company, was suspended from a five foot length of linen thread, with the poles of the magnet in a horizontal plane. Behind the magnet was placed a scale consisting of an arc of a circle five feet in radius marked off in inches and fractions, see Figure 4. A piece of the helmet sheet is brought into contact with the poles of the magnet, and then moved to the right along the arc of the five foot circle. The reading on the scale is made at the point where the magnet separates from the helmet sheet. The

2. W.A. 710/430 "Helmets - Development of a Test for Hadfield Manganese Steel Helmets" J. H. Hollomon.

stronger the magnetism of the steel, the further will the magnet be raised along the arc of the circle before separation occurs.

Four 3x4" pieces were cut from various heats of helmet steel and magnetic tests were conducted upon both sides of each piece. Detailed results of the magnetic test are given in Appendix A.

Steel E, which has no discernible decarburization, gave readings of from 2½ to 4 inches deflection before the magnet separated from the steel, while the decarburized steels gave readings up to 19-1/4 inches. Steel C, which contains the martensite streak gave readings as high as 43 inches.

The results obtained indicate that some sort of magnetic test may prove useful in detecting decarburized helmet steel. By correlating the results of a magnetic test with production performance of lots of steel it will undoubtedly be possible to evaluate steels as satisfactory or unsatisfactory for the helmet application.

e. Hardness Surveys

Rockwell B hardness readings made on numerous samples of the various heats of steel indicate that the degree of decarburization present in the subject steels does not noticeably affect the hardness. For example, steel E, having no surface decarburization, has an average Rockwell B hardness of 91.5, while one of the Sharon Steel Corporation discs having a 0.0017" layer of martensite at the surfaces, see Figure 3F, has an average hardness of Rockwell B 89. The annealed steels varied in hardness over the range of Rockwell B 88-94 with no apparent relation to the degree of decarburization.

f. Cupping Tests

Some preliminary work has been done at this Arsenal with an Olsen Cup Tester. The results obtained to date indicate that the cupping test provides useful information regarding the deep drawing characteristics of helmet steel and shows promise as an aid in evaluating the steels. Laminations such as found in the steel of items C and D result in early failure in the cupping test, giving a characteristic break. Decarburization to the degree prevalent in the decarburized steels is revealed by the characteristic surface cracking occurring during cupping as well as by a lower Olsen value.

More complete experiments are being conducted with the Olsen machine and will be reported in detail at a later date.

5. General Considerations

Defects in helmet stock which have been found to impair its deep drawing qualities consist of:

a. Undissolved carbides;

b. Decarburization;

c. Martensite streaks resulting from uncropped ingot piping.

Of these defects, both decarburization and martensite streaks can be detected by microscopic examination, magnetic tests, and cupping tests. Undissolved carbides can be detected by microscopic examination, but not by any magnetic test.[3] It is as yet uncertain that the deleterious effects of undissolved carbides can be shown by a cup test. Microscopic examination thus appears to be the best and most certain means of revealing defects in helmet stock, and its use as an inspection tool is worthy of consideration.

From the investigation of helmet steels performed at this Arsenal it may be concluded that the deep drawing of the M1 helmet in one major operation is so severe a cold deformation that, unless the steel is absolutely free of all defects, considerable draw breakage will occur.

A. Hurlich
A. Hurlich,
Assistant Metallurgist.

APPROVED:

G. L. COX,
Lt. Col., Ord. Dept.,
Executive Officer.

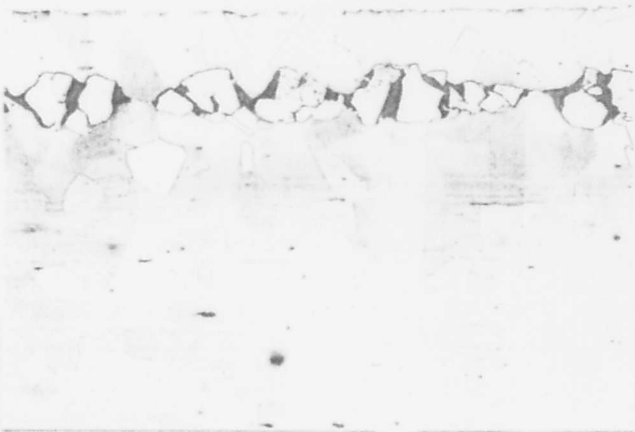
3. See footnote #2, page 7.

10

FIGURE 1

Nital Etch -A- X100
Steel A. Surface decarburization. 0.0025" thick layer of martensite.

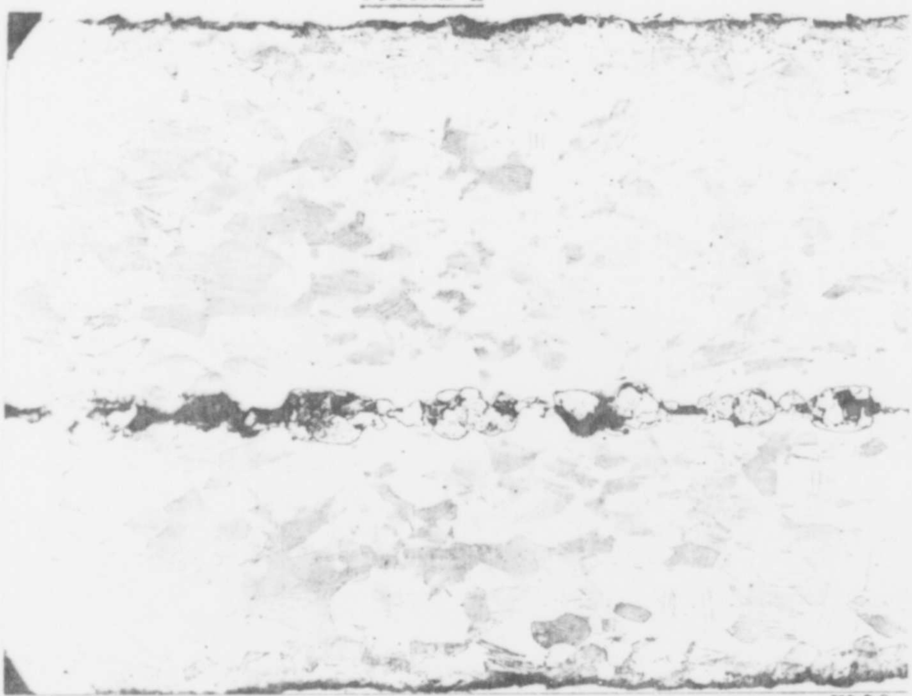
Nital Etch -B- X250
Steel B. Cracking of brittle martensite layer resulting from cold forming of helmets. 0.001" decarburized layer of martensite.



Nital Etch -C- X100
Steel C. Streak of fragmented grains of martensite, probably residual ingot piping rolled out in sheet.

Nital Etch -D- X250
Steel C. Same as -C-. Hard brittle grains of martensite. No decarburization at surface of sheet.

FIGURE 2



Nital Etch -A- X100

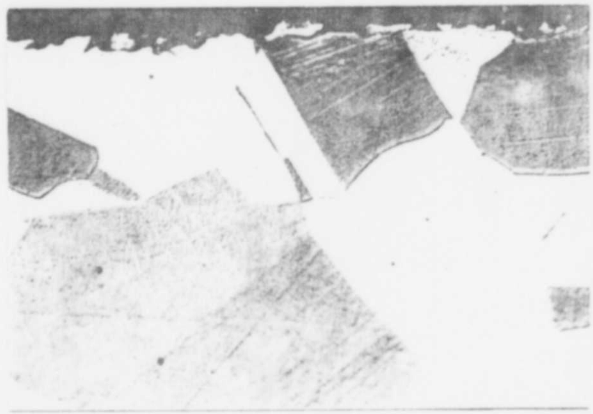
Steel D. Streak of martensite into which crack resulting from deep drawing extends.

Nital Etch -B- X750

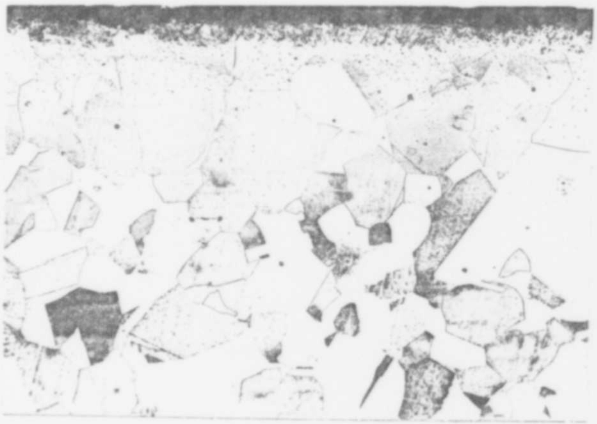
Steel D. Same as above. Fragmented grains of martensite probably resulting from residual ingot piping rolled out into streak.

FIGURE 3

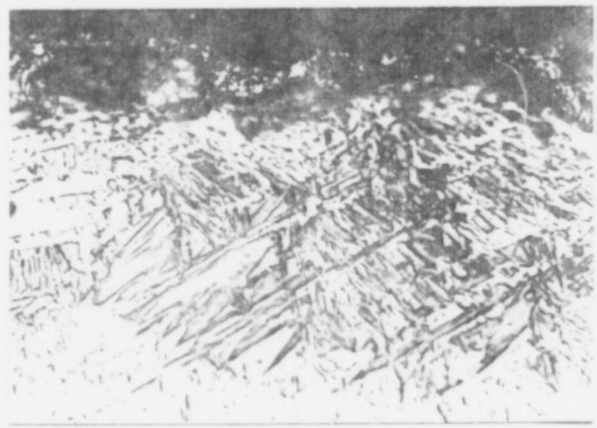
Steel E. -A- X100
Satisfactory for helmet application. No decarburization.



Steel E. -B- X750
Same as -A-. No decarburization to martensite.

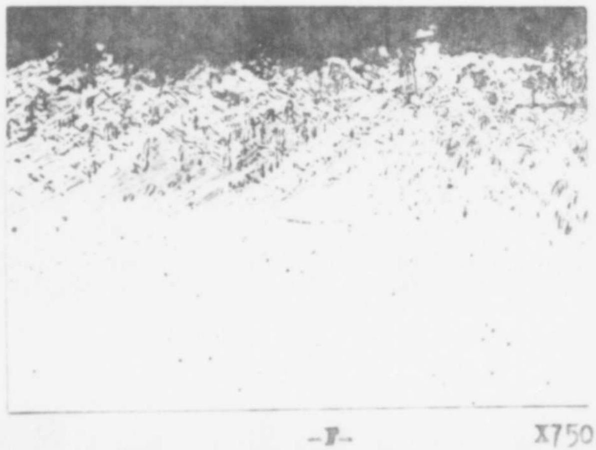


Steel E. -C- X100
Reheat-treated at Watertown Arsenal. 1600°F. - 1 hour - water. No atmosphere control. Surface decarburized to martensite.

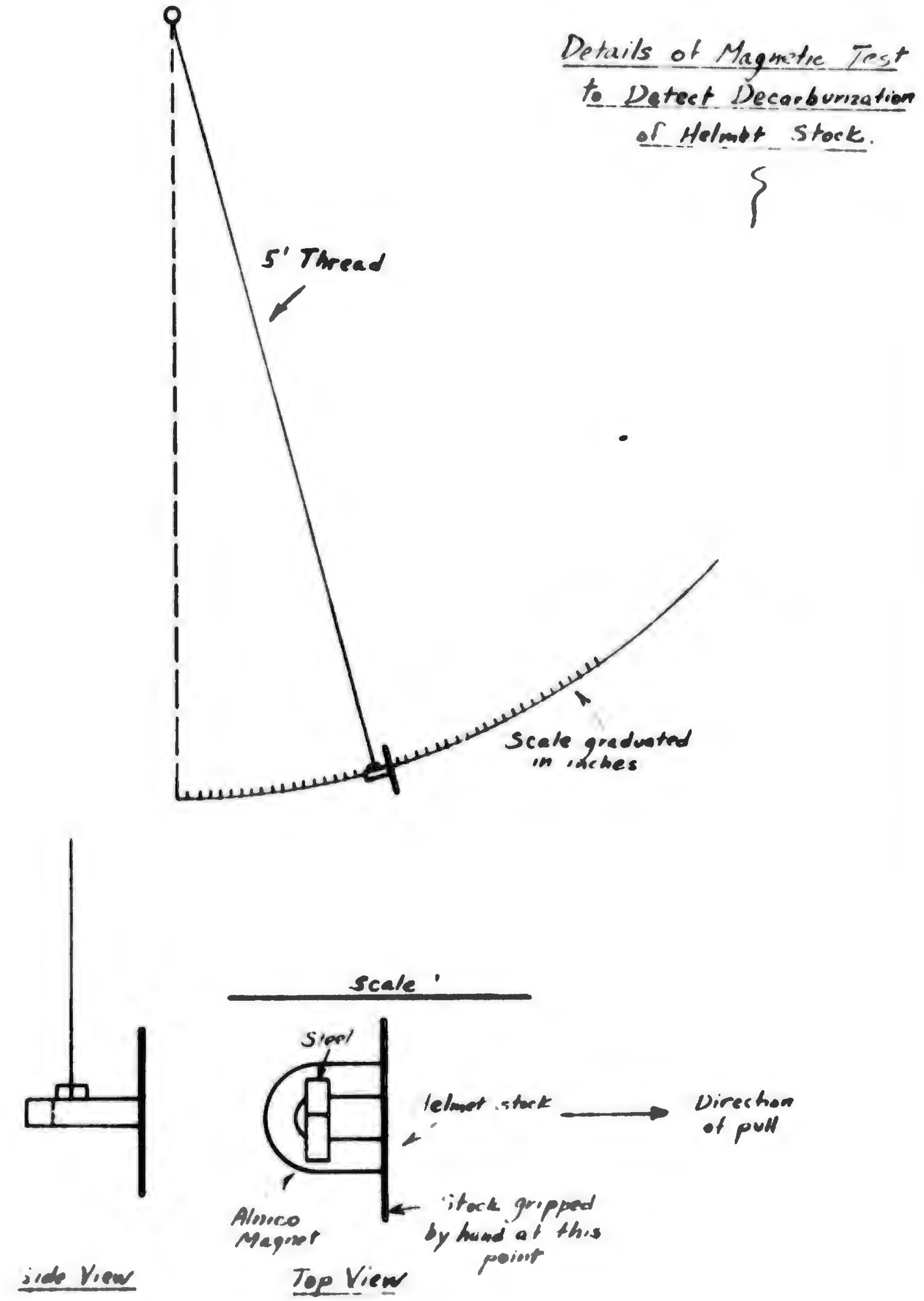


Steel E. -D- X1000
Same as -C-. Martensite needles at surface. 0.002" layer decarburized to martensite.

-E- X100
Sharon "Rough Surface". Decarburized surface typical of [illegible] found on several [illegible] Sharon and Carnegi[illegible]



-F- X750
Sharon "Rough Surface". Martensite layer [illegible] surface. 0.0017" layer decarburized to martensite.



Details of Magnetic Test
to Detect Decarburization
of Helmet Stock.
5' Thread
Scale graduated
in inches
Scale
Steel
Helmet stock
Direction
of pull
Alnico
Magnet
Stock gripped
by hand at this
point
Side View
Top View

Figure 4.

Appendix A

Results of Magnetic Test to Reveal Decarburization

Item	Manufacturer's Heat No.	Inches Deflection*
A -1	72312	15
-2	"	15
-3	"	14-1/4
-4	"	13
C -1	72044	27
-2	"	35
-3	"	8
-4	"	10

(Item C contains laminations, evidently not uniformly distributed.)

Item	Manufacturer's Heat No.	Inches Deflection*
E -1	72195	3-1/2
-2	"	4
-3	"	2-1/2
-4	"	2-3/4
Sharon Steel) 1	-	19
Corp.) 2	-	19-1/4
(Rough Surface)) 3	-	18-1/2
4	-	18-1/2
Carnegie-Illinois)1	-	7-1/2
Steel Corp.)2	-	7-1/4
(Rough Surface))3	-	7-1/2
4	-	7-1/2
1 -1	72257	5
-2	"	4-1/2
2 -1	72257	4
-2	"	4
-3	"	4
-4	"	5
4 -1	72202	9-1/4
-2	"	10-1/2
-3	"	9
-4	"	10
5 -1	72202	11
-2	"	11-1/2
-3	"	11
-4	"	9-3/4

*The values for the deflection are the average of three tests. These tests were performed only upon annealed, not cold-worked, 3x4" sections.