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HELMETS

Ballistic and Metallurgical Investigation of

Anole Steel Helmets

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Ballistic and Metallurgical Investigation of
Amola Steel Helmets

OBJECT

To determine if the 0.70% carbon magnetic Amola steel is a satisfactory substitute for the nonmagnetic Hadfield Manganese steel for the manufacture of the M1 helmet.

CONCLUSIONS

1. The results of this investigation indicate that the ferritic (magnetic) 0.70% carbon Amola steel is a satisfactory ballistic substitute for the Hadfield Manganese steel which is now being used in the manufacture of the M1 helmet. The ballistic limit of the Amola steel helmet when austempered to a hardness of Rockwell C 47-49 is comparable to the Hadfield Manganese steel helmet.

2. The Amola steel cannot be successfully drawn in a die set-up designed for the forming of the standard Hadfield Manganese steel helmet. The variations in gauge observed from brim to crown in the Amola steel shells undoubtedly can be corrected by the use of a properly designed die set-up.

3. The ballistic properties of the Amola steel helmets austempered to a hardness of Rockwell C 47-49 were superior to those Amola steel helmets quenched and drawn to the same hardness.

4. Among the helmets investigated no difference was observed between the microstructure of the satisfactory and poor quality helmets austempered or quenched and drawn to a hardness range of Rockwell C 47-49.

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INTRODUCTION

This investigation was initiated as the result of a request[1] received from the Office, Chief of Ordnance, dated January 31, 1942, relative to recommendations for substitute steels which could be used to produce the new type M1 helmet as a replacement for the nonmagnetic Hadfield Manganese steel.

It was the opinion of the Office, Chief of Ordnance, early in 1942 that the manganese steel situation would undoubtedly become critical within a short period; therefore, data were requested on the forming and ballistic properties of other types of steels which might be used for this purpose.

Just preliminary to this correspondence, this Arsenal was conducting a cooperative research program with the American Steel and Wire Co. on the ballistic properties of cold rolled spheroidized 0.70% carbon Amola sheet stock, .044" thick which had been subsequently austempered and also quenched and drawn to a hardness range of Rockwell C 45-53.

The results of these preliminary investigations which indicated that this Amola steel had promising ballistic properties, austempered to a Rockwell C hardness of 47-49 were reported to the Office, Chief of Ordnance.[2]

Since this type of steel was readily available, large quantities being made in the open hearth furnace, it was decided to investigate in detail its ballistic and forming properties. Accordingly, a contract was issued to the American Steel and Wire Co. for a development order which included the supply of cold rolled spheroidized 0.70% carbon Amola steel sheet .040" thick necessary to form 200 helmets, the austempering to be conducted subsequent to the forming of the helmets at the McCord Radiator and Manufacturing Co.

Due to the fact that the Amola steel helmets were formed on dies specially designed for the standard Hadfield Manganese steel M1 helmet, of the 200 blanks supplied the McCord Radiator and Manufacturing Co., only 150 helmets were formed without cracks. About 50% of these helmets showed evidence of wrinkles on the crown.

Ballistic tests were made on helmets, with and without these forming defects after subsequent austempering and also after quenching and drawing.

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1. W.A. 421/248, O.O. 421/930, Jan. 31, 1942, see Appendix A.
2. W.A. 421/248, O.O. 421/930, Feb. 13, 1942, see Appendix A.

The helmets, austempered to a hardness of Rockwell C 47-49, showed promising ballistic properties. These results[3] were forwarded to the Office, Chief of Ordnance.

The reports on the forming characteristics of the Amola steel submitted by the McCord Radiator and Manufacturing Co. and the report on the physical tests of Amola steel and the austempering of the helmets as conducted by the American Steel and Wire Co. are given in Inclosure A.

Correspondence pertaining to this investigation is found in Appendix A.

TEST MATERIALS AND PROCEDURE

1. Physical Properties of 0.70% Carbon Amola Steel

The physical properties of the cold rolled spheroidized 0.70% Carbon Amola steel as reported by the American Steel and Wire Co. and which are given in Inclosure A are summarized below:

Tensile Strength Lbs./Sq.In.	% Elong. in 2"	Rockwell B Hardness	Erichsen Cup Test
79,500-83,400	27.5-28	80-83	9.65-10.10 mm.

2. Drawing of the Helmet Shells

The results of preliminary and subsequent drawing of the Amola steel shells as reported by the McCord Radiator and Manufacturing Co. are given in Inclosure A. It was clearly demonstrated that this steel is not satisfactory for drawing on dies that are designed for the present Hadfield Manganese steel. The Amola steel breaks or wrinkles considerably during the forming operation.

3. Austempered 0.70% Carbon Amola Samples Submitted for Test

The following samples listed in Table I were submitted for test by the American Steel and Wire Co.:

3. W.A. 421/304, June 18, 1942, see Appendix A.

TABLE I

Samples Submitted for Test by American Steel and Wire Co.

Date Submitted	Material	Heat Treatment
May 21-22, 1942	9 sheets 12x12x.044"	Austempered to Rockwell C hardness of 45-53.
May 21-22, 1942	3 sheets 12x12x.044"	Quenched and drawn to Rockwell C hardness of 49-49.5.
Since the above tests were promising, the following additional tests were made:		
June 10-11, 1942	5 helmets wrinkled	Austempered to Rockwell C hardness 49-51.
June 10-11, 1942	5 helmets good quality	Austempered to Rockwell C hardness 49-51.
June 10-11, 1942	5 helmets wrinkled	Austempered to Rockwell C hardness 47-49.
June 10-11, 1942	5 helmets good quality	Austempered to Rockwell C hardness 47-49.
June 10-11, 1942	5 helmets wrinkled	Quenched and drawn to Rockwell C hardness of 51.
June 10-11, 1942	5 helmets good quality	Quenched and drawn to Rockwell C hardness of 51.
June 10-11, 1942	5 helmets wrinkled	Quenched and drawn to Rockwell C hardness of 47-49.
June 10-11, 1942	5 helmets good quality	Quenched and drawn to Rockwell C hardness of 47-49.
June 10-11, 1942	5 helmets wrinkled	Austempered to Rockwell C hardness of 51-53.
June 10-11, 1942	5 helmets good quality	Austempered to Rockwell C hardness of 51-53.

As a result of the superior performance of helmets austempered to a hardness of Rockwell C 47-49, a request was made for 50 more helmets austempered to this hardness range. Twenty-five helmets of this lot were tested at Watertown Arsenal, August 18, 19, 1942, and the remaining 25 helmets were sent to the McCord Radiator and Manufacturing Co. for test, August 19, 1942.

4. Ballistic Tests

Ballistic tests were conducted at Watertown Arsenal on development flat sheets and helmets as follows:

a. An Army ballistic limit was obtained on the flat sheets and also on the sides of each helmet using the specially loaded caliber .45 lead ball ammunition fired at normal from a caliber .45 revolver at a range of 25 feet.

b. One round of standard caliber .45 service ball ammunition was fired at normal at the top of the crown of each helmet.

c. Striking velocities were recorded by means of an Aberdeen chronograph.

5. Metallurgical Examination

After completion of the ballistic tests several of the satisfactory and poor quality helmets were selected for metallurgical examination which included the following: chemical analysis, microscopic examination, thickness and hardness surveys. Transverse and longitudinal cross-sectional strips were taken from several satisfactory and poor quality helmets, heat treated to 47-49 Rockwell C hardness for thickness and hardness surveys. Thickness and hardness surveys were made every half inch on these strips.

RESULTS AND DISCUSSION

1. Ballistic Tests

A summary of the ballistic tests some of which were made on the flat sheet stock, the fifty helmets austempered and quenched and drawn to several hardness levels and the last lot of twenty-five helmets austempered to a hardness of Rockwell C 47-49 are given in Tables II, III, and IV. The results of a companion lot of 25 helmets austempered to a hardness of Rockwell C 47-49 and tested at the McCord Radiator and Manufacturing Co. are given in Table V.

a. 12 Sheets - 12x12x.044" - Austempered or Quenched and Drawn to Several Hardness Levels

The results of the ballistic tests (see Table II) indicated that the samples austempered to a hardness of Rockwell C 45-50 were more ductile than those austempered to a higher hardness. The fact that the sheets showed evidence of tearing at this hardness range indicates a ductility desirable in helmet stock. The ballistic limits recorded are relatively high for material of this gauge.

The sheets quenched and drawn to a hardness of Rockwell C 49-49.5 were brittle.

b. 50 Helmets Austempered or Quenched and Drawn to Several Hardness Levels

Typical satisfactory and poor quality helmets are shown in Figures 1-3 inclusive.

The results of these tests which are shown in Table III are summarized below:

(1) Series 16-20 inclusive, free from wrinkles in the forming process and austempered to a Rockwell C hardness of 47-49, showed the best all round performance. Helmet No. 16 of this series failed due to a punching only but with no indication of brittleness as noted in some of the other failures.

(2) Series 1-5 inclusive which were wrinkled in the forming process showed good ballistic properties as austempered to a Rockwell C hardness of 49-51. On the other hand, Series 6-10 inclusive which were free from wrinkles were relatively more brittle when austempered to the same hardness range. The hardness range of 49-51 Rockwell C is not recommended for this type of steel.

(3) Series 21-40 inclusive which were quenched and drawn to a Rockwell C hardness of 47-49 and 51 respectively show indications of brittleness under the ballistic test.

(4) The Amola steel helmets, austempered to a Rockwell C hardness of 51-53, were entirely too brittle.

c. 25 Helmets Austempered to a Hardness of Rockwell C 47-49 - Tested at Watertown Arsenal

Figure 4 illustrates typical good and poor quality helmet shells.

The results of these tests presented in Table IV indicated that helmet Nos. 11, 13, 15, 16, 28 and 38 failed at the top of the crown. This may have been due to a reduction in gauge in this particular location on the helmet. It was determined that the thickness at the brim varied from .049-.055", while at the top of the crown, the thickness varied between .035-.042".

Helmets, Nos. 45 and 49, failed by tearing and punching when tested normal to the side of the helmet at striking velocities noted in Table IV and in Figures 7 and 8.

Generally speaking, with the exception of helmet No. 13, there were no pronounced cracks associated with penetrations in helmets austempered to a hardness of Rockwell C 47-49.

d. 25 Helmets Austempered to a Hardness of Rockwell C 47-49 - Tested at McCord Radiator and Manufacturing Co.

Figure 5 shows typical satisfactory and poor quality helmets.

The results of these tests are summarized in Table V.

Ballistic tests confirm the results of the companion set of 25 helmets, austempered to 47-49 Rockwell C described in c. Helmets, Nos. M5, M8, M14, M24, M37 and M39, failed by punching at the top of the crown. Undoubtedly failure was due to a reduction of the gauge at the top of the crown as demonstrated in Figure 8.

2. Metallurgical Examination

a. Chemical Analyses

Chemical analyses of the Amola Steel as reported by the American Steel and Wire Co. and as determined at Watertown Arsenal are given below in Table VI.

TABLE VI

Chemical Analyses

	C	Mn	Si	S	P	Mo	Ni	Cr	V	Cu	Al
Reported by American Steel and Wire Co.	.70	.90	-	-	-	.25	-	-	-	-	-
Watertown Arsenal	.69	.98	.27	.015	.009	.21	.18	.02	nil	.02	.02

This type of steel corresponds closely to the steel designated as AISI 4070.

b. Microscopic Examination

Figure 6 illustrates the microstructure of typical satisfactory and poor quality helmets austempered or quenched and drawn to a Rockwell C hardness of 45. No particular difference can be detected between the microstructure of good and poor quality helmets, austempered or quenched and drawn to the same hardness range.

Some occasional decarburization was detected on the austempered Amola steel shells, extending to a depth of .00008-.00015". The Amola steel was fairly free from segregations of nonmetallic inclusions.

c. Thickness Measurements

The thickness measurements were made on midsections of satisfactory and poor quality helmets, austempered to a Rockwell C hardness of 47-49, see Figure 8. For comparison, measurements were included in Figure 8 of an experimental Hadfield Manganese steel shell.[4]

The thickness of the brim of these Amola steel shells varied from .046 to .052" while at the top of the crown the average thickness was .033". The average thickness at the top of the crown of the Hadfield Manganese steel was .038", while at the brim, thicknesses of .044-.048" were obtained.

In some cases, the Amola helmets which failed at the top of the crown had a thickness at this location about 20% less than that of satisfactory helmets.

d. Hardness Surveys

Hardness surveys which were made on the same Amola sections on which thickness measurements were determined are presented in Figure 7. The results of hardness surveys made on a Hadfield Manganese steel helmet are also included.

These results are summarized below:

Helmet Steel	Hardness Range Rockwell C
M27 Satisfactory - (Longitudinal Section)	45.5-49
M41 Satisfactory - (Transverse Section)	42.5-47.5
M5 Failed - (Longitudinal Section)	44.5-49.0
M14 Failed - (Transverse Section)	44.5-48.5
Hadfield - (Longitudinal Section)	31.0-50
Hadfield - (Transverse Section)	28.0-43.5

As noted above and also shown in Figure 7, there was a considerable hardness variation in the sections tested as compared to the intended hardness range of 47-49 Rockwell C.

4. W.A. Report 710/433 - "Helmets - Comparison of Helmets Made from NAX and Hadfield Manganese Steel", June 20, 1942.

SUMMARY

Of the 0.70% Carbon Amola steels investigated those austempered to a hardness of Rockwell C 47-49 had the best ballistic properties.

The ballistic limits of these helmets compared favorably with those obtained on the standard Hadfield Manganese steel helmet. For example, these Amola steel shells resisted impacts varying from 975 f/s to 1060 f/s, caliber .45 ball ammunition, while it has been determined that the Hadfield Manganese steel helmet of approximately the same gauge will resist impacts varying from 863 f/s to 1092 f/s when tested under the same conditions.

Very little cracking was observed on the Amola steel helmets under the ballistic test, at least when austempered to a hardness of Rockwell C 47-49. When penetration occurred at these relatively high velocities, punchings and occasional tears were observed.

The depth of indentation on the Amola steels was somewhat less than that observed on the standard Hadfield Manganese steel shells under comparable conditions of thickness and striking velocity. Furthermore, the depth of indentation was less on the top of the crowns of the Amola steel as compared to that on the same location on the Hadfield Manganese steel helmet, although the gauge of the Amola steel was lighter in this section.

The Amola steel cannot be drawn successfully in the same die set-up on which is drawn the Hadfield Manganese steel helmet. Excessive breaking and wrinkling of the helmet shell was observed. Furthermore, using the Hadfield steel die set-up, the reduction in gauge at the top of some of the crowns of the Amola steel shells is about 20% greater than that of the Hadfield Manganese steel shells.

It is believed that excessive variation in gauge and the pronounced cracking and wrinkling during the forming of the Amola steel could be eliminated by properly designed die set-up.

Correlations between ballistic properties and gauge thickness indicate that the top of the crown of the Amola steel helmet should not be less than .034" in order to possess satisfactory ballistic resistance.

Details relative to the austempering of large lots of Amola helmets and the elimination of possible distortion during heat treatment could undoubtedly be satisfactorily solved.

The results of this investigation indicate that the ferritic magnetic Amola steel is a possible substitute for the Hadfield Manganese steel.

TABLE II

Summary of Ballistic Tests Made on

12x12x.044" Austempered 0.70% Carbon Amola Sheets

Ammunition - Caliber .45 Ball, 230 Grain

Plate No.	Rockwell C Hardness	Heat Treatment	Ballistic Limit Caliber .45 Ball F/S	Remarks
1	52-53	Austempered	989 HP*	Good ductility.
2	52-53	Austempered	982 HP*	Broke in clamps only. Good ductility.
3	52-53	Austempered	-	Failed in hammer marks.
4	50	Austempered	-	Failed at striking velocity of 938 f/s. Cracked.
5	50	Austempered	938 Est.	Some radial cracks.
6	50	Austempered	996	Good ductility.
7	46	Austempered	952	Tears evident.
8	45	Austempered	964	Tears evident.
9	45	Austempered	944 CP**	Tears evident.
10	49	Quenched and drawn	976	Cracks at impacts.
11	49.5	Quenched and drawn	-	Sheet cracked at 963 f/s striking velocity.
12	49	Quenched and drawn	-	Sheet cracked at 1009 f/s striking velocity.

*HP = Highest Partial.
**CP = Complete Penetration.
NOTE: In some cases, cracks developed from sharp corners from which metallographic samples were removed.

TABLE III

Summary of Ballistic Tests Made at Watertown Arsenal on Fifty

0.70% Carbon Amola Steel Helmets Austempered and Quenched and Drawn to Several Hardness Levels

Ammunition - Caliber .45 Ball, 230 Grain

No.	Thick. at Brim Inches	Heat Treatment	Helmet Condition	Rockwell C Hardness	Ballistic Test				Remarks
					Side of Helmet		Top of Helmet		
					Striking Velocity F/S	Max. Depth Indent. Inches	Striking Velocity F/S	Max. Depth Indent. Inches	
1	.048	Austempered	Wrinkled	49-51	1050 PP	1.31	Service velocity approx. 780	.6[illegible]	Satisfactory
2	.049	"	"	49-51	1046 PP	.85	"	.86	"
3	.046	"	"	49-51	1052 PP	.67	"	.94	"
4	.048	"	"	49-51	1060 PP	.91	"	.64	"
5	.050	"	"	49-51	1039 PP	.72	"	.81	"
6	.046	"	Satisfactory	49-51	1025 PP	1.01	"	.72	"
7	.048	"	"	49-51	1025 BL Irregular break	.81	"	.90	Failed
8	.047	"	"	49-51	985 BL Irregular break	.84	"	-	"
9	.048	"	"	49-51	935 BL Irregular opening, crack.	.89	"	.91	"
10	.049	"	"	49-51	1020 PP	.89	"	.85	Satisfactory
11	.050	"	Wrinkled	47-49	1027 BL 3" crack	.94	"	.90	Failed
12	.050	"	"	47-49	1019 BL approx. Punching, cracks.	.91	"	.89	"
13	.048	"	"	47-49	1015 PP	.71	"	1.02	Satisfactory
								.92	"

9	.048	"	"	49-51	Irregular opening, crack.	.89			
10	.049	"	"	49-51	1020 PP	.89	"	.85	Satisfactory
11	.050	"	Wrinkled	47-49	1027 BL 3" crack	.94	"	.90	Failed
12	.050	"	"	47-49	1019 BL approx. Punching, cracks.	.91	"	.85	"
13	.048	"	"	47-49	1015 PP	.71	"	1.02	Satisfactory
14	.050	"	"	47-49	979 PP	.91	"	.92	"
15	.048	"	"	47-49	987 PP	1.02	"	.88	"
16	.049	"	Satisfactory	47-49	940 CP approx. 1.7" diameter tear".	.78	"	.92	Failed
17	.051	"	"	47-49	996 PP	.85	"	.84	Satisfactory
18	.052	"	"	47-49	975 PP	.98	"	.77	"
19	.049	"	"	47-49	1015 PP	1.26	"	.84	"
20	.048	"	"	47-49	1027 PP	1.16	"	.85	"
21	.049	Quenched and drawn	Wrinkled	51	1017 PP	.95	"	.84	Satisfactory
22	.047	"	"	51	1013 PP	1.12	"	.86	"
23	.046	"	"	51	1017 CP, crack	.70	" crack	.81	Failed
24	.046	"	"	51	1010 PP	1.12	"	.79	Satisfactory
25	.046	"	"	51	1027 PP	.97	"	1.03	"
26	.046	"	Satisfactory	51	1007 PP	.59	"	.29	"
27	.048	"	"	51	987 PP	1.01	"	1.06	"
28	.046	"	"	51	1049 PP	1.23	" 1" square punching, 3" crack.	-	Failed
29	.047 (Near crown .035)	"	"	51	1010 CP Irregular hole, crack to top.	-	" Top not tested, too brittle.	-	"
30	.046	"	"	51	1010 PP	1.25	" 1-3/4" hole.	-	"
31	.046	"	Wrinkled	47-49	966 PP	.99	"	1.18	Satisfactory
32	.049	"	"	47-49	1010 PP	1.13	"	1.12	"
33	.045	"	"	47-49	989 PP	-	"	-	"
34	.047	"	"	47-49	989 CP Irregular hole.	-	"	.90	Failed
35	.049	"	"	47-49	985 PP	.78	"	.74	Satisfactory
36	.046	"	Satisfactory	47-49	1003 PP	1.15	"	.81	"
37	.046	"	"	47-49	978 PP	.63	" 1/2x1" hole, crack.	-	Failed

31	.046	"	Wrinkled	47-49	966 PP	.99	"	1.18	Satisfactory
32	.049	"	"	47-49	1010 PP	1.13	"	1.12	"
33	.045	"	"	47-49	989 PP	-	"	-	"
34	.047	"	"	47-49	989 CP Irregular hole	-	"	.90	Failed
35	.049	"	"	47-49	985 PP	.78	"	.74	Satisfactory
36	.046	"	Satisfactory	47-49	1003 PP	1.15	"	.81	"
37	.046	"	"	47-49	978 PP	.63	" 1/2x1" hole, crack.	-	Failed
38	.046	"	"	"	1038 PP	1.22	" 3-1/4x3-1/4" hole, cracks.	-	"
39	.046 (Near crown .035	"	"	"	1033 PP	1.16	" 1-1/4x1-1/2" hole, cracks.	-	"
40	.047	"	"	"	1003 PP	1.09	"	.96	Satisfactory
41	.046	Austempered	Wrinkled	51-53	994 CP cracks	-	" Too brittle to test.	-	Failed
42	.047	"	"	51-53	939 CP 1.1x.8" hole	.85	"	.73	"
43	.049	"	"	51-53	909 CP 2-1/8x1-5/8" hole, cracks, shattered.	.71	"	.68	"
44	.048	"	"	51-53	989 CP 2-7/8x7/8" hole, 3" crack.	.75	" Too brittle to test.	-	"
45	.045	"	"	51-53	987 CP Holes and cracks.	.44	" Too brittle to test.	-	"
46	.047	"	Satisfactory	51-53	966 CP 3⅛x4-1/4" punching, shattered.	.92	" Too brittle to test.	-	"
47	.046	"	"	51-53	933 CP 12" crack	.77	" Too brittle to test.	-	"
48	.050	"	"	51-53	914 CP Shattered	-	"	.76	"
49	.048 (Near crown .039	"	"	51-53	943 CP Shattered	.52	" Too brittle to test.	-	"
50	.048 (Near crown .037	"	"	51-53	927 CP 1⅛x⅝" hole, 2" crack.	.66	" Too brittle to test.	-	"

*This failure is not of the brittle type but consisted of a tear only.

TABLE IV

Summary of Ballistic Tests Made at Watertown Arsenal on Twenty-Five

0.70% Carbon Amola Steel Helmets Austempered to Rockwell C Hardness of 48

Ammunition - Caliber .45 ball, 230 grain

No.	Thickness at Brim Inches	Side of Helmet				Remarks
		Striking Vel. F/S	Max. Depth of Indentation Inches	Striking Vel. F/S	Depth of Indentation Inches	
1	.049	927PP, 982PP	1-1/8	750 PP	7/8	Good quality.
2	.054	982 PP	3/4	760 PP	3/4	Good quality.
3	.052	976 PP	15/16	741 PP	29/32	Good quality.
4	.054	982 PP	15/16	754 PP	13/16	Good quality.
6	.052	982 PP	31/32	738 PP	11/16	Good quality.
7	.052	989 PP	1	738 PP	29/32	Good quality.
10	.053	969 PP	1-1/32	741 PP	13/16	Good quality.
11	.051	976 PP	1	758 CP	-	Poor quality. 1x3/4" punching top of helmet. 1/2" crack from one corner.
13	.052	982 PP	1-1/32	741 CP	1-1/16	Poor quality. 3" crack top of crown.
15	.049	982 PP	1-3/32	760 CP	-	Poor quality. 15/16x15/16" punching top of helmet. 3/16" crack from one corner.
16	.052	969 PP	1-3/32	738 CP	-	Poor quality. 1x1-3/32" punching top of helmet.
17	.049	989PP, 982PP	15/16	750 PP	1-1/32	Good quality.
18	.052	989 PP	1	741 PP	1	Good quality.
19	.053	982 PP	1	740 PP	13/16	Good quality.
20	.053	976PP, 969PP	1-5/32	745 PP	7/8	Good quality.
22	.051	989 PP	1	738 PP	29/32	Good quality.
25	.052	989 PP	1-1/16	741 PP	27/32	Good quality.
28	.050	976 PP	1-1/32	741 CP	-	Poor quality. 1-3/8x1 1/2"punching top of helmet.
29	.053	927PP, 958PP	15/16	745 PP	1	Good quality.
34	.055	982 PP	1	731 PP	13/16	Good quality.
38	.050	977 PP	1-1/32	741 CP	-	Poor quality. 1-3/4x1" punching top of helmet.
40	.055	969 PP	1-1/32	738 PP	7/8	Good quality.
42	.050	974 PP	1-9/32	741 PP	11/16	Good quality.
45	.051	989CP, 976PP	5/8	741 PP	29/32	Poor quality. 2-5/8x2-3/4" tear side of helmet.
49	.052	989CP, 927 CP 880 PP	31/32	738 PP	15/16	Poor quality. 1-3/8x1"punching side of helmet penetrating opposite side edge. 1-7/8x1-1/8" punching side of helmet penetrating opposite side, t

Note: PP - Partial Penetration
CP - Complete Penetration

TABLE V

Summary of Ballistic Tests Made at McCord Radiator and Manufacturing Co. on Twenty-Five 0.70% Carbon Amola Steel Helmets Austempered to Rockwell C Hardness of 48

No.	Ave. Gauge before Draw Inches	Gauge at Top of Helmet Inches	Ballistic Test Top of Helmet Str. Vel. F/S	Ballistic Test Top of Helmet Indentation Inches	Remarks
M5	.046	.032	758 CP	-	Failed
M8	.046	.032	762 CP	-	Failed
M9	-	.035	781 PP	31/32	Satisfactory
M12	-	.038	758 PP	25/32	Satisfactory
M14	.046	.031	761 CP	-	Failed
M21	-	.038	767 PP	29/32	Satisfactory
M23	-	.038	769 PP	30/32	Satisfactory
M24	.046	.034	774 CP	-	Failed
M26	.046	.036	769 PP	30/32	Satisfactory
M27	-	.037	773 PP	29/32	Satisfactory
M30	-	.038	761 PP	28/32	Satisfactory
M31	.047	.037	733 PP	29/32	Satisfactory
M32	.047	.036	746 PP	28/32	Satisfactory
M33	-	.036	769 PP	28/32	Satisfactory
M35	-	.037	761 PP	29/32	Satisfactory
M36	.047	.039	752 PP	28/32	Satisfactory
M37	.045	.034	781 CP	-	Failed
M39	.046	.033	769 CP	-	Failed
M41	-	.039	787 PP	30/32	Satisfactory
M43	.047	.036	761 PP	29/32	Satisfactory
M44	.047	.037	787 PP	29/32	Satisfactory
M46	. -	.037	788 PP	30/32	Satisfactory
M47	-	.038	752 PP	28/32	Satisfactory
M48	.047	.037	782 PP	30/32	Satisfactory
M50	.047	.038	762 PP	28/32	Satisfactory

NOTE: In all penetrations, the impact area punched out, slug falling free of the helmet.

FIGURE 1

Photographs of 0.70% Carbon Amola Steel Helmets after Ballistic Test Made at Watertown Arsenal - Outside View

Helmet No. 1 - Wrinkled, austempered - Rockwell C 49-51.
Satisfactory ballistic properties.

Helmet No. 7 - No wrinkles on helmet, austempered - Rockwell C 49-51.
Poor ballistic properties.

Helmet No. 10 - No wrinkles on helmet, austempered - Rockwell C 49-51.
Satisfactory ballistic properties.

Helmet No. 12 - Wrinkled, austempered - Rockwell C 47-49.
Poor ballistic properties.

Helmet No. 13 - Wrinkled, austempered - Rockwell C 47-49.
Satisfactory ballistic properties.

Helmet No. 16 - No wrinkles on helmet, austempered - Rockwell C 47-49.
Poor ballistic properties.
Note tear, round No. 1.

WATERTOWN ARSENAL
HELMET BALLISTIC TEST JUNE 22 1942 W.A.710-1888

FIGURE 1

FIGURE 2

Photographs of 0.70% Carbon Amola Steel Helmets after Ballistic Test Made at Watertown Arsenal - Outside View

Helmet No. 19 - No wrinkles on helmet, austempered - Rockwell C 47-49.
Satisfactory ballistic properties.

Helmet No. 22 - Wrinkled, quenched and drawn - Rockwell C 51.
Satisfactory ballistic properties.

Helmet No. 23 - Wrinkled, quenched and drawn. Rockwell C 51.
Poor ballistic properties.

Helmet No. 26 - No wrinkles on helmet, quenched and drawn - Rockwell C 51.
Satisfactory ballistic properties.

Helmet No. 29 - No wrinkles on helmet, quenched and tempered - Rockwell C 51.
Poor ballistic properties.

Helmet No. 34 - Wrinkled, quenched and drawn - Rockwell C 47-49.
Poor ballistic properties.

WATERTOWN ARSENAL
HELMET BALLISTIC TEST JUNE 22 1942 W.A.710-1890

FIGURE

FIGURE 3

Photographs of 0.70% Carbon Amola Steel Helmets after Ballistic Test Made at Watertown Arsenal - Outside View

Helmet No. 35 - Wrinkles on helmet, quenched and drawn - Rockwell C 47-49 Satisfactory ballistic properties.

Helmet No. 36 - No wrinkles on helmet, quenched and drawn - Rockwell C 47-49. Satisfactory ballistic properties.

Helmet No. 39 - No wrinkles on helmet, quenched and drawn - Rockwell C 47-49. Poor ballistic properties.

Helmet No. 42 - Wrinkled, austempered. Rockwell C 51-53. Failed by punching. Poor ballistic properties.

Helmet No. 44 - Wrinkled, austempered - Rockwell C 51-53. Failed by shattering. Poor ballistic properties.

Helmet No. 49 - No wrinkles on helmet, austempered - Rockwell C 51-53. Failed by shattering. Poor ballistic properties.

WATERTOWN ARSENAL
HELMET BALLISTIC TEST JUNE 22 1942 W.A.710-1892

FIGURE

FIGURE 4

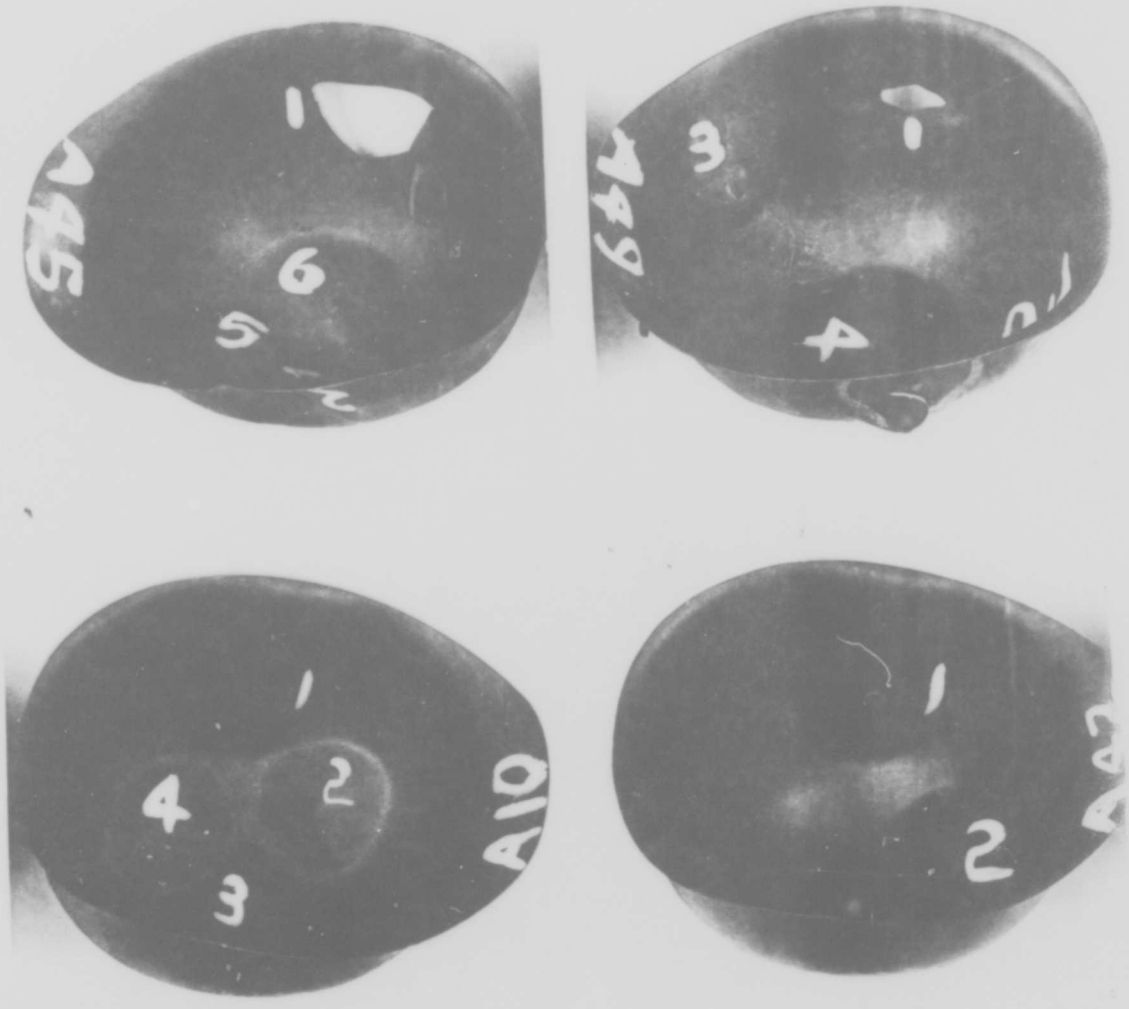
Photographs of Typical Satisfactory and Poor Amola Steel Helmets
From a Lot of 25 Helmets, Austempered to a Hardness of Rockwell C 47-49
Ballistic Tests Made at Watertown Arsenal

Helmet No. 49 - Failed by punching.

Helmet No. 45 - Failed by tearing.

Helmet No. 10 - Satisfactory.

Helmet No. 42 - Satisfactory.



WATERTOWN ARSENAL

AUSTEMPERED AMOLA STEEL HELMETS
OCTOBER 22 1942 WTN.710-1945

FIGURE

FIGURE 5

Photographs of Typical Satisfactory and Poor Amola Steel Helmets from a Lot of 25 Helmets, Austempered to a Hardness of Rockwell C 47-49

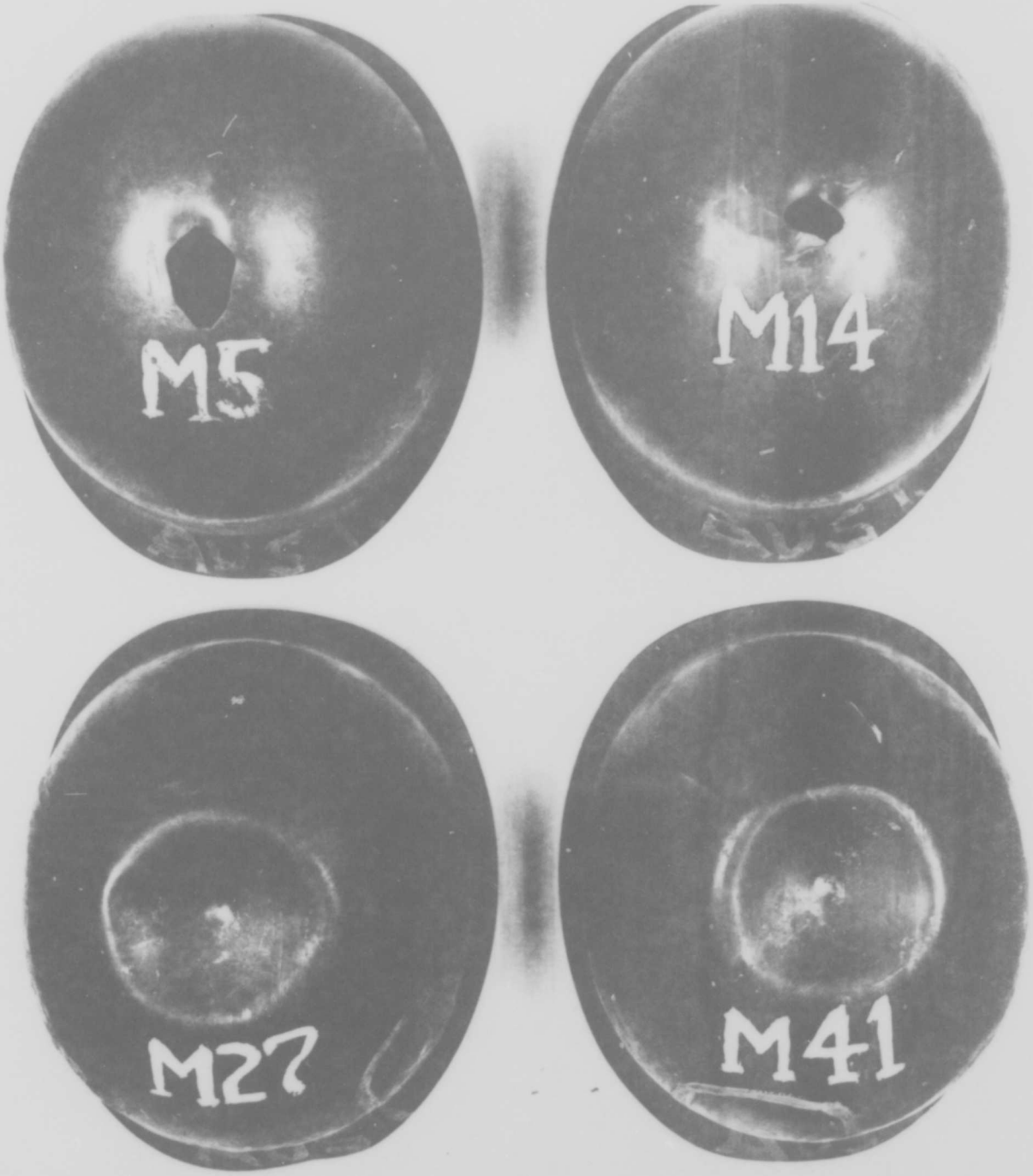
Ballistics Tests Made at McCord Radiator and Manufacturing Co.

Helmet No. M5 - Failed by punching.

Helmet No. M45 - Failed by punching.

Helmet No. 10 - Satisfactory.

Helmet No. 42 - Satisfactory.

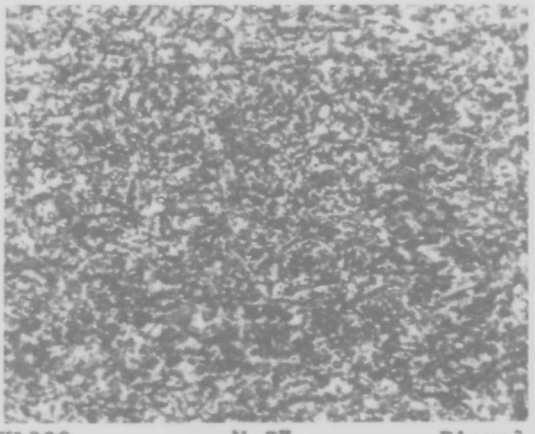


WATERTOWN ARSENAL

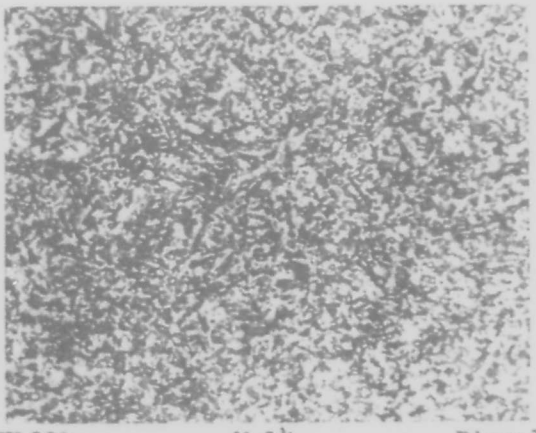
AUSTEMPERED AMOLA STEEL HELMETS TESTED BY MC CORD RADIATOR CO
FEBRUARY 3 1943 OUTSIDE VIEW WTN.710-2010

FIGURE 5

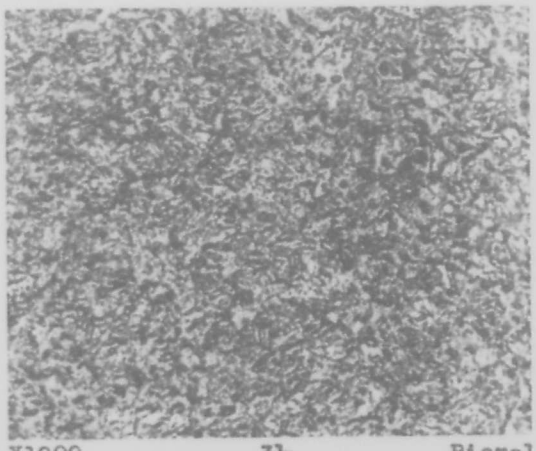
Microstructure of Typical Satisfactory and
Poor Quality 0.70% C Amola Steel Helmets Austempered and
Heat Treated to a Hardness of Rockwell C 47-49



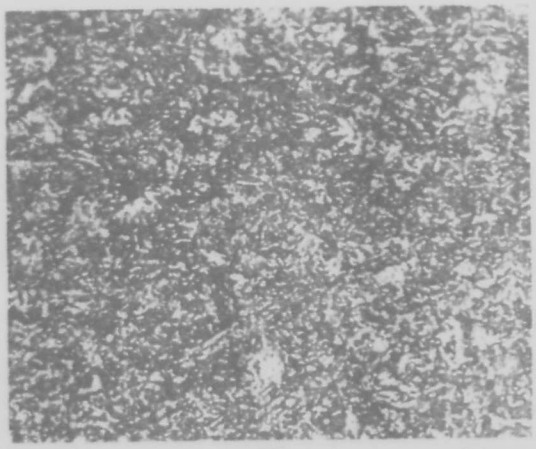
X1000 M-27 Picral
Austempered helmet. Satisfactory ballistic properties. Bainite.



X1000 M-14 Picral
Austempered helmet. Unsatisfactory ballistic properties. Bainite.



X1000 31 Picral
Quenched and drawn helmet. Satisfactory ballistic properties. Tempered martensite.



X1000 37 Picral
Quenched and drawn helmet. Unsatisfactory ballistic properties. Tempered martensite.

WTN. 639-5402

FIGURE

FIGURE 7

ROCKWELL "C" HARDNESS SURVEY

(Readings taken every half-inch.)

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	39.0	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		

.70% Carbon Amola Steel

Longitudinal

M27 Satisfactory

Sta.	Rc	Sta.	Rc
5	46.0	16	47.0
6	46.5	17	47.5
7	47.5	25	48.0
8	46.5	26	48.0
9	46.5	29	45.5
10	46.0	30	47.5
11	45.5	31	48.5
12	45.5	32	49.0
15	46.0	33	48.5

M5 Failed

4	45.0	22	45.0
5	44.5	23	45.0
6	45.0	28	45.5
8	47.5	30	48.0
10	45.5	31	47.5
14	45.0	32	47.0
16	46.5	34	46.5
17	47.5	35	47.0
18	45.0	36	49.0

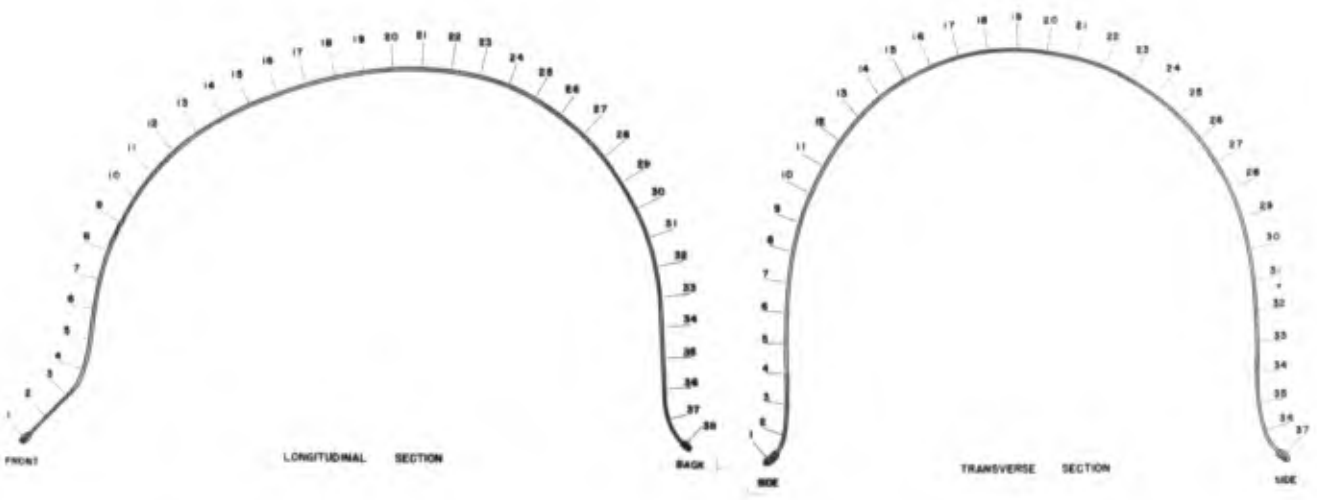
Transverse

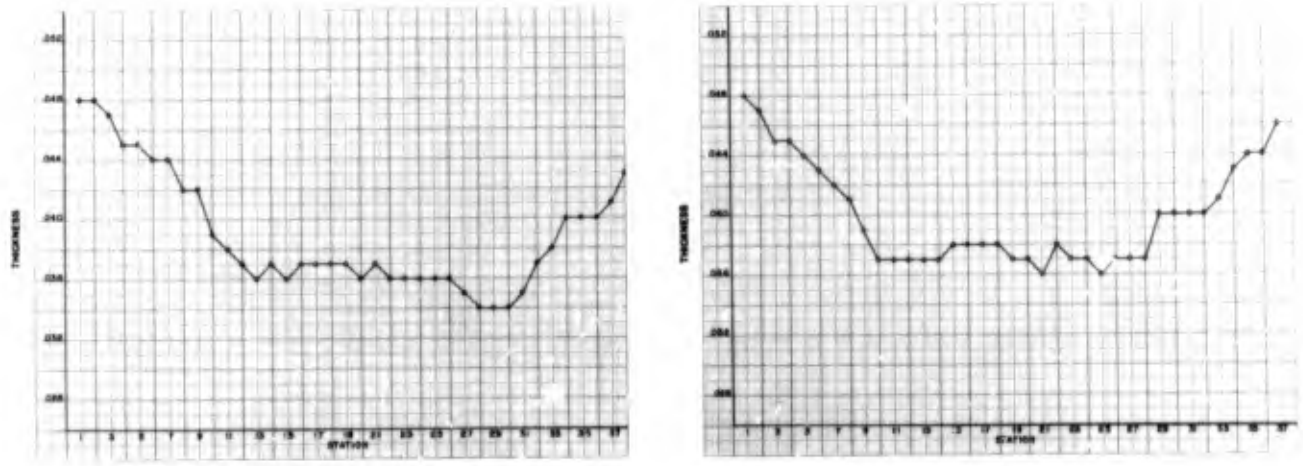
M41 Satisfactory

Sta.	Rc	Sta.	Rc
5	46.5	18	43.5
6	45.5	25	46.0
7	46.5	27	44.5
11	46.0	29	45.0
12	44.0	30	45.0
14	45.5	31	43.5
15	46.0	32	43.5
16	45.0	33	47.5
17	42.5		

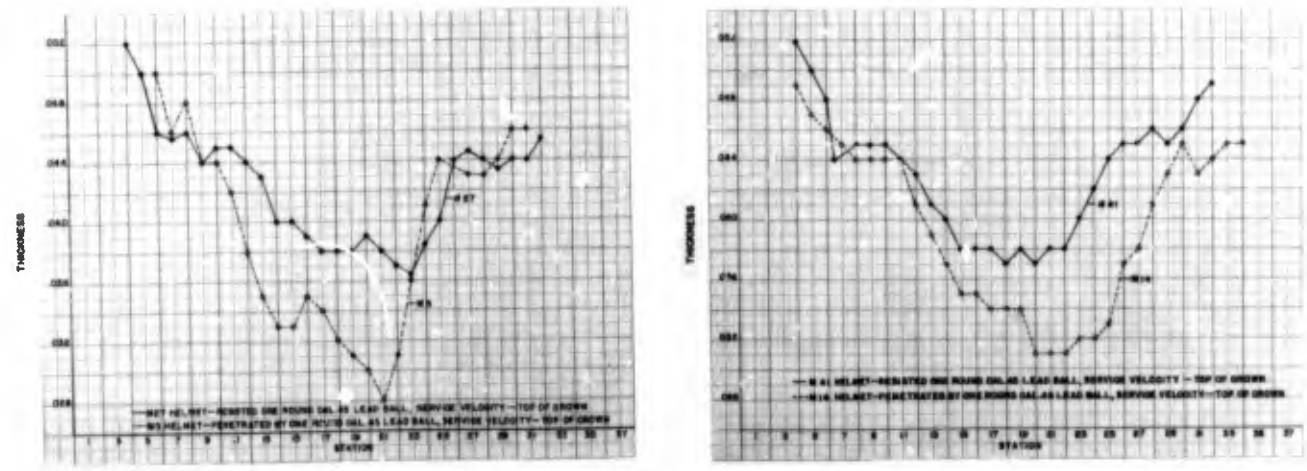
M14 Failed

4	46.5	17	48.0
5	45.0	19	46.5
6	45.5	20	47.5
7	48.0	21	47.0
8	47.5	22	46.5
9	47.5	24	46.5
10	47.5	25	46.0
11	46.5	26	47.0
12	44.5	29	45.0
13	45.5	30	44.5
16	48.5	32	44.0





HADFIELD MANGANESE STEEL



0.70 % CARBON AMOLA STEEL

WATERTOWN ARSENAL

THICKNESS MEASUREMENTS ON CROSS SECTIONS OF HELMETS
7 AUGUST 1943 WTN.639-5388

FIGURE 8

INCLOSURE A

C O P Y

2/23/42

McCORD RADIATOR & MFG. CO.

PRELIMINARY FORMING DATA ON AMOLA ARMY HELMET STEEL

The following test work was performed on February 12.

The following lots of Amola steel were drawn on the Toledo Press:

No. Pcs.	Mark	Dia.	Gauge	Weight	Type
25	"A"	16-1/2"	.038 to .041"	20 lbs.	Cold rolled
5	"AM"	16-1/2"	.040"		

The 25 pieces were in McCord stock for some time.
The 5 pieces are the material referred to in Mr. Barter's letter of January 28th.

Mr. R. H. Barnes, Division Metallurgist, and Mr. H. R. Steele, of the Detroit office of the American Steel & Wire Company were present during the drawing operation.

The following data on the 5-piece lot was received from Mr. Barnes:

C	Mn	Mo	Grain Size	Rb	Finish	Edge
.70	.90	.25	7/8	80/83	C.R. #2	#3 (Slit)

After the drawing, trimming, and spank operations, they intend to austemper the helmet to obtain a hardness of Rc 52. The austempering operation is briefly as follows:

> Heat to 1550°F., quench in salt held at 530°F. and hold until transformation has been completed. By austempering, the steel develops much greater toughness than when heat treated to the same hardness by the usual method.

To find the proper die adjustment and lubricant for forming, the test was started using the lot marked "A". Results as follows:

No.	Mark	Lubricant	Die Adjustment	Result
1	A	L. Mch. Oil	As used in Prod.	Broke at start of draw
2	A	"	Loosened	Excessive wrinkles
3	A	"	Tightened	"
4	A	"	"	Less wrinkles
5	A	"	"	"
6	A	"	"	"
7	A	10K-90 Mch.Oil	Same as #6	Slightly less wrinkles

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McCORD RADIATOR & MFG. CO.

No.	Mark	Lubricant	Die Adjustment	Result
8	A	10K-90 Mch.Oil	Same as #6	Excessive wrinkles one side
9	A	Kerosene	"	Broke at start of draw
10	A	20K-80 Mch. Oil	"	Broke in crown
11	A	"	"	"
12	A	"	"	"
13	A	10K-90 Mch.Oil	"	Excessive wrinkles one side
14	A	"	"	"
15	A	"	"	Broke in crown
16	A	15K-85 Mch.Oil	"	"
17	A	"	"	"
18	A	"	"	Slight wrinkles one side
19	A	"	"	Excessive wrinkles
1	AM	"	"	Broke in crown
2	AM	10K-90 Mch.Oil	"	"
3	AM	L. Mch. Oil	Same as #6	Excessive wrinkles
20	A	10K-90 Mch.Oil	"	"
4	AM	L. Mch. Oil	"	"
5	AM	10K-90 Mch.Oil	"	"
21	A	"	"	"
22	A	"	"	"
23	A	"	"	"
24	A	Circle held in Metallurgical Dept.		
25	A	Circle shipped to Mr. Barnes		

28 pieces drawn: 11 broke (40%); 17 excessive wrinkles. No. 18 formed best.

The following helmets were selected by Mr. Barnes and have been sent to his office for austempering and testing:

No.	Mark	Trimmed	Spanked
4	AM	"	"
5	AM	"	"
4	A	"	"
7	A	"	"
14	A	"	"
18	A	"	"
21	A	not "	not "
25	A	not "	not "

Seven helmets stored in McCord Raw Stock

No.	Mark	Trimmed	Spanked
2	A	not	not
3	A	not	not
6	A	not	not
8	A	not	not
20	A	not	not
22	A	not	not
23	A	not	not

2/23/42

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C O P Y

McCORD RADIATOR & MFG. CO.

Three helmets and one circle held in McCord Metallurgical Dept.

No.	Mark	Trimmed	Spanked
5	A	"	"
13	A	"	"
19	A	"	"

The following information was obtained on the helmets and sheet held in the Metallurgical Dept.:

		Gauge	HB
25	A	.040-.040"	82/83

DRAWN HELMETS

No.	Mark	Front	Back	Front	Top	Back
5	A	.038	.032	92/94	96	93/98
13	A	.033	.031			
19	A	.032	.030			

Summary:

The results indicate that this steel is not satisfactory for drawing on dies that are satisfactory for our present high-carbon-manganese helmet steel. It either breaks or wrinkles. We believe two factors should be investigated in attempting to make helmets out of steel that is not austenitic. Steels that are austenitic work harden rapidly and, therefore, obtain the necessary hardness to meet the ballistic requirements during the draw. With non-austenitic steels, that will require heat-treatment in order to obtain the required hardness, consideration should be given to the possibility of using dies designed to form with the least amount of cold working. The other factor suggested for consideration is whether the steel is in a physical condition best suited to deep drawing. Therefore, it is suggested that the following information be furnished before the steel is drawn:

Chemical analysis
Grain size
Hardness
Micro-structure, annealed, normalized, spheroidized, etc.
Erichsen test
Tensile strength, elastic limit, and elongation.

A study of the above information and the drawability of the steel, should indicate the trend to follow in further experimentation to find the best substitute for high carbon-manganese steel.

2/23/42

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McCord Metallurgical Dept.
5/4/42

LIST OF EXPERIMENTAL AMOLA ARMY HELMETS SHIPPED MAY 5, 1942
to American Steel & Wire Co., Worcester, Mass.
Attention of Mr. Robert Knight

LOTS	A	B		C	
Helmet No.	Condition	Helmet No.	Condition	Helmet No.	Condition
8	3 and 9	1	2 and 9	3	2 and 9
15	3 and 9	2	2 and 9	6	3 and 9
16	2 and 9	3	2 and 9	8	1 and 9
17	3 and 9	4	1, 8 and 9	9	1
24	3 and 9	5	2 and 9	11	3 and 9
25	3 and 9	6	2 and 9	18	2 and 9
27	2 and 9	9	1 and 9	19	1 and 9
28	1 and 9	10	1 and 9	20	3 and 9
29	2 and 9	12	1 and 9	21	3 and 9
30	1 and 9	13	1	23	2 and 9
31	2 and 9	15	1 and 8	24	1 and 9
32	3 and 9	19	1	25	2
33	2 and 9	20	2	26	1, 8 and 9
34	3 and 9	23	3 and 9	28	1 and 8
35	3 and 9	25	1	29	2 and 9
36	2 and 9	26	1	30	1 and 8
37	2 and 9	27	1	31	2 and 9
38	2 and 9	28	1 and 8	32	3 and 9
42	3 and 9	31	1	33	1 and 9
44	3 and 9	32	1 and 9	35	3 and 9
45	3 and 9	36	3 and 9	36	2 and 9
46	3 and 9	39	3 and 9	37	3 and 9
47	3 and 9	43	2 and 9	44	3 and 9
48	2 and 9			45	3 and 9
49	3 and 9			50	3 and 9
53	3 and 9			51	3 and 9
54	3 and 9			52	2 and 9
55	3 and 9			53	3 and 9
57	3 and 9				
58	3 and 9				
59	2 and 9				
60	2 and 9				
61	3 and 9				
62	2 and 9				

Condition Legend:

1 - Good 2 - Passable 3 - Wrinkles 8 - Undergauge
9 - Overweight

Any helmet having the condition rating numbers 3, 8, and 9 is a reject.

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5-23-42

MEMORANDUM

Mr. H. J. Elmendorf

HEAT TREATMENT OF HELMETS

5-23-42 to be ready for Ballistic Test at Watertown June 1st.

Sort helmets by number.

Select (25 fairly free from wrinkles (1) Good
for 5 (25 wrinkled (2) Wrinkled
lots (
Note the number already marked on each helmet by McCord Radiator.

Then:

Austemper 5 good (1))
5 wrinkled (2))
Protect surface from oxidation (charcoal briquettes or
(gas line cover?)

Lot A Heat 7 minutes at 1550°F - Salt 585°F. 1-1/2 hours
Aim 51-53 C Rockwell

Lot B Heat 7 minutes at 1550°F - Salt 635°F. 1-1/2 hours
Aim 49-51 C Rockwell

Lot C Heat 7 minutes at 1550°F - Salt 670°F. 1 hour
Aim 47-49 C Rockwell

Quench and Temper

Lot D Heat 7 minutes at 1550°F. Quench in oil
Try test piece Draw 670°F. for 1 hour
Aim 49-51 C Rockwell

Lot E Heat 7 minutes at 1550°F. Quench in oil
Try test piece Draw 700°F
Aim 47-49 C Rockwell

Mark suitably with grey paint for identification.

R. H. Barnes

RHB/emt

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Our No.	McCord No.	Helmet Condition	Heat Temp.	Heat Time	Oil Temp.	Draw Temp.	Draw Time	Aust. Salt Temper.	Aust. Salt Temper.
1	A-3	Wrinkled	1550° F	7 min.	–	–	–	635° F	1½ Hr.
2	A-4	"	"	"	–	–	–	"	"
3	A-19	"	"	"	–	–	–	"	"
4	A-20	"	"	"	–	–	–	"	"
5	B-7	"	"	"	–	–	–	"	"
6	A-8	Good	"	"	–	–	–	"	"
7	A-24	"	"	"	–	–	–	"	"
8	A-25	"	"	"	–	–	–	"	"
9	A-28	"	"	"	–	–	–	"	"
10	A-34	"	"	"	–	–	–	"	"
11	B-8	Wrinkled	1550° F	"	–	–	–	665° F	1 Hr.
12	B-17	"	"	"	–	–	–	"	"
13	B-34	"	"	"	–	–	–	"	"
14	B-35	"	"	"	–	–	–	"	"
15	B-40	"	"	"	–	–	–	"	"
16	A-35	Good	"	"	–	–	–	"	"
17	A-45	"	"	"	–	–	–	"	"
18	A-46	"	"	"	–	–	–	"	"
19	A-57	"	"	"	–	–	–	"	"
20	A-58	"	"	"	–	–	–	"	"
21	B-42	Wrinkled	1550°F	"	100° F	665°F	1½hr.	–	–
22	C-7	"	"	"	"	"	"	–	–
23	C-15	"	"	"	"	"	"	–	–
24	C-34	"	"	"	"	"	"	–	–
25	C-38	"	"	"	"	"	"	–	–
26	A-60	Good	"	"	"	"	"	–	–
27	A-62	"	"	"	"	"	"	–	–
28	B-6	"	"	"	"	"	"	–	–
29	B-12	"	"	"	"	"	"	–	–
30	B-15	"	"	"	"	"	"	–	–
31	C-46	Wrinkled	"	"	"	705°F	"	–	–
32	C-47	"	"	"	"	"	"	–	–
33	C-48	"	"	"	"	"	"	–	–
34	C-40	"	"	"	"	"	"	–	–
35	C-39	"	"	"	"	"	"	–	–
36	B-20	Good	"	"	"	"	"	–	–
37	B-32	"	"	"	"	"	"	–	–
38	B-43	"	"	"	"	"	"	–	–
39	C-9	"	"	"	"	"	"	–	–
40	C-24	"	"	"	"	"	"	–	–
41	B-54	Wrinkled	"	"	–	–	–	585° F	2 Hr.
42	B-55	"	"	"	–	–	–	"	"
43	B-56	"	"	"	–	–	–	"	"
44	B-57	"	"	"	–	–	–	"	"
45	B-60	"	"	"	–	–	–	"	"
46	C-26	Good	"	"	–	–	–	"	"
47	C-30	"	"	"	–	–	–	"	"
48	C-33	"	"	"	–	–	–	"	"
49	C-44	"	"	"	–	–	–	"	"
50	C-52								

All helmets have been identified by numbers in grey paint on the front of each and may be correctly separated by reference to the above tables. Numbers ending in 1 to 5 are wrinkled helmets and 6 to 0 are good helmets.

Group 41-50 - Austempered to 51-3 RC
Group 1-10 - " " 49-51 RC
Group 11-20 - " " 47-49 RC

Group 21-30 - Quenched and tempered to 49-51 RC
" 31-40 - " " " " 47-49 RC

HJE

APPENDIX A

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WAR DEPARTMENT
OFFICE OF THE CHIEF OF ORDNANCE Moore/db
WASHINGTON

January 31, 1942

W.A. 421/248
O.O.421/930
Attn: Small Arms Division
Industrial Service

Subject: Steel for Use in Helmet M1

To: Commanding General
Watertown Arsenal
Watertown, Mass.

1. Reference is made to personal memorandum from Lt. N. A. Matthews, Laboratory, dated January 27, 1942, subject, Military Requirements for Helmets, which read as follows:

"1. Colonel Zornig has requested that I write to you informally to ascertain the O.C.M. number which specifies the military requirements for helmets. Please indicate also what that requirement is.

"2. It is suggested that you indicate on the bottom or reverse side of this sheet the information desired."

2. Reference is also made to a letter dated January 26, 1942, addressed to Major G. L. Cox, Acting Chairman, Subcommittee Helmet Steels and Body Armor, by Mr. P. L. Barter, Vice President of the McCord Radiator Company of Detroit.

3. The steel situation for use in helmets will no doubt become critical within a very short period. At the present time only the Carnegie Illinois Company has produced the required Hadfield type of steel used in the body of the Helmet M1. It is understood that the Allegheny-Ludlum Steel Corporation is making a study to see if its corporation will be able to produce either this type of steel or a suitable substitute. It is believed that the Helmet Subcommittee has contacted a number of companies in order to determine if a suitable steel could be produced.

4. Within the near future orders will be placed for exceedingly large quantities of helmets. At the present time it appears that production of helmets should reach, by June or July of this year, a production rate of approximately 400,000 helmets per month, which will require in the neighborhood of one and a quarter million pounds of steel per month.

5. In reply to the arsenal's request, the following is supplied.

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To: Watertown Arsenal 1/31/42

The ballistic requirements for the Helmet M1 were set forth in a letter from the Office of the Chief of Infantry to the Adjutant General, through the Chief of Ordnance, dated February 3, 1941. These requirements were: (1) To withstand perforation by a 230 grain, .45 caliber bullet, at 750 to 800 f.s., and (2) To show no dents greater than 1-3/16 inches by a 230 grain, .45 caliber bullet, at 575 to 620 f.s.

These requirements were carried over from the actual properties of the 1917 Helmet. The specification requirements for the 1917 Helmet were considerably below actual performance.

6. While the present requirements call for a non-magnetic type of steel, it is believed that these requirements can be changed so as to permit the use of other types of steels if a suitable steel can be found for this purpose. Data received in the Ordnance Office in regard to steel such as NAX indicate that these steels are inferior to the present standard material in producing helmets of the same weight. As the arsenal knows, the maximum weight of the helmet is critical. It was found that the maximum weight of the steel helmet body, including paint, edging, chin strap, etc., must be less than 39.275 ounces in order to meet the overall requirements, as specified by the using service, that the complete helmet, including helmet liner, must not weight more than three pounds.

7. It is requested that Watertown Arsenal study the above requirements and advise the Ordnance Office, Small Arms Division, Industrial Service, as to the most suitable type of substitute steel that could be used in fabricating the Helmet M1.

By order of the Chief of Ordnance:

W. T. MOORE
Lt. Col., Ord. Dept.
Assistant

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O.O. 421/930
W.A. 421/248

1st Ind. NAM/HLR/amv

Watertown Arsenal, Watertown, Massachusetts, February 13, 1942.
To: Chief of Ordnance, U.S.A., Washington, D. C.
Attn: Small Arms Division - Industrial Service

1. Reference basic communication and letter dated January 28, 1942, written by Mr. P. L. Barter to Major G. L. Cox of this arsenal, this arsenal has taken preliminary steps to procure steel sheet in sufficient quantity to make two hundred (200) helmet blanks from the American Steel and Wire Company. A letter has been written to Mr. R. H. Barnes, American Steel & Wire Company inquiring into the possibility of negotiating a small development contract covering the furnishing of the necessary steel for two hundred (200) helmets and the heat treatment of the helmet bodies after forming.

2. The steel which will be investigated more completely has shown remarkable ballistic properties in the austempered condition at a Rockwell C hardness of approximately 50. The approximate analysis is as follows:

C	Mn	Mo
.70	.90	.20

The steel is known as Amola and is made in great quantities in open hearth furnaces. It is certain that the ballistic qualities of the helmets will be satisfactory; the question which remains to be determined is the drawability of the steel in the spheroidized-anneal condition.

3. Additional cooperative work is being carried out with the Kearny Laboratory of the U. S. Steel Corporation, and it is hoped that another low alloy analysis will be developed soon which can be utilized in the preparation of steel for a development project.

4. Your office will be contacted as soon as possible regarding funds which may be required. It is recommended that the McCord Radiator & Mfg. Co. exert every effort to provide facilities for the drawing of the experimental helmet bodies at the earliest possible date.

For the Commanding General:

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

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NLR/ZAN/amv

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June 18, 1942

W.A. 421/304
Laboratory-NLR

Subject: Ballistic Tests of Amola Steel Helmets

To: Chief of Ordnance, U.S.A.
Pentagon Building
Washington, D. C.

Attn.: Industrial Service - Small Arms Division

1. In reference to the cooperative program between Watertown Arsenal and the American Steel & Wire Company (letter reference W.A. 421/301 dated May 22, 1942, to Office, Chief of Ordnance, attention Industrial Service - Small Arms Division) on the development of Amola steel helmets, ballistic tests have been made on fifty of these helmets, austempered and quenched and drawn to several hardness levels with the results reported on the attached data sheets.

2. The results of these tests are summarized below:

a. Series 16-20 inclusive, free from wrinkles in the forming process and austempered to a Rockwell C hardness of 47-49, showed the best all around performance. Helmet No. 16 of these series failed due to a punching only but with no indication of brittleness as noted in some of the other failures.

b. Series 1-5 inclusive which were wrinkled in the forming process showed good ballistic properties as austempered to a Rockwell C hardness of 49-51. On the other hand, Series 6-10 inclusive which were free from wrinkles were relatively brittle when austempered to the same hardness range. The hardness range of 49-51 Rockwell C is not recommended for this type of steel.

c. Series 21-40 inclusive which were quenched and drawn to a Rockwell C hardness of 47-49 and 51 respectively show indications of brittleness under the ballistic test.

d. The Amola steel helmets, austempered to a Rockwell C hardness of 51-53 were entirely too brittle.

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3. As the result of this preliminary investigation, instructions are being sent to American Steel & Wire Company to austemper another lot of fifty helmets to a Rockwell C hardness of 47-49 and submit them to Watertown Arsenal and McCord Radiator & Mfg. Company for ballistic test. Results of these tests will be forwarded to his office.

For the Commanding General:

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

Incl. - Data Sheets
cc-Detroit Ordnance Dist.

(Note: The Date Sheets are inclosed in body of report.)

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C O P Y

McCORD RADIATOR & MFG. CO.
DETROIT, MICHIGAN

May 6th, 1942 H. E. MOSER

Mr. Raleigh H. Barnes
American Steel & Wire Company
Rockerfeller Bldg.
Cleveland, Ohio

Dear Mr. Barnes:

We shipped on May 4th, eighty-five experimental Amola helmets by motor freight to:

American Steel & Wire Company
Attention of Mr. Robert Knight
Superintendent of Spring Mill
South Works, Worcester, Mass.

The following table is a summary of the helmets shipped:

	LOT			
Condition	"A"	"B"	"C"	Total
Good	2	12	8	22
Passable	11	7	8	26
Wrinkles	21	4	12	37
Total	34	23	28	85

The above classifications are based on shape and wrinkles only. Those included under "wrinkles" are rejects. Also included under "good" and "passable" are some that are rejects due to overweight and gauge.

Each hat has its number stenciled on the inside of the visor. The table on the enclosed sheet gives the identity and rating of the helmets shipped. The helmets are in the report as formed, trimmed and spanked condition. A detailed report on the entire test will be submitted later.

The balance of the unbroken test helmets are being held in the Metallurgical department. These are all rejects due to wrinkles, gauge or over-weight.

If you require anything further, please let us know. Also we will appreciate receiving any work as to the results of the austempering and ballistics. If possible we would like to receive a few helmets that have been treated.

Yours very truly,
McCORD RADIATOR & MFG. CO.

Chief Metallurgist

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