WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL 710/611

ARMOR PLATE - ROLLED

Investigation of Experimental Heat Treatments of 3/8 Inch Thick Homogeneous Armor Plate

BY

E. L. REED
Research Metallurgist

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WATERTOWN ARSENAL
WATERTOWN, MASS.

V-NOTCH CHARPY IMPACT VALUES OF AUSTEMPERED OR QUENCHED & TEMPERED 8" THICK ARMOR PLATE

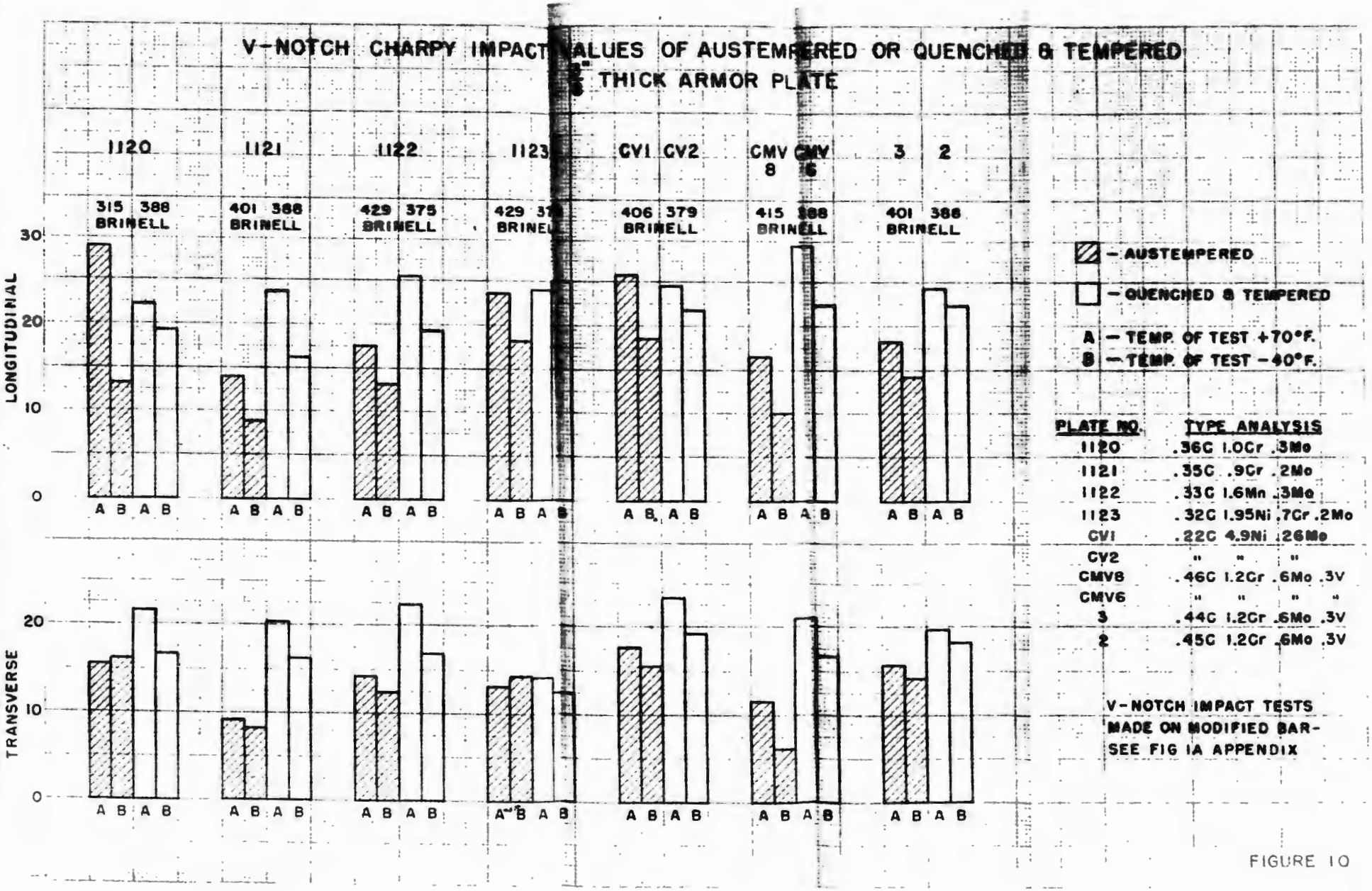

PLATE NO.	TYPE ANALYSIS
1120	.36C 1.0Cr .3Mo
1121	.35C .9Cr .2Mo
1122	.33C 1.6Mn .3Mo
1123	.32C 1.95Ni .7Cr .2Mo
CV1	.22C 4.9Ni .26Mo
CV2	" " "
CMV8	.46C 1.2Cr .6Mo .3V
CMV6	" " " "
3	.44C 1.2Cr .6Mo .3V
2	.45C 1.2Cr .6Mo .3V

V-NOTCH IMPACT TESTS MADE ON MODIFIED BAR- SEE FIG IA APPENDIX

FIGURE 10

(1)

Watertown Arsenal Laboratory
Report Number WAL 710/611
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24 July 1944

ARMOR PLATE - ROLLED

Investigation of Experimental Heat Treatments of 3/8 Inch Thick Homogeneous Armor Plate

OBJECT

To determine the ballistic and metallurgical properties of experimental and production analyses of 3/8 inch thick homogeneous armor plate which has been austempered or quenched and tempered to hardnesses common to hard homogeneous armor.

CONCLUSIONS

1. Satisfactory ballistic and metallurgical properties have been obtained on two types of steels in the austempered condition which contained the following percentages of alloying elements: (a) 1.95 Ni, .7 Cr, .2 Mo and (b) 4.9 Ni, .26 Mo.

2. No superiority over the quenched and tempered condition was achieved in any steel and, therefore, consideration of austempering for heat treatment of armor is not justified because of the excessive hardenability (in consideration of the section thickness) required to produce satisfactory shock properties.

3. Inhomogeneity of microstructure, and the presence of high temperature transformation products, which were present in poor quality austempered plates, were characteristics which were reflected by the presence of crystallinity in the fibre fracture test and low notched bar impact values.

4. The ratio of the yield - tensile strength properties of the austempered plates containing high and low temperature transformation products was lower than in the case of quenched and tempered plates.

5. In most cases, the quenched and tempered plates had satisfactory ballistic and metallurgical properties.

6. The fibre fracture test can be satisfactorily applied to thin armor heat treated to 388-429 Brinell hardness.

E. L. Reed

E. L. REED
Research Metallurgist

APPROVED:

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

INTRODUCTION

In connection with the development of hard homogeneous aircraft armor to meet the requirements of Specification ANOS-1 as outlined at the meeting of the Research Sub-Group for light aircraft armor held in the latter part of 1942, a series of 3/8 inch thick experimental and production plates were experimentally heat treated at Watertown Arsenal. These tests were made in order to determine if austempered low and high alloy content plate had any special merit over the standard quenched and tempered plate.

Ballistic results have been reported in part previously to some of the industrial members of the Subcommittee on Rolled Armor. This report has been written in order to provide a complete record of the ballistic and metallurgical study of the compositions referred to below.

Four experimental 800 lb. ingots of several compositions were cast at Watertown Arsenal and forwarded to the Simonds Saw and Steel Company where each ingot was rolled into 3/8 inch thick plates for subsequent heat treatment. Two 10"x12" plates of each analysis were austempered at Watertown Arsenal and two companion plates were quenched and tempered at Simonds Saw and Steel Company. In addition, several 3/8 inch thick Disston high nickel-molybdenum and chromium-molybdenum-vanadium plates and also 3/8 inch thick low nickel-molybdenum plates manufactured by the Ingersoll Steel and Disc Company were included in the above series of heat treatments.

With the exception of two plates the series of plates were heat treated to a hardness range of 375-429 Brinell. The details on the fabrication of the experimental plates are given in Appendix A.

TEST PROCEDURE

1. Ballistic Tests.

Ballistic tests were made as follows:

a. Army ballistic limits were obtained on the plates with cal. .30 AP M2 ammunition in accordance with Specification AXS-488, Revision 2 for hard homogeneous armor plate.

b. The plates were subjected to a shock test consisting of 3 rounds of cal. .50 M2 ball ammunition fired at normal impact at a striking velocity of 2450 feet-per-second. Also, representative plates were tested with one round of cal. .50 AP M2 ammunition fired at normal at a striking velocity of 2450 feet-per-second.

2. Metallurgical Examination.

After completion of the ballistic tests, the plates were sectioned for a metallurgical study which included the following tests: chemical analyses, macroscopic examination, microscopic examination and Brinell hardness tests made on the cross sections of representative plates.

In addition fracture tests for fibre characteristics were made on each plate. Sections 2"x8" were nicked perpendicularly to the longitudinal axis and broken quickly under the drop hammer. Also, special V-notch Charpy impact bars .360x.394" with the notch cut on the .394" face width, parallel to the surface of the plate, and also .252" diameter tensile bars were machined from representative plates.

RESULTS AND DISCUSSION

1. Ballistic Tests.

Photographs of typical austempered and quenched and tempered plates after the ballistic tests are shown in Figures 1-4 inclusive. The results of the ballistic tests are given in Table I. Generally speaking, the austempered plates were more brittle under the shock test than the quenched and tempered plates. For example, of the thirteen austempered plates investigated, only four possessed satisfactory resistance to the shock test, namely, plates 1123-1, 1123-2 (1.95 Ni, .7 Cr, .2 Mo), CV-1 (4.9 Ni, .26 Mo) and 14582 (1.3 Ni, .4 Mo).

Apparently, in most cases, the hardenability of the compositions was insufficient to prevent the formation of intermediate temperature transformation products during the quench.

The ballistic limits of the austempered series were inferior to those of the quenched and tempered group. The ballistic limits of the austempered plates varied from 79 feet-per-second below to 70 feet-per-second in excess of the requirements whereas the ballistic limits of the quenched and tempered plates varied from 5 to 85 feet-per-second in excess of the Specifications.

Although the austempered plates CV-1 and 14582 passed the shock test, the ballistic limits were respectively 1 foot-per-second in excess and 60 feet-per-second below the requirements.

2. Metallurgical Examination.

a. Chemical Analyses.

Chemical analyses of the plates are given in Table II.

Samples Nos. 1120-1123 inclusive were the experimental low alloy heats made at Watertown Arsenal. Samples Nos. CV-1, CV-2, CMV-6, CMV-8, 3 and 2 are high nickel-molybdenum and chromium-molybdenum-vanadium steels manufactured by the Henry Disston and Sons, Inc. whereas plates Nos. 14582 and 14932 are low nickel-molybdenum and chromium-molybdenum-vanadium steels furnished by the Ingersoll Steel and Disc Co.

b. Macroscopic Examination.

The macrostructures of the longitudinal and transverse sections after deep etching in hot acid are shown in Figures 5 and 6. Generally speaking, the samples are free from pronounced segregations and with the exception of plates Nos. 14932 and CMV-6 are fairly well cross rolled. A short fine lamination is evident in the longitudinal sections of plates Nos. 1121 and 1122. Also, some decarburization is present on both surfaces of plate No. 3.

c. Microscopic Examination.

Photomicrographs, illustrating the microstructure of the heat treated plates are shown in Figures 8 and 9.

Satisfactory austempered plate had microstructures consisting essentially of bainite resulting from decomposition of austenite between 550°F and 600°F whereas good quality quenched and tempered plate was heat treated to yield tempered martensite.

A description of the several microstructures is given in the following. The microstructure of the brittle plates Nos. 1120-1 and 1122-2 consists of martensite, some ferrite and other intermediate temperature transformation products. The brittle sample No. 1121-2 contains martensite, some ferrite and intermediate temperature transformation products. The presence of martensite in the above mentioned samples resulted from the fact that it was necessary to isothermally treat them at 450°F or the temperature at which austenite partially transforms to martensite in order to maintain a hardness level of 388/400 Brinell which was desired for the entire series of experimental plates.

The quenched and tempered ductile plates Nos. 1120 and 1121 had a microstructure consisting of tempered martensite whereas tempered martensite and high temperature transformation products were present in the brittle plate No. 1122, see Figure 7. The ductile austempered plates Nos. 1123-1 and CV-1 had a microstructure consisting essentially of acicular bainite resulting from a decomposition of austenite between 550°F and 600°F, with evidence of more carbides being present in sample CV-1. Tempered martensite was present in the ductile companion plates Nos. 1123 and CV-2 as quenched and tempered. The brittle plate, CMV-8 contained mixtures of acicular bainite and intermediate temperature transformation products whereas the ductile plate CMV-6 contained uniform tempered martensite, see Figure 8.

The brittle austempered plates Nos. 3 and 14932 contained essentially intermediate temperature transformation products whereas the ductile quenched and tempered plates of the same series Nos. 2 and 14932-1 had a microstructure of tempered martensite. Apparently the banded condition noted in the quenched and tempered plates Nos. 2 and 14932-1 does not result in brittleness under the shock test applied. Plate No. 14582 which was penetrated under the impact of cal. .50 M2 ball ammunition, but showed no evidence of brittleness had a microstructure consisting of carbides in a lamellar configuration and possibly some martensite. The companion plate No. 14582-1 which had a tempered martensitic structure possessed better ballistic properties than the austempered plate.

d. Fracture Tests for Fibre.

The results of the fracture tests for fibre characteristics are given in Table III. The samples which had been quenched and tempered to a tempered martensitic structure all showed a fibrous fracture although the hardness varied from 375-429 Brinell hardness. The satisfactory ballistic samples Nos. CV-1 and 1123-1 austempered to essentially bainite and both having a Brinell hardness of 406, exhibited a silky and fibrous fracture. The balance of the austempered samples showed evidence of crystallinity in the fractures which was associated with poor microstructures and brittleness under the applied shock test. Apparently, bainite structures of the type found in the nickel-molybdenum steel CV, which is the result of the austenite-bainite reaction at about 550-600°F are not associated with brittleness when subjected to the shock tests applied.

e. V-notch Charpy Impact Tests.

The results of the V-notch Charpy Impact Tests are presented in Table IV and also graphically shown in Figure 10. Since these tests were made on a special impact bar, see Figure 1A, Appendix A, these results only serve to indicate a comparison of the impact values of the austempered or quenched and tempered material.

A review of these data shows that the impact values of the quenched and tempered samples tested at 470°F and at -40°F are in general somewhat superior to the values reported on the samples austempered to the same hardness. The two austempered samples Nos. 1123-2-3 and CV1-1, which had good shock resisting properties and also a fairly uniform structure, possessed relatively high impact values.

The austempered samples of the CV series containing 4.9% Ni and .26% Mo not only retained a fairly satisfactory impact value at -40°F in consideration of the hardness involved, but also revealed a silky fracture when broken at this temperature. Since this austempered composition was the only one of the series which did not show crystallinity at -40°F, it is evident that the resulting bainitic structure shown in Figure 8 is not conducive to shock failures.

f. Tensile Tests.

The results of the tensile tests are given in Table V.

A review of these results shows that the ratio of the yield - tensile strength of the austempered plates is relatively low as compared to that of the quenched and tempered plates. This is probably associated with the presence of high and medium temperature transformation products in the material which was previously described.

In a few cases, plates which were brittle under the shock test had a somewhat lower ductility than the ductile plates. On the other hand, no definite inverse correlation was established between ductility in the tensile test and brittleness resulting from shock failures.

g. Brinell Hardness Tests.

The results of the Brinell hardness tests are given in Table V with the exception of plates Nos. 1120-1 and 1120-2. The austempered plates had a range of 388-429 Brinell hardness whereas the quenched and drawn plates were heat treated to 375-429 Brinell.

3. Discussion

Although preliminary austempering treatments made on small sections of the selected low and high alloy steels investigated showed in most cases a nearly complete austenite-bainite transformation with an accompanying hardness of 388-400 Brinell at an austempering temperature at 550-600°F, in many cases, the ballistic test plate failed after the same austempering cycle to possess the same microstructure and similar hardness. This was due in most cases to the inadequate hardenability of the steels. In some cases, high and intermediate temperature transformation products were formed during the quench which resulted in poor metallurgical and ballistic properties. Furthermore since it was desired to heat treat all ballistic plates to a Brinell hardness range of 388-400, it became necessary to isothermally treat three of the low alloy plates Nos. 1120-1, 1121-2 and 1122-3 at 450°F which was in the austenite-martensite temperature range and hence, the explanation of the presence of martensite in these samples.

The austempering of armor plate is not practical since only relatively small samples can be satisfactorily treated. For example, it has been determined[1] that small size samples (4x6x1/2") of Cr-Mo-V steels similar to Nos. CMV-8, 3, 14932, had high ballistic resistance when austempered to a bainite structure and with a Brinell hardness of 444. On the other hand, this same type of steel in sections 10x12x3/8" when austempered under the same conditions and to the same hardness level failed to possess satisfactory shock resistance although the resistance to

1. Watertown Arsenal Laboratory Report No. 710/198(r) "Study of New Methods of Heat Treating Armor Plate, Austempering Delayed Quenching", dated May 1937.

penetration was considerably above the requirements. These larger plates, in all cases, contained some high temperature transformation products.

The two austempered steels which showed promising ballistic and metallurgical properties in this investigation were the 1.95 Ni, .7 Cr, .2 Mo and 4.9 Ni, .2 Mo steels. These steels showed no marked superiority over the quenched and tempered companion plates and therefore, the austempering process is not justified since excessive hardenability is required for the thickness of plates involved.

It has been demonstrated that the fibre test can be applied satisfactorily to light plate heat treated to about 388-429 Brinell hardness.

TABLE I

Austempered and Quenched and Tempered 3/8" Thick Armor Plate

Ballistic Limit .30 APM2		Ballistic Properties — Shock Test: 1 - 3 Rounds Cal. .50 M2 Ball Approximately 2450 F/S Striking Velocity	Ballistic Properties — Shock Test: 1 Round Cal. .50 APM2 Approximately 2450 F/S Striking Velocity	Remarks
Actual	Spec			
1771* 1773)**	1648	Max. Exit Dia. 3/4x5/8" Punchings Max. ht of bulge on back - none	—	Punchings due to low hardness Satisfactory
1725* 1711)	1636	Max. Exit Dia. 7/8x1/2" 2" crack	PTP Exit Dia. 7/8x11/16"	Failed Low BL - Poor Ductility
1743 1768)	1775	PPLB Max. ht of bulge on back 5/16"	PTP Exit Dia. 3/4x9/16"	Satisfactory
1832 1853)	1779	PPLB	—	Satisfactory
1784 1731)	1715	Plate cracked into 2 pieces Max. ht of bulge on back - 1/4"	One Section of Broken plate tested PTP - Plate shattered	Failed
1804 1815)	1719	7" crack thru plate	—	Failed
1745 1710)	1735	Max. Exit Dia. 15/16x1-1/2" Max. ht of bulge on back 3/8"	PTP Exit Dia. 3/4x3/4"	Borderline
1814 1779)	1735	PPLB	—	Satisfactory

etermined in accordance with Spec. AXS-488, Revision 2, machinable homogeneous
accordance with Spec. AXS-488, Revision 2, hard homogeneous armor.
ess of Spec. AXS-488, Revision 2.

TABLE I (CONT'D)

Ballistic Limit Lot .30 APM2 Actual	Ballistic Limit Lot .30 APM2 Spec	Ballistic Properties — Shock Test: 1 - 3 Rounds Cal. .50 M2 Ball Approximately 2450 F/S Striking Velocity	Ballistic Properties — Shock Test: 1 Round Cal. .50 APM2 Approximately 2450 F/S Striking Velocity	Remarks
54 79)	1743	2x2-1/2" spall. Right hand corner of plate broken off. Max. ht of bulge on back - none	PTP 1-15/16x1" B.S.	Failed Low BL - Poor Ductility
52 4)	1763	5" crack thru plate	—	Failed Low BL - Poor Ductility
50 5)	1755	13/16x1-1/8" B.S. Cracks Max. ht of bulge on back 5/16"	PTP 1-11/16x1-9/16"	Failed Low BL - Poor Ductility
35 27)	1798	PPLB	—	Satisfactory
17 70)	1687	PPLB Max. ht of bulge on back 5/16"	—	Satisfactory
30 39)	1731	PPLB	PTP Exit Dia. 7/8x1/2"	Satisfactory
13 36)	1707	PPLB Max. ht of bulge on back 3/8"	PTP Exit Dia. 1/2x7/16"	Satisfactory
2 5)	1667	PPLB	—	Satisfactory
4)	1743	PPLB Max. ht of bulge on back 3/8"	PTP Exit Dia. 1/2x1/2"	Satisfactory
9)	1711	PPLB Max. ht of bulge on back 5/16"	Exit Dia. 3/8x3/8"	Satisfactory

TABLE I (CONT'D)

Plate No.	Thickness inches	Type Analysis				Heat Treatment	BHN	Ballistic Properties: Ballistic Limit Cal. .30 APM2 Actual	Ballistic Properties: Ballistic Limit Cal. .30 APM2 Spec	Ballistic Properties: Shock Test: 1 - 3 Rounds Cal. .50 M2 Ball Approximately 2450 F/S Striking Velocity	Ballistic Properties: Shock Test: 1 Round Cal. .50 APM2 Approximately 2450 F/S Striking Velocity	Remarks
14582	.377	C .47	Ni 1.3		Mo .4	Austemper	388	1723 (-60)	1783	PTP Max. Exit Dia. 5/8x5/8"	PTP 3/8x3/8"	Failed - Low B.L. Satisfactory Ductility
14582-1	.375	"	"		"	Quench and Temper	375	1801	1775	PPMB Max. ht of bulge on back 3/16"	PTP 3/8x3/8"	Satisfactory
CMV-6	.380	C .45	Cr 1.2	Mo .6	V .3	Austemper	415	—	—	Plate broke into 4 pieces	—	Failed - Poor Ductility
CMV-6	.370	"	"	"	"	Quench and Temper	388	1877 (+22)	1755	PPLB Max. ht of bulge on back 1/4"	PTP 1/2x7/16"	Satisfactory
3	.395	C .44	Cr 1.2	Mo .6	V .3	Austemper	401	1858 (+7)	1851	PPLB Max. ht of bulge on back 3/16"	PTP 1/2x7/8" 1-1/2" crack to Cal. .30 round	Borderline
2	.402	.45	1.2	.6	.3	Quench and Temper	388	1926 (+49)	1877	PPLB Max. ht of bulge on back 1/8"	PTP 7/16x7/16"	Satisfactory
14932	.383	C .5	Cr 1.2	Mo .9	V .2	Austempered	415	1838 (+33)	1805	Plate broke into 2 pieces Max. ht of bulge on back - none.	PTP 3/8x3/8"	Failed
14932-1	.373	"	"	"	"	Quench and Temper		1834 (+71)	1763	PPMB Max. ht of bulge on back 1/4"	PTP 3/8x3/8"	Satisfactory

TABLE II

Chemical Analyses

Sample No.	Type	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	B
1120	Cr-Mo	.36	.69	.37	.022	.010	-	1.03	.33	-	-	-
1121	Cr-Mo	.35	.71	.47	.021	.010	-	.86	.22	-	-	-
1122	Mn-Mo	.33	1.60	.31	.022	.010	-	-	.33	-	-	-
1123	Ni-Cr-Mo	.32	.66	.31	.021	.010	1.95	.68	.22	-	-	-
CV-1	Ni-Mo	.22	.45	.24	.015	.015	4.81	.07	.26	.08	-	-
CV-2	Ni-Mo	.22	.45	.24	.015	.015	4.81	.07	.26	.08	-	-
14582	Ni-Mo	.47	.46	.16	.016	.018	1.31	-	.40	-	-	-
CMV-6	Cr-Mo-V	.46	.72	.19	.013	.022	.17	1.15	.60	.30	.105	.0011
CMV-8	Cr-Mo-V	.46	.72	.19	.013	.022	.17	1.15	.60	.30	.105	.0011
2	Cr-Mo-V	.45	.67	.18	.015	.018	Trace	1.16	.56	.26	.04	.001
3	Cr-Mo-V	.44	.78	.31	.017	.017	Trace	1.18	.64	.30	.06	Trace
14932	Cr-Mo-V	.52	.60	.21	.012	.012	-	1.24	.91	.24	-	-

TABLE III

Fibre Characteristics

Sample No.	Type Analysis	Heat Treatments	BHN	Fracture	Behavior Under Shock Test
1120-1	C .36 Cr 1.0 Mo .3	Austemper	331	Crystalline	Punchings, No cracking
1120-2	"	"	315	"	Failed
1120	C .35 Cr .9 Mo .2	Quench & Temper	388	Fibrous	Satisfactory
1120-3	"	" "	388	"	"
1121-1	C .35 Cr .9 Mo .2	Austemper	401	Crystalline	Failed
1121-2	"	"	401	"	"
1121	"	Quench & Temper	388	Fibrous	Borderline
1121-3	"	" "	401	"	Satisfactory
1122-1	C .33 Mn 1.6 Mo .3	Austemper	429	Crystalline	Failed
1122-2	"	"	420	"	"
1122	"	Quench & Temper	375	Fine Crystalline	"
1122-3	"	" "	429	Fibrous	Satisfactory
1123-1	C .32 Ni 1.95 Cr .7 Mo .2	Austemper	406	Silky	Satisfactory
1123-2	"	"	429	"	"
1123	"	Quench & Temper	388	Fibrous	"
1123-3	"	" "	379	"	"
CV-1	C .22 Ni 4.9 Mo .26	Austemper	406	Fibrous	Satisfactory
CV-2	"	Quench & Temper	379	"	"

TABLE III (CONT'D)

Sample No.	Type Analysis				Heat Treatments	BHN	Fracture	Behavior Under Shock Test
14582	C .47	Ni 1.3		Mo .4	Austemper	415	Fine Crystalline	Punchings, No cracking
14582-1	"	"		"	Quench & Temper	388	Fibrous	Satisfactory
CMV-8	C .46	Cr 1.2	Mo .6	V .3	Austemper	415	Crystalline	Failed
CMV-6	"	"	"	"	Quench & Temper	388	Fibrous	Satisfactory
3	C .44	Cr 1.2	Mo .6	V .3	Austemper	415	Fine Crystalline	Borderline
2	.45	"	"	"	Quench & Temper	388	Fibrous	Satisfactory
14932	C .5	Cr 1.2	Mo .9	V .2	Austemper	415	Fine Crystalline	Failed
14932-1	"	"	"	"	Quench & Temper	388	Fibrous	Satisfactory

TABLE IV

Results of V-Notch Charpy Impact Tests

(.360x.394" notched bar)

Sample No.	Type Analysis C	Cr	Mo	Direction	Heat Treatment	BHN	Temp. of Test	V-Notch Charpy Impact Value Ft./Lbs.	Description of Fracture (V-notch Test Bar)	Performance of Plate under Shock Test
1120-2-3	.36	1.0	.3	Long.	Austemper	315	+70°F	29.0	Bright Crystalline	
1120-2-1	"	"	"	Trans.	"	"	+70°F	15.5	" "	Failed
1120-2-4	"	"	"	Long.	"	"	-40°F	13.1	" "	(Brittle)
1120-2-3	"	"	"	Trans.	"	"	-40°F	16.1	" "	
1120-3	"	"	"	Long.	Quench & Temper	388	+70°F	22.2	Fibrous	
1120-1	"	"	"	Trans.	" "	"	+70°F	21.5	"	
1120-4	"	"	"	Long.	" "	"	-40°F	19.4	Fibrous matrix with spots of crystallinity	Satisfactory
1120-2	"	"	"	Trans.	" "	"	-40°F	16.6	"	
	C	Cr	Mo							
1121-1-3	.35	.9	.2	Long.	Austemper	401	+70°F	14.0	Bright Crystalline	
1121-1-1	"	"	"	Trans.	"	"	+70°F	9.4	" "	Failed
1121-1-4	"	"	"	Long.	"	"	-40°F	8.9	" "	(Brittle)
1121-1-2	"	"	"	Trans.	"	"	-40°F	8.3	" "	
1121-3	"	"	"	Long.	Quench & Temper	388	+70°F	23.6	Fibrous	
1121-1	"	"	"	Trans.	" "	"	+70°F	20.1	"	
1121-4	"	"	"	Long.	" "	"	-40°F	16.2	Fibrous matrix with spots of crystallinity	Borderline
1121-2	"	"	"	Trans.	" "	"	-40°F	16.2	"	

TABLE IV (CONT'D)

Sample No.	Type Analysis				Direction	Heat Treatment	BHN	Temp. of Test	V-Notch Charpy Impact Value Ft./Lbs.	Description of Fracture (V-notch Test Bar)	Performance of Plate under Shock Test
	C	Mn		Mo							
1122-1-1	.33	1.6		.3	Long.	Austemper	429	+70°F	17.5	Bright Crystalline	
1122-1-2	"	"		"	Trans.	"	"	+70°F	14.2	" "	Failed
1122-1-2	"	"		"	Long.	"	"	-40°F	13.1	" "	(Brittle)
1122-1-4	"	"		"	Trans.	"	"	-40°F	12.4	" "	
1122-1	"	"		"	Long.	Quench & Temper	375	+70°F	25.5	Fibrous matrix with spots of crystallinity	
1122-3	"	"		"	Trans.	" "	"	+70°F	22.2	"	Failed
1122-2	"	"		"	Long.	" "	"	-40°F	19.4	"	(Brittle)
1122-4	"	"		"	Trans.	" "	"	-40°F	16.9	"	
	C	Ni	Cr	Mo							
1123-2-3	.32	1.95	.7	.2	Long.	Austemper	429	+70°F	23.6	Silky	
1123-2-1	"	"	"	"	Trans.	"	"	+70°F	13.0	"	
1123-2-4	"	"	"	"	Long.	"	"	-40°F	18.1	Dull Crystalline	Satisfactory
1123-2-2	"	"	"	"	Trans.	"	"	-40°F	14.4	" "	
1123-1	"	"	"	"	Long.	Quench & Temper	388	+70°F	24.0	Fibrous	
1123-3	"	"	"	"	Trans.	" "	"	+70°F	14.2	"	
1123-2	"	"	"	"	Long.	" "	"	-40°F	25.8	"	Satisfactory
1123-4	"	"	"	"	Trans.	" "	"	-40°F	12.5	"	
	C	Ni		Mo							
CV1-1	.22	4.9		.26	Long.	Austemper	406	+70°F	25.8	Silky	
CV1-2	"	"		"	Trans.	"	"	+70°F	17.5	"	
CV1-3	"	"		"	Long.	"	"	-40°F	18.5	"	Satisfactory
CV1-4	"	"		"	Trans.	"	"	-40°F	15.5	"	

TABLE IV (CONT'D)

Sample No.	Type Analysis				Direction	Heat Treatment	BHN	Temp. of Test	V-Notch Charpy Impact Value Ft./Lbs.	Description of Fracture (V-notch Test Bar)	Performance of Plate under Shock Test
	C	Ni		Mo							
CV2-1	.22	4.9		.26	Long.	Quench & Temper	379	+70°F	24.5	Fibrous	
CV2-2	"	"		"	Trans.	" "	"	+70°F	23.4	"	Satisfactory
CV2-3	"	"		"	Long.	" "	"	-40°F	21.6	"	
CV2-4	"	"		"	Trans.	" "	"	-40°F	19.3	"	
	C	Cr	Mo	V							
CMV8-1	.46	1.2	.6	.3	Long.	Austemper	415	+70°F	16.6	Bright Fine Crystalline	
CMV8-2	"	"	"	"	Trans.	"	"	+70°F	11.5	"	Failed
CMV8-3	"	"	"	"	Long.	"	"	-40°F	10.0	"	(Brittle)
CMV8-4	"	"	"	"	Trans.	"	"	-40°F	6.0	"	
CMV6-1	"	"	"	"	Long.	Quench & Temper	388	+70°F	29.5	Fibrous	
CMV6-2	"	"	"	"	Trans.	" "	"	+70°F	20.7	"	Satisfactory
CMV6-3	"	"	"	"	Long.	" "	"	-40°F	22.2	"	
CMV6-4	"	"	"	"	Trans.	" "	"	-40°F	16.8	"	
	C	Cr	Mo	V							
3-1	.44	1.2	.6	.3	Long.	Austemper	401	+70°F	18.1	Bright Fine Crystalline	
3-3	"	"	"	"	Trans.	"	"	+70°F	15.7	"	
3-2	"	"	"	"	Long.	"	"	-40°F	14.2	"	Borderline
3-4	"	"	"	"	Trans.	"	"	-40°F	14.2		
	C	Cr	Mo	V							
2-3	.45	1.2	.6	.3	Long.	Quench & Temper	388	+70°F	24.3	Fibrous	
2-1	"	"	"	"	Trans.	" "	"	+70°F	19.8	"	
2-4	"	"	"	"	Long.	" "	"	-40°F	22.2	"	Satisfactory
2-2	"	"	"	"	Trans.	" "	"	-40°F	18.3	"	

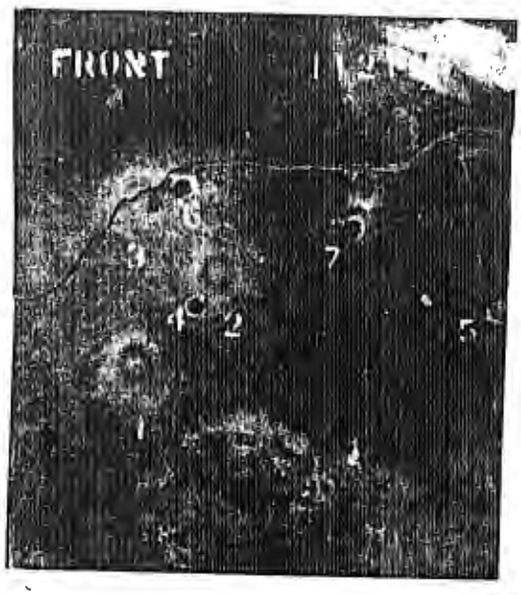
TABLE V

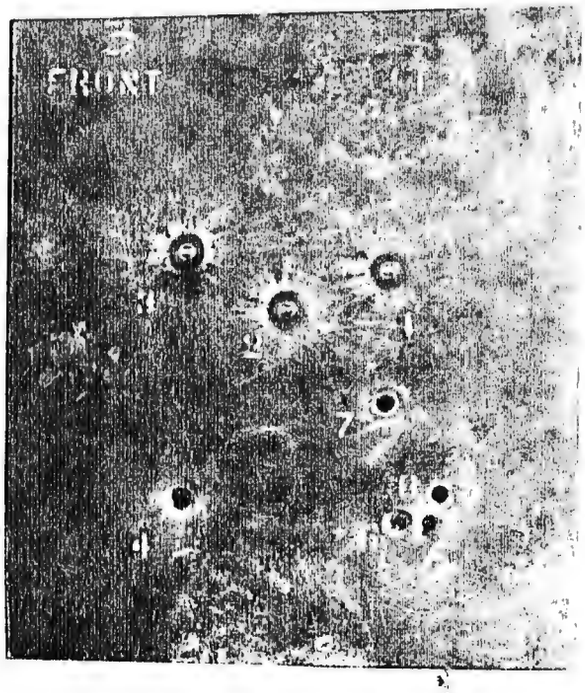
Tensile Tests of Experimentally Heat Treated 3/8" Thick Armor Plate

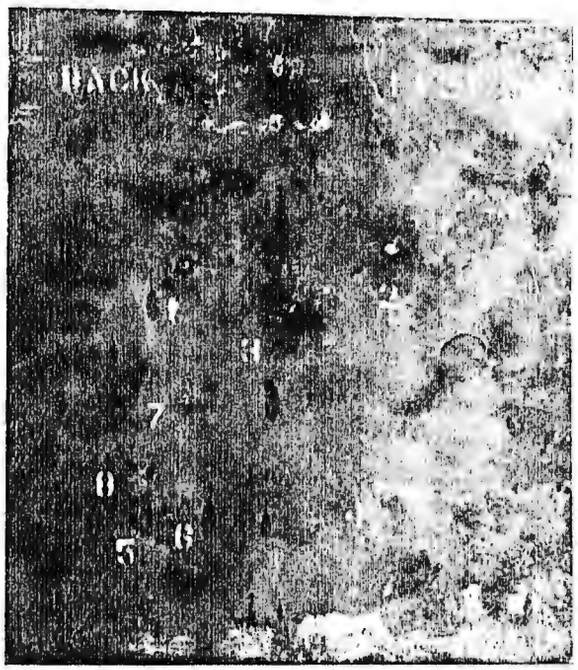
Plate No.	Type Analysis	Direction of Test	Heat Treatment	BHN	Y. S. .1% Set Lbs./Sq.In.	T. S. Lbs./Sq.In.	% Elon.	% Red. Area	Performance Under Shock Test
	C Cr Mo								
1120-1	.36 1.0 .3	Long.	Austemper	331	110,000	160,900	13.5	51.4	Satisfactory
1120-1	" " "	Trans.	"		119,000	163,200	13.0	49.2	
1120	" " "	Long.	Quench & Temper	388	173,000	186,700	11.0	50.1	Satisfactory
1120	" " "	Trans.	" "		179,000	198,800	9.5	42.2	
	C Cr Mo								
1121-1	.35 .9 .2	Long.	Austemper	401	140,000	222,900	10.0	40.1	Failed
1121-1	" " "	Trans.	"		127,000	202,500	9.8	39.2	
1121	" " "	Long.	Quench & Temper	388	172,000	191,500	11.0	50.6	Borderline
1121	" " "	Trans.	" "		178,000	195,000	9.0	44.0	
	C Mn Mo								
1122-1	.33 1.6 .3	Long.	Austemper	429	119,500	212,000	9.5	37.2	Failed
1122-1	" " "	Trans.	"		147,400	208,000	6.5	33.6	
1122	" " "	Long.	Quench & Temper	375	167,000	184,200	11.0	49.0	Failed
1122	" " "	Trans.	" "		165,500	182,600	9.5	44.6	
	C Ni Cr Mo								
1123-2	.32 1.95 .7 .2	Long.	Austemper	429	151,500	202,800	12.5	53.1	Satisfactory
1123-2	" " " "	Trans.	"		138,500	192,100	8.5	40.2	
1123	" " " "	Long.	Quench & Temper	388	168,500	184,000	10.0	49.8	Satisfactory
1123	" " " "	Trans.	" "		178,500	192,600	9.0	41.3	
	C Ni Mo								
CV-1	.22 4.9 .26	Long.	Austemper	406	152,000	193,300	11.5	52.2	Satisfactory
CV-1	" " "	Trans.	"		164,000	199,800	10.0	52.0	
CV-2	" " "	Long.	Quench & Temper	379	173,000	182,200	10.0	48.6	Satisfactory
CV-2	" " "	Trans.	" "		172,500	182,200	10.0	47.2	

TABLE V (CONT'D)

Plate No.	Type Analysis				Direction of Test	Heat Treatment	BHN	Y. S. .1% Set Lbs./Sq.In.	T. S. Lbs./Sq.In.	% Elon.	% Red. Area	Performance Under Shock Test
	C	Ni	Mo									
14582	.47	1.3	.4		Long.	Austemper	388	164,000	214,000	12.5	39.8	Satisfactory
14582	"	"	"		Trans.	"		163,000	214,000	12.5	37.2	
14582-1	"	"	"		Long.	Quench & Temper	375	181,000	193,200	17.5	52.0	Satisfactory
14582-1	"	"	"		Trans.	" "		177,000	188,000	12.5	42.8	
	C	Cr	Mo	V								
CMV-8	.46	1.2	.6	.3	Long.	Austemper	415	154,000	200,000	10.0	42.4	Failed
CMV-8	"	"	"	"	Trans.	"		152,000	200,000	10.0	38.6	
CMV-6	"	"	"	"	Long.	Quench & Temper	388	180,000	189,400	11.0	47.0	Satisfactory
CMV-6	"	"	"	"	Trans.	" "		185,000	194,300	10.0	37.8	
	C	Cr	Mo	V								
3	.44	1.2	.6	.3	Long.	Austemper	401	142,000	194,000	13.0	50.4	Borderline
3	"	"	"	"	Trans.	"		154,000	196,400	11.0	42.4	
2	.45	1.2	.6	.3	Long.	Quench & Temper	388	194,000	206,800	12.0	43.4	Satisfactory
2	"	"	"	"	Trans.	" "		196,000	206,400	11.0	41.6	
	C	Cr	Mo	V								
14932	.5	1.2	.9	.2	Long.	Austemper	415	164,000	214,200	12.5	39.8	Failed
14932	"	"	"	"	Trans.	"		163,000	214,000	12.5	37.2	
14932-1	"	"	"	"	Long.	Quench & Temper	388	181,000	193,200	17.5	52.0	Satisfactory
14932-1	"	"	"	"	Trans.	" "		177,000	188,000	12.5	42.8	





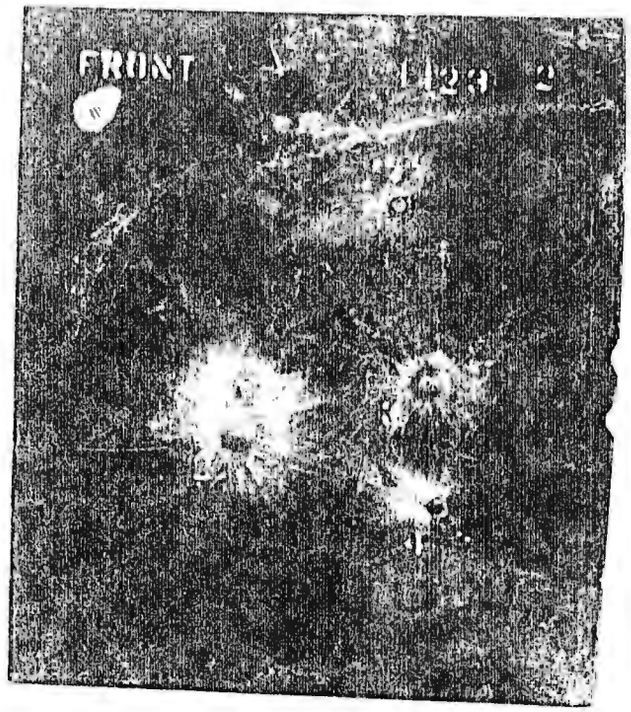


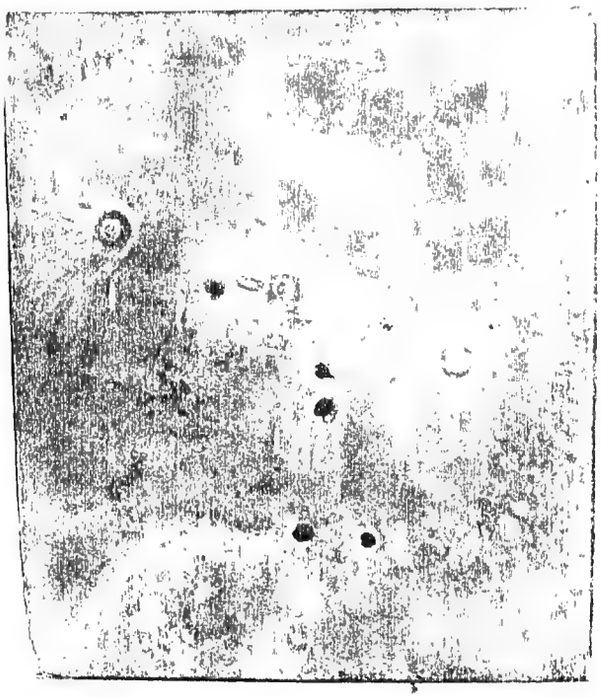
C .35 MN .71 P .010 S .021 SI .47 CR .86 MO .22

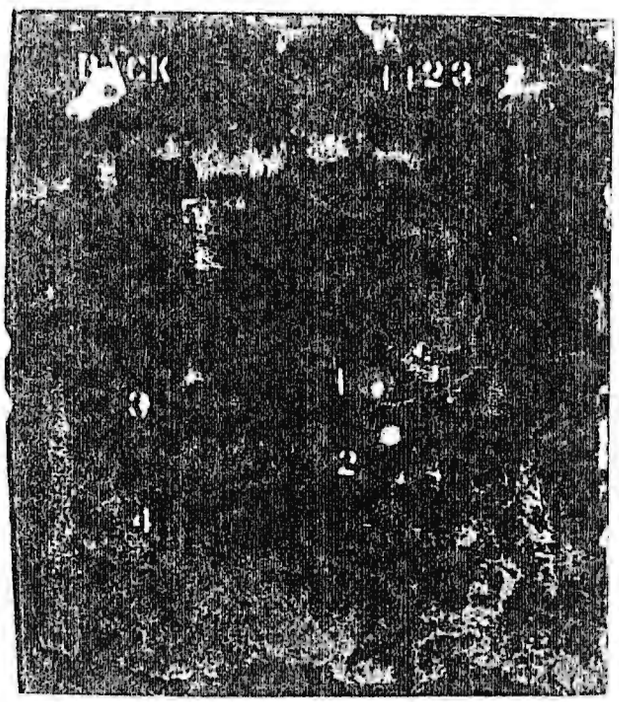
AUSTEMPERED QUENCHED & DRAWN

BALLISTIC TESTS OF AUSTEMPERED & QUENCHED AND DRAWN 3/8" THICK HARD HOMOGENEOUS PLATES. 21 DECEMBER 1943 WTN.710-2226

FIGURE





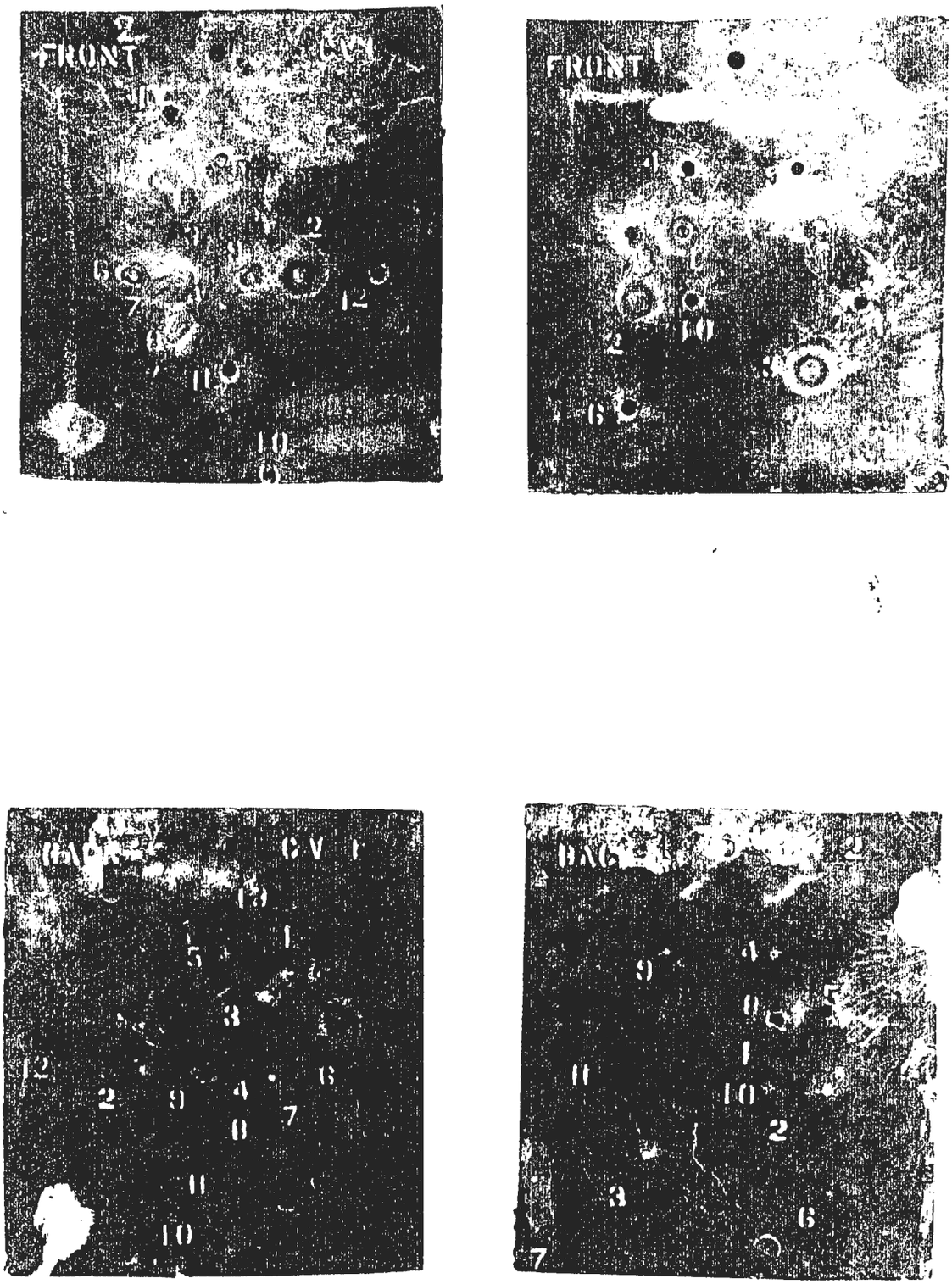


C.32 MN.66 P.010 S.021 SI.31 NI 1.95 CR.68 MO.22

AUSTEMPERED QUENCHED & DRAWN

BALLISTIC TESTS OF AUSTEMPERED AND QUENCHED & DRAWN 3/8" THICK HARD HOMOGENEOUS PLATES. 21 DECEMBER 1943 WTN.710-2228

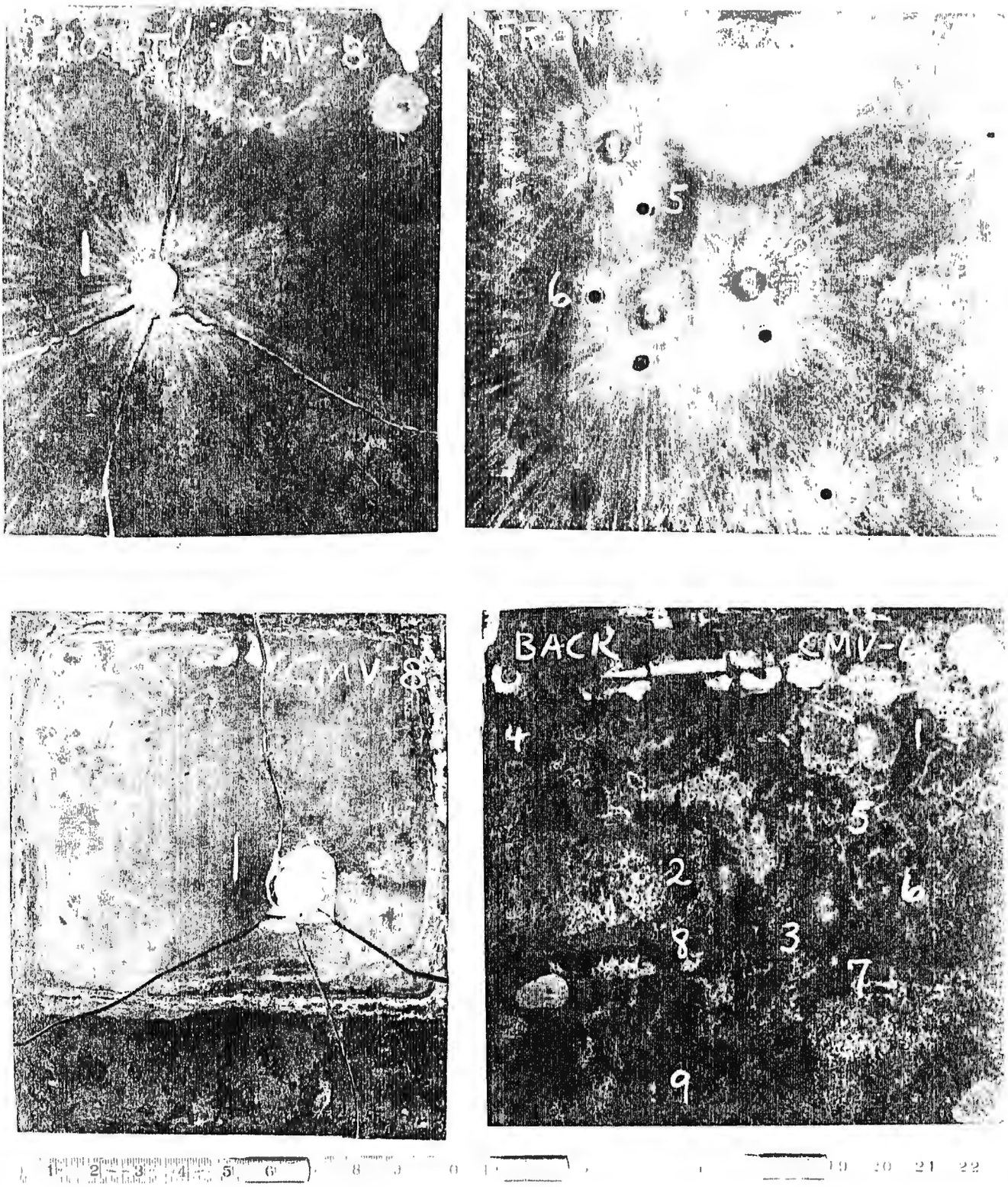
FIG. 1



C.22, MN.45, P.015, S.015, SI.24, NI 4.81, MO.26, CR.07, V.08,
AUSTEMPERED QUENCHED & DRAWN

BALLISTIC TESTS OF AUSTEMPERED AND QUENCHED & DRAWN 3/8" THICK HARD HOMOGENEOUS ARMOR. 21 DECEMBER 1943 WTN.710-2229

FIGURE



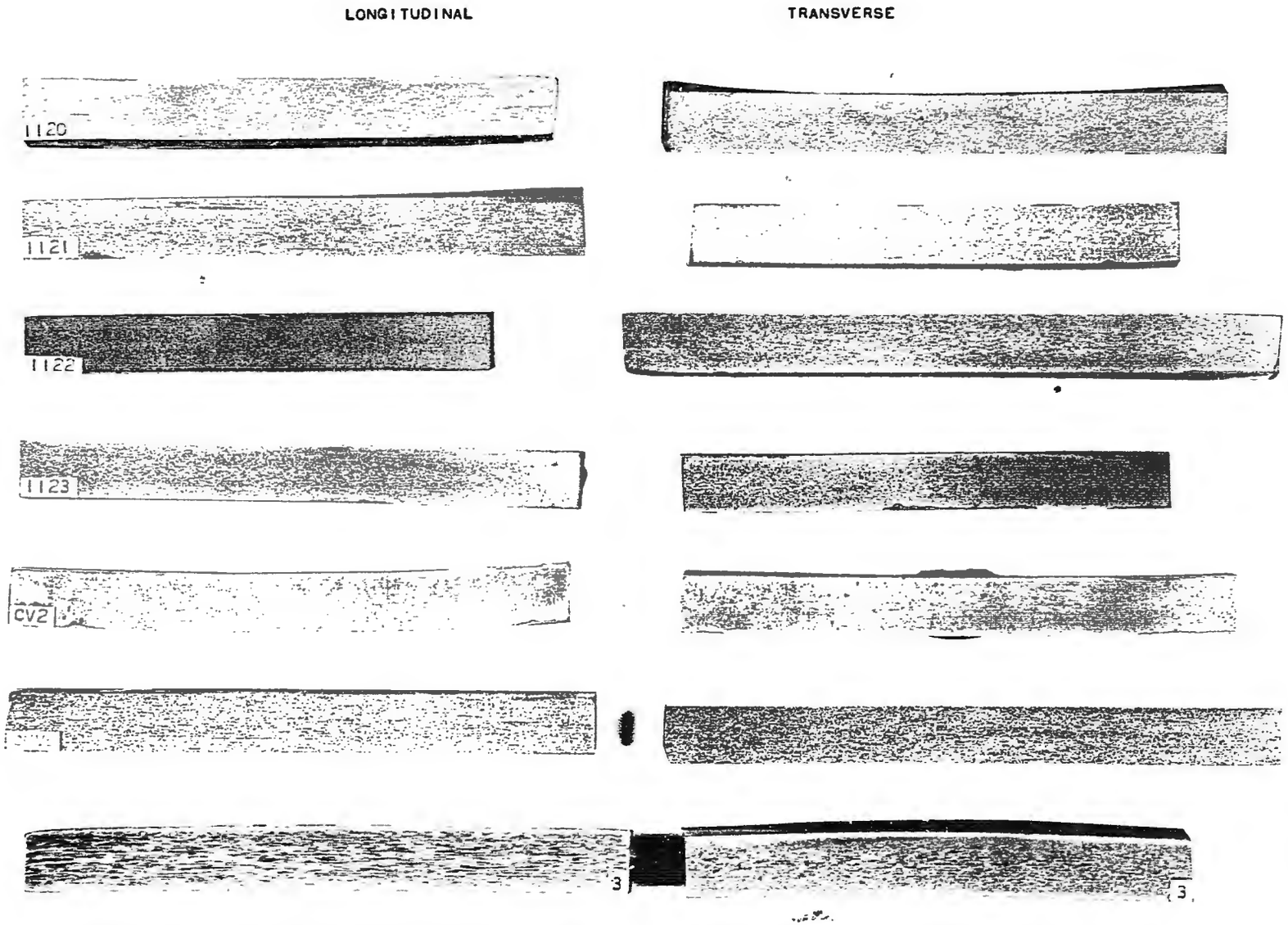
C.46 MN.72 SI .19 S.013 P.022 NI .17 CR 1.15 MO.60 V.30 CU .105 B.0011

AUSTEMPERED QUENCHED & DRAWN

BALLISTIC TESTS OF AUSTEMPERED AND QUENCHED & DRAWN 3/8" THICK HARD HEMOGENEOUS PLATES

8 JANUARY 1944 WTN.710-2243

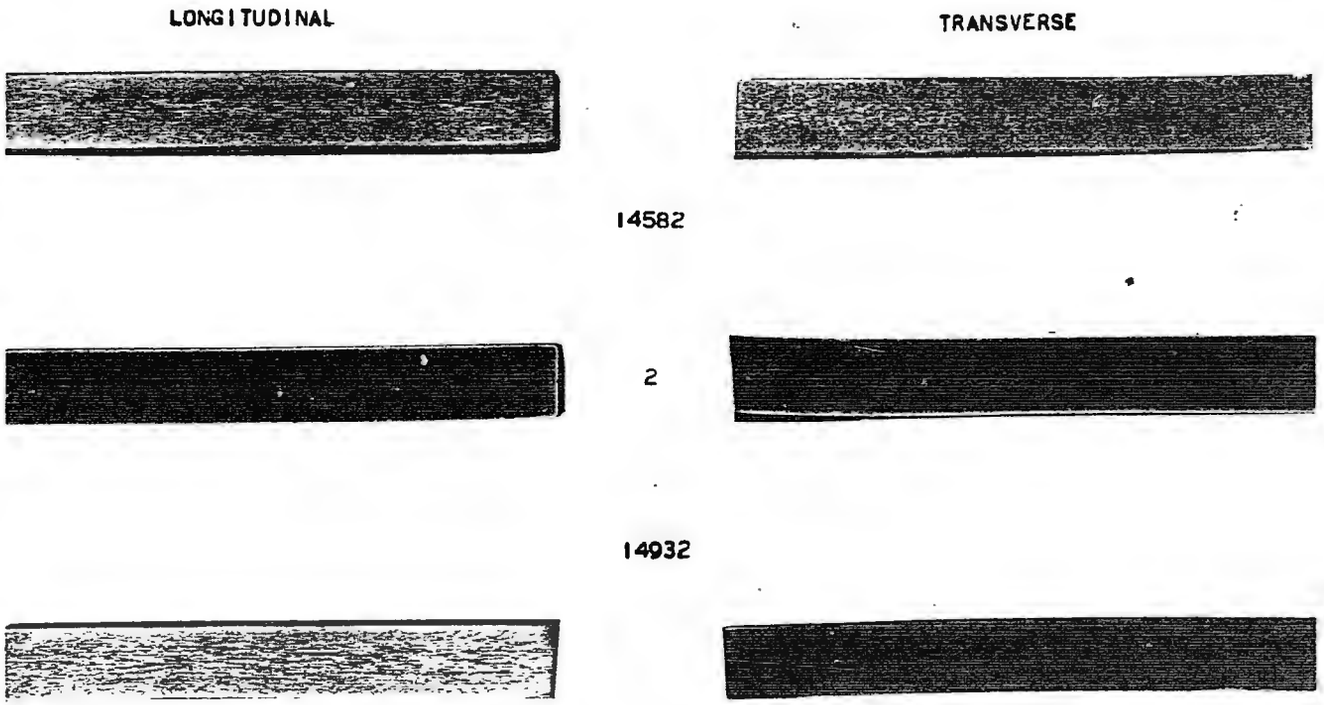
FIGURE



WATERTOWN ARSENAL

MACRO STRUCTURE OF 3/8" THICK PLATE
22 JAN 1944 WTN.710-2251
MAG. IX

FIGURE 5



ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

MACROSTRUCTURE OF 3/8" THICK PLATE.
15 MAY 1944 WTN.710-2305

FIGURE 6

Microstructure of Austempered or Quenched and Tempered 3/8" Thick Plates

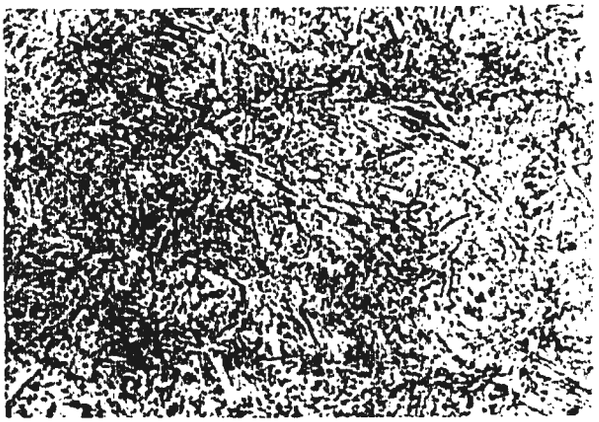
Austempered

No. 1120-1
Martensite, ferrite and intermediate temperature transformation products.

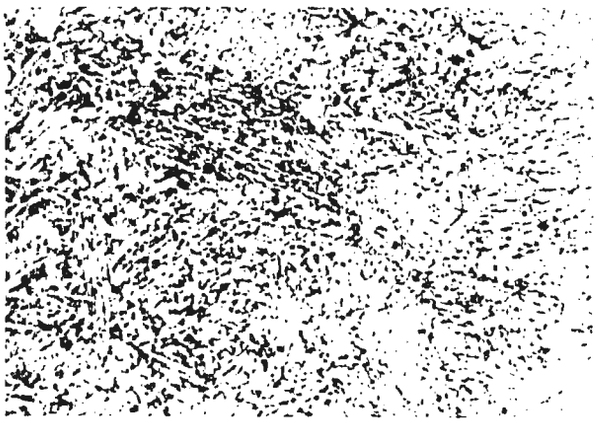
No. 1121-2
Martensite, ferrite and intermediate temperature transformation products.

No. 1122-2
Martensite, ferrite and intermediate temperature transformation products.

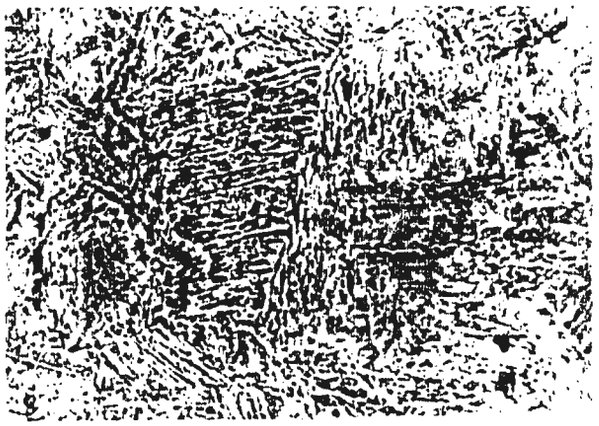
Quenched and Tempered



No. 1120
Tempered martensite.



No. 1121
Tempered martensite.



No. 1122
Tempered martensite and intermediate temperature transformation products.

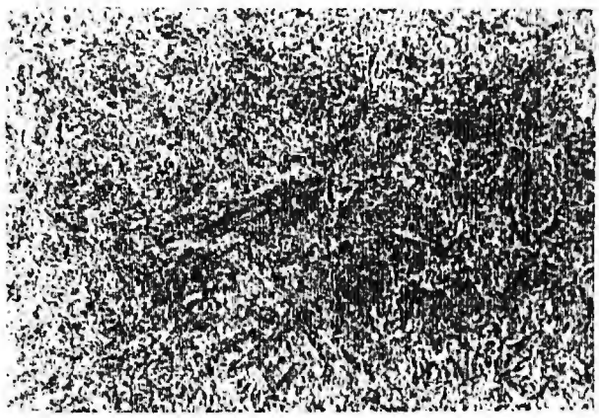
Photomicrographs taken at X1000, Samples Etched in Picral

FIGURE 7

WIN.639-6972

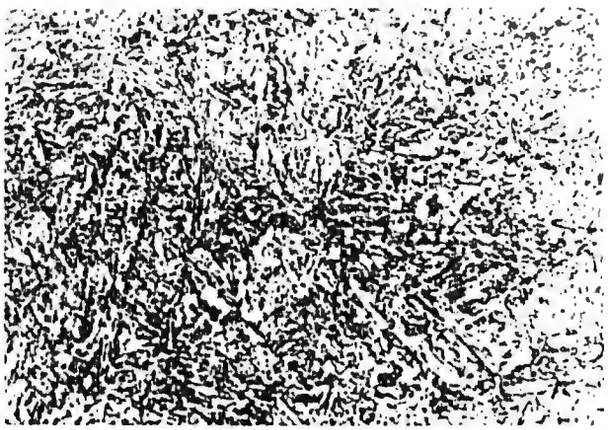
Microstructure of Austempered or Quenched and Tempered 3/8" Thick Plates

Austempered

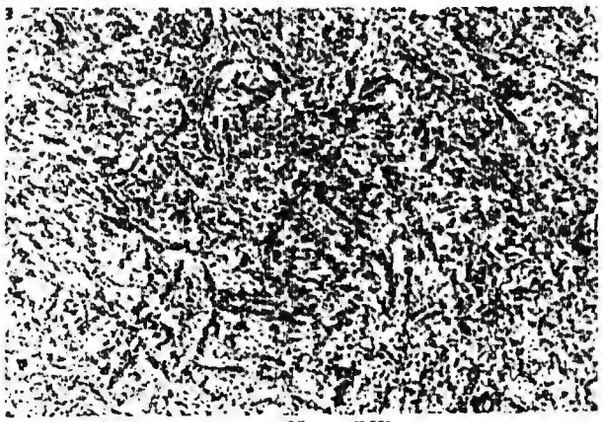


No. 1123-1
Uniform isothermally transformed structure.

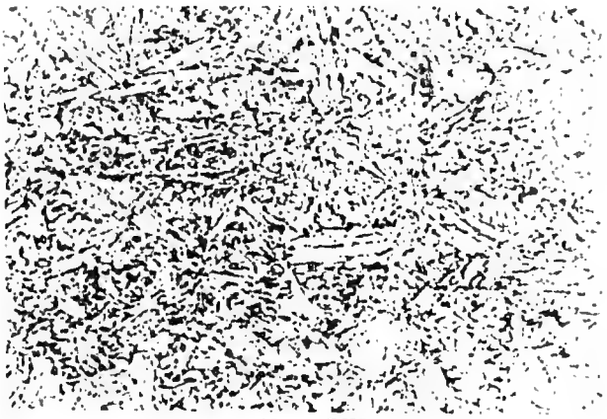
Quenched and Tempered



No. 1123
Tempered martensite.

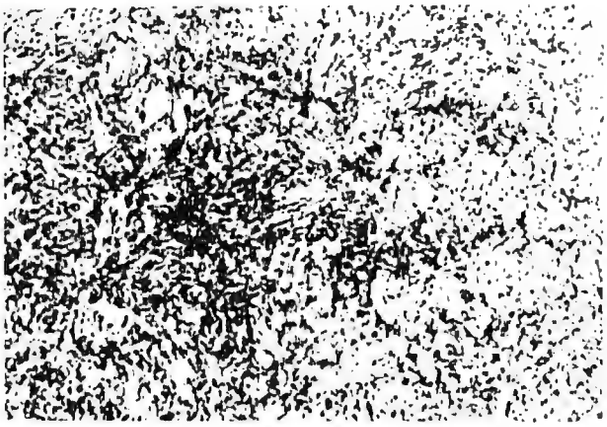


No. CV1
Uniform isothermally transformed structure.



No. CV2
Tempered martensite.

No. 14582
Fine carbides in lamellar configuration and some areas of martensite.



No. 14582-1
Tempered martensite.

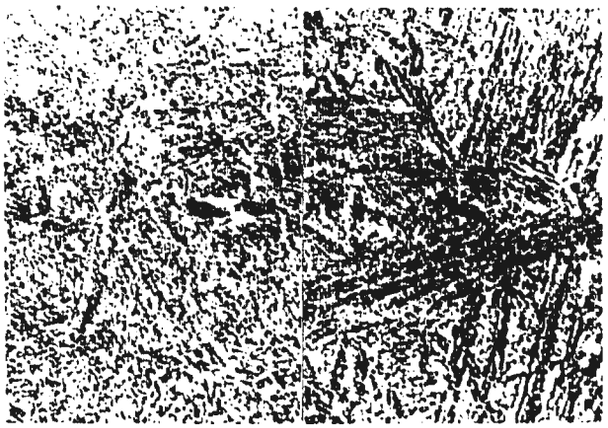
Photomicrographs taken at X1000, Samples Etched in Picral

FIGURE 8.

WTN.639-6073

Microstructure of Austempered or Quenched and Tempered 3/8" Thick Plates

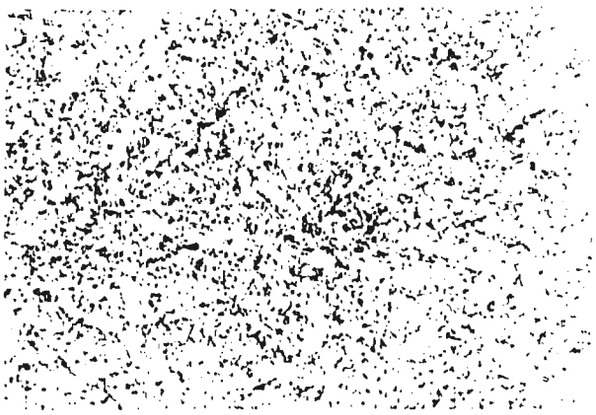
Austempered



No. CMV-8

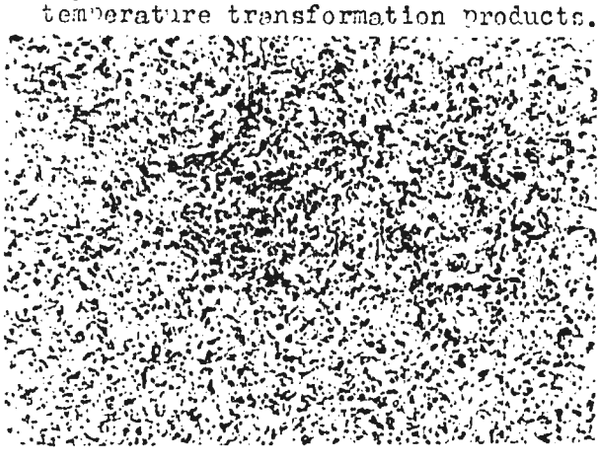
Mixtures of bainite and intermediate temperature transformation products.

Quenched and Tempered



No. CMV-6

Tempered martensite.

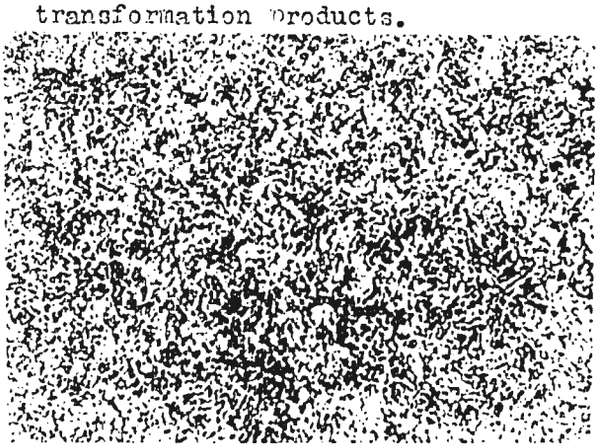


No. 3

Essentially intermediate temperature transformation products.

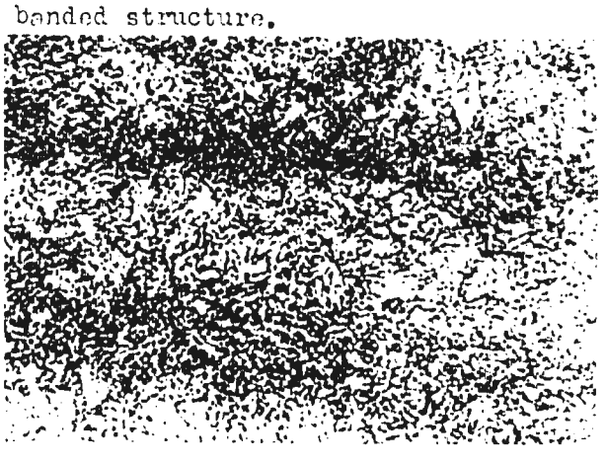
No. 2

Tempered martensite and carbides - banded structure.



No. 14932

Essentially intermediate temperature transformation products.



No. 14932-1

Tempered martensite - banded structure.

Photomicrographs taken at X1000, Samples Etched in Picral

FIGURE 3.

WIN.639-6974

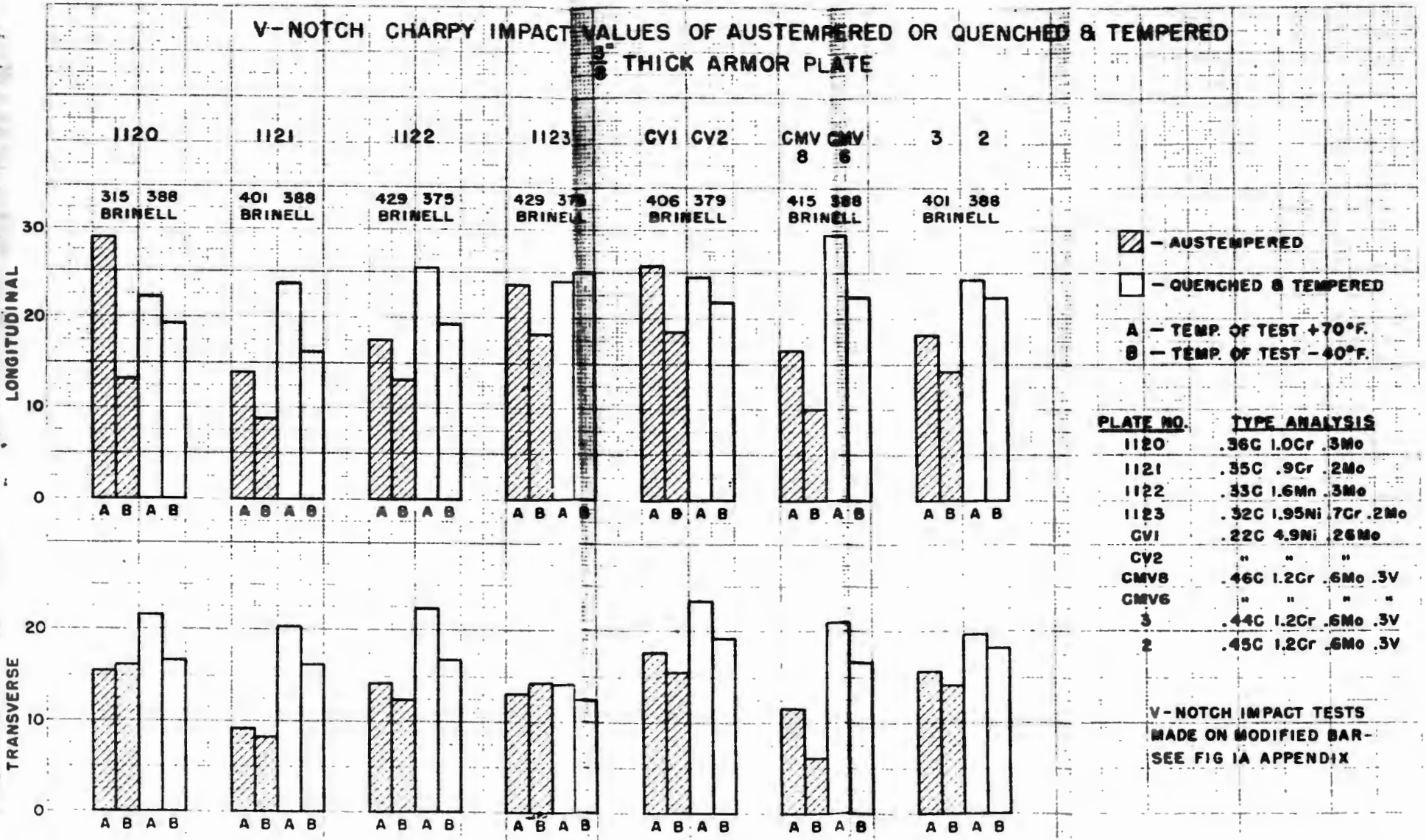

V-NOTCH CHARPY IMPACT VALUES OF AUSTEMPERED OR QUENCHED & TEMPERED
2" THICK ARMOR PLATE
1120
1121
1122
1123
CV1
CV2
CMV 8
CMV 6
3
2
315 388 BRINELL
401 388 BRINELL
429 375 BRINELL
429 379 BRINELL
406 379 BRINELL
415 388 BRINELL
401 388 BRINELL
V-NOTCH IMPACT FOOT-POUNDS LONGITUDINAL
V-NOTCH IMPACT FOOT-POUNDS TRANSVERSE
30
20
10
0
A B A B
AUSTEMPERED
QUENCHED & TEMPERED
A — TEMP. OF TEST +70°F.
B — TEMP. OF TEST -40°F.
PLATE NO. TYPE ANALYSIS
1120 .36C 1.0Cr .3Mo
1121 .35C .9Cr .2Mo
1122 .33C 1.6Mn .3Mo
1123 .32C 1.95Ni .7Cr .2Mo
CV1 .22C 4.9Ni .26Mo
CV2 " " "
CMV8 .46C 1.2Cr .6Mo .3V
CMV6 " " " "
3 .44C 1.2Cr .6Mo .3V
2 .45C 1.2Cr .6Mo .3V
V-NOTCH IMPACT TESTS MADE ON MODIFIED BAR- SEE FIG IA APPENDIX

FIGURE 10

APPENDIX A

Sketch of Modified V-Notch Charpy Bar,
Fabrication of Experimental Armor Plates,
Heat Treatments of 3/8" Thick Armor Plate,
and Ballistic Data

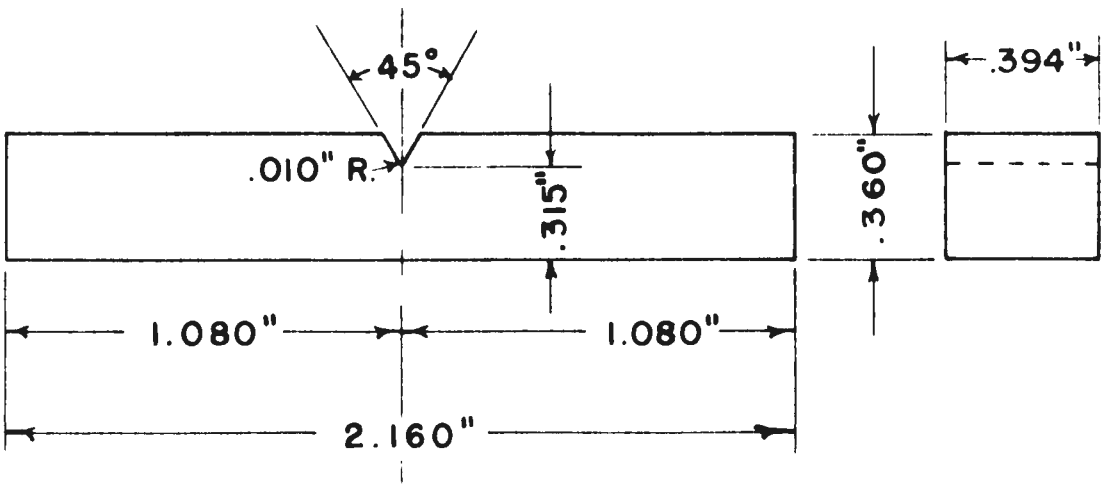


FIG. 1A

MODIFIED V-NOTCH CHARPY BAR

SCALE: $\frac{2}{1}$

Fabrication of Experimental Armor Plates

1. Steel Making Practice

The four experimental heats were made at Watertown Arsenal in an induction acid lined furnace and cast in the form of 800-lb. ingots, measuring 6" x 12" x 36" including the hot top. The heats were aluminum killed (aluminum 1 lb./ton).

2. Rolling of Ingots

The ingots were slabbed and cross rolled into 3/8" thick plate at the plant of the Simonds Saw and Steel Company.

3. Heat Treatment of Plates

The preliminary austempering treatments were determined on 1/4" x 1/4" x 1" samples of the compositions listed in Table I. The austempering cycle was determined which resulted in an austenite-bainite reaction varying from 90-100% complete. It was noted that due to insufficient hardenability of several of the steels investigated that high and intermediate temperature transformation products were retained after quenching from the austenitizing temperature.

TABLE I-A

Heat Treatments of 3/8" Thick Armor Plate

Plate No.	Type Analysis				Heat Treatment	Aust. Temp.	Time at Temp.	Austempering Temp. (Salt Bath)	Time in Salt Bath	Coolant	BHN
1120-1	C .36	Cr 1.0	Mo .3		Austemper	1600°F	1-1/4 hrs.	450°F	15 min.	Water	331
1120-2	"	"	"		"	"	"	"	30 min.	"	315
*1120	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	388
					Temper	850°F	2 hrs.				
*1120-3	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	388
					Temper	700°F	2 hrs.				
1121-1	C .35	Cr .9	Mo .2		Austemper	1600°F	1-1/4 hrs.	450°F	1 hr.	Water	401
1121-2	"	"	"		"	"	"	"	½ hr.	"	401
*1121	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	388
					Temper	850°F	2 hrs.			"	
*1121-3	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	401
					Temper	700°F	2 hrs.			"	
1122-1	C .33	Mn 1.6	Mo .3		Austemper	1600°F	1-1/4 hrs.	450°F	30 min.	Water	429
1122-2	"	"	"		"	"	"	"	15 min.	"	420
*1122	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	375
					Temper	850°F	2 hrs.			"	
*1122-3	"	"	"		Quench	1600°F	1-1/4 hrs.			Water	429
					Temper	750°F	2 hrs.			"	
1123-1	C .32	Ni 1.95	Cr .7	Mo .2	Austemper	1600°F	1-1/4 hrs.	550°F	1 hr.	Water	406
1123-2	"	"	"	"	"	"	"	"	3 hrs.	"	429
*1123	"	"	"	"	Quench	1600°F	1-1/4 hrs.			Water	388
					Temper	900°F	2 hrs.			"	
*1123-3	"	"	"	"	Quench	1600°F	1-1/4 hrs.			Water	379
					Temper	750°F	2 hrs.			"	

TABLE I-A (Continued)

Plate No.	Type Analysis				Heat Treatment	Aust. Temp.	Time at Temp.	Austempering Temp. (Salt Bath)	Time in Salt Bath	Coolant	BHN
CV-1	C .22		Ni 4.9	Mo .26	Austemper	1600°F	1-1/4 hrs.	600°F	1½ hrs.	Water	406
CV-2	"		"	"	Quench Temper	1600°F 850°F	1-1/4 hrs. 2 hrs.			Oil Air	379
14582	C .47		Ni 1.3	Mo .4	Austemper	1600°F	1-1/4 hrs.	600°F	15 min.	Water	388
14582-1	"		"	"	Quench Temper	1600°F 1025°F	1-1/4 hrs. 2 hrs.			Oil Air	375
CMV-8	C .46	Cr 1.2	Mo .6	V .3	Austemper	1600°F	1-1/4 hrs.	700°F	3 hrs.	Water	415
CMV-6	"	"	"	"	Quench Temper	1600°F 1200°F	1-1/4 hrs. 2 hrs.			Oil Air	388
3	C .44	Cr 1.2	Mo .6	V .3	Austemper	1600°F	1-1/4 hrs.	625°F	3 hrs.	Water	401
2	.45	"	"	"	Quench Temper	1600°F 1150°F	1-1/4 hrs. 2 hrs.			Oil Air	388
14932	C .5	Cr 1.2	Mo .9	V .2	Austemper	1600°F	1-1/4 hrs.	650°F	3 hrs.	Water	415
14932-1	"	"	"	"	Quench Temper	1600°F. 1150°F.	1-1/4 hrs. 2 hrs.			Oil Air	388

* Plate Nos. 1120, 1120-3, 1121, 1121-3, 1122, 1122-3, 1123, 1123-3 were heat treated at Simonds Saw and Steel Co., the balance of the plates were heat treated at Watertown Arsenal.

BALLISTIC DATA SHEET NO. 1

Plate No. 1120-1 — 9 x 10 x 3/8" — Austempered

Actual Thickness .377"

Brinell Hardness 331

Chemical Analysis

C	Cr	Mo
.36	1.03	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2466	PTP, 5/16" x 3/4" punching.
2	187 gr.	2486	PTP, 3/4" x 5/8" punching.

Maximum height of bulge on back - none.

Cal. .30 AP M2 Firings:

3	29 gr.	1728	CP, pinhole.
4	28 gr.	1694[a]	CP, core shattered, nose in plate.
5	27.5 gr.	1648[a]	PP, SB.

[a] Actual Ballistic Limit - 1671 f/s.
Specified Ballistic Limit - 1648 f/s. - Spec. AXS-488, Rev. 2, Machinable Homogeneous Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 2

Plate No. 1120-2 — 9 x 10 x 3/8" — Austempered

Actual Thickness .374"

Brinell Hardness 315

Chemical Analysis

C	Cr	Mo
.36	1.03	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2466	PTP, 11/16 x 13/16" punching. 2" crack extending through plate.
2	186 gr.	2437	PTP, 7/8 x 1" punching.
Maximum height of bulge on back - none.			
Cal. .30 AP M2 Firings:			
3	P.L. 1800f/s	1699	CP, pinhole.
4	27.5 gr.	1651	CP, pinhole.
5	27 gr.	1637	Hit edge of plate.
6	27 gr.	1647[a]	CP, pinhole.
7	26.7 gr.	1603[a]	PP, LB.
Cal. .50 AP M2 Firings:			
8	187 gr.	2442	PTP, 7/8 x 11/16".

[a]Actual Ballistic Limit - 1625 f/s.
Specified Ballistic Limit - 1636 f/s. - Spec. AXS-488, Rev. 2, Machinable Homogeneous Plate

PLATE UNSATISFACTORY - Low ballistic limit. Brittle under shock test applied.

BALLISTIC DATA SHEET NO. 3

Plate No. 1120 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .375"

Brinell Hardness 388

Chemical Analysis

C	Cr	Mo
.36	1.03	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Result
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, LB
2	187 gr.	"	PP, LB
3	187 gr.	"	PP, LB

Maximum height of bulge on back of plate - 5/16".

Cal. .30 AP M2 Firings:			
4	P.L. 1900 f/s	1872	CP, small pinhole.
5	30 gr.	1853[a]	CP, small pinhole.
6	28 gr.	1757	PP, MB
7	29 gr.	1777	PP, MB.
8	29.5 gr.	1810[a]	PP, LB
Cal. .50 AP M2 Firings:			
9	187 gr.	2440	PTP, 3/4 x 9/16".

[a]Actual Ballistic Limit - 1832 f/s.
Specified Ballistic Limit - 1779 f/s. Spec. AXS-488, Rev. 2, Hard Homogeneous Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 4

Plate No. 1120-3 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .376"

Brinell Hardness 388

Chemical Analysis

C	Cr	Mo
.36	1.03	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2450 est.	PP, LB
2	"	"	PP, LB - near edge.
3	"	"	PP, LB
4	"	"	PP, LB

Maximum height of bulge on back of plate - 5/16".

Cal. .30 AP M2 Firings:			
5	P.L. 1900 f/s	1824[a]	CP, pinhole.
6	29 gr.	1786[a]	PP, LB

[a] Actual ballistic limit - 1843 f/s.
Specified ballistic limit - 1775 f/s. - Spec. AXS-463, Rev. 2, Hard Homogeneous Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 5

Plate No. 1121-1 — 9 x 10 x 3/8" — Austempered

Actual Thickness .360"

Brinell Hardness 401

Chemical Analysis

C	Cr	Mo
.35	.86	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2446	PP, LB
2	"	2450	PP, LB
3	"	2456	PP, LB - plate broke into two pieces.
Maximum height of bulge on back of plate - 1/4".			
Cal. .30 AP M2 Firings:			
4	P.L. 1800f/s	1708[a]	CP, pinhole.
5	27.5 gr.	1718	Hit edge of plate.
6	27 gr.	1632	Hit edge of plate.
7	27.2 gr.	1660[a]	PP, LB
Cal. .50 AP M2 Firings:			
8	187 gr.	2446	Plate shattered.

[a]Actual ballistic limit - 1684 f/s
Specified ballistic limit - 1715 f/s - Spec. AXS-488, Rev. 2, Hard Homogeneous Plate

PLATE UNSATISFACTORY - low ballistic limit and brittle under shock test applied.

BALLISTIC DATA SHEET NO. 6

Plate No. 1121-2 — 9 x 10 x 3/8" — Austempered

Actual Thickness .361"
Brinell Hardness 401

Chemical Analysis

C	Cr	Mo
.35	.86	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2466	PP, LB
2	"	2466	PP, LB
3	"	2427	PP, LB - 7" crack extending through plate.
Cal. .30 AP M2 Firings:			
4	P.L. 1900f/s	1796	CP, 1/16x1/32".
5	27 gr.	1718[a]	CP, pinhole.
6	26 gr.	1640	PP, SB
7	26.5 gr.	1685	Hit rd. # 6.
8	26.5 gr.	1690[a]	PP, MB

[a] Actual Ballistic Limit - 1704 f/s.
Specified Ballistic Limit - 1719 f/s. - Spec. AXS-488, Rev. 2, Hard Homogeneous Plate

PLATE UNSATISFACTORY - low ballistic li... and brittle under shock test applic...

BALLISTIC DATA SHEET NO. 7

Plate No. 1121 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .365"
Brinell Hardness 388

Chemical Analysis

C	Cr	Mo
.35	.86	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2450 est.	PP, LB
2	"	"	PTP, 15/16 x 1⅛" punching.
3	"	"	PP, LB
Maximum height of bulge on back of plate - 3/8".			
Cal. .30 AP M2 Firings:			
4	30 gr.	1795	CP, pinhole.
5	29 gr.	1770[a]	CP, pinhole.
6	28 gr.	1700	PP, MB
7	28.5 gr.	1724[a]	PP, MB
Cal. .50 AP M2 Firings:			
8	187 gr.	2440	PTP, 3/4 x 3/4".

[a]Actual Ballistic Limit - 1745 f/s.
Specified Ballistic Limit - 1735 f/s. - Spec. AXS-488, Rev. 2, Hard Homogeneous Plate.

PLATE SATISFACTORY - Borderline

BALLISTIC DATA SHEET NO. 8

Plate No. 1121-3 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .365"
Brinell Hardness 401

Chemical Analysis

C	Cr	Mo
.35	.86	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, LB
2	"	"	PP, LB - small star crack.
3	"	"	PP, LB - small star crack.
Cal. .30 AP M2 Firings:			
6	30 gr.	1766	PP, MB - cracks on bulge.
7	31 gr.	1834[a]	CP, pinhole.
8	30.5 gr.	1794[a]	PP, LB

[a]Actual Ballistic Limit - 1814 f/s.
Specified Ballistic Limit - 1735 f/s. - Spec. AXS-488, Rev. 2, Hard Homogeneous Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 9

Plate No. 1122-1 — 9 x 10 x 3/8" — Austempered

Actual Thickness .367"
Brinell Hardness 429

Chemical Analysis

C	Mn	Mo
.33	1.60	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2446	PTP, lower right hand corner broken off. 2x2⅛" DS.

Maximum height of bulge on back of plate - none.

Cal. .30 AP M2 Firings:			
2	P.L. 1600 f/s	1657[a]	CP, pinhole.
3	27 gr.	1641[a]	PP, MB
Cal. .50 AP M2 Firings:			
4	187 gr.	2450est.	PTP, 1-15/16 x 1" DS.

[a]Actual Ballistic Limit - 1664 f/s.
Specified Ballistic Limit - 1743 f/s. Spec. AXS-488, Rev. 2, Hard. Homo. Plate
PLATE UNSATISFACTORY - low ballistic limit and brittle when shock test applied.

BALLISTIC DATA SHEET NO. 10

Plate No. 1122-2 — 9 x 10 x 3/8" — Austempered

Actual Thickness .372"

Brinell Hardness 420.

Chemical Analysis

C	Mn	Mo
.33	1.60	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2556	PP, LB - 5" crack through plate.
Cal. .30 AP M2 Firings:			
2	P.L. 1900 f/s	1892	CP, 1/16 x 1/16".
3	P.L. 1800 f/s	1669	PP, MB
4	30 gr.	1770	Hit edge of plate.
5	"	1786[a]	CP, pinhole.
6	28 gr.	1708	PP, MB
7	29 gr.	1738[a]	PP, MB

[a]Actual Ballistic Limit - 1762 f/s.
Specified Ballistic Limit - 1763 f/s. Spec. AXS-486, Rev. 2, Hard Homo. Plate

PLATE UNSATISFACTORY - low ballistic limit and brittle under shock test applied.

BALLISTIC DATA SHEET NO. 11

Plate No. 1122 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .370"

Brinell Hardness 375

Chemical Analysis

C	Mn	Mo
.33	1.60	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	166 gr.	2450 est.	PP, LD - 1 x 1-1/8" punching started.
2	"	"	CP, crack to rd. #1.
3	"	"	PP, LD - cracking on bulge.
4	"	"	PTP, BS 13/16 x 1-1/8".
Maximum height of bulge on back of plate - 5/16".			
Cal. .30 AP M2 Firings:			
5	31 gr.	1662	
6	P.L. 1900 f/s	—	Hit edge of plate.
7	P.L. 1900 f/s	1644	Hit rd. #4.
8	P.L. 1900 f/s	1650	Hit rd. #1.
9	P.L. 1900 f/s	1652	CP 1/16" x 1/16".
10	30 gr.	1630	CP, small pinhole.
11	28 gr.	1760[a]	CP, small pinhole.
12	26 gr.	1690	PP, SD
13	27 gr.	1740[a]	PP, MD
Cal. .50 AP M2 Firings:			
14	167 gr.	2450 est.	PTP, 1-11/16 x 1-9/16" BS.

[a] Actual Ballistic Limit - 1760 f/s.
Specified Ballistic Limit - 1755 f/s. - Spec. AXS-466, Rev. 2, Hard Homo. Plate

PLATE UNSATISFACTORY - brittle under shock test applied.

BALLISTIC DATA SHEET NO. 12

Plate No. 1122-3 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .381"
Brinell Hardness 429

Chemical Analysis

C	Mn	Mo
.33	1.60	.33

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2450 est.	PP, LB
2	"	"	PTP, 1-7/16 x 1-1/16" exit diameter. Hit rd. #1.
3	"	"	PP, LB
4	"	"	PP, LB
Cal. .30 AP M2 Firings:			
5	P.L. 1900 f/s	-	Hit rd. #1.
6	P.L. 1900 f/s	1776	PP, MB
7	30 gr.	1844[a]	CP, small pinhole.
8	29 gr.	1786	PP, MB
9	29.5 gr.	1805[a]	PP, LB

[a]Actual Ballistic Limit - 1825 f/s.
Specified Ballistic Limit - 1798 f/s. - Spec. AXS-483, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 13

Plate No. 1123-1 — 9 x 10 x 3/8" — Austempered

Actual Thickness .353"
Brinell Hardness 406

Chemical Analysis

C	Ni	Cr	Mo
.32	1.95	.68	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450est.	PP, LB
2	"	"	PP, LB - small cracks on rear bulge.
3	"	"	PP, LB - small cracks on rear bulge.
Cal. .30 AP M2 Firings:			
4	P.L. 1900 f/s	1776[a]	CP, 1/16 x 1/16" punching started.
5	27 gr.	1670	PP, SB
6	28 gr.	1738[a]	PP, MB

[a]Actual Ballistic Limit - 1757 f/s.
Specified Ballistic Limit - 1687 f/s. - Spec. AXS-483, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC SHEET NO. 14

Plate No. 1123-2 — 9 x 10 x 3/8" — Austempered

Actual Thickness .364"
Brinell Hardness 429

Chemical Analysis

C	Ni	Cr	Mo
.32	1.95	.68	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2437	PP, LB
2	186 gr.	2427	PP, LB
3	187 gr.	2437	PP, LB
Maximum height of bulge on back of plate - 5/16".			
Cal. .30 AP M2 Firings:			
4	P.L. 1900 f/s	1848[a]	PP, LB
5	31 gr.	1872	CP, CIP Base destroyed, nose thru plate 1/16".
Cal. .50 AP M2 Firings:			
6	187 gr.	2442	PTP, 7/8 x 1/2".

[a]Actual Ballistic Limit - 1860 f/s.
Specified Ballistic Limit - 1731 f/s. - Spec. AXS-488, Rev. 2, Hard Homo.Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 15

Plate No. 1123 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .358"
Brinell Hardness 388

Chemical Analysis

C	Ni	Cr	Mo
.32	1.95	.68	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2466	PP, LB
2	187 gr.	2466	PP, LB
3	187 gr.	2556	PP, LB
Maximum height of bulge on back of plate - 3/8".			
Cal. .30 AP M2 Firings:			
4	26 gr.	1670	PP, MB
5	27 gr.	1690	PP, MB
6	27.3 gr.	1700	PP, MB
7	P.L. 1900 f/s	1853	CP, small pinhole
8	29 gr.	1786[a]	CP, small pinhole
9	27.5 gr.	1737	Hit rd. #2
10	27.5 gr.	1740[a]	PP, MB
Cal. .50 AP M2 Firings:			
11	187 gr.	2470	PTP - 1/2" x 7/16".

[a]Actual Ballistic Limit - 1763 f/s.
Specified Ballistic Limit - 1707 f/s. Spec. AXS-488,Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 16

Plate No. 1123-3 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .348"
Brinell Hardness 379

Chemical Analysis

C	Ni	Cr	Mo
.32	1.95	.68	.22

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, LB
2	187 gr.	"	PP, LB
3	187 gr.	"	PP, LB
Cal. .30 AP M2 Firings:			
4 P.L.	1800 f/s	1697	PP, hit near Rd. #1.
5	29 gr.	1757[a]	CP, 1/16 x 1/16".
6	28.5 gr.	1737	PP, LB, Punching started.
7	28.5 gr.	1749[a]	PP, LB

[a]Actual Ballistic Limit - 1752 f/s
Specified Ballistic Limit - 1667 f/s - Spec. AXS-466, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 17

Plate No. CV-1 — 9 x 10 x 3/8" — Austempered

Actual Thickness .367"
Brinell Hardness 406

Chemical Analysis

C	Ni	Mo
.22	4.61	.26

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, LB
2	187 gr.	"	PP, LB
3	187 gr.	"	PP, LB
4	187 gr.	"	PP, LB

Maximum height of bulge on back of plate - 3/8".

Cal. .50 AP M2 Firings:			
5	187 gr.	2450 est.	PTP, 1/2 x 1/2".
Cal. .30 AP M2 Firings:			
6	30 gr.	1846	CP, CIP, nose thru plate 1/4".
7	28.5 gr.	1700	PP, CIP
8	28.5 gr.	1710	PP, hit rd. #4.
9	28.5 gr.	1700	Yawed impact
10	29.5 gr.	1800	CP, CIP, nose thru plate 1/4".
11	29 gr.	1706	CP, CIP at edge of plate.
12	28.5 gr.	1697	PP, MB
13	29 gr.	1747[a]	CP, pinhole light.
14	28.7 gr.	1740[a]	PP, LB

[a]Actual Ballistic Limit - 1744 f/s
Specified Ballistic Limit - 1743 f/s - Spec. AXS-466, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 18

Plate No. CV-2 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .359"
Brinell Hardness 379

Chemical Analysis

C	Ni	Mo
.22	4.81	.26

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	167 gr.	2450 est.	PP, LB
2	167 gr.	"	PP, LB
3	167 gr.	"	PP, LB
Maximum height of bulge on back of plate - 5/16".			
Cal. .50 AP M2 Firings:			
4	167 gr.	2450 est.	PTP, 3/8" x 3/8".
Cal. .30 AP M2 Firings:			
5	29.5 gr.	1807	CP, 1/16 x 1/16".
6	29.0 gr.	1739	CP, pinhole light.
7	28.0 gr.	1700	PP, MB
8	P.L. 1900 f/s	1915	Hit edge of plate.
9	30.0 gr.	1790	Hit rd. no. 1.
10	30.0 gr.	1796	CP, pinhole light.
11	28.5 gr.	1727[a]	CP, pinhole light.
12	28.0 gr.	1711[a]	PP, MB

[a]Actual Ballistic Limit - 1719 f/s
Specified Ballistic Limit - 1711 f/s - Spec. AXS-466, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 19

Plate No. 14562 — 10 x 12 x 3/8" — Austempered

Actual Thickness .377"
Brinell Hardness 388

Chemical Analysis

C	Ni	Mo
.47	1.31	.40

Plate Round No.	Powder Charge	Striking Velocity F/S	RESULTS
Cal. .50 M2 Ball Firings:			
1	167 gr.	2542	PTP, 5/8 x 5/8".
2	167 gr.	2450 est.	PP, MB
3	167 gr.	2450 est.	PP, MB
Cal. .50 AP M2 Firings:			
4	167 gr.	2450 est.	PTP, hit rd. #3, 3/4" x 5/8".
5	167 gr.	2450 est.	PTP, 3/8 x 3/8".
Cal. .30 AP M2 Firings:			
6	31 gr.	1747[a]	CP, pinhole light.
7	30 gr.	1622	PP, SB
8	30.2 gr.	1641	PP, SB
9	30.5 gr.	1661	PP, SB
10	30.8 gr.	1699[a]	PP

[a]Actual Ballistic Limit- 1723 f/s
Specified Ballistic Limit - 1783 f/s - Spec. AXS-466, Rev. 2, Hard Homo. Plate

PLATE UNSATISFACTORY - low ballistic limit

BALLISTIC DATA SHEET NO. 20

Plate No. 14582-1 — 12 x 12 x 3/8" — Quenched and Drawn

Actual Thickness .375"
Brinell Hardness 375

Chemical Analysis

C	Ni	Mo
.47	1.31	.40

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2466	PP, MD
2	186.5 gr.	2450 est.	PP, MD
3	186.5 gr.	"	PP, MD

Maximum height of bulge on back of plate - 3/16".

Cal. .50 AP M2 Firings:

4	186.5 gr.	2450 est.	PTP, 3/8 x 3/8".

Cal. .30 AP M2 Firings:

5	30.7 gr.	1684	PP, SD
6	30.9 gr.	1716	PP, SD
7	31.0 gr.	1728	PP, MD
8	31.2 gr.	1757	PP, MD
9	31.5 gr.	1767	PP, MD
10	31.7 gr.	1824	CP, hit rd. #6
11	31.6 gr.	1777[a]	PP, MD
12	31.7 gr.	1824[a]	CP, hit rd. #6

[a]Actual Ballistic Limit - 1801 f/s
Specified Ballistic Limit - 1775 f/s - Spec. AXS-438, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 21

Plate No. CMV-8 — 10 x 12 x 3/8" — Austempered

Actual Thickness .380"
Brinell Hardness 415

Chemical Analysis

C	Cr	Mo	V
.46	1.15	.60	.30

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	Plate broke into 4 pieces.

PLATE UNSATISFACTORY - Brittle Under Shock Test Applied

BALLISTIC DATA SHEET NO. 22

Plate No. CMV-6 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .370"
Brinell Hardness 388

Chemical Analysis

C	Cr	Mo	V
.46	1.15	.60	.30

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, LB
2	"	"	PP, LB - fine crack on bulge.
3	"	"	PP, LB
Maximum height of bulge on back of plate - 1/4".			
Cal. .50 AP M2 Firings:			
4	187 gr.	2450 est.	PTP, 1/2 x 7/16".
Cal. .30 AP M2 Firings:			
5	P.L. 1800 f/s	1679	PP, no bulge.
6	P.L. 1900 f/s	lost	CP, pinhole light.
7	31 gr.	lost	PP, SB
8	32 gr.	1699	PP, SB
9	34 gr.	1853[a]	PP, LB
10	35 gr.	1901[a]	CP, pinhole light.

[a]Actual Ballistic Limit - 1877 f/s
Specified Ballistic Limit - 1755 f/s - Spec. AXS-488, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY

BALLISTIC DATA SHEET NO. 23

Plate No. 3 — 10 x 12 x 3/8" — Austempered

Actual Thickness .395"
Brinell Hardness 401

Chemical Analysis

C	Cr	Mo	V
.44	1.18	.64	.30

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2450 est.	PP, MB
2	"	"	PP, MB
3	"	"	PP, MB
Maximum height of bulge on back of plate - 3/16".			
Cal. .30 AP M2 Firings:			
4	34 gr.	1970	CP, pinhole light.
5	33 gr.	1882[a]	CP, pinhole light.
6	32 gr.	1834[a]	PP, MB
Cal. .50 AP M2 Firings:			
7	187 gr.	2450 est.	PTP - 7/16 x 1/2" - 1 1/8" crack to round #6.

[a]Actual Ballistic Limit - 1858 f/s
Specified Ballistic Limit - 1851 f/s - Spec. AXS-488, Rev. 2, Hard Homo. Plate

PLATE - Borderline

BALLISTIC DATA SHEET NO. 24

Plate No. 2 — 10 x 12 x 3/8" — Quenched and Tempered

Actual Thickness .402"
Brinell Hardness 388

Chemical Analysis

C	Cr	Mo	V
.45	1.16	.56	.26

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	186 gr.	2450 est.	PP, MB
2	186 gr.	"	PP, MB
3	186 gr.	"	PP, MB
Maximum height of bulge on back of plate - 1/8".			
Cal. .30 AP M2 Firings:			
4	35 gr.	lost	CP, pinhole light
5	34 gr.	1950[a]	CP, pinhole light
6	33 gr.	1901[a]	PP, MB
Cal. .50 AP M2 Firings:			
7	187 gr.	2450 est.	PTP - 7/16 x 7/16" exit diameter.

[a]Actual Ballistic Limit - 1926 f/s
Specified Ballistic Limit - 1877 f/s - Spec. AXS-488, Rev. 2, Hard Homo. Plate

PLATE UNSATISFACTORY - under Shock Test Applied

BALLISTIC DATA SHEET NO. 25

Plate No. 14932 — 10 x 12 x 3/8" — Austempered

Actual Thickness .363"
Brinell Hardness 415

Chemical Analysis

C	Cr	Mo	V
.52	1.24	.91	.24

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2450 est.	PP, MB
2	187 gr.	"	PP, MB
3	187 gr.	"	Plate broke into 2 pieces.
Cal. .50 AP M2 Firings:			
4	187 gr.	2450 est.	PTP - 3/8 x 3/8".
Maximum height of bulge on back of plate - none.			
Cal. .30 AP M2 Firings:			
5	32.2 gr.	1846[a]	CP
6	32.0 gr.	1829[a]	PP, MB

[a]Actual Ballistic Limit - 1838 f/s
Specified Ballistic Limit - 1805 f/s - Spec. AXS-488, Rev. 2, Hard Homo. Plate

PLATE UNSATISFACTORY

BALLISTIC DATA SHEET NO. 26

Plate No. 14932-1 — 12 x 12 x 3/8" — Quenched and Drawn

Actual Thickness .373"
Brinell Hardness 388

Chemical Analysis

C	Cr	Mo	V
.52	1.24	.91	.24

Plate Round No.	Powder Charge	Striking Velocity F/S	Results
Cal. .50 M2 Ball Firings:			
1	187 gr.	2437	PP, MB
2	"	2450 est.	PP, MB
3	"	"	PP, MB

Maximum height of bulge on back of plate - 1/4".

Cal. .50 AP M2 Firings:

4	187 gr.	2450 est.	PTP 3/8" x 3/8".

Cal. .30 AP M2 Firings:

5	31 gr.	lost	PP, MB
6	31.5 gr.	1800	PP, MB
7	32.0 gr.	1824[a]	PP, nose in plate - core shattered.
8	32.2 gr.	1844[a]	CP, pinhole light.

[a]Actual Ballistic Limit - 1834 f/s
Specified Ballistic Limit - 1763 f/s - Spec. AXS-488, Rev. 2, Hard Homo. Plate

PLATE SATISFACTORY