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REPORT NO. 710/44
SUPPLEMENTARY REPORT #710/44-1

STUDY OF RIVETS FOR CONSTRUCTION OF ARMOR PLATE SHIELDS FOR GUN DIRECTOR MARK XXXV1

By

E. L. Reed
H. G. Carter

November 25, 1936

WATERTOWN ARSENAL
WATERTOWN, MASS.

Frankford Arsenal—2-11-36—1000

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November 25, 1935

Study of Rivets for Construction of Armor Plate Shields for Gun Director Mark XXXVI

Purpose

The purpose of this investigation was to determine the proper composition and design of rivets for use in the construction of armor plate shields for the Gun Director Mark XXXVI.

Conclusions

1. The hot driven buttonhead rivets under consideration, namely, Chromansil SAE No. 2315, SAE No. 4615, were all satisfactory from the point of view of ballistic efficiency and freedom of pronounced cracks and brittleness.

2. The ballistic limits of the rivets exceeded that of one-half inch thick heat treated armor plate when tested with a caliber .30 M 1922 A.P. service velocity ammunition at a distance of 100 yards. The maximum depth of penetration in the rivet heads was 1 1/16", while the armor plate was completely penetrated.

3. The buttonhead, 3/4 inch straight diameter shank rivet with a minus tolerance of 1/32 inch is recommended.

4. The ballistic properties of heat treated rivets were not superior to those of rivets "as received".

5. Electric heating of rivets is recommended.

6. There was no appreciable decrease in hardness detected in the heat treated armor plate adjacent to the driven rivet.

7. The results of this investigation indicate that rivets, either made of SAE No. 2315 or SAE No. 4615 compositions, may be used in the construction of the armor plate shields under consideration.

Material

1. Rivet Steel Compositions

(a) Chromansil hot formed buttonheads, 3/4" diameter shank were furnished by the Electro Metallurgical Company, New York. The shanks were machined to dimensions covered by Type 1, Figure 1.

(b) SAE No. 2315 - 1 1/2" round bar stock from which buttonhead two diameter rivets, Type 1, Figure 1 and buttonhead straight shank rivets Type 2, Figure 2 were machined.

(c) SAE No. 4615 - 1 1/2" round bar stock from which buttonhead two diameter rivets, Type 1, Figure 1 and buttonhead straight shank rivets, Type 2, Figure 2 were machined.

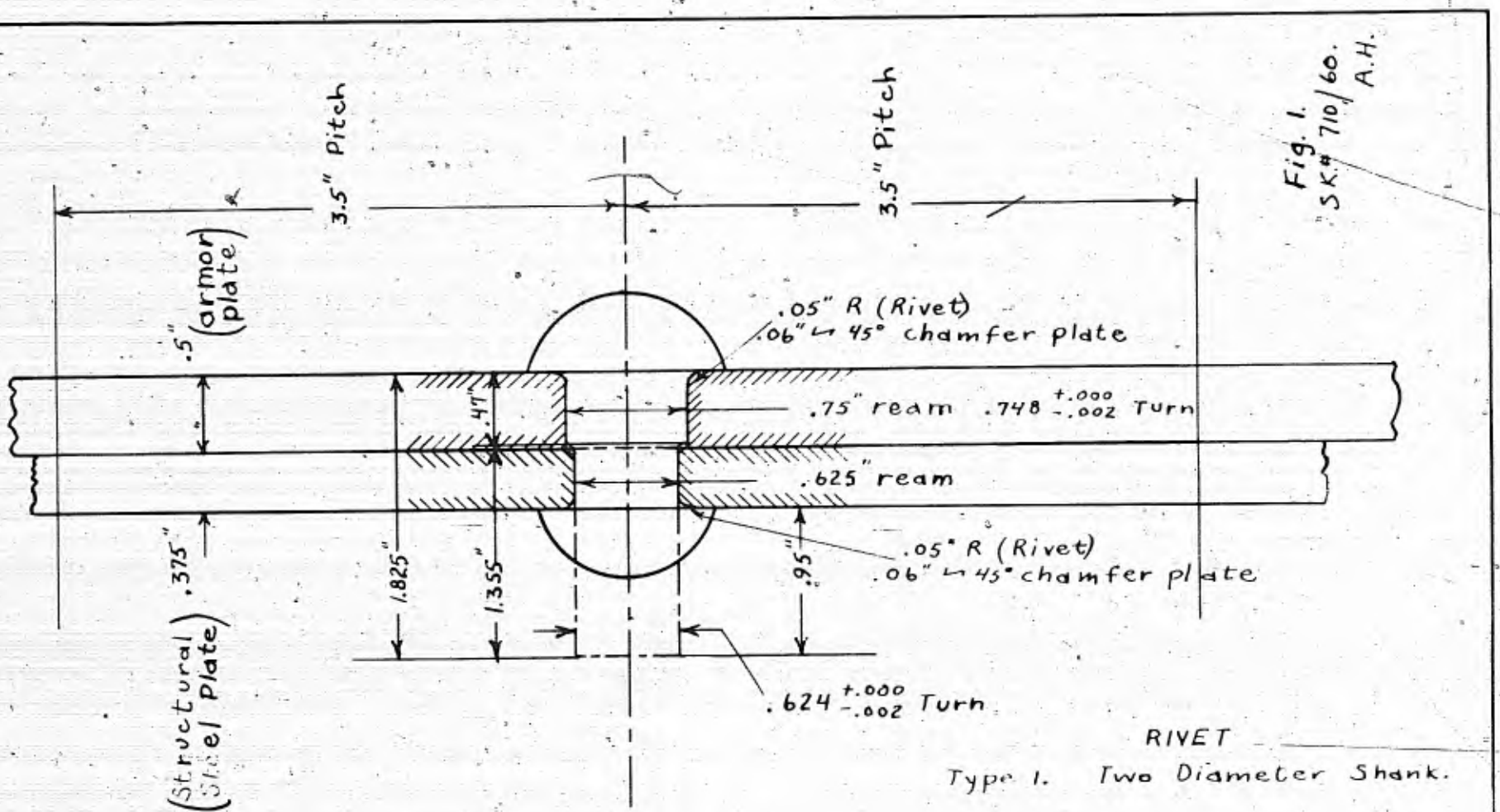


Fig. 1.
SK# 710/60.
A.H.

RIVET

Type 1. Two Diameter Shank.

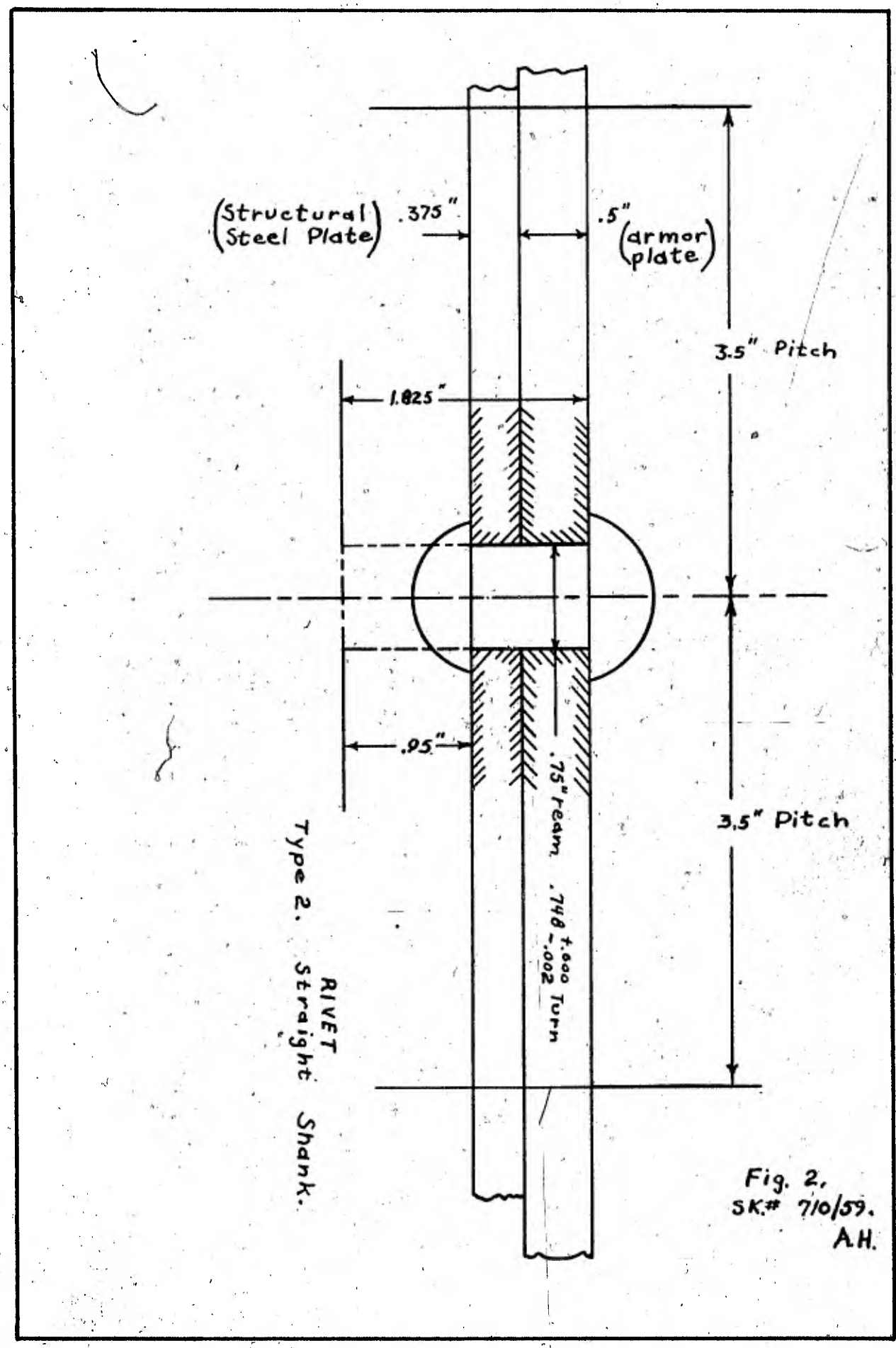


Fig. 2,
SK.# 710/59.
A.H.

2. Plate for Riveted Sections

(a) Strips of armor plate of standard composition, about 12" long, 4" wide and 1/2" thick. Armor plate was hardened and tempered to Brinell hardness 430-444.

(b) Carbon steel plates 12" square, 3/8" thick.

Experimental Procedure

1. Riveted Sections

Three riveted sections were constructed by riveting three strips of heat treated armor plate of standard composition, 12" long, 4" wide, 1/2" thick to a carbon steel plate 12" square and 3/8" thick. Three buttonhead rivets were hot driven in each strip of armor plate.

The composition and design of the rivets used in each riveted section are given below:

A. Section 1 (a) Chromansil two diameter, minus 1/32" tolerance, Figures 3 and 4.

(b) SAE No. 2315, two diameter, minus 1/32" tolerance, Figures 3 and 4.

(c) SAE No. 4615, two diameter, minus 1/32" tolerance, Figures 3 and 4.

B. Section 2 (a) Heat treated Chromansil, two diameter, minus 1/32" tolerance, Figures 5 and 6.

(b) Heat treated SAE No. 2315, two diameter, minus 1/32" tolerance, Figures 5 and 6.

Figure 3

Riveted Section 1

Front Before Ballistic Test

Strips of heat treated Armor Plate 12" long, 4" wide, 1/2" thick riveted to carbon steel plate 12" square, 3/8" thick.

Each strip of Armor Plate riveted with three chromansil, three SAE 2315 and three SAE 4615 hot driven button head two diameter rivets with a minus 1/32" tolerance.

Chromansil rivets upset hot as received. SAE 2315 and SAE 4615 rivets machined from 1 1/2" round stock.

Rivets were electrically heated and driven with a hand pneumatic riveter.

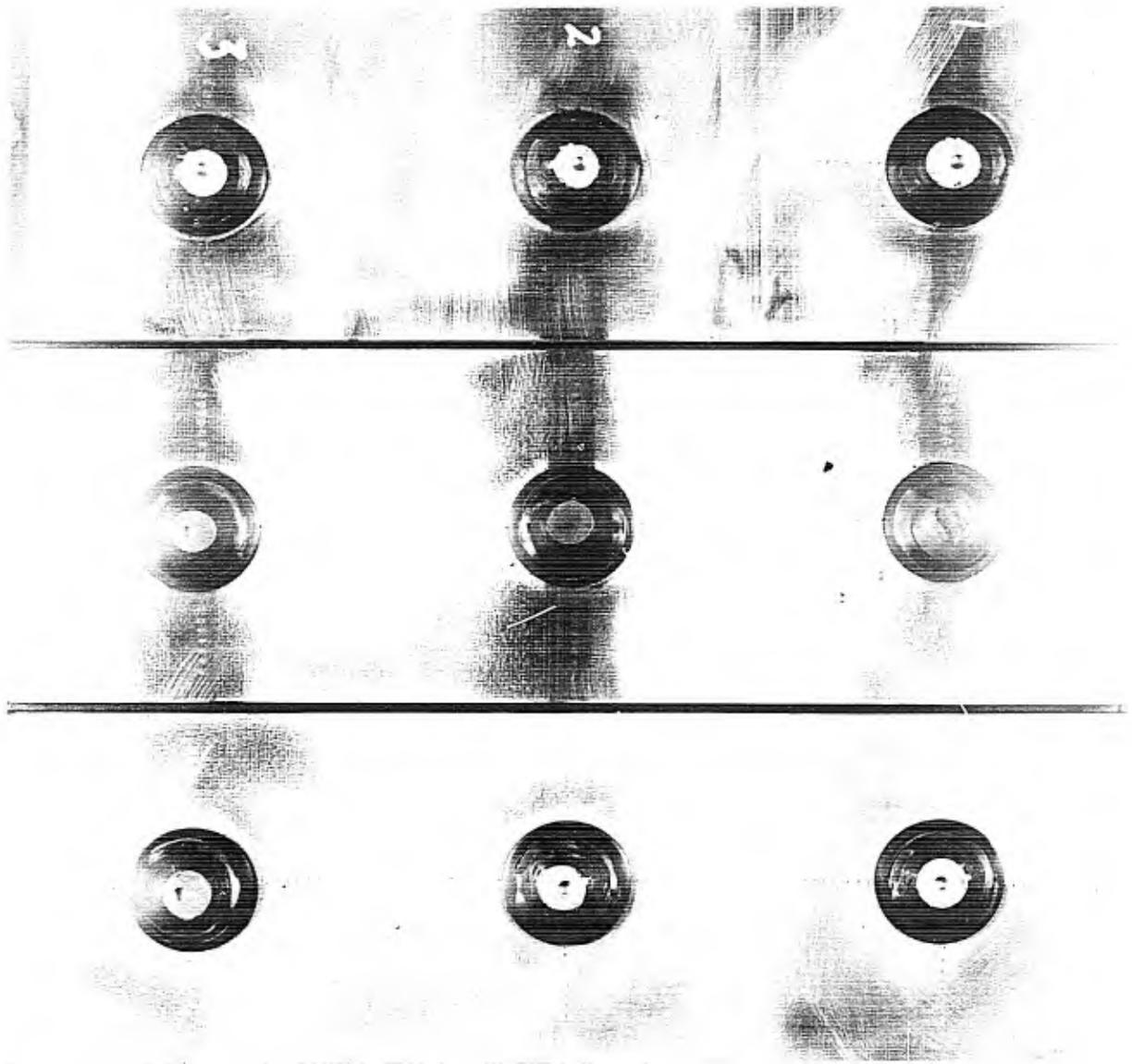

3
2

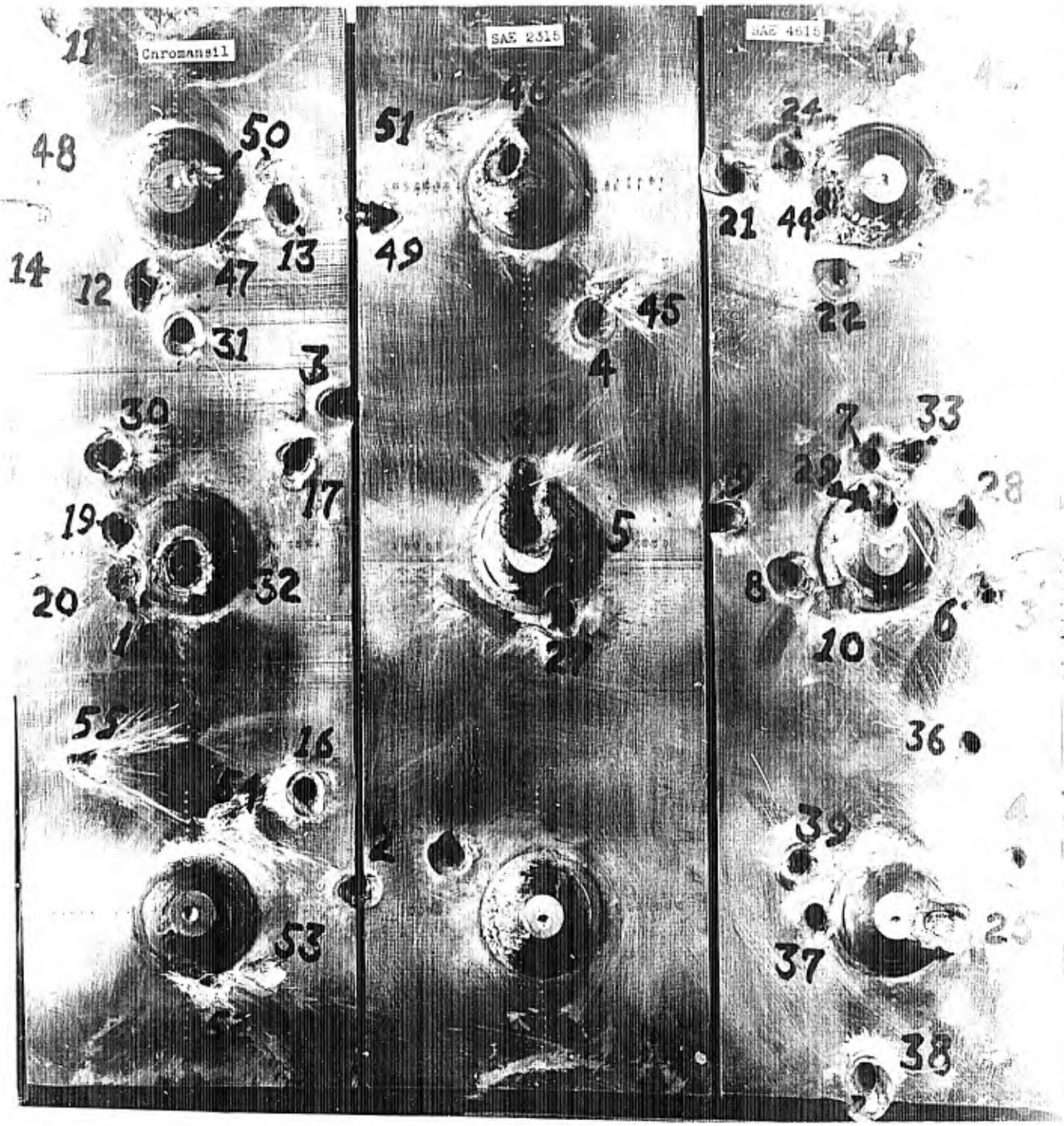
Figure 3A

Riveted Section 1

Front After Ballistic Test

Ammunition - Cal. .30 M1922 A.P.

Service Velocity: distance - 100 yards.


Chromansil
SAE 2315
SAE 4615
11
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51
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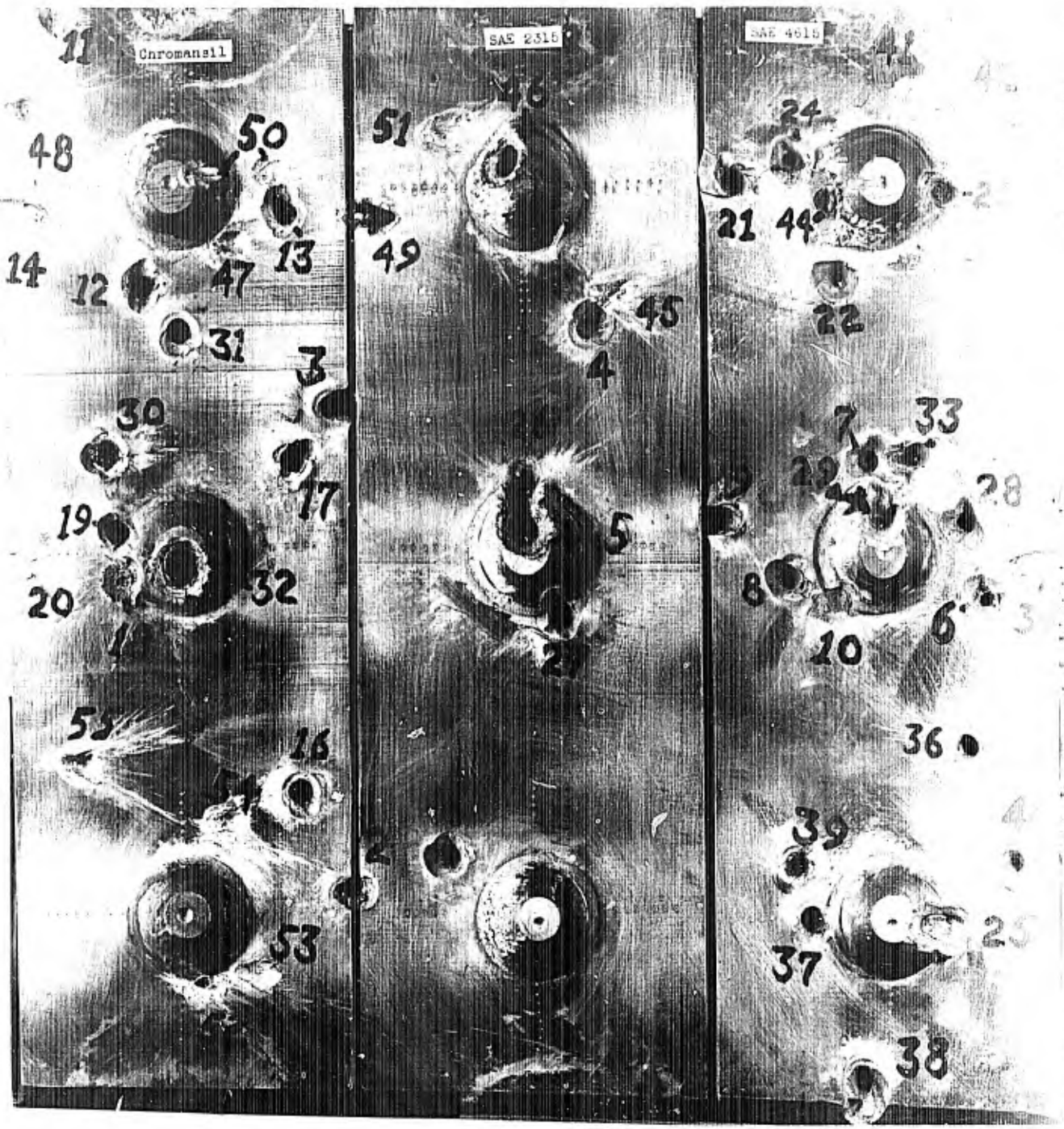
Chromansil
SAE 2315
SAE 4615

Figure 4

Riveted Section 1

Back of Plate Before Ballistic Test

Rivets were headed hot on back face of plate.

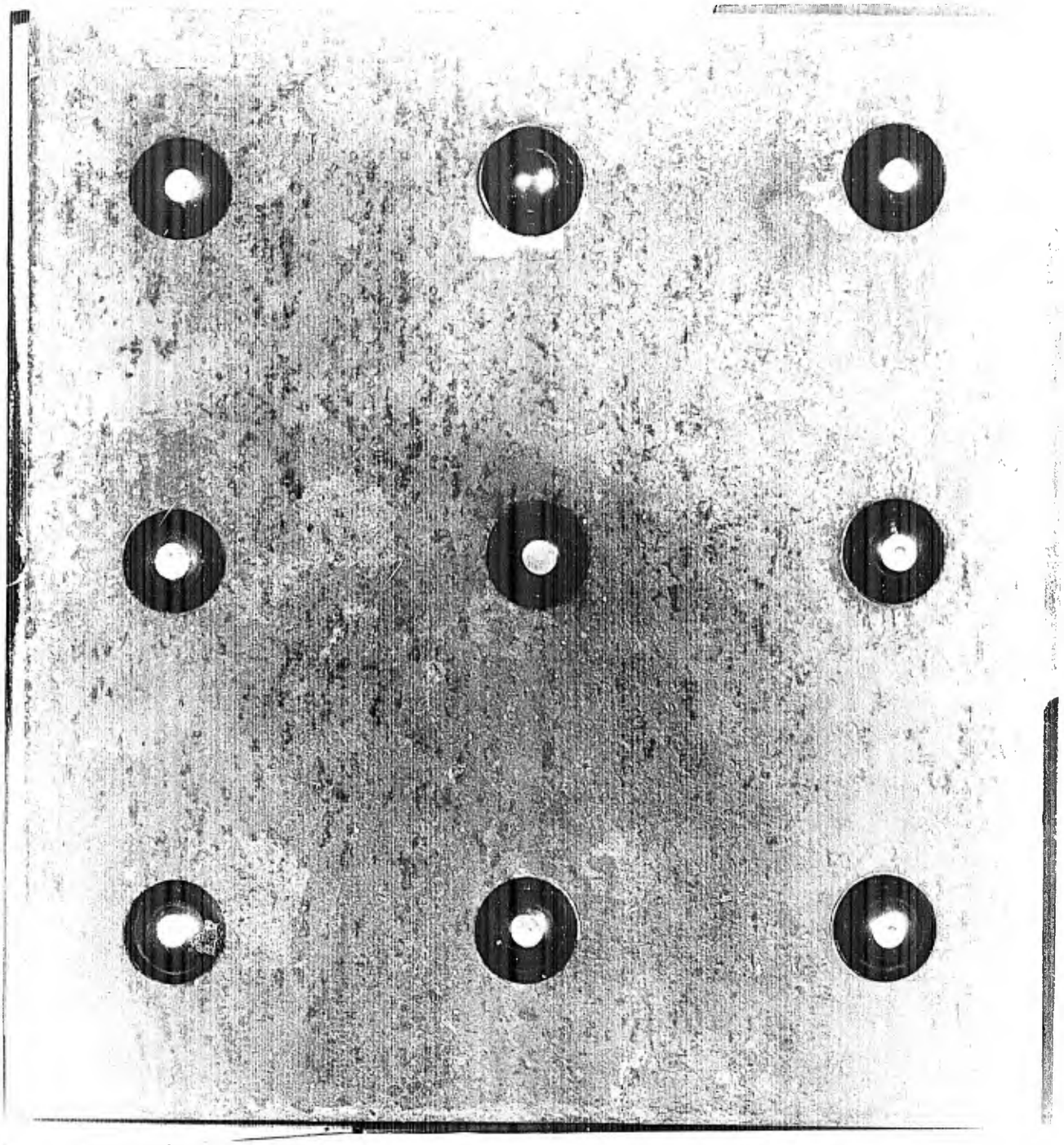

Figure 4A

Riveted Section 1

Back After Ballistic Test

All rivets were tight after ballistic test.

Figure 4

Riveted Section 1

Back of Plate Before Ballistic Test

Rivets were headed hot on back face of plate.

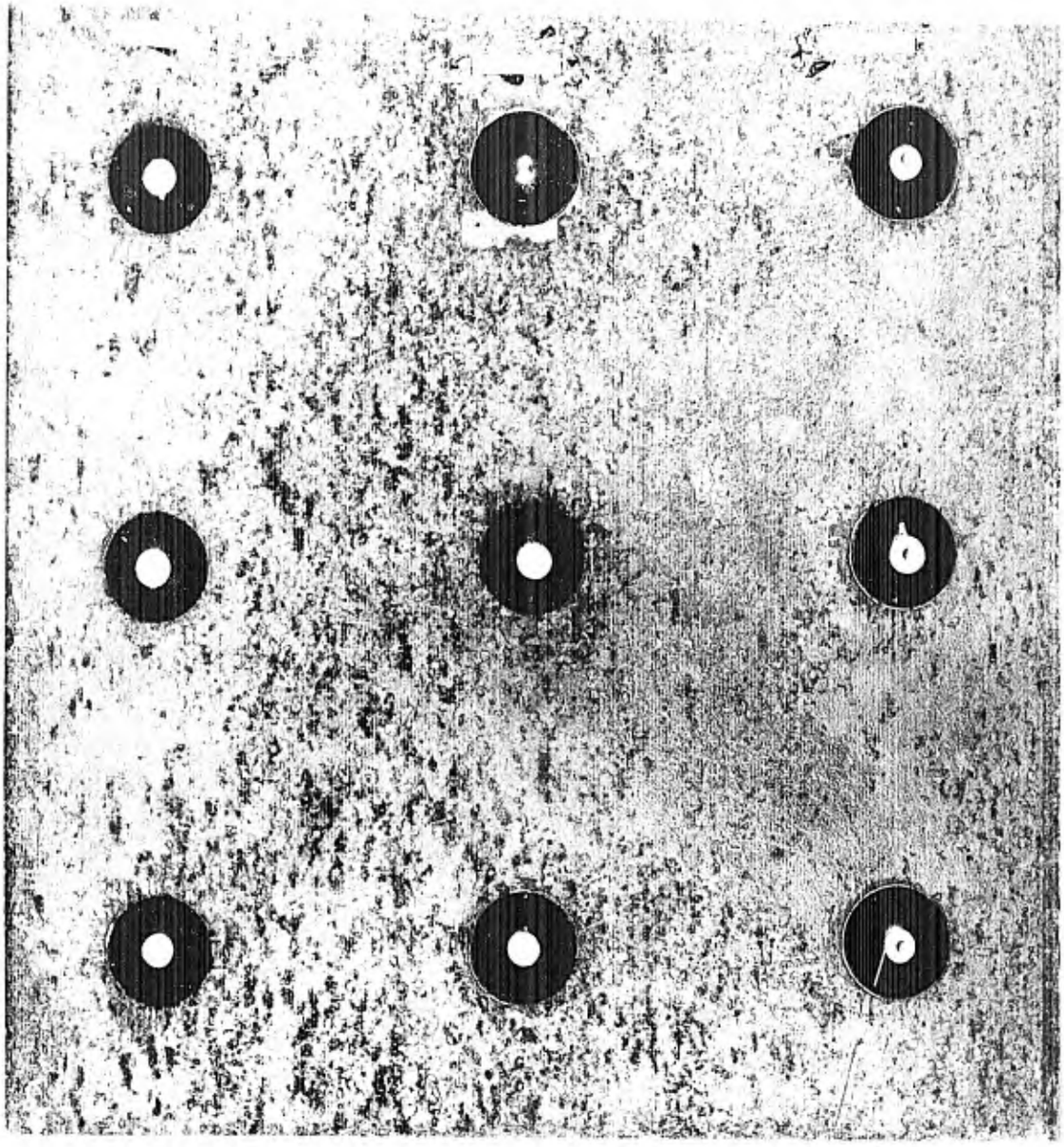

Figure 5

Riveted Section 2

Front Before Ballistic Test

Strips of heat treated Armor Plate 12" long 4" wide, 1/2" thick riveted to Carbon Steel Plate 12" square, 3/8" thick.

Each strip of Armor Plate riveted with three heat treated Chromansil, three SAE 2315, and three SAE 4615, hot driven button head two diameter rivets with a minus 1/32" tolerance.

Chromansil - Heat to 1700°F, 1 hour, quench in oil.
SAE 2315 - " " 1550°F, 1 hour, " " "
SAE 4615 - " " 1550°F, 1 hour, " " "

Rivets were electrically heated and driven with a hand pneumatic riveter.

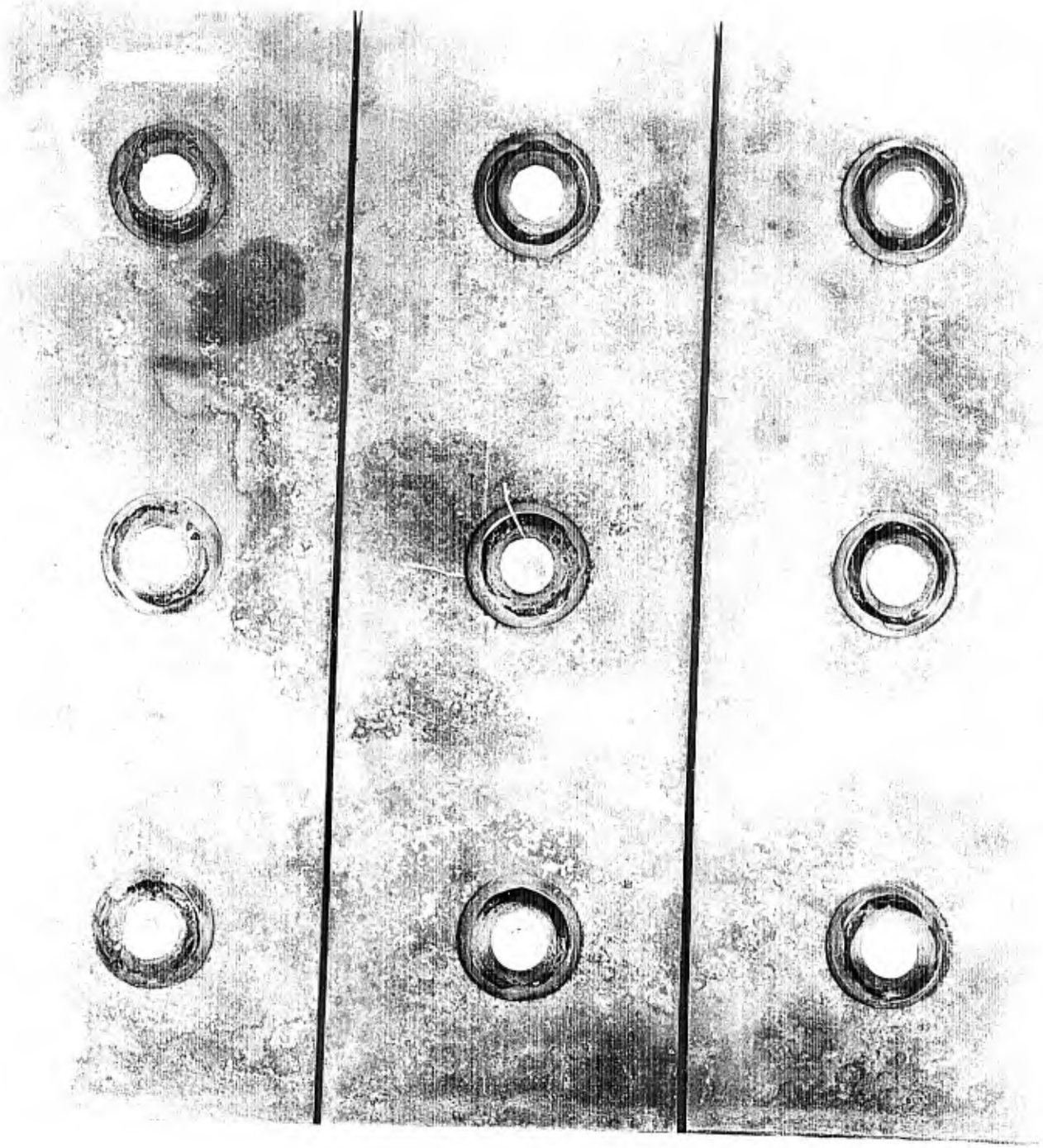

Figure 5A

Riveted Section 2

Front After Ballistic Test

Ammunition - Cal. .30 M1922 A.P.

Service Velocity: distance - 100 yards


48
47
46
45
44
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9
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4
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64
71
73
85

Figure 6

Riveted Section 2

Back Before Ballistic Test

Rivets were headed hot on back of plate.

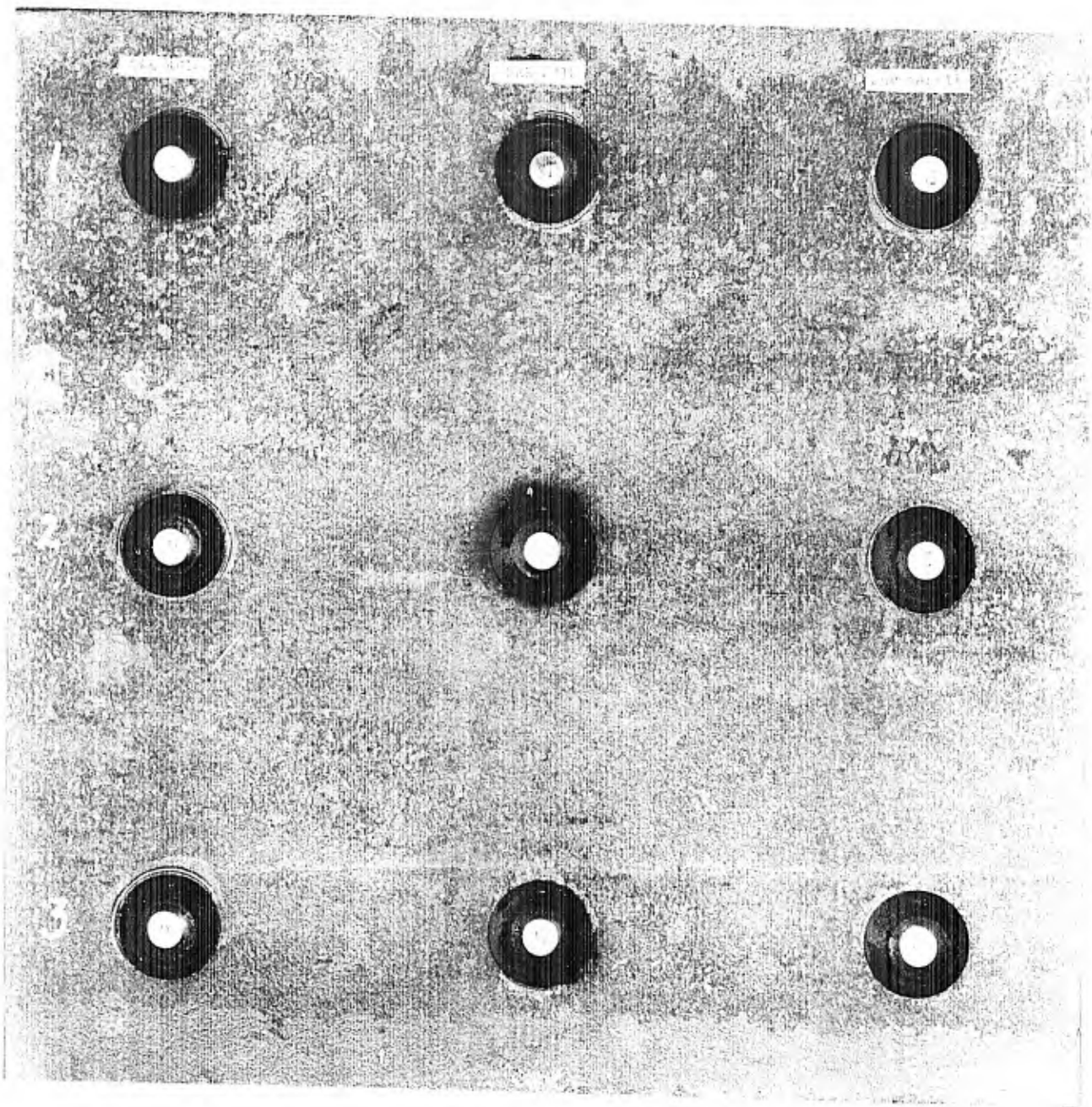


Figure 6A

Riveted Section 2

Back After Ballistic Test

All rivets were tight after ballistic test.

1
1
2
3

Figure 7

Riveted Section 3

Front Before Ballistic Test

Strips of heat treated armor plate 12" long, 3" wide, 1/2" thick riveted to carbon steel plate 12" square 3/8" thick.

Each strip of Armor Plate riveted with three SAE 2315 rivets of different minus tolerances.

Strip 2 - Straight shank button head rivet with minus 1/32" tolerance.

Strip 3 - Two diameter button head rivet with minus 1/64" tolerance.

Strip 4 - Two diameter button head rivet with minus 1/32" tolerance.

All rivets machined from 1 1/2" diameter stock. Rivets electrically heated and driven with hand pneumatic riveter.

2
1
3
2
3
1
4
2
3

Figure 7A

Riveted Section 3

Front After Ballistic Test

Ammunition Cal. .30 M1922 A.P.

Service Velocity: distance - 100 yards.

Figure 8

Riveted Section 3

Back before Ballistic Test.

Rivets were headed not on back of Plate.

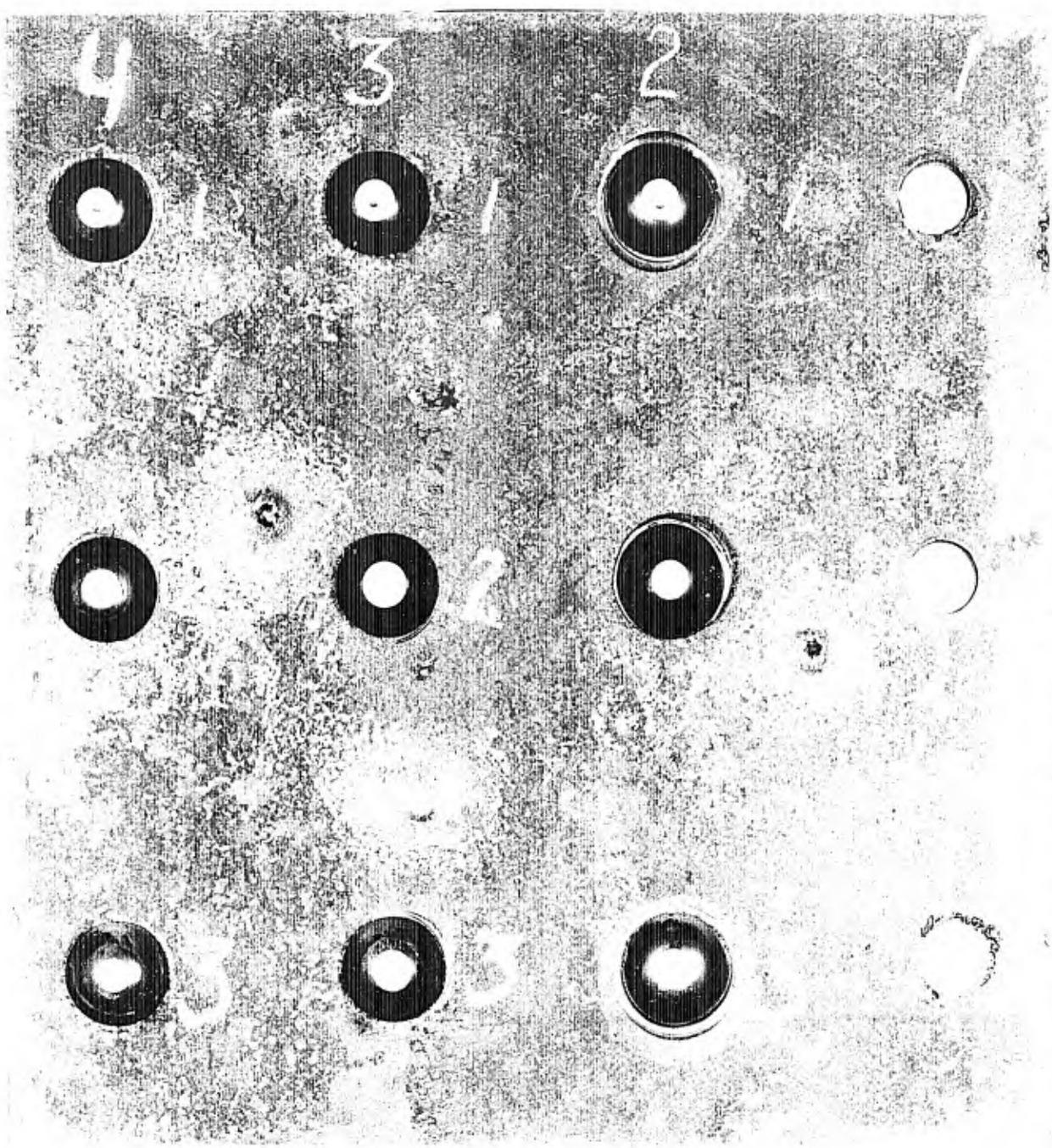
1
2
3

Figure 8A

Riveted Section 3

Back After Ballistic Test

All rivets were tight after Ballistic Test.


4
3
2
1

(c) Heat treated SAE No. 4615, two diameter, minus 1/32" tolerance, Figures 5 and 6.

C. Section 3 (a) SAE No. 2315, straight shank, minus 1/32" tolerance, Figures 7 and 8.

(b) SAE No. 2315, two diameter, minus 1/64" tolerance, Figures 7 and 8.

(c) SAE No. 2315, two diameter, minus 1/32" tolerance, Figures 7 and 8.

2. Heat Treatment of Rivets

A. Chromansil - Heat to 1700°F for one hour, quench in oil.

B. SAE 2315 - Heat to 1550°F for one hour, quench in oil.

C. SAE 4615 - Heat to 1550°F, for one hour, quench in oil.

3. Heating of Rivets

All rivets were electrically heated and driven with a hand pneumatic riveter. The rivet head on the rear face of the plate was formed in the riveter.

4. Ballistic Tests

Each riveted section was subjected to firing tests, normal to fire and at an angle of impact of 45 degrees from normal using caliber .30 M 1922 A.P. service velocity ammunition at a distance of 100 yards.

5. Hardness Tests

Brinell hardness tests were made on the rivet heads as received and after riveting.

After ballistic tests were made, each riveted strip was sectioned and a hardness survey was made on the driven rivet and on the armor plate adjacent to the rivet.

6. Tolerance vs Type of Rivet Joint

A study of the rivet joint was made relative to the minus tolerance allowed for expansion of the rivet during the heating and riveting operations.

7. Microstructure of Riveted Joints after Ballistic Tests

Microscopic examination was made on some typical rivets and riveted joints in order to determine:

(a) The amount of cold deformation near the penetration of the bullet.

(b) The effect of riveting temperature on the microstructure of the heat treated armor plate adjacent to the driven rivet.

Experimental Results

Chemical analyses of the rivet steels are given in Table 1.

Table 1
Chemical Analyses of Rivet Steels

Type	C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo. %
Chromansil	.065	1.37	.022	.024	.710	-	.45	-
SAE No. 2315	.18	.35	.013	.026	.230	3.37	-	-
SAE No. 4615	.15	.51	.030	.017	.235	1.87	-	.32

Physical properties of the rivet steel compositions are given in Table 2.

Table 2

Physical Properties of Rivet Steels

Type	Prop.Lim. Lb/sq.in.	Ten.Str. Lb/sq.in.	Elong. % in 2"	Reduction Area %
Chromansil*	58,000	84,750	12.0	71.4
SAE No. 2315**	55,000	78,250	30.5	59.8
SAE No. 4615***	45,000	94,500	24.0	60.5

Note: * Tensile bar machined from shank of 3/4" diameter rivet.

** & *** Tensile bars machined from center of 1 1/2" round hot rolled bars.

Ballistic Tests

The riveted sections were subjected to firing tests using the following number of rounds of caliber .30 M 1922 A.P. service velocity ammunition at a distance of 100 yards, Figures 3A, 4A, 5A, 6A, 7A and 8A.

Section 1 - 55 rounds

Section 2 - 85 rounds

Section 3 - 104 rounds

A Summary of the Maximum Depth of Penetrations in the Rivet Heads is given in Table 3.

Table 3

Summary of Maximum Penetrations in Rivet Heads

Caliber .30M 1922 A.P. service velocity ammunition
100 yards

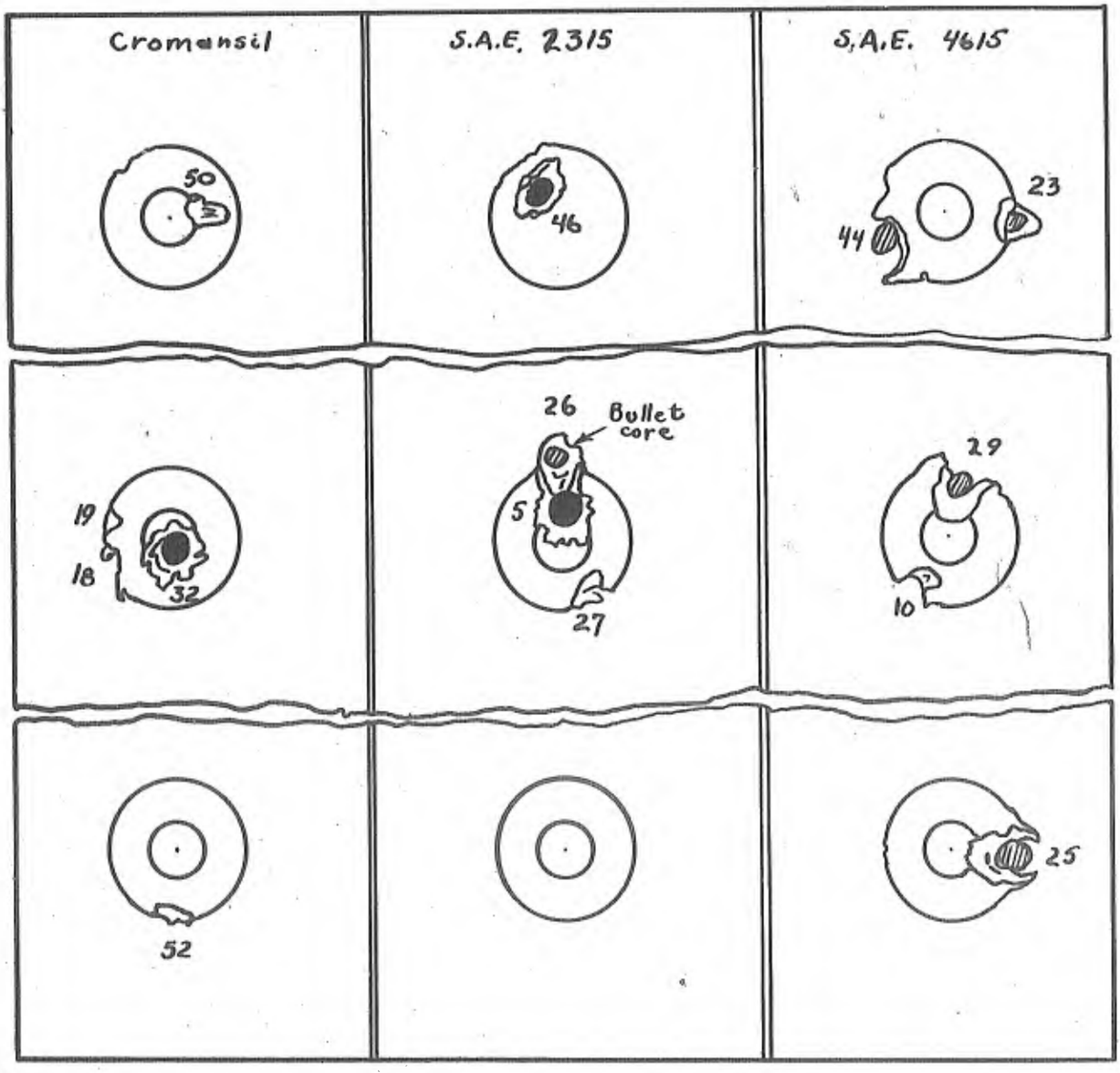
Type	Treatment	Tolerance	Section	Maximum Depth of Penetration	
				Normal	Angle of Impact 45°
Chromansil - two dia.	as rec'd	1/32"	1, Fig. 9	15/16"	-
SAE No. 2315 - two dia.	as rec'd	1/32"	1, Fig. 9	15/16"	11/16"
SAE No. 4615 - two dia.	as rec'd	1/32"	1, Fig. 9	-	-
Chromansil - two dia.	heat treated	1/32"	2, Fig. 10	1 1/16"	-
SAE No. 2315 - two dia.	heat treated	1/32"	2, Fig. 10	1 1/16"	-
SAE No. 4615 - two dia.	heat treated	1/32"	2, Fig. 10	15/16"	-
SAE No. 2315 - straight shank	as rec'd	1/32"	3, Fig. 11	15/16"	1 1/8" *
SAE No. 2315 - two dia.	as rec'd	1/64"	3, Fig. 11	7/8"	-
SAE No. 2315 - two dia.	as rec'd	1/32"	3, Fig. 11	-	-

* Two shots fired at same spot.

The one-half inch thick heat treated armor plate was completely penetrated.

Sketches showing ballistic data are shown in Figures 9, 10, and 11.

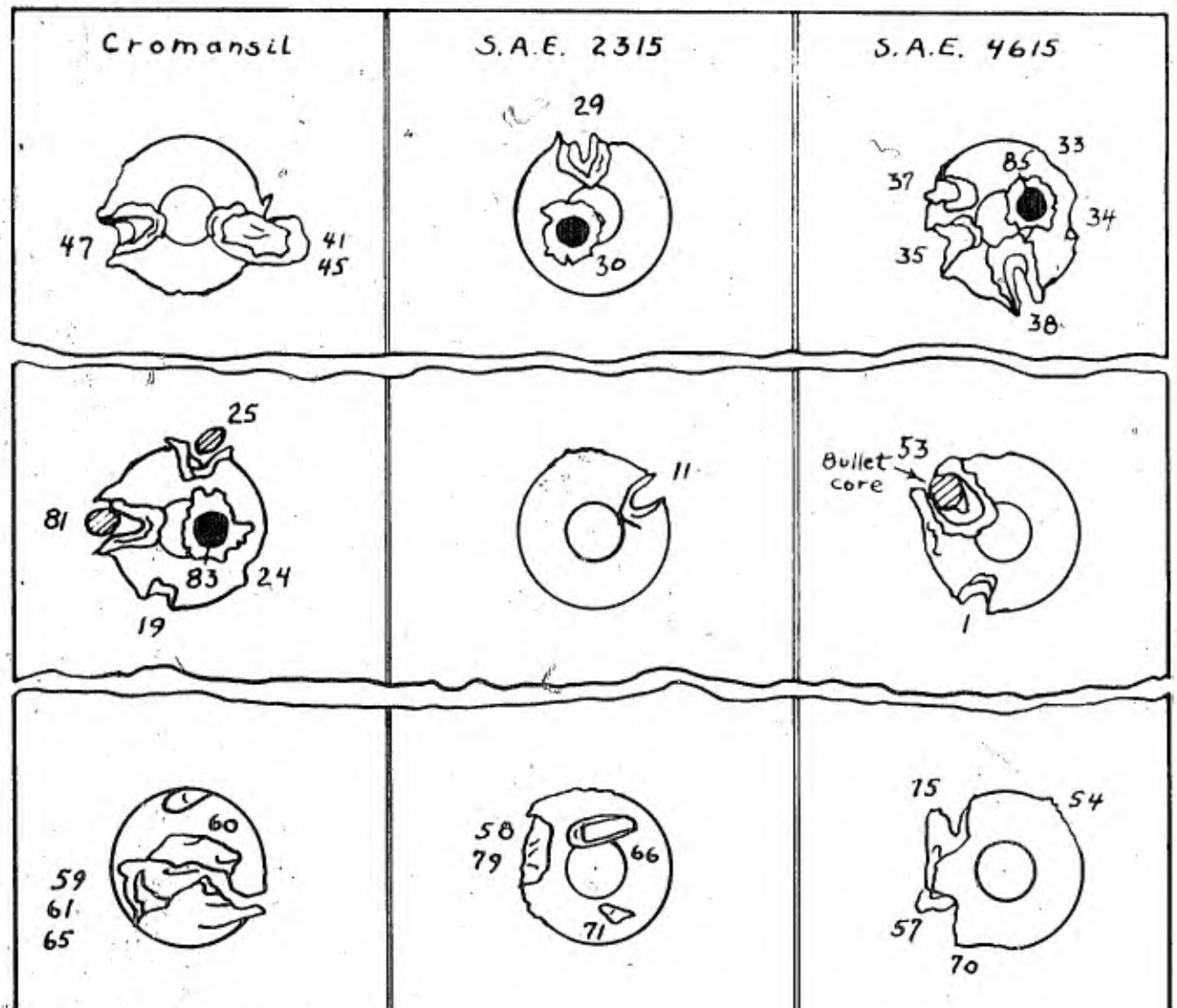
Section 1.



Ballistic Test of Riveted Armor Plate on Carbon Steel.
Rivets - Two Diameter, Minus 1/32" Tolerance.
Bullet, Caliber .30 M1922 A.P. Service Velocity.

Round No.	Depth of Penet.	Remarks.	Round No.	Depth of Penet.	Remarks.
18	1/8"	Graze - normal	25	5/8"	Graze - 45°L
19	1/2"	" "	29	11/16"	Graze - normal
32	15/16"	Direct Hit - n.	44	5/8"	Wedge - 45°L
50	1/16"	Graze - 45°L	5	15/16"	Direct Hit - n.
52	1/8"	" "	26	13/16"	Graze - normal
10	1/8"	Graze - normal	27	7/16"	" "
23	3/16"	Graze - normal	46	11/16"	Direct Hit - 45°L

Fig. 9.
SK.# 710/58.
A.H.

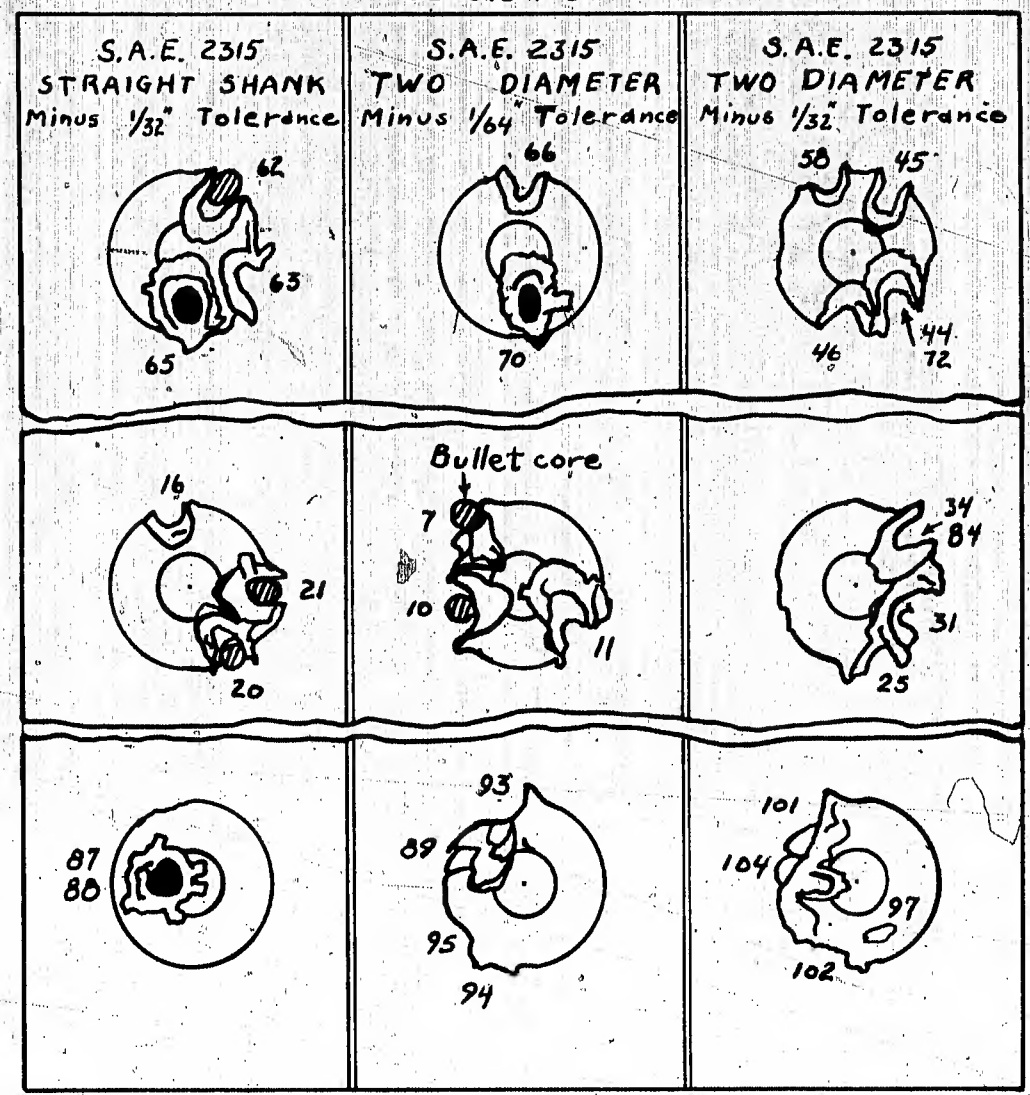


Ballistic Test of Riveted Armor Plate on Carbon Steel. Heat Treated Rivets - Two Diameter, Minus 1/32" Tolerance. Bullet, Caliber .30 M1922 A.P. Service Velocity.

Round No.	Depth of Penetr.	Remarks
11	1/4"	Graze-normal
29	1/4"	" "
30	1 1/16"	Direct Hit - norm.
58	—	Wedge 45°L
66	—	Graze 45°L
71	—	" "
79	—	Wedge 45°L
1	1/8"	Graze-normal
33	1/2"	" "
34	1/8"	" "
35	1/8"	" "
37	1/8"	" "
38	3/8"	Side Penet.-n.
53	11/16"	" " "
54	—	Graze - 45°L
57	—	Wedge - 45°L

Round No.	Depth of Penetr.	Remarks
70	—	Wedge - 45°L
75	—	Graze 45°L
85	15/16"	Direct Hit - n.
19	1/4"	Graze - normal
24	1/2"	" "
25	1/4"	" "
41	3/16"	" "
45	—	" "
47	3/8"	" "
59	—	Graze - 45°L
60	—	" "
61	—	Direct Hit - 45°L
65	—	" " "
81	3/16"	Graze - normal
83	1 1/16"	Direct Hit - n.

Fig. 10. SK.# 710/57
A.H.



Ballistic Test of Riveted Armor Plate on Carbon Steel.
Bullet.- Caliber .30 M1922 A.P. Service Velocity

Round No.	Depth of Pen.	Remarks	Round No.	Depth of Pen.	Remarks
7	1/4"	Graze normal	87	1 1/8"	Direct Hit. 45°
10	—	Graze normal	88	1 1/8"	Direct Hit. 45°
11	—	Side Penet. n.	25	—	Graze normal
66	1/4"	Graze normal	31	—	Graze normal
70	7/8"	Direct Hit. n.	34	—	Graze normal
89	—	Wedge 45°L	44	—	Graze normal
93	—	Wedge 45°L	45	1/4"	Graze normal
94	—	Wedge graze 45°	46	—	Graze normal
95	—	Direct Hit 45°	58	1/4"	Graze normal
16	1/8"	Graze normal	72	—	Graze normal
20	—	Graze normal	84	—	Graze normal
21	—	Graze normal	97	—	Graze 45°L
62	1/4"	Side Penet. n.	101	—	Wedge 45°L
63	3/8"	Graze normal	102	—	Wedge graze 45°
65	15/16"	Direct Hit. n.	104	—	Wedge 45°L

Fig. 11.
SK.# 710/56.
A.H.

Hardness Tests

Brinell hardness tests made on the rivet heads as received and after riveting both on the front and rear plate of the riveted sections are given in Tables 4, 5, and 6.

The maximum increase in hardness of the hot driven rivet heads is shown in Table 7.

Table 7

Summary of Hardness Tests on Heads of Rivets.

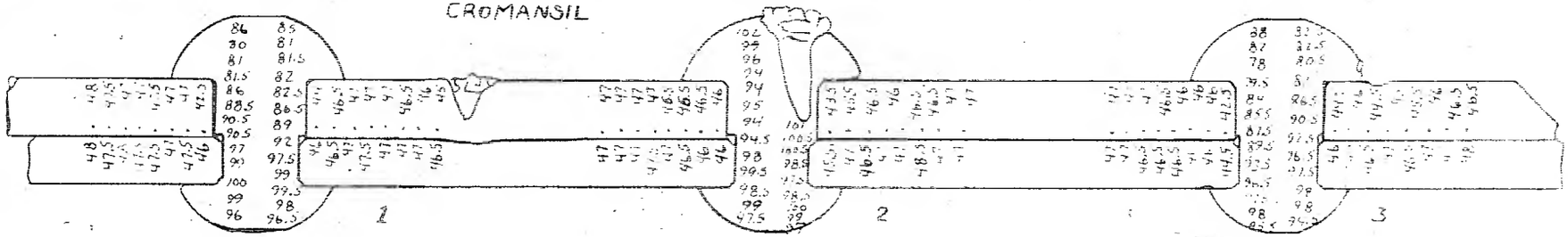
Type	Treatment	*Maximum increase in Hardness Driven Rivet Head Front Plate	Rear Plate
Chromansil	As rec'd.	34	92
SAE No. 2315	" "	137	238
SAE No. 4615	" "	61	177
Chromansil	Heat treated	-4	45
SAE No. 2315	" "	48	77
SAE No. 4615	" "	-20	85

*Maximum increase in hardness is defined as the difference in hardness of rivets as received and after riveting.

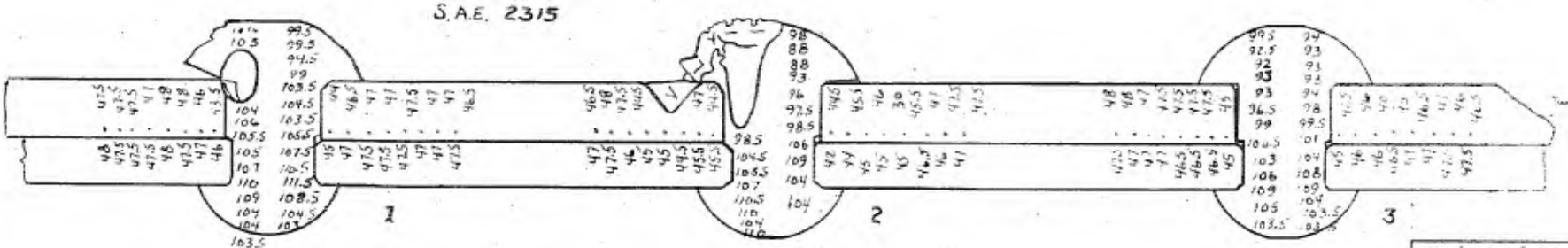
Rockwell hardness surveys made on sections cut through the riveted strips of the three riveted sections are illustrated in Figures 12, 13 and 14.

Hardness Tests of Driven Rivets and Adjacent Armor Plate
Rivets - 2 Diameter, Minus 1/32" Tolerance.

CROMANSIL

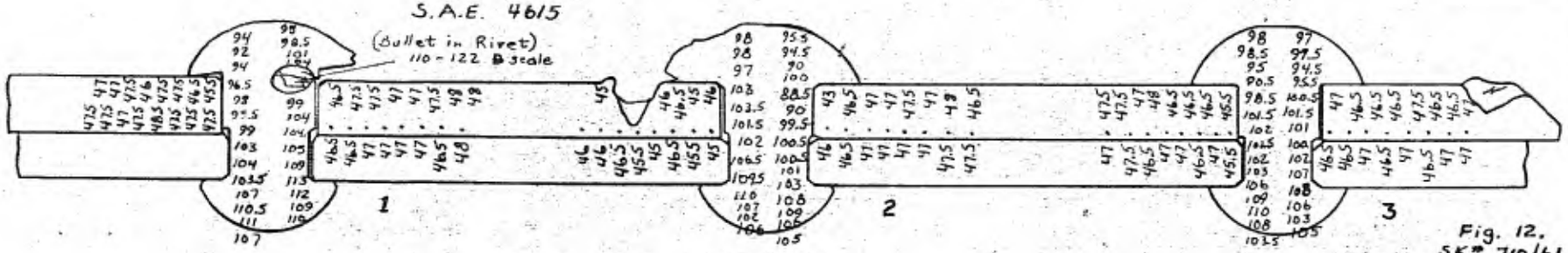


S.A.E. 2315



Hardness Scales.
Rivets - B Scale
Rockwell - 100 KG. Ld
Armor Plate - C.
Scale Rockwell
150KG. Load.

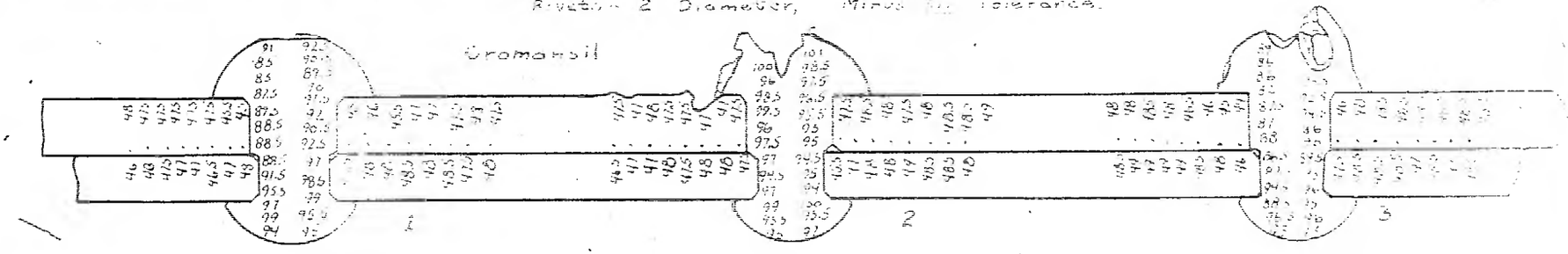
S.A.E. 4615
(Bullet in Rivet)
110 - 122 B Scale

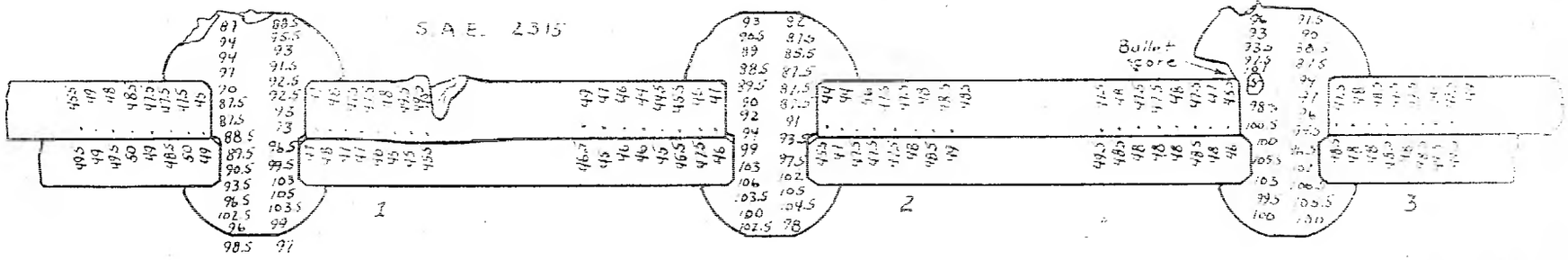


Section I.

Fig. 12.
SK.# 710/61
A.H.

Hardness Tests of Heat Treated Driven Rivets and Adjacent Armor Plate.
Rivets - 2 Diameter, Minus .001" Tolerance.





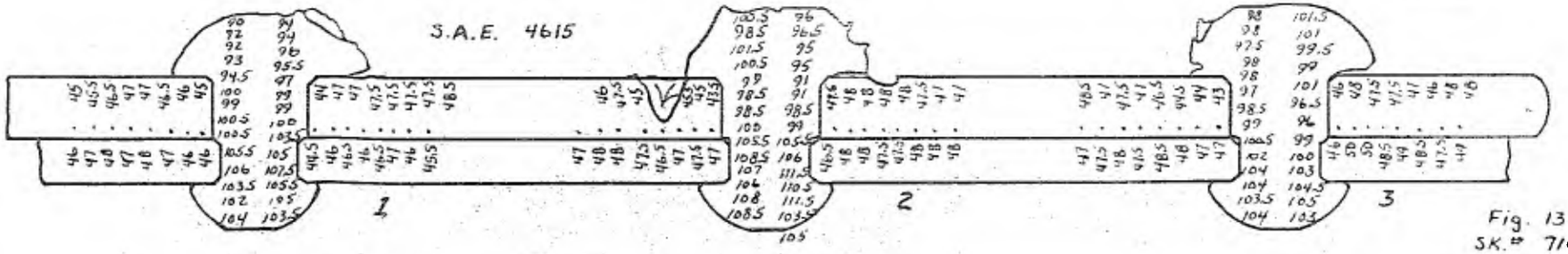


Fig. 13
SK.# 710/62
A.H.

Section 2.

Hardness Tests of Driven Rivets and Adjacent Armor Plate
Rivets made of S.A.E. No. 2315

Straight Shank
minus 1/32" Tolerance

1 2 3

Two Diameter
Minus 1/32" Tolerance

1 2 3

Hardness Scale
Rivets - B Scale
Rockwell
Armor Plate
Scale Rockwell

Two Diameter
Minus 1/64" Tolerance

1 2 3

Section 3

Fig. 14.
SK. 7/10/63.
A.H.

Table 4

Brinell Hardness Tests on Heads of Rivets

Section 1

Rivets - 2 diameter minus 1/32" Tolerance.

Type		Rivet Head As Received	Rivet Head Driven	Increase In Hardness
Chromansil	1	156	(187 F (228 R	(31 (72
"	2	163	(196 F (241 R	(33 (78
"	3	149	(183 F (241 R	(34 (92
SAE No. 2315	1	156	-	-
"	2	156	-	-
"	3	149	(286 F (387 R	(137 (238
SAE No. 4615	1	187	(248 F (352 R	(61 (145
"	2	187	(241 F (364 R	(54 (177
"	3	187	(248 F (302 R	(61 (115

Note: F indicates head of rivet on front plate of riveted section.

R indicates head of rivet on rear plate of riveted section.

Table 5

Brinell Hardness Tests on Heads of Rivets

Section 2

Heat Treated rivets - 2 diameter minus 1/32" Tolerance.

Type		Rivet Head As Received	Rivet Head Driven	Increase In Hardness
Chromansil	1	196	(192 F (228 R	(-4 F (32 B
"	2	196	(187 F (235 R	(-9 F (39 B
"	3	196	(187 F (241 R	(-9 F (45 B
SAE No. 2315	1	255	(207 F (332 R	(48 F (77 B
"	2	302	-	-
"	3	255	(196 F (321 R	(-59F (66 B
SAE No. 4615	1	255	(228 F (302 R	(-27 F (47 B
"	2	255	(235 F (340 R	(-20 F (85 B
"	3	255	(228 F (340 R	(-27 F (85 B

Note: F indicates head of rivet on front plate of riveted section.

R indicates head of rivet on rear plate of riveted section

Table 6

Brinell Hardness Tests on Heads of Rivets

Section 3

Series of SAE No. 2315 Rivets - Tolerances stated below.

Type		Rivet Head As received	Rivet Head Driven	Increase In Hardness
Straight Shank Minus 1/32" Tolerance	1	156	(241 F (302 R	(85 F (146 R
"	2	163	(235 F (311 R	(72 F (148 R
"	3	159	(269 F (302 R	(130 F (143 R
Two diameter Minus 1/64" Tolerance	1	163	(269 F (364 R	(103 F (201 R
"	2	156	(207 F (375 R	(51 F (219 R
"	3	153	(235 F (364 R	(82 F (211 R
Two diameter Minus 1/32" Tolerance	1	163	(196 F (364 R	(33 F (201 R
"	2	159	(217 F (364 R	(58 F (205 R
"	3	156	(241 F (375 R	(85 F (219 R

Note: F indicates head of rivet on front plate of riveted section.

R indicates head of rivet on rear plate of riveted section.

Discussion

The three alloy steels, namely Chromansil, SAE 2315, SAE 4615, which were made up with two diameter buttonhead rivets and hot driven "as received" and after heat treatment in the armor plate sections all exhibited a high degree of ductility during the riveting operations. All rivets were tight before and after the ballistic tests as confirmed by tapping the rivet heads with a hammer.

An examination of the cross sections of the riveted joints of all rivets having a minus tolerance of 1/32" readily showed voids between the upper part of the shank and the hole in the armor plate as illustrated in Figures 15, 16, 17, 18, 19, and 20. Therefore, in order to determine the correct clearance necessary for a satisfactory riveted joint, comparative riveting tests were made on two diameter and straight shank rivets made of SAE No. 2315 composition with minus tolerances of 1/32" and 1/64" respectively.

It was determined that no voids were present in the cross section of rivet sections of two diameter rivets with a minus 1/64" tolerance and straight shank rivets with a minus tolerance of 1/32". Figures 21, 22 and 23.

The two diameter rivet was essentially designed

Figure 15

Cross section of plate riveted with chromansil rivets subjected to Ballistic Test, Section 1, see Figure 3A.

Chromansil rivets as received, minus 1/32" tolerance.

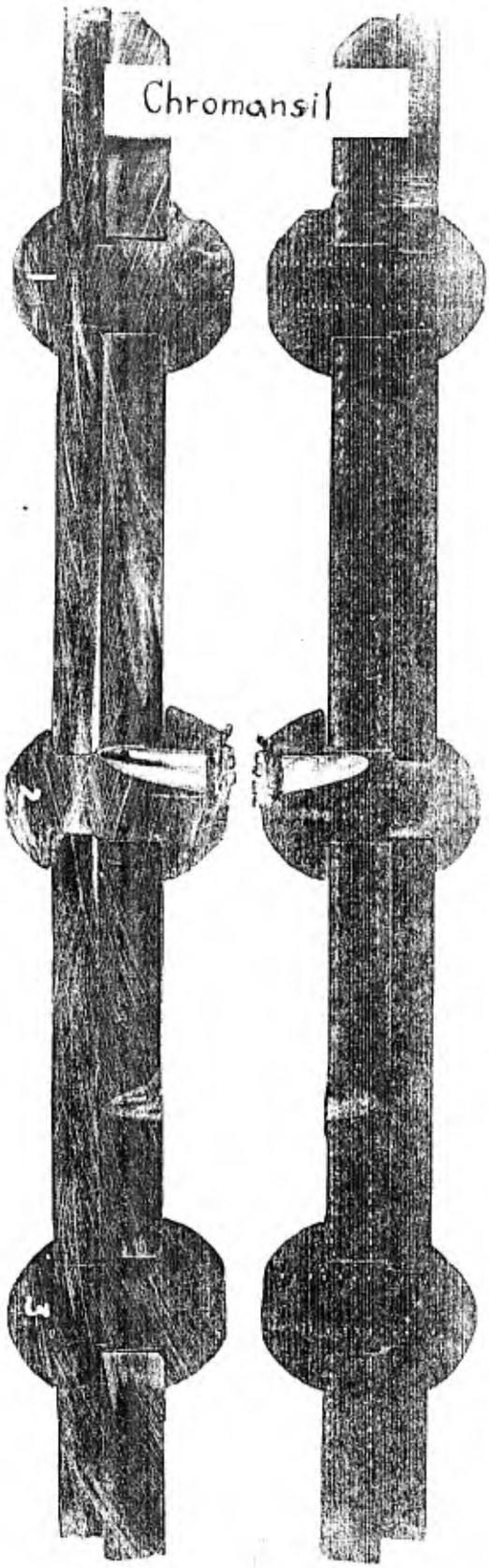


Figure 16

Cross section of plate riveted with SAE 2315 rivets subjected to Ballistic Test, Section 1, see Figure 3A.

SAE 2315 rivets machined from 1 1/2" round bar with minus 1/32" tolerance.

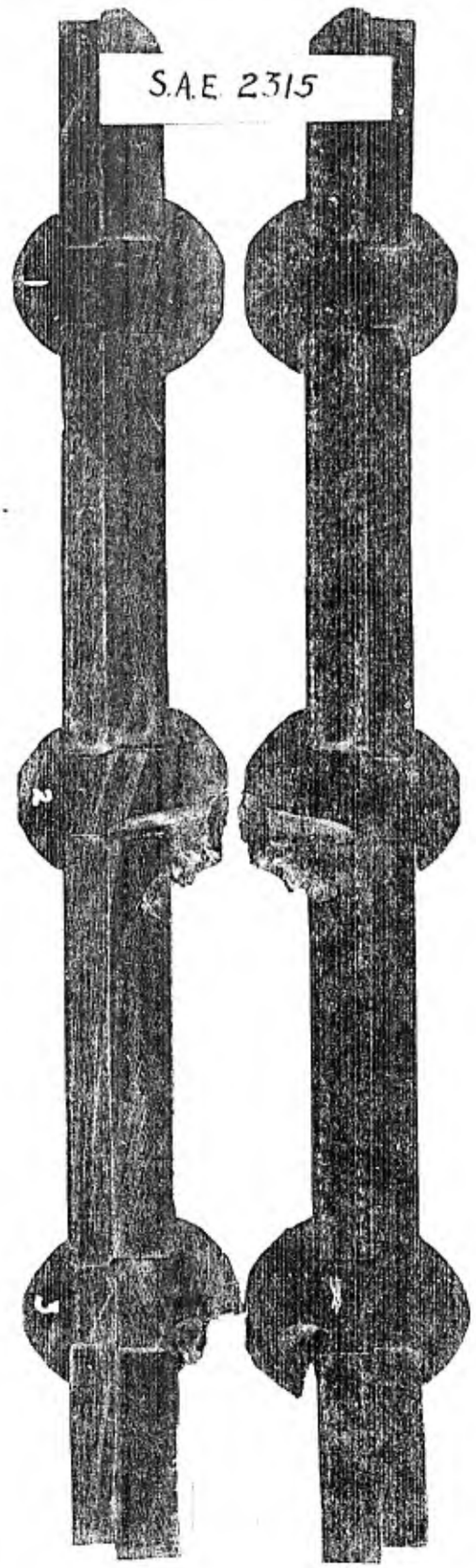
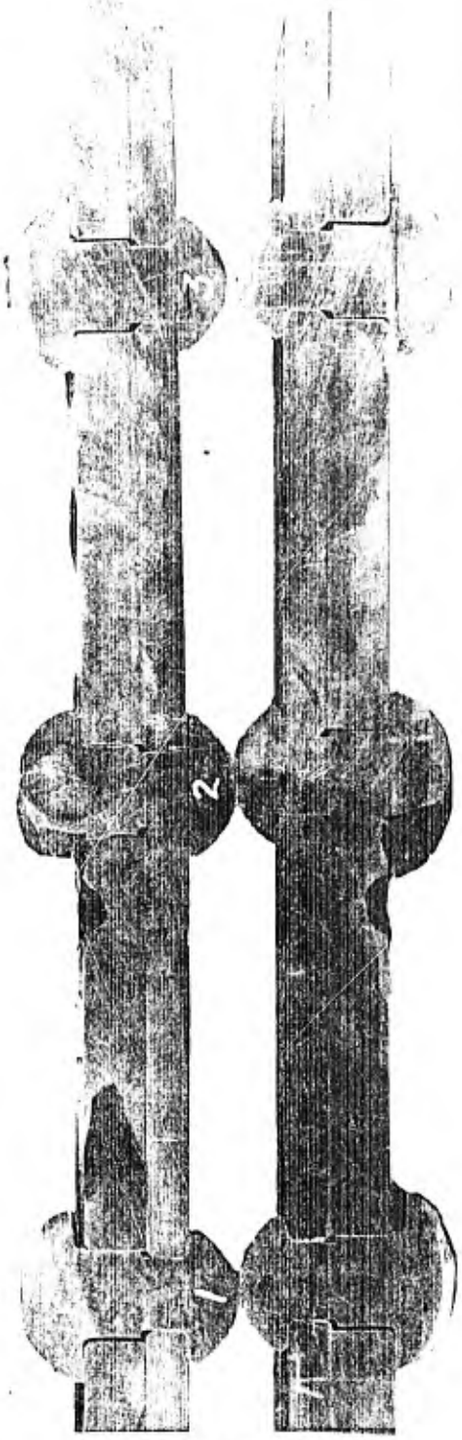


Figure 17

Cross section of plate riveted with SAE 4615 rivets subjected to Ballistest. Section 1, see Figure 3A.

SAE 4615 rivets machined from 1 1/2" round bar with minus 1/32" tolerance.



SAE 4615

Figure 18

Cross Section of Plate

Riveted with heat treated chromansil rivets subjected to Ballistic Test, Section 2, see Figure 5A. Rivets with minus 1/32" tolerance.

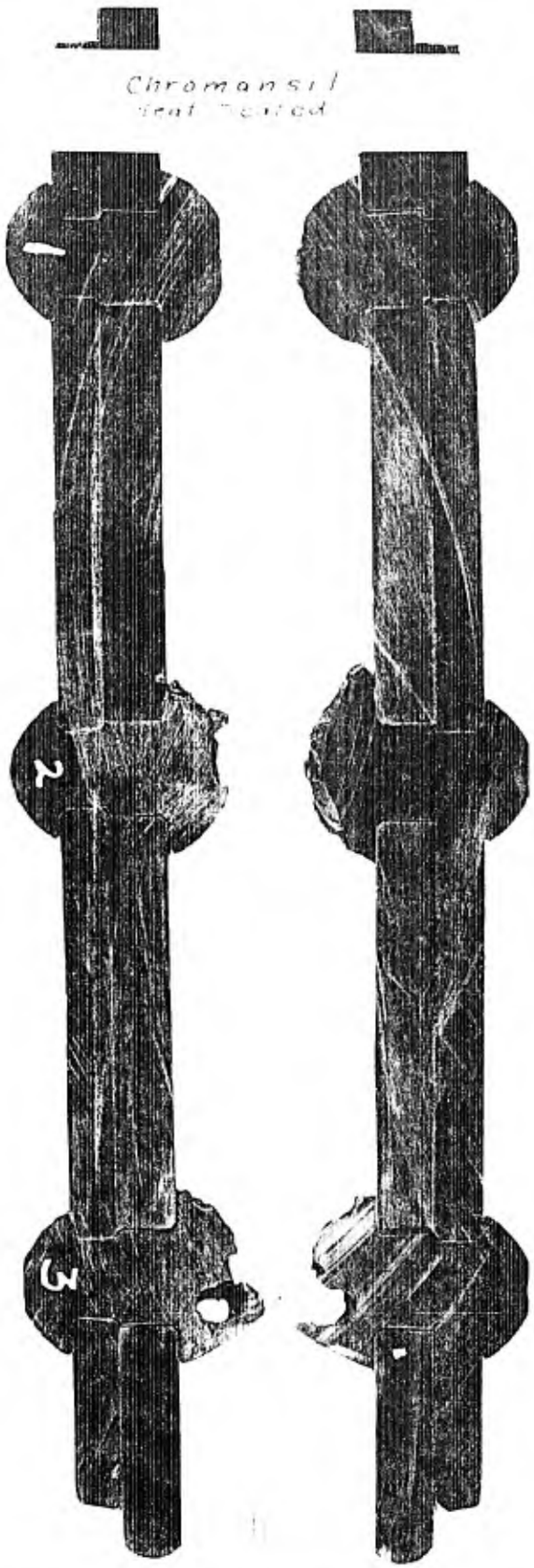


Figure 19

Cross section of Plate riveted with heat treated SAE 2315 rivets subjected to Ballistic Test, Section 2, see Figure 5A. Rivets with minus tolerance of 1/32".

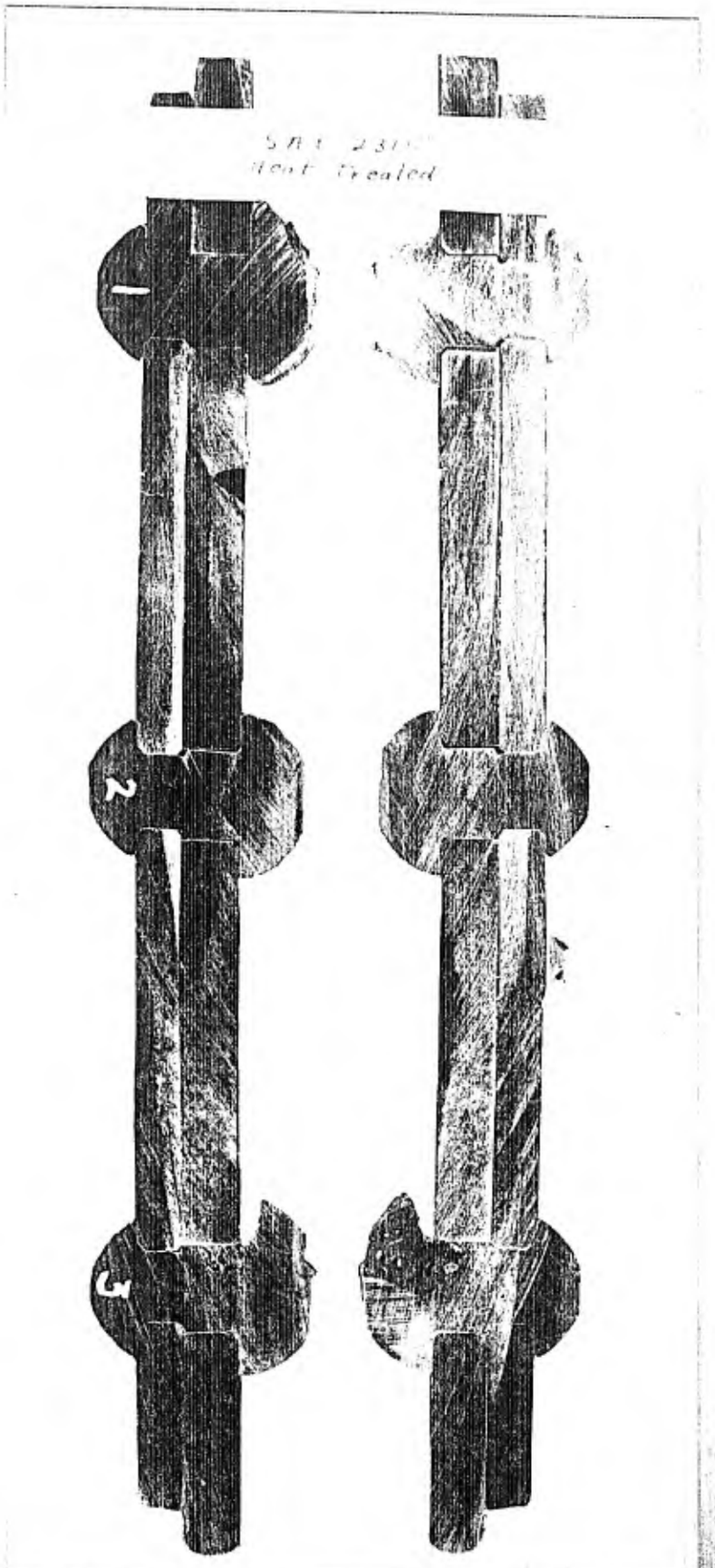


Figure 20

Cross section of plate with heat treated SAE 4615 rivets subjected to Ballistic Test, Section 2, see Figure 5A. Rivets with a minus 1/32" tolerance.

to prevent the forcing out of the shank of the rivet under fire if the rivet head was accidentally shot off.

In all cases under drastic firing tests, it was impossible to shear off the rivet heads of either the two diameter rivets of all compositions or the straight shank rivets made of the SAE No. 2315 composition. In several cases the rivet heads were partially shot away, Figure 7a, or penetrated to a depth of 1 1/16 - 1 1/8", Figure 11. In another case, with the riveted section at an angle of impact of 45 degrees from normal, three bullet cores were driven under the rivet head near the same spot without shearing off the head, Figure 22.

In several cases, some jacket metal and lead splash was detected under the heads and in the voids between the shanks of the two diameter rivets having a minus tolerance of 1/32". In no case was the jacket metal and lead splash found near the lower reduced section of this type of rivet.

Only traces of jacket metal were found under the head of the straight shank with a minus tolerance of 1/32" and the two diameter rivet having a minus tolerance of 1/64".

Results

The results of this investigation indicate that the buttonhead straight shank rivet with a minus tolerance of 1/32" will satisfy the demands in service.

Figure 21

Cross section of plate #2 riveted with straight shank SAE 2315 rivets after Ballistic Test, Section 3, see Figure 7A. Rivets with minus 1/32" tolerance.

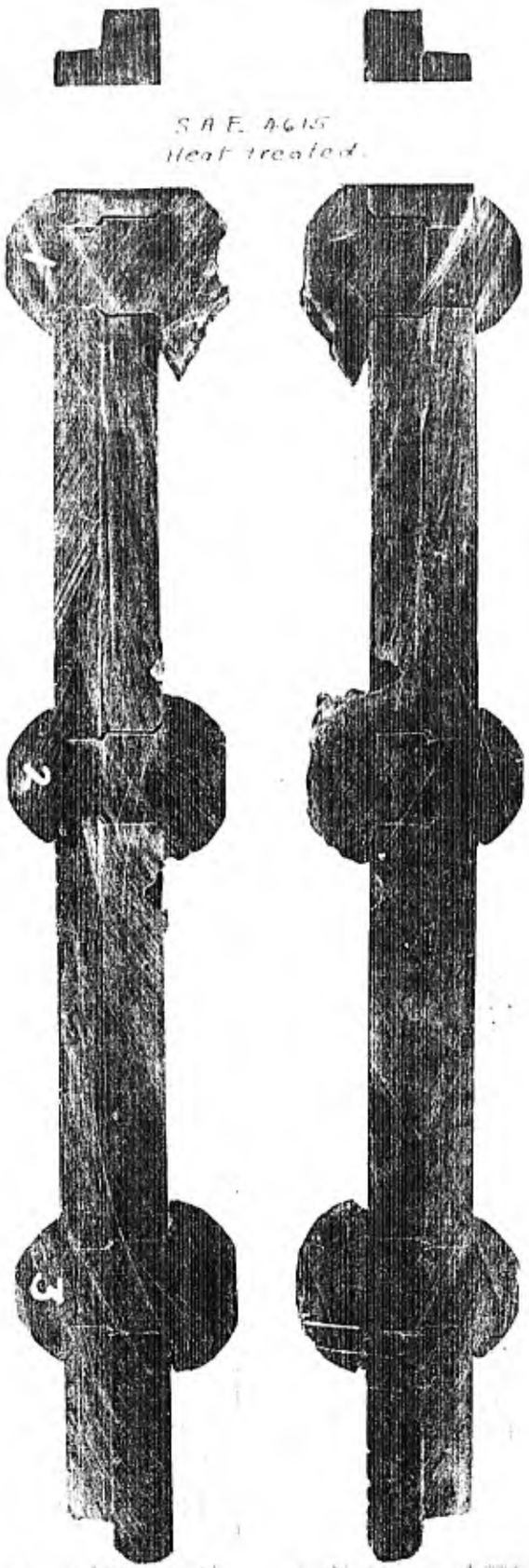


Figure 22

Cross section of plate #3 riveted with SAE 2315 two diameter rivets after Ballistic Test. Section 3, see Figure 7A. Rivets with minus 1/64" tolerance.

The average depth of penetration of the normal impacts of the caliber .30M 1922 A.P. service velocity ammunition in the rivet heads, irrespective of hardness, was 15/16". The armor plate was occasionally penetrated completely, therefore, the ballistic limit of the rivets exceeded that of the armor plate.

Electric heating of the rivet proved to be a satisfactory and efficient method of heating.

The ballistic properties of the heat treated rivets were not superior to those of the rivets "as received".

The SAE No 2315 composition apparently has the greatest air hardening characteristics, although this fact evidently has no bearing on the ballistic properties of this steel.

No marked decrease in hardness was detected in the heat treated armor plate adjacent to the driven rivets as shown in Figures 12, 13 and 14.

A metallographic study of some typical rivets and riveted joints is presented by Mr. Carter in a separate report.

Recommendations

It is recommended that similar tests be made on SAE steels Nos. 4815 and 4820.

Respectfully submitted,

E. L. Reed,
Research Metallurgist

Report No. 710/44-1
Watertown Arsenal

December 10, 1935

Study of Rivets for Construction of Armor Plate Shield. Supplementary Report - Metallographic Study

Four riveted armor plate sections, representative of specimens from the above study, were submitted by Dr. E. L. Reed. The extent of coldwork caused by the penetration of the bullet was desired in specimens R1, R2, and R3. The extent, if any, of structural changes of the armor plate caused by the heat from the hot rivet at the time of riveting, the grain size of the rivet (indicating possible overheating before riveting) was desired in specimen R4.

Conclusions

1. The extent of measurable coldwork caused by the bullet, measured at the bourrelet of the bullet cavity in the rivet specimens were:

   a. R1 .75 mm.

   b. R2 .82 mm.

   c. R3 .52 mm.

2. Little, if any, change of structure was caused by placing the hot rivet in place and heading it.

3. The rivet body had a A.S.T.M. Std's. grain size of 2. It was, therefore, not overheated nor burned.

Discussion

Panorama micrographs were taken at X500 at the bourrelet of the bullet cavity in the rivet specimens. Measurement of the distorted metal was made and given in the conclusions.

Figure 1, Spec. R1
" 2 " R2
" 3 " R3

Study of the armor plate Spec. R4 showed it to be banded somewhat, Figure 4. No marked change in structure was observable at X1000 near the rivet, (.1 mm from the edge of the hole into which the rivet had been inserted).

Normal structure, Figure 5

Near rivet hole, Figure 6

The heating of the rivet for heading caused a grain growth to A.S.T.M. Std. grain size #2 which is not excessive and indicates the temperature was comparatively low, well below the burning range. Figure 7.

Respectfully submitted,

H. G. Carter

Figure 1

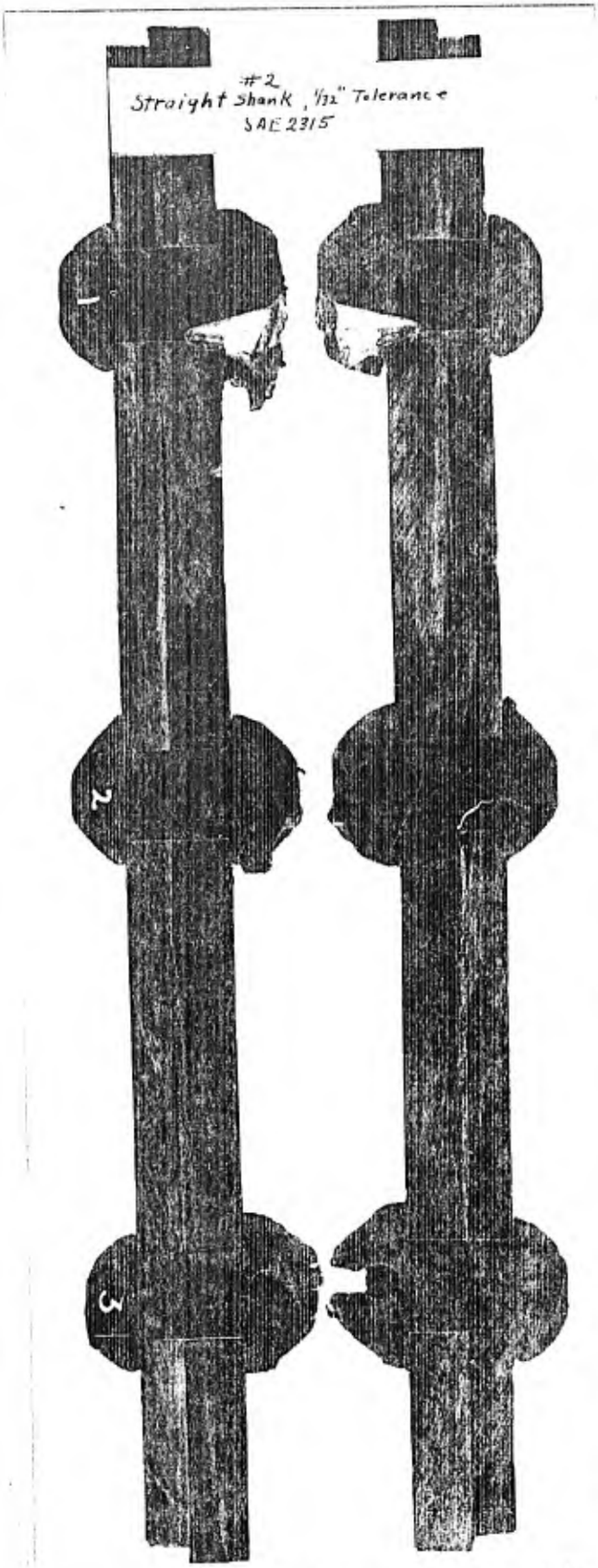
X500, 1% Nital etched Spec. R1 Rivet Head. Bourrelet of bullet cavity coldworked by bullet penetration .75 mm. MA 55

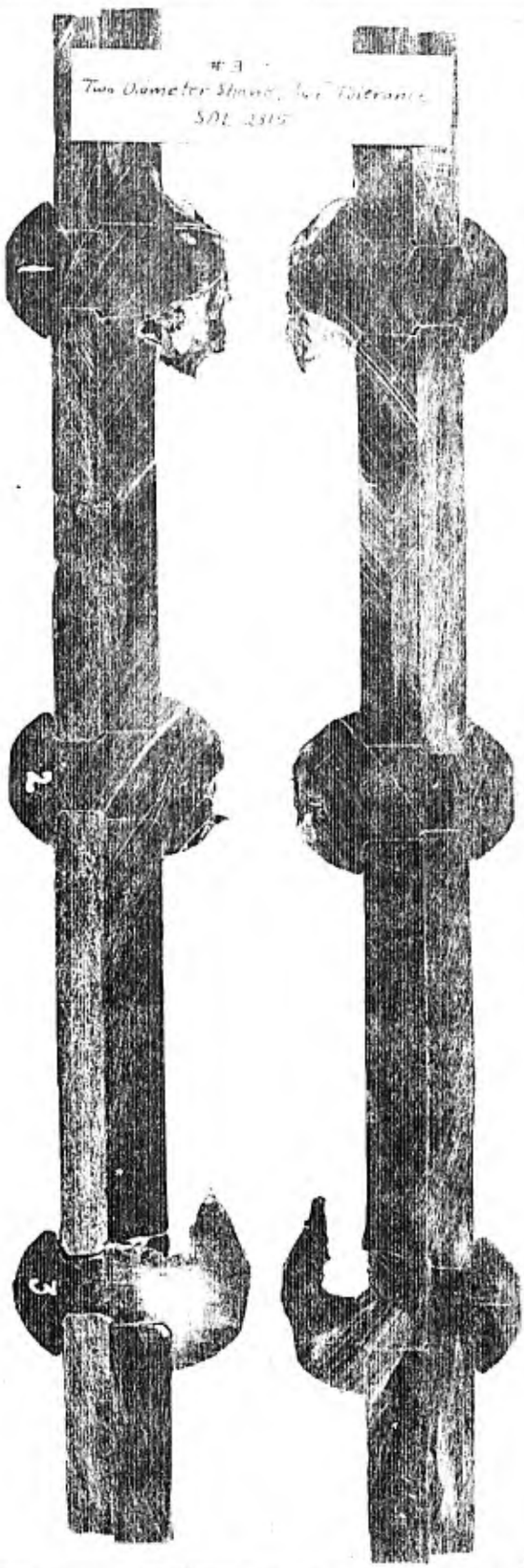
Figure 2

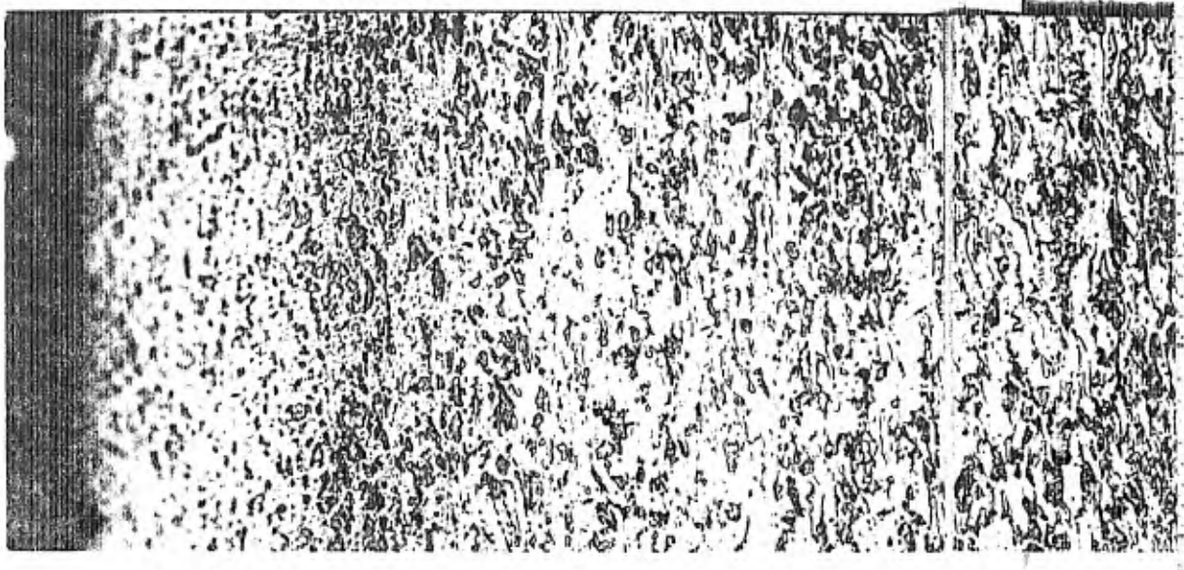
X500, 1% Nital etched Spec. R2 Rivet Head. Bourrelet of bullet cavity coldworked by bullet penetration .82 mm. MA 56

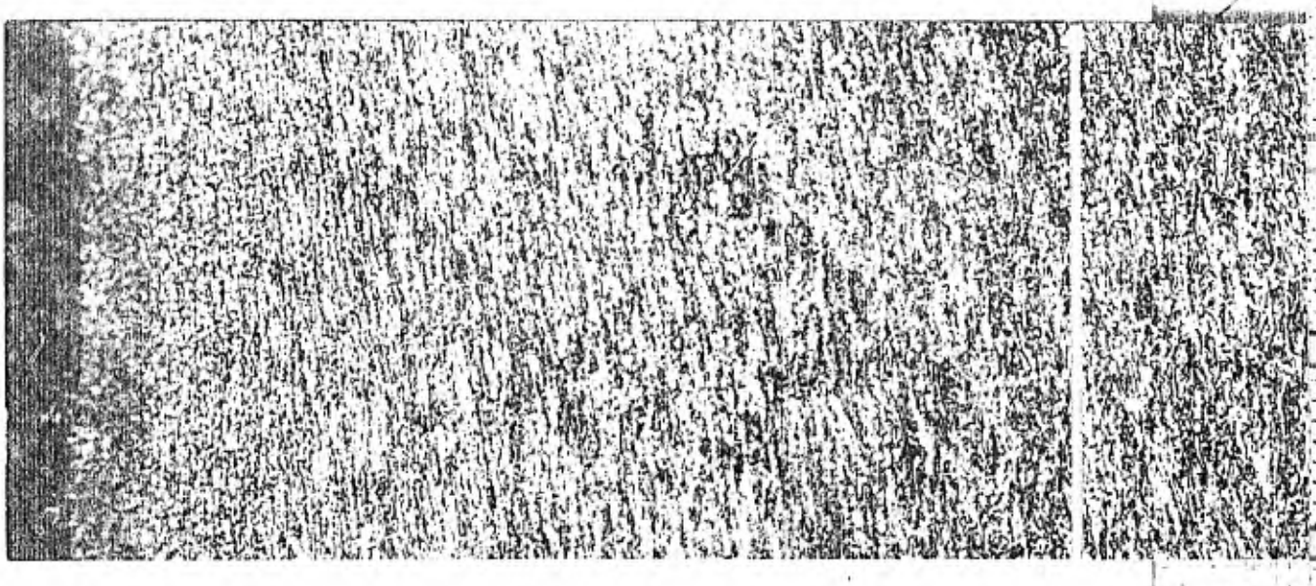
Figure 3

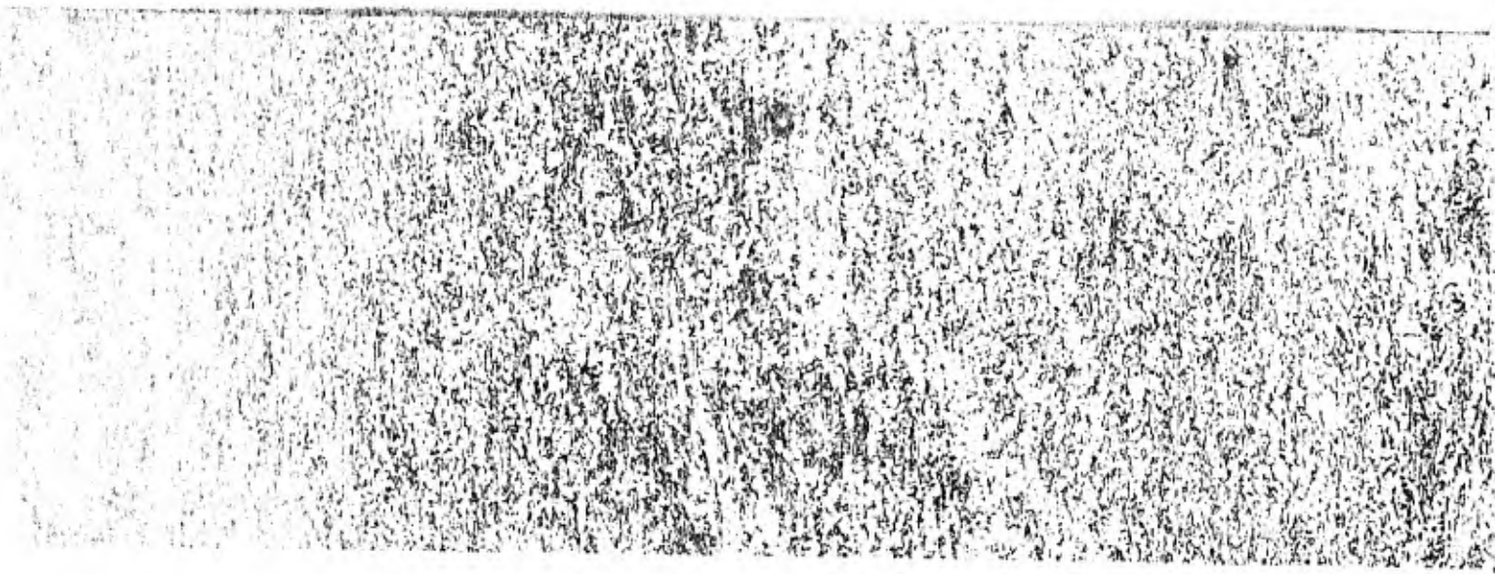
X500, 1% Nital etched Spec. R3 Rivet Head, Bourrelet of bullet cavity coldworked by bullet penetration .52 mm. MA 57

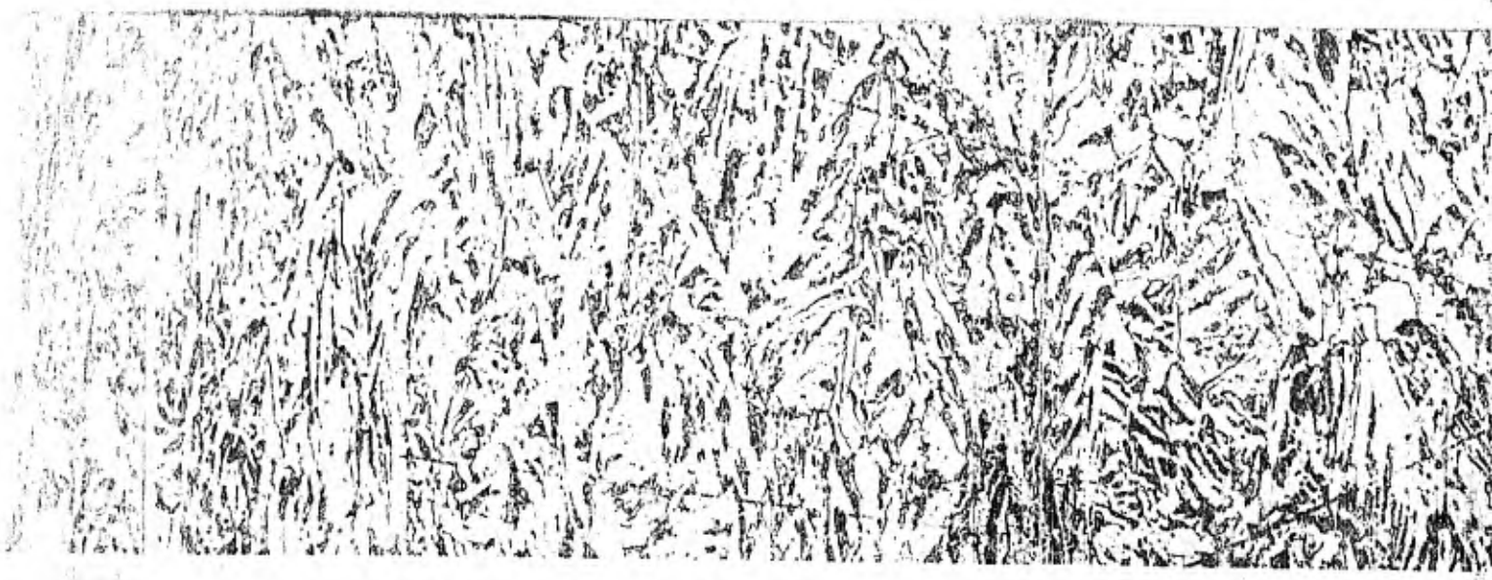












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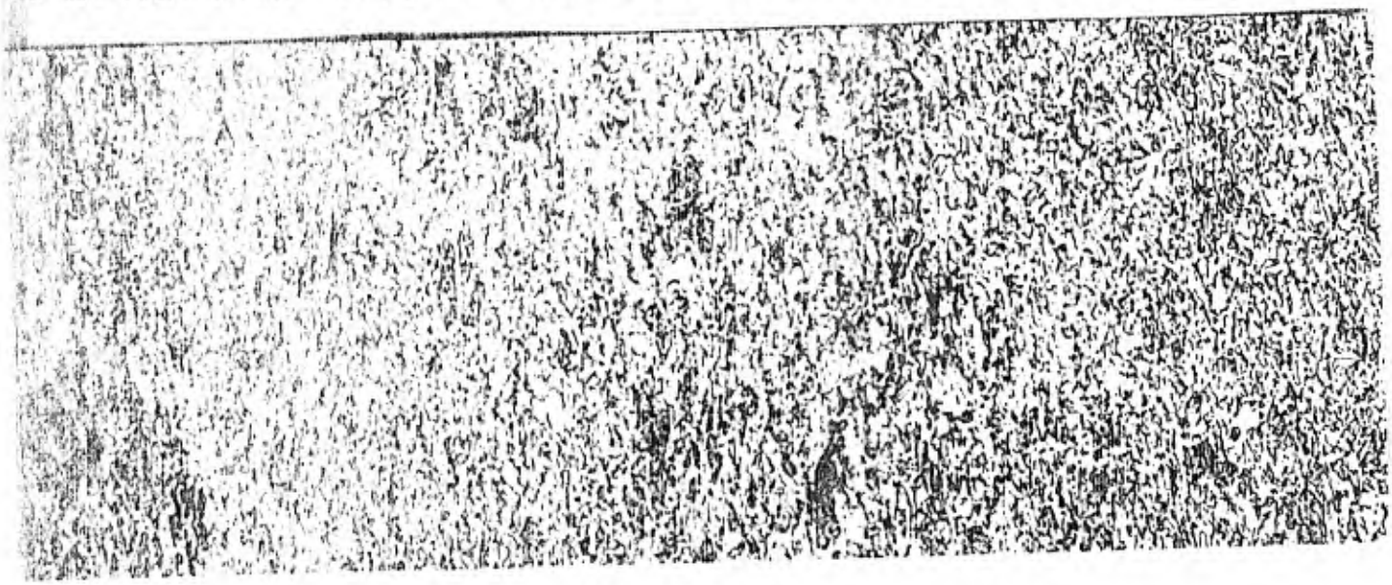


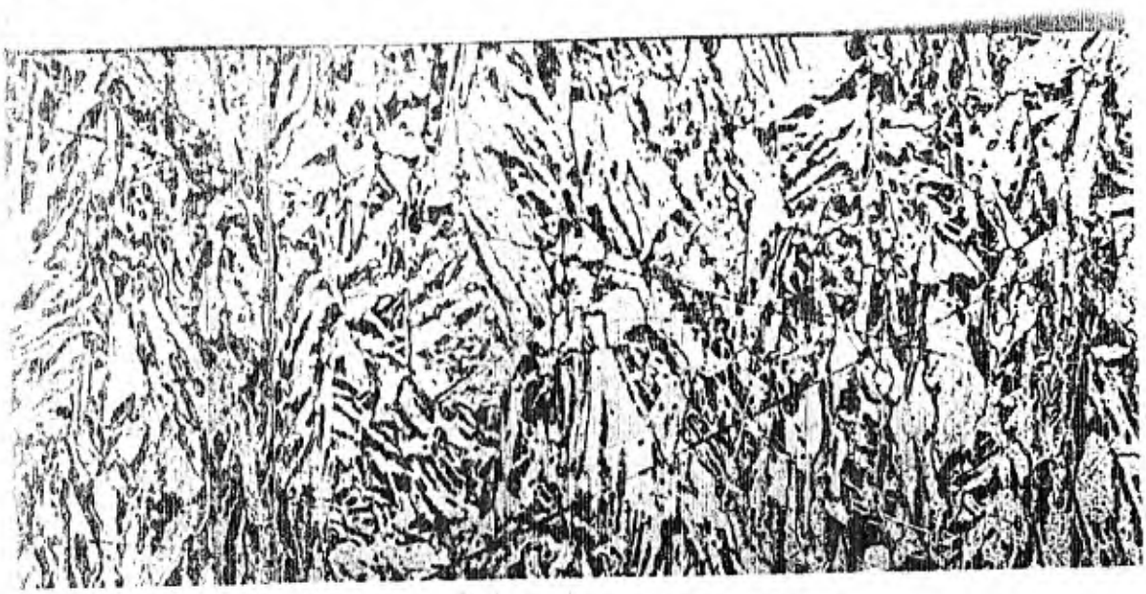
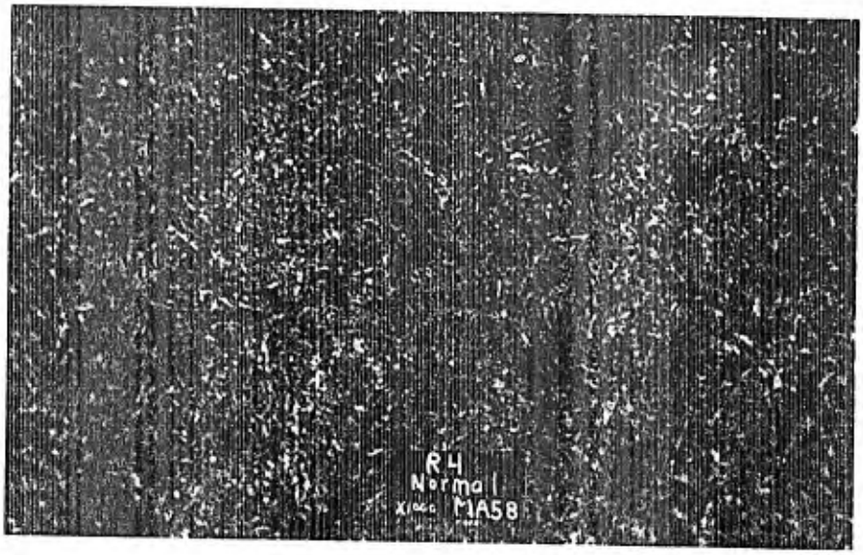


Figure 5

X1000, 1% Nital etched Spec. R4 Armor Plate section.
Normal structure Troostito-Sorbite. MA 58

Figure 6

X1000, 1% Nital etched Spec. R4 Armor Plate section.
Same as Figure 5 except about .1 mm from Rivet Hole. Structure practically the same as Figure 5 e.g. Troostito-Sorbite. MA 59



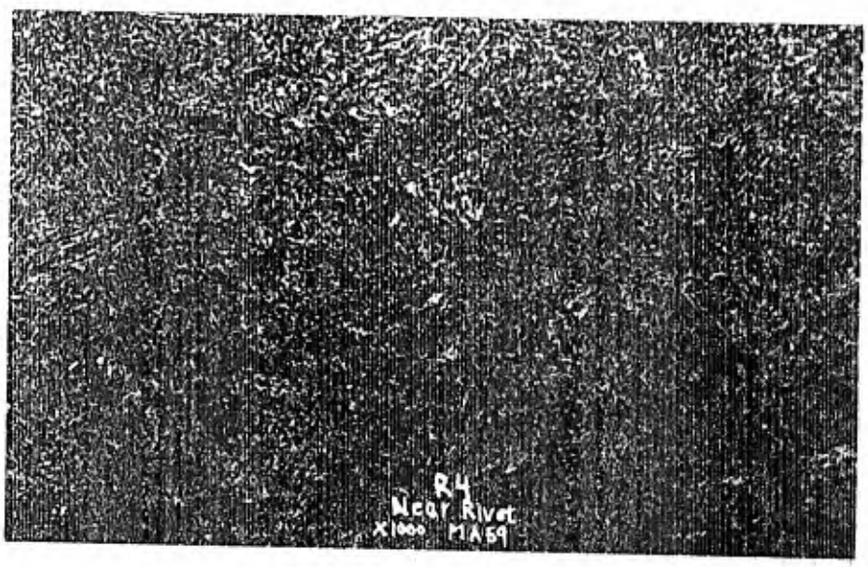


Figure 4

X100, 1% Nital etched Spec. R4 Armor Plate section.
Somewhat banded structure. MA 60

Figure 7

X100, 1% Nital etched Spec. R4 Rivet body. Grain size #2 A.S.T.M. Std. Specimen not overheated.

MA 61