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METALLURGICAL EXAMINATION OF 1/2" COUNTERSUNK RIVETS

by

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November 2, 1941

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Report No. 710/395
Watertown Arsenal
Restricted

November 4, 1941

Metallurgical Examination of 1/2" Countersunk Rivets

Purpose

The purpose of this investigation was to study the metallurgical characteristics of 1/2" SAE 2330 countersunk rivets (60° and 90°) which had been employed in the assembly of an experimental riveted section and tested ballistically at Aberdeen Proving Ground to determine the characteristics of the riveted joint under the impact of armor piercing projectiles.

Introduction

In reference to correspondence O.O. 451.25/9293, A.P.G.451.21/162-156 2nd Ind. dated October 4, 1940, and W.A. 470.5/2421, 470.5/712 1st Ind. dated November 13, 1940, riveted test plate No. 3 was submitted for metallurgical analysis. This plate was made up of an 18"x18"x1/2" face-hardened armor plate riveted to an 18"x18"x1/4" soft steel back plate with ten half-inch rivets with 90° countersunk heads in front, and fifteen half-inch rivets with 60° countersunk heads in front. Both sets of rivets had straight shanks and standard button points on the back. The rivets in this section were fractured and the button points dislodged under the impact of caliber .30 A.P. M2, Cal. .30 A.P. M1922, Cal. .50 A.P. M1, 37 mm. A.P. M51, and 37 mm. A.P. M39

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projectiles.

Conclusions

1. Failure of the rivets in the section under the impact of armor piercing projectiles may be attributed to:

a. Excessive hardness resulting from the relatively high carbon content (0.34%) in conjunction with the nickel alloy content. (See Figure 7.)

b. The absence of filleting at the junction of the shanks and button points of the rivets producing stress concentrations. (See Figure 1.)

Test Procedure and Materials

Test plate No. 3 was made up of an 18"x18"x1/2" face-hardened armor plate riveted to an 18"x18"x1/4" soft iron back plate with 25 half-inch rivets - ten rivets of the 90° countersunk type and fifteen rivets of the 60° countersunk type. The rivets were arranged in five rows of five rivets each. The ten 90° countersunk rivets were placed in two vertical rows at the left of the plate, the fifteen 60° countersunk rivets were placed in three vertical rows to the right. The rivets were evenly spaced on 3" centers. (See Figure 1.) All rivets were made of SAE 2330 nickel steel stock.

Plate No. 3 was tested ballistically on September 27, 1940 at Aberdeen Proving Ground and then sent to Watertown Arsenal for metallurgical analysis.

Results

The individual rivets are numbered, starting at the bottom and to the left as rivet No. 1 and counting to the top. Figure 2 shows the front of the riveted section and Figure 3 the rear after the ballistic tests.

1. Ballistic Test

The results of the ballistic test are given in Table I.

X

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TABLE I

Plate No. 3 - Normal Impacts

Round	Projectile	Striking Velocity	Results
1	.50 Cal. A.P. M1	2044 f/s	Hit one inch left and high from rivet #7. About one third of front head of rivet #7 broken off.
2	"	2043 "	Hit one inch right and high from rivet #7.
3	"	2055 "	Hit one inch under rivet #7, breaking off the front head and loosening rivet #7.
4	"	2065 "	Direct hit on rivet #8, which was knocked completely out.
5	"	1796 "	Hit two inches left and high from rivet #9.
6	"	1787 "	Hit three inches left and low from rivet #9.
7	"	1761 "	Hit one and one-half inches left and high from rivet #9.
8	"	1806 "	Hit at edge of rivet shank #9. The projectile knocked four-fifths of front head of rivet #9 off, lodged in the plate, and caused a bulge in the soft iron back plate which pried the button point of the rivet off. The shank of the rivet stayed in place.
9	"	1781 "	Hit edge of front head of rivet #10. No observed effect other than small indentation.
10	"	1834 "	Hit two inches left and high from rivet #10.
11	"	1848 "	Hit one and one-quarter inches left and high from rivet #10. Button point of rivet #5 (directly above rivet #10) broke off.
12	"	1812 "	Hit one inch low and right from rivet #10. Most of the front head of rivet #10 broke off.

TABLE I (CONT'D)

Round	Projectile	Striking Velocity	Results
13	.30 Cal. A.P. M2	2369 f/s	Hit between rivets #1 and #2.
14	"	2379 "	Hit three inches low and right from rivet #6.
15	"	2446 "	Hit one and one-half inches high and right from rivet #6.
16	"	2448 "	Hit on round #15 impact.
17	"	2447 "	Direct hit on rivet #6 which was knocked completely out.
18-50	.30 Cal. A.P. M1922	Service	Machine gun burst at lower half of plate. No rivets hit.
51-84	.30 Cal. A.P. M1922	Service	Machine gun burst at lower half of plate. Rivet #19 knocked out and through a three-quarter inch plywood backstop. One-third of front head of rivet #21 broken off.
1	37 mm. A.P. M51	1600 f/s approx.	Fired at 20° obliquity, between rivets #3 and #13. Projectile went through plate. Button point of rivet #14 and front head of rivet #15 broken off.
2	"	"	Fired at 20° obliquity, between rivets #11 and #12. Projectile went through plate. Button point of rivet #16 and front head of rivet #21 broken off. Rivet #11 taken out by projectile.
3	37 mm. A.P. M39	"	Fired at 20° obliquity, between rivets #13 and #18. Projectile went through plate. Button points of rivets #24 and #18 broken off.

2. Chemical Analysis

	C	Mn	Ni
Specification SAE 2350	.45/.55	0.60/0.90	3.25/3.75
Rivet #13	.34	.61	3.62
Rivets #3 and #4	.34	.70	3.50

These analyses indicate that the rivet material was of SAE 2330 grade and not SAE 2350 as supposed.

3. Microscopic Examination

The following rivets were examined: #3 and #4, 90° countersunk heads, and #13, #16, and #22, 60° countersunk heads. Both rivets #3 and #4 were fractured at the junction of the countersunk head and the shank, while rivet #16 was fractured at the junction of the button point and the shank. Rivets #13 and #22 were not fractured. No cracks were found in any of the rivets other than the fractured surfaces, and no laps or seams were found under the button points of the rivets examined. No allowance was made for the formation of adequate fillets under the button points and consequently sharp corners were formed which were made more dangerous from the standpoint of stress concentration by surface grain boundary oxidation resulting from heating the rivets prior to driving and also by numerous strain lines in the vicinity of the corners. (See Figures 4a and 4b, X100.)

All rivets examined showed marked variations in grain size. (See Table II.)

TABLE II

Location	A.S.T.M. Grain Size				
	Rivet No. 3	No. 4	No. 13	No. 16	No. 22
Countersunk Head	-	-	4-5	4	4
Shank	4	4-5	3	3-4	3-4
Outer Zone - Button Point	2-3	2	1	-	2
Inner Zone - Button Point	7	7	7-8	-	7-8

Figures 5a and 5b, X3, illustrate the variation in grain size over the cross-section of the rivets, and also the lack of proper fillets under the button points. The microstructure is decidedly martensitic. Figure 6, X250, shows the relatively coarse martensitic structure of the shank of rivet #13. This martensitic condition is typical of all the rivets examined.

4. Rockwell Hardness Tests

Hardness surveys were made along the cross-sections of the five rivets studied using the Superficial Rockwell Hardness Tester with a 30 kg. load and the N-Brale penetrator, and converting the results to their corresponding Rockwell C values. Figure 7 shows that the hardness of the rivets varied from 49 to 56 Rockwell C.

Discussion

In spite of the fact that the rivet stock was much below the specification for carbon content, the rivets were brittle because of the high hardness resulting from the chilling induced by the plate metal surrounding the rivet as it was being driven. A carbon content

of 0.34% in conjunction with the nickel content is too high for satisfactory ductility under the cooling conditions present.

To provide for satisfactory shock resistance, some provision, such as, countersinking the rivet holes in the back plate should be made to allow for generous filleting at the junction of the shank and the button point. In this connection reference should be made to the Memorandum Report W.A. 719/373 entitled "Cold Heading versus Hot Heading and Rivet Design", dated July 8, 1941, in which it was recommended that all rivets used in armor fabrication be provided with generous fillets.

Respectfully submitted,

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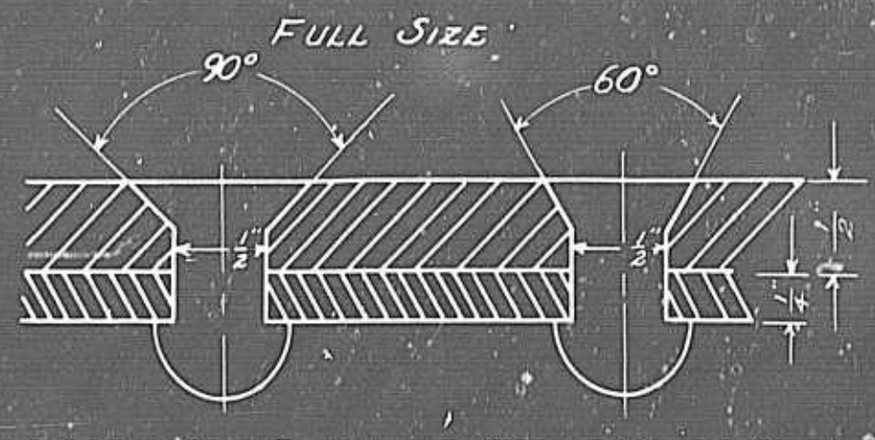
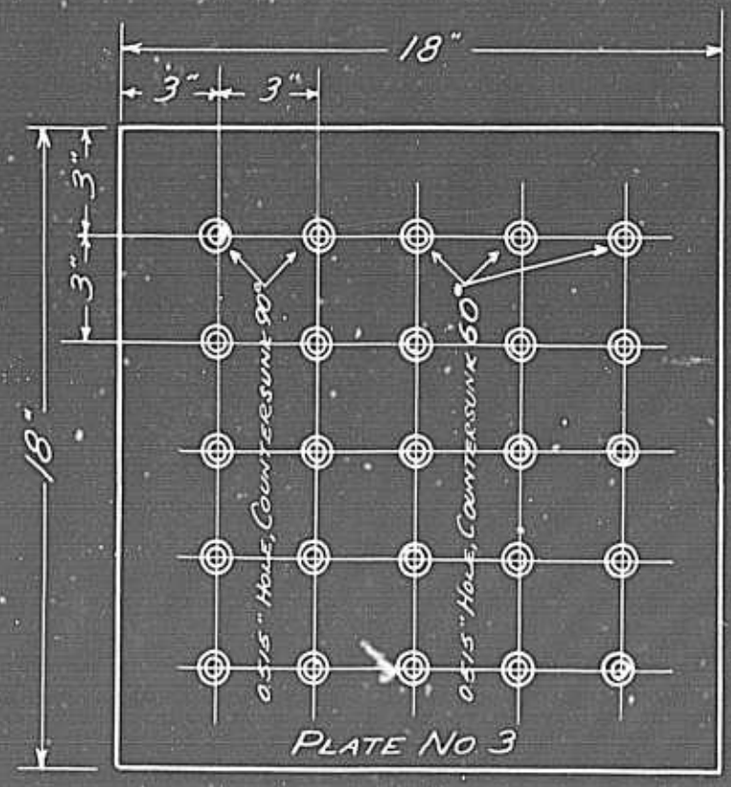
APPROVED:

S. B. Ritchie,
Lt. Col., Ord. Dept.,
Director of Laboratory.



LEFT TWO ROWS RIGHT THREE ROWS

RIVETS IN PLATE #3



SCALE $\frac{3}{16}$" = 1"

FIG. 1

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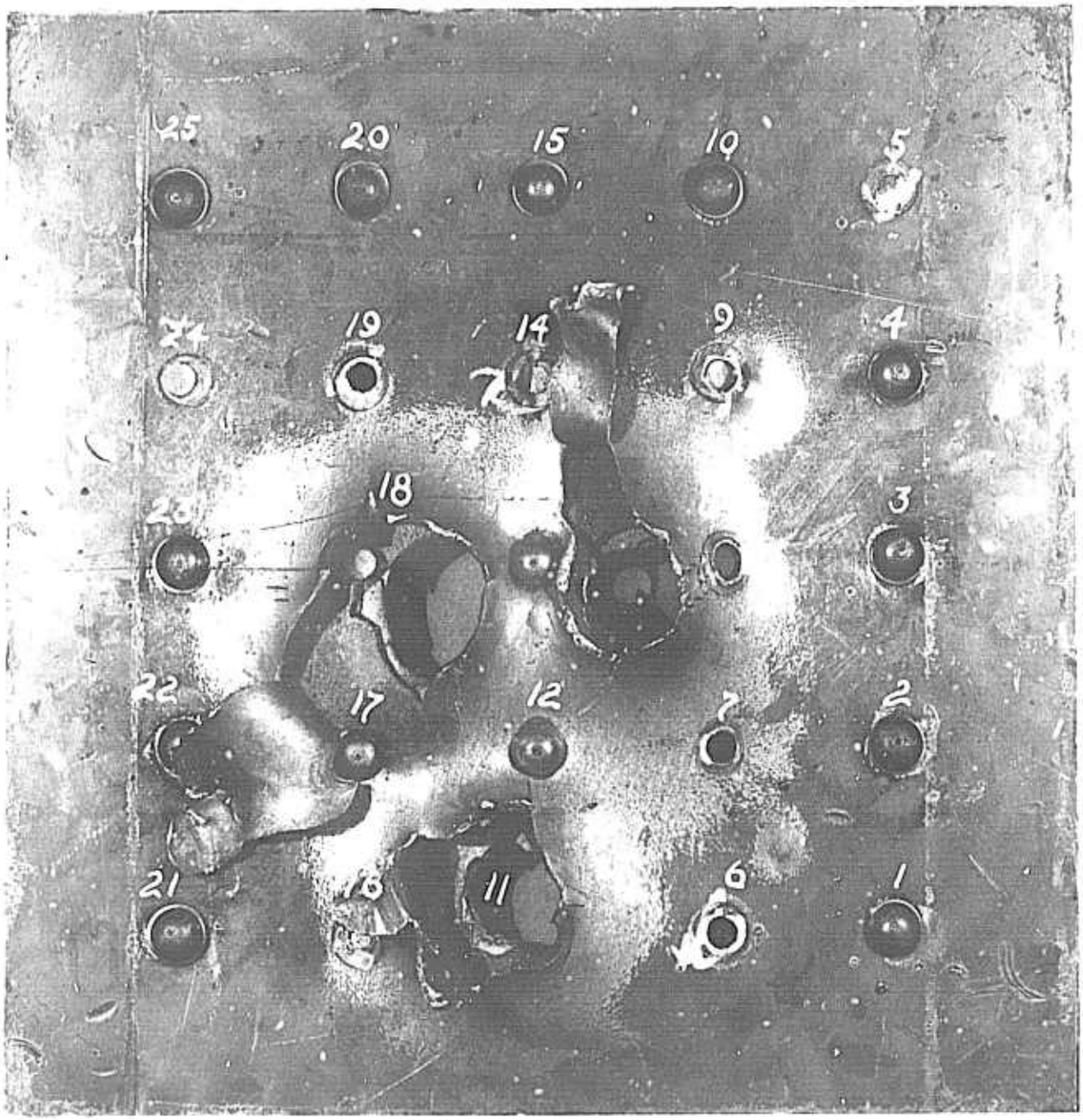
WATERTOWN ARSENAL
3/4" Riveted Armor Plate
April 3,1941 W.A.710-1116

FIG. 2



WATERTOWN ARSENAL
3/4" Riveted Armor Plate
April 3,1941 W.A.710-1117

FIG. 3

Figure 4

Microstructure of Rivets

(a) Junction of shank and rivet head of rivet #4 showing absence of adequate fillet.

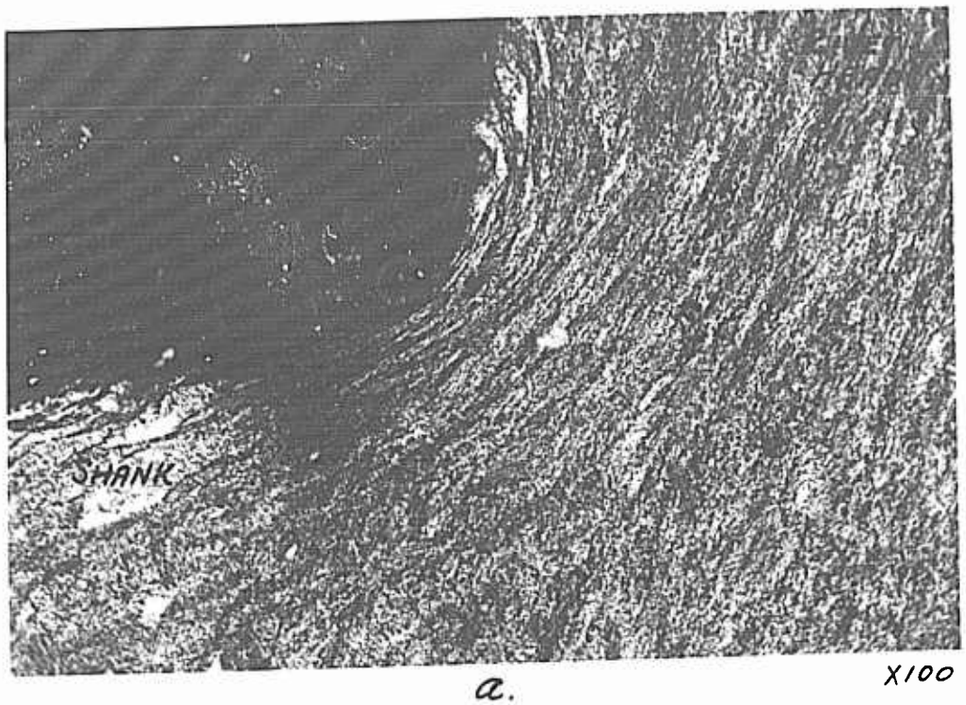
X100 MA-3359

(b) Junction of shank and rivet head of rivet #22 showing absence of adequate fillet. Grain boundary oxidation at rivet surface intensifies poor stress resisting qualities in this area.

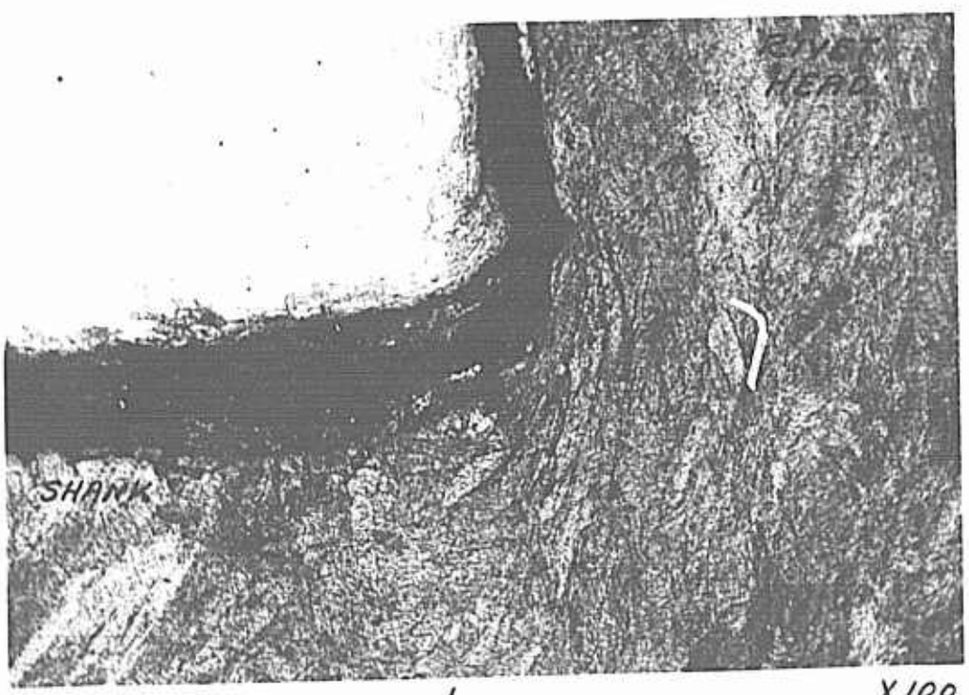
X100 MA-3353

Figure 4.

MICROSTRUCTURE OF RIVETS



a. X100



b. X100

Specimens etched with Vilella's reagent.

W.A.639-3633

Figure 5

Macrostructure of Rivets

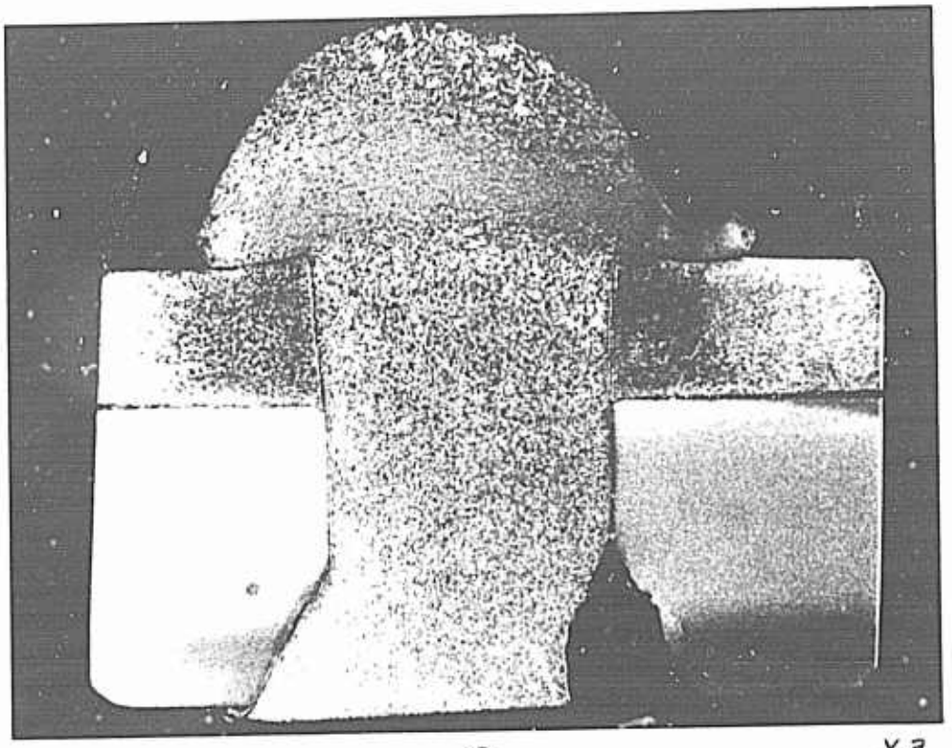
(a) Rivet #22, showing variation in grain size over the cross-section of the rivet. Note sharp corners at junction of shank and button point caused by lack of allowance for adequate fillets.

X3 MA-3356

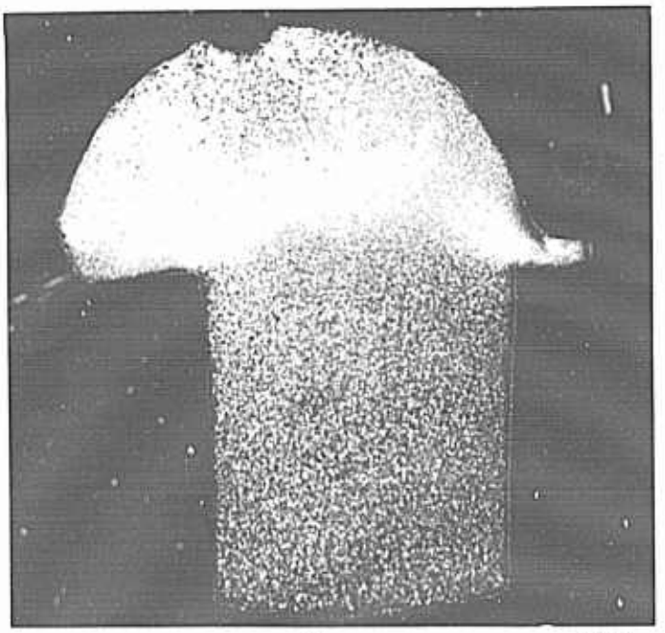
(b) Rivet #3-1. - The variation in grain size over the cross-section of the rivet is typical of all rivets studied. The outer zone of the button point is very coarse grained, the inner zone of the button point is very fine grained, while the shank and the countersunk head are medium coarse to medium fine grained.

X3 MA-3360

Figure 5.
MACROSTRUCTURE OF RIVETS



a. X3



b. X3

Specimens etched with Vilella's reagent. W.A.639-3634

Figure 6

Microstructure of Rivets

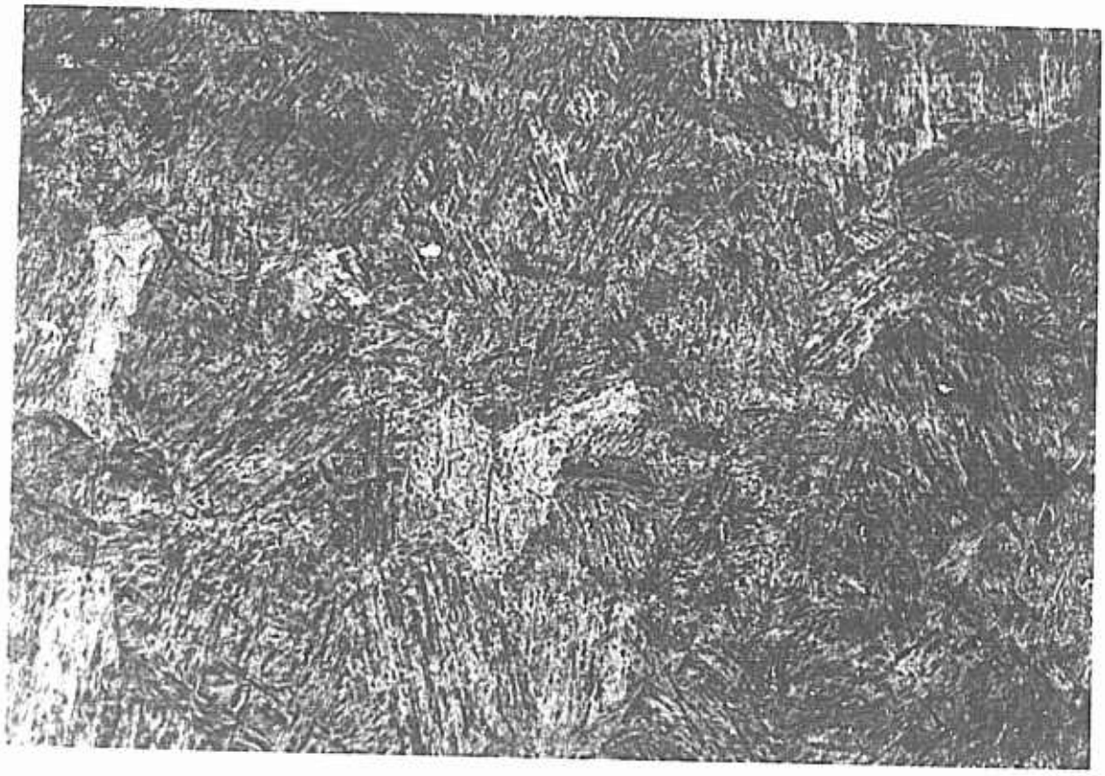
Rivet #13

Medium coarse martensitic structure in shank of rivet #13. This martensitic structure is typical of the microstructure of all rivets examined.

X250 MA-3357

Figure 6.

MICROSTRUCTURE OF RIVETS



X 250

Specimen etched with Vilella's reagent.

W.A.639-3635

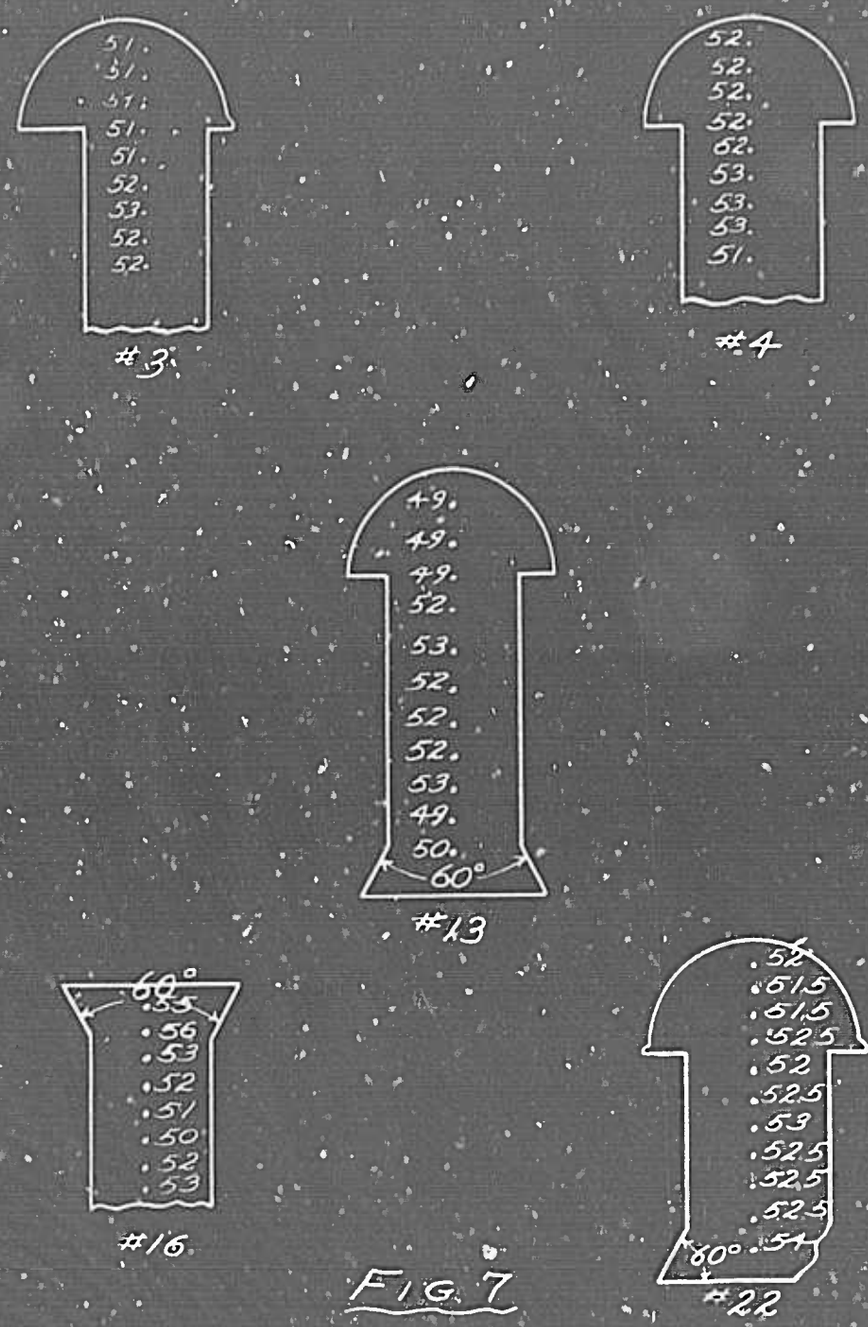


FIG. 7

HARDNESS READINGS TAKEN WITH
SUPERFICIAL ROCKWELL HARDNESS TESTER
30 KG. LOAD N-BRALE PENETRATOR
CONVERTED TO ROCKWELL "C" SCALE
READINGS 0.1" APART

W.A.F.T.J. 8-14-41