# NATIONAL BUREAU OF STANDARDS REPORT

9417

## EXAMINATION OF TYPE 431 STAINLESS STEEL ALLOY T-BOLTS USED IN MARMAN V-BAND COUPLINGS

By
W. F. Gerhold

To
Materials Division
Air Systems Command
Department of the Navy
Project Number RRMA 2122

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Examination of Type 431 Stainless Steel Alloy T-Bolts Used In Marman V-Band Couplings

<u>References</u>: (a) NBS Report No. 8361, "Failed Marman Type Clamps From A Model J79 Engine S/N 62-12184 and S/N 62-12189", dated June 8, 1964.

(b) NBS Report No. 9077, "The Examination of a Failed 431 Stainless Steel alloy T-Bolt (Marman Clamps)", dated April 1, 1966

(c) Bureau of Naval Weapons letter RRMA-223: GMY/58, dated 10 June 1964.

<u>Introduction</u>: Numerous failures in service of type 431 stainless steel alloy T-bolts used in Marman V-band couplings have prompted the comprehensive examination reported herein. Of the three failures examined at NBS, two were attributed to stress corrosion, Reference (a) and one to stress corrosion and fatigue, Reference (b). In each instance, well defined carbide layers were noted at the peripheral areas and at areas in and adjacent to secondary cracks in the bolts examined. These bolts were identified as having been manufactured prior to November 1962.

Subsequent to examination of the aforementioned bolts, the Naval Air Station at North Island found an unsatisfactory bolt lot. Reference (c) requested that bolts in this lot be examined to determine whether they were unsuitable as a result of marginal heat treating practice or other material conditions.

<u>Material</u>: Two Marman couplings, each with a type 431 stainless steel alloy T-bolt from the lot of unsatisfactory bolts were submitted for examination. The bolts were labeled North Island, lot 1, items a and b for identification purposes in this report.

Prior to completing the examination of the North Island, lot 1 items, additional materials were submitted for examination. These included the following:

1. Bolts from various stages of manufacture.

2. Bolts removed, under AFC(change) 200, from aircraft that had never flown.

3. Bolts from production lots.

4. Experimental bolts.

To facilitate examination, the material was sorted into groups identified by modification (Mod) numbers. The Mod numbers assigned are related to various head stamp markings, slotted grooves and dimples on the thread end and thread dye markings. The markings originally established the approximate date of manufacture and processing procedures employed.

Table 1 lists all of the known dates of manufacture, identifications, processing variables and heat treatment for each Mod. Mods 1 through 8 include production bolts still in use. Mods 9X through 17X are experimental materials. Mod 13X, 14X and 15X were subjected to the first stages of processing given Mod 7 bolts. No materials were submitted from the Mod 4 category.

Each of the bolts submitted was labeled by lot and item number for additional identification purposes. Table 2 includes a summarization of the materials by lot, item, number of pieces and appropriate Mod number.

Bend Tests: Guided bend test were performed on representative bolts from each lot with the exception of lot 1, 5, (item c) and 6. The results obtained from these tests are given in Table 3. The bend tests performed on bolts from lot 2 were of an unrestrained nature, while tests on bolts from all of the other lots tested were performed with the bolts held rigid at the "T" head and at the threaded end. The specimens were bent until failure occurred and the maximum bend angle obtained was recorded. All bend test specimens failed at the last thread of the bolt shank.

There did not appear to be any significant trend in bend angles other than that obtained for the ¼ inch-28 bolts from Mods 7 and 8. For these bolts the bend angles were 10 degrees and 15 degrees, respectively. The bend angle for 10-32 bolts from Mod 7 was higher (17 degrees). For materials from lots 4 and 5, processed in accordance with conditions specified for Mods 1, 2 or 3 and 5 or 6, the bend angles varied between 10 degrees and 30 degrees.

The lower structural yield load values obtained for some of the bolts may be attributed to a notch effect at the last thread on the shank.

Bolts taken from any of the Mods, when clamped at the shank end in a bench vise, were capable of being bent through an angle of 180 degrees at the unthreaded shank, without failure. Marman Process Bulletin MPB 200.030 C specifies that the bolts shall be capable of being bent without failure to an angle of 90 degrees over a mandrel having a diameter twice that of the bolt shank.

Tensile Tests: Tensile tests were performed on bolts from each lot, with the exception of those from lots 1 and 2. The tensile tests were conducted in accordance with ASTM specification A-370-64, Supplement III, Steel Fasteners. The maximum load to produce failure and the total elongation of each bolt tested are given in Table 3.

Marman MPB 200.030 C specifies, for 180 Ksi bolts, minimum tensile values of 3600 lbs and 6552 lbs, respectively, for 10-32 and ¼-28 bolts. The total elongations specified are 0.058 inch minimum for a 10-32 bolt and 0.077 inch minimum for a ¼"-28 bolt.

The results of the tensile tests show that 2 bolts from lot 4 and 3 bolts from lot 5 failed to meet the minimum tensile requirement for ¼-28 bolts. These bolts were from lots that had been removed from F-4 aircraft (under AFC (change) 200). These bolts were processed in accordance with the procedures specified for Mods 1, 2 or 3 and had been manufactured prior to May 31, 1962.

All of the other bolts tested had tensile properties within specification limits.

There was no significant improvement in the tensile properties of bolts that had been shot peened or Harperized (Lot 7, items 2, 3 and 4).

Lot 8 bolts showed a decrease in breaking load and an increase in elongation over that obtained in testing bolts of the same Mod number from lot 3, item a; lot 4, item c; and lot 5, item c.

Hardness: Knoop hardness (500g load) determinations were made on transverse sections cut from the unthreaded shank areas of representative bolts from each lot. These determinations converted to Rockwell C, are given in Table 3. The first value was obtained at areas adjacent to the specimen edge and the second value was obtained from an area adjacent to the center of the specimen.

A hardness of 45 Rc maximum and an ultimate tensile strength of 180,000 psi minimum are specified for 431 stainless steel alloy T bolts in Marman Process Bulletin MPB 200.030c. The hardness for a tensile value of 180,000 psi is approximately Rc 39.

Using hardness values as criteria for acceptance in procurement, a hardness, Rc 37, for one bolt from lot 3, item b and a high hardness, Rc 47, for one bolt from lot 7, item 1, may or may not be cause for rejection, inasmuch as these values were obtained from areas adjacent to the surface only. The extremely low hardness values obtained for the two bolts from lot 4 and the three bolts from lot 5 that failed to meet the minimum tensile requirements would definitely be cause for rejection. By comparing the hardness obtained for lot 6, items 1 and 2 (annealed material) with the hardness of two bolts from lots 4 and 5 it appears that the latter were still in the annealed condition. The higher hardness, Rc 22-29, obtained for the other bolt from lot 5 indicates that this bolt had received insufficient heat tratment or had been tempered in the temperature range of 1040° to 1125°F. This is a higher tempering temperature than that specified for a 180 ksi bolt, but, may be normal for a 125 ksi bolt, (hardness Rc 26-34). The hardness of all of the other bolts examined was within the limits specified for a 180 ksi bolt.

<u>Metallographic Examination</u>: Sections were cut from bolts from each lot for metallographic examination.

Examination of transverse sections, obtained from unthreaded shank areas of bolts from lot 1, items a and b, revealed that the microstructure was tempered martensite with no evidence of delta ferrite, Figure 1. After repolishing and etching of the same sections, carbides were found randomly distributed throughout the sections. However, the carbides were more abundant at the bolt periphery than at the bolt center, Figures 2a and 2b. The carbide distribution in these bolts was similar to that noted and previously discussed for the failed bolts. As noted in Table 2, these bolts were identified as having been manufactured prior to May 31, 1962.

In the case of the bolts from lots 2 and 3 the carbide distribution was random and there was no evidence of a carbide layer at the surface, Figures 3a and 3b. The microstructure was tempered martensite with delta ferrite, Figure 4. These bolts were manufactured between November 1962 and February 1965 by Standard Pressed Steel under more rigid heat treatment controls.

Examination of transverse sections cut from lot 4 and 5 bolts that failed to meet the tensile and hardness requirements revealed the following:

(1) Four tensile test specimens, 2 from each lot still in the annealed condition, Figure 5. Figure 6 shows, for purpose of comparison, the annealed microstructure of material as received from the mill (example is from lot 6, item 1).

(2) One tensile test specimen from lot 5 (hardness Rc 22-29) had been heat treated. The microstructure in this specimen was martenstic with no metallographic evidence of delta ferrite, Figure 7. The evidence of a heat treated structure here would tend to substantiate that there was an improper heat treatment or that a higher tempering temperature than that in the previous cases was employed.

The microstructure of bolts from lot 6, items 3 and 4 were similar to that shown for the lot 2 and 3 bolts. In the case of item 5 and 6 bolts, it was observed that the abundance of carbides was considerably reduced, Figures 8a and 8b. The microstructure of the item 5 and 6 bolts was tempered martensite with delta ferrite and there was some grain growth, Figure 9.

The reduction in the amount of carbides and the grain growth may be related to the heat treatment accorded the item 5 and 6 bolts. Table 1 shows an increase in time at the austenitizing temperature for item 5 and the inclusion of a refrigeration treatment before double tempering at 550 degrees F for item 6. As noted in Table 1, the increase in time at the austenitizing temperature and the double temper at 550 degrees F are now recommended for 431 stainless steel T-bolts for use in Marman V-band couplings.

The microstructure of bolts from lot 7, items 1, 2, 3, 4 and A-2 was essentially the same as that shown in Figure 9 and the carbide distribution was similar to that shown in Figures 8a and 8b. These bolts were drawn from lots representative of the latest heat treatment. The microstructure for the bolts from item A-1 was similar to that shown in Figure 4 and the distribution of carbides was similar to that shown in Figures 3a and 3b for the lot 2 and 3 bolts.

Examination of the bolts from lot 8 revealed that the microstructure was tempered martensite with delta ferrite. However, it was noted that there was a considerable increase in the amount of delta ferrite over that previously observed in all of the other specimens examined, Figure 10. The distribution of carbides was similar to that shown in Figure 3a and 3b.

Conclusions: Type 431 stainless steel alloy T-bolts examined included the following materials:

(1) Material from various stages of manufacture.

(2) Bolts from production lots.

(3) Bolts that had been removed from aircraft that had never flown.

(4) Experimental bolts that had been subjected to various heat treatments and/or surface cold working.

The results obtained from hardness and tensile test revealed that 4 bolts removed from aircraft that had never flown were still in the annealed condition and that one bolt may have been tempered at a temperature higher than that recommended for a 180 ksi bolt. These conditions were confirmed by metallographic examination. Bolts in this category were identified as having been manufactured prior to May 31, 1962. Metallographic examination revealed undesirable carbide layers adjacent to the periphery in other bolts manufactured during this period. The microstructures observed were tempered martensite with no metallographic evidence of delta ferrite. The failures of type 431 stainless steel alloy T-bolts, previously reported in references (a) and (b) were attributed to stress corrosion and to strees corrosion and fatigue respectively. In each instance failure was linked to the presence of excessive carbides, particularly at surface areas. In addition, the failed bolts were indentified as belonging to the same period of manufacture (pre May 31, 1962).

The results obtained from tensile and hardness tests showed that variations in heat treatment (time at austenitizing temperature and tempering alterations) did not significantly alter tensile and hardness properties. However, austenitizing for 1 hour and double tempering at 550 degrees F improved the solution of carbides. It was found that surface cold working, shot peening and Harperizing, did not alter the tensile or hardness properties.

The results obtained from guided bend tests did not reveal any significant correlation. The structural yield load varied within each lot tested. The variation is believed to be due to a notch effect at the last thread on the shank. Specimens from any period of manufacture were when clamped in a vise capable of being bent through an angle of 180 degrees without failure.

It is evident from the large number of modifications and identifications that a "store" problem has been created in supplying acceptable T-bolts from new installations and replacement. As the first step in alleviating this situation, it is recommended that all bolts identified as having been manufactured prior to May 31, 1962 be removed from supply bins or other access because of the unreliability of manufacturing procedures during this period.

Table 1. Bolt identification, processing variables and heat treatment for various modifications (Mod No's).

| Mod. No. | Period of Manufacture | Identification | Processing Variable | Heat Treatment |
|---|---|---|---|---|
| 1 | 11-19-54 to 11-1-61 | Complete "T" bolt dye blue (a) | Bolts processed using normal heat treatment and military type of receiving and inspection. | Anneal at 1400°F and within 1½ hrs austenitize at 1890°F ±10° for 20 min. Oil quench within 30 sec in 75-140°F oil. Degrease. Temper at 600°F for 2 hrs and air cool. Furnace atmosphere-dry N2 or Ar2. Dew point of gas -40 max. |
| 2 | 11-1-61 to 5-31-62 | ¼ inch of thread end dyed blue (a) | Bolts were processed using Marman improved heat treatment with tightened requirements for heat treatment and receiving inspection tests (embrittlement, static load and metallurgical examination). | In accordance with MIL-H-6875 for 180 ksi min. tensile strength. |
| 3 | 5-31-62 to 10-12-62 | Same as for Mod 2 plus dimple punch on thread end (a) | Requirements of Mod 2 plus additional requirement of shaved wire stock (improved surface finish). | Same as for Mod 2. |
| 4 | 10-12-62 to 11-2-62 | "T" head dyed blue. Dimple punch on thread end to indicate shaved wire. (a) | Requirements of Mods 2 or 3 except heat treated by SPS to their published test procedure. | In accordance with MIL-11-6875 and to develop mechanical properties specified in Marman MPB 200.030 (b) |

Table 1. (cont.)

| Mod. No. | Period of Manufacture | Identification | Processing Variable | Heat Treatment |
|---|---|---|---|---|
| 5 | 10-12-62 to 11-2-62 | "T" head dyed blue head stamp plus dot. (c) | Complete processing by SPS to Marman MPB 200.021. | Same as Mod 4. |
| 6 | 11-2-62 to 4-14-64 | One inch of thread end dyed blue, head stamp plus dot. | Threads rolled after treatment. Complete processing by SPS. | Same as Mods 4 and 5 except tightened heat treating requirements -- details not available. |
| 7 | 4-14-64 to 2-16-65 | One inch of thread end dyed blue, head stamp plus dot plus dash. Also grooved slot in thread end for visual examination. | Same as Mod 6. | Same as Mod 6. |
| 8 | 2-16-65 on. | Head stamp plus dot plus dash. Also grooved slot in thread end for visual examination. | Same as Mod 6. | Improved heat treatment which includes increase in austenitizing time to 1 hr and a double temper at 550°F. |
| 9X | Experimental Material | Same as Mod 8. | Threads rolled after heat treatment plus shot peened on head and unthreaded shank. | Same as Mod 8. |
| 10X | Same as Mod 9X. | Same as Mod 8. | Threads rolled after heat treatment, except Harperized before roll threading | Same as Mod 8. |

Table 1. (cont.)

| Mod. No. | Period of Manufacture | Identification | Processing Variable | Heat Treatment |
|---|---|---|---|---|
| 11X | Same as Mod 9X | Same as Mod 8. | Threads rolled after heat treatment plus Harperized | Same as Mod 8. |
| 12X | Same as Mod 9X | Head stamp plus dot. | Material high in free ferrite. | Unknown |
| 13X | Stage material from lot 6 (Table 2). | NONE | Shaved wire stock to meet chemical requirements of MIL-S-18732-C. | Annealed as received from the mill. |
| 14X | Same as Mod 13X | Head stamp plus dot plus dash. | Same as Mod 13X except cold headed. | Same as Mod 13X |
| 15X | Same as Mod 13X | Same as Mod 8. | Same as Mod 14X | Same as Mod 8. |
| 16X | Experimental Material | One inch of thread end dyed blue, head stamp plus dot plus dash. | Roll threaded after head treatment. | Same as Mod 6 except austenitizing time is 1 hr. |
| 17X | Same as Mod 16X | Same as Mod 14X | Same as Mod 16X | In accordance with par. 3, 4, 1 (Ht 200 condition) of MIL-S-18732C. |

(a) Bolts from Mods 1 through 4 may or may not have had the head stamp identification.

(b) Mechanical properties specified in Marman MPB 200.030 C for 180,000 psi bolts:

| Bolt Size | Min. Tensile Value, lbs. | Min. Elongation | Hardness $R_c$ |
|---|---|---|---|
| 10-32 | 3,600 | 0.058 | No greater than 46 |
| ¼-28 | 6,552 | 0.077 | No greater than 46 |

(c) Identification used in error.

Table 2. Additional identification of Materials submitted for identification.

| Mod. No. | Lot No. | Item No. | No. of Pieces | Head Stamp | Bolt Size |
|---|---|---|---|---|---|
| 1 or 2 | 1 | a | 1 | NONE | ¼" - 28 |
| 1 or 2 | 1 | b | 1 | NONE | ¼" - 28 |
| 6 | 2 | a | 5 | flying A. | ¼" - 28 |
| 6 | 2 | b | 5 | flying A. | 10 - 32 |
| 7 | 2 | c | 1 | flying A.- | ¼" - 28 |
| 7 | 3 | a | 10 | flying A.- | ¼" - 28 |
| 7 | 3 | b | 10 | flying A.- | 10 - 32 |
| 1 or 2(3) | 4(1) | a | 1 | NONE | ¼" - 28 |
| 1 or 2(3) | 4(1) | b | 6 | flying A | ¼" - 28 |
| 5 or 6(3) | 4(1) | c | 6 | flying A. | ¼" - 28 |
| 1 or 2(3) | 5(2) | a | 32 | NONE | ¼" - 28 |
| 1 or 2(3) | 5(2) | b | 7 | flying A | ¼" - 28 |
| 5 or 6(3) | 5(2) | c | 1 | flying A. | ¼" - 28 |
| 13 X | 6 | 1 | 2 | (4) | ¼" dia |
| 14 X | 6 | 2 | 10 | flying A.- | ¼" - 28 |
| 15 X | 6 | 3 | 10 | flying A.- | ¼" - 28 |
| 8 | 6 | 4 | 10 | flying A.- | ¼" - 28 |
| 16 X | 6 | 5 | 10 | flying A.- | ¼" - 28 |
| 17 X | 6 | 6 | 10 | flying A.- | ¼" - 28 |
| 8 | 7 | 1 | 10 | flying A.- | ¼" - 28 |
| 9 X | 7 | 2 | 10 | flying A.- | ¼" - 28 |
| 10 X | 7 | 3 | 10 | flying A.- | ¼" - 28 |
| 11 X | 7 | 4 | 10 | flying A.- | ¼" - 28 |
| 3 | 7 | A-1 | 10 | flying A.- | ¼" - 28 |
| 8 | 7 | A-2 | 10 | flying A.- | ¼" - 28 |
| 12 X | 8 | 1 | 10 | flying A. | ¼" - 28 |

(1) Bolts submitted by McDonnell Aircraft, St. Louis, Mo.; removed, under AFC (change) 200, from aircraft that had never flown.

(2) From F-4B-150493 Oceana aircraft; removed under AFC (change) 200.

(3) Dye markings were indeterminate or suspect due to adherent grease or dirt.

(4) Bar stock, annealed material.

Table 3. Mechanical properties of representative T-bolts submitted for examination.

| Lot No. | Item | Hardness Rockwell C (1) | Tensile Properties: Breaking load, lbs. | Tensile Properties: Total Elongation Inches | Bend Properties: Structural yield, load, lbs. | Bend Properties: Bend Angle degrees |
|---|---|---|---|---|---|---|
| 1 | a | 42-43 | | | | |
| | b | 43-42 | | | | |
| 2 | a | 42-44 | | | 2030 | 40 |
| | | 41-41 | | | 2035 | 40 |
| | b | 46-44 | | | 1025 | 17 |
| | | 42-40 | | | 800 | 10 |
| | c | 46-43 | | | 1825 | 10 |
| 3 | a | | | | 1755 | 10 |
| | | | | | 1760 | 10 |
| | | | | | 2240 | 10 |
| | | 46-44 | 8100 | 0.16 | | |
| | | 46-47 | 8025 | 0.20 | | |
| | | 46-45 | 8125 | 0.17 | | |
| | b | | | | 1750 | 17 |
| | | | | | 1875 | 17 |
| | | | | | 1810 | 17 |
| | | 42-45 | 4230 | 0.12 | | |
| | | 44-42 | 4270 | 0.12 | | |
| | | 37-41 | 4240 | 0.12 | | |
| 4 | a | ----- | 7400 | ---- | | |
| | b | | | | 2170 | 10 |
| | | | | | 1500 | 10 |
| | | | | | 3140 | 25 |
| | | 97-100 $R_B$ | 4225 | | | |
| | | 95-97 $R_B$ | 4100 | | | |
| | c | | | | 3410 | 25 |
| | | | | | 2130 | 15 |
| | | | | | 1960 | 10 |
| | | | 7975 | | | |
| | | | 8925 | | | |
| | | | 8575 | | | |

Table 3. (cont.)

| Lot No. | Item | Hardness Rockwell C (1) | Tensile Properties | | Bend Properties | |
|---|---|---|---|---|---|---|
| | | | Breaking load, lbs. | Total Elongation Inches | Structural yield, load, lbs. | Bend Angle degrees |
| 5 | a | | | | 3160 | 30 |
| | | | | | 3200 | 30 |
| | | | | | 3450 | 30 |
| | | | 7325 | | | |
| | | | 7250 | | | |
| | | | 7600 | | | |
| | | 22-29 | 5000 | | | |
| | | | 7000 | | | |
| | | | 7375 | | | |
| | | | 7050 | | | |
| | b | | | | 2260 | 20 |
| | | | | | 1590 | 10 |
| | | | 7225 | | | |
| | | | 7150 | | | |
| | | 95-96 $R_B$ | 4375 | | | |
| | | 96-97 $R_B$ | 4175 | | | |
| | | | 7425 | | | |
| | c | | 8500 | | | |
| 6 | 1 | 95-97 $R_B$ (2) | | | | |
| | 2 | 100-99 $R_B$ (2) | | | | |
| | 3 | 43-45 | | | | |
| | 4 | 46-46 | | | | |
| | | | 7900 | 0.090 | | |
| | | | 7925 | 0.091 | | |
| | | | 7975 | 0.096 | | |
| | 5 | 45-43 | | | | |
| | | | 8075 | 0.098 | | |
| | | | 8050 | 0.099 | | |
| | | | 8075 | 0.100 | | |
| | 6 | 40-40 | | | | |
| | | | 8025 | 0.096 | | |

Table 3. (cont.)

| Lot No. | Item | Hardness Rockwell C (1) | Tensile Properties | | Bend Properties | |
|---|---|---|---|---|---|---|
| | | | Breaking load, lbs. | Total Elongation Inches | Structural yield, load, lbs. | Bend Angle degrees |
| | | | 8075 | 0.091 | | |
| | | | 7975 | 0.097 | | |
| 7 | 1 | | | | 2180 | 15 |
| | | | | | 2400 | 15 |
| | | | | | 1700 | 17 |
| | | 47-46 | 8125 | 0.093 | | |
| | | | 7775 | 0.094 | | |
| | | | 7850 | 0.087 | | |
| | 2 | | | | 1730 | 15 |
| | | | | | 1820 | 15 |
| | | | | | 1560 | 15 |
| | | 46-46 | 8025 | 0.090 | | |
| | | | 7825 | 0.088 | | |
| | | | 7975 | 0.090 | | |
| | 3 | | | | 2780 | 15 |
| | | | | | 2600 | 15 |
| | | | | | 2050 | 15 |
| | | 44-43 | 7925 | 0.096 | | |
| | | | 7975 | 0.094 | | |
| | | | 7900 | 0.090 | | |
| | 4 | | | | 2150 | 15 |
| | | | | | 2260 | 15 |
| | | 46-43 | 7975 | 0.084 | | |
| | | | 8025 | 0.089 | | |
| | | | 7975 | 0.096 | | |
| | A-1 | | | | 3180 | 20 |
| | | | | | 2590 | 20 |
| | | | | | 2860 | 20 |
| | | 44-43 | 7750 | 0.080 | | |
| | | | 7675 | 0.074 | | |
| | | | 7850 | 0.091 | | |

Table 3. (cont.)

| Lot No. | Item | Hardness Rockwell C (1) | Tensile Properties | | Bend Properties | |
|---|---|---|---|---|---|---|
| | | | Breaking load, lbs. | Total Elongation Inches | Structural yield, load, lbs | Bend Angle degrees |
| 8 | 1 | 43-40 | 7115<br>7215<br>7175 | 0.116<br>0.121<br>0.110 | 2280<br>2070<br>2415 | 25<br>25<br>25 |

(1) Hardness values are converted from Knoop (500g) determinations. First value was obtained at area adjacent to the edge; second value was obtained at area adjacent to the center. All determinations were made on transverse bolt sections.

(2) Annealed material.

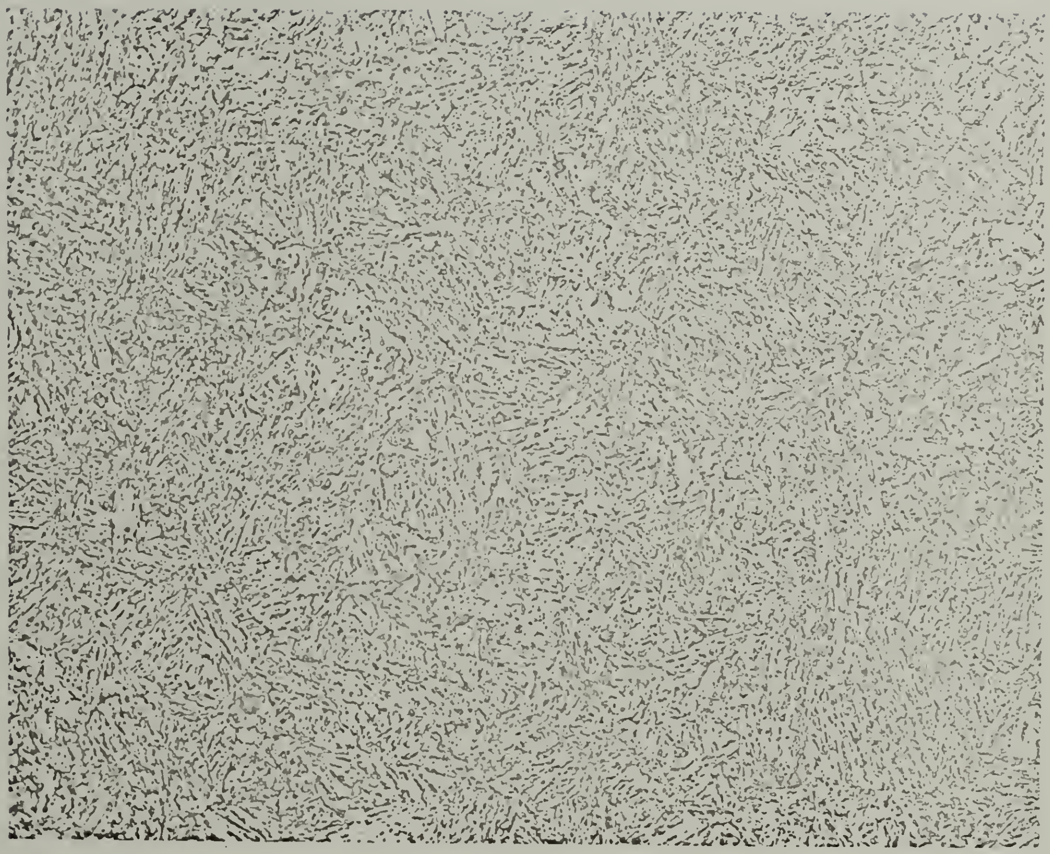
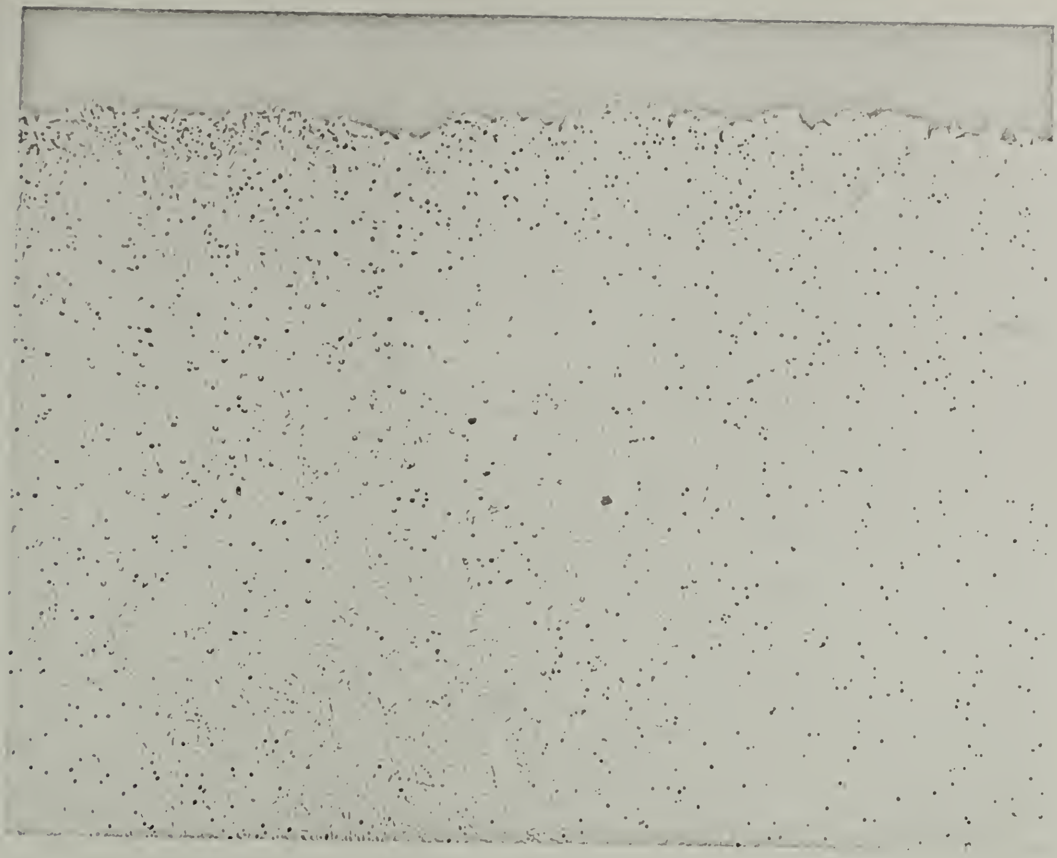
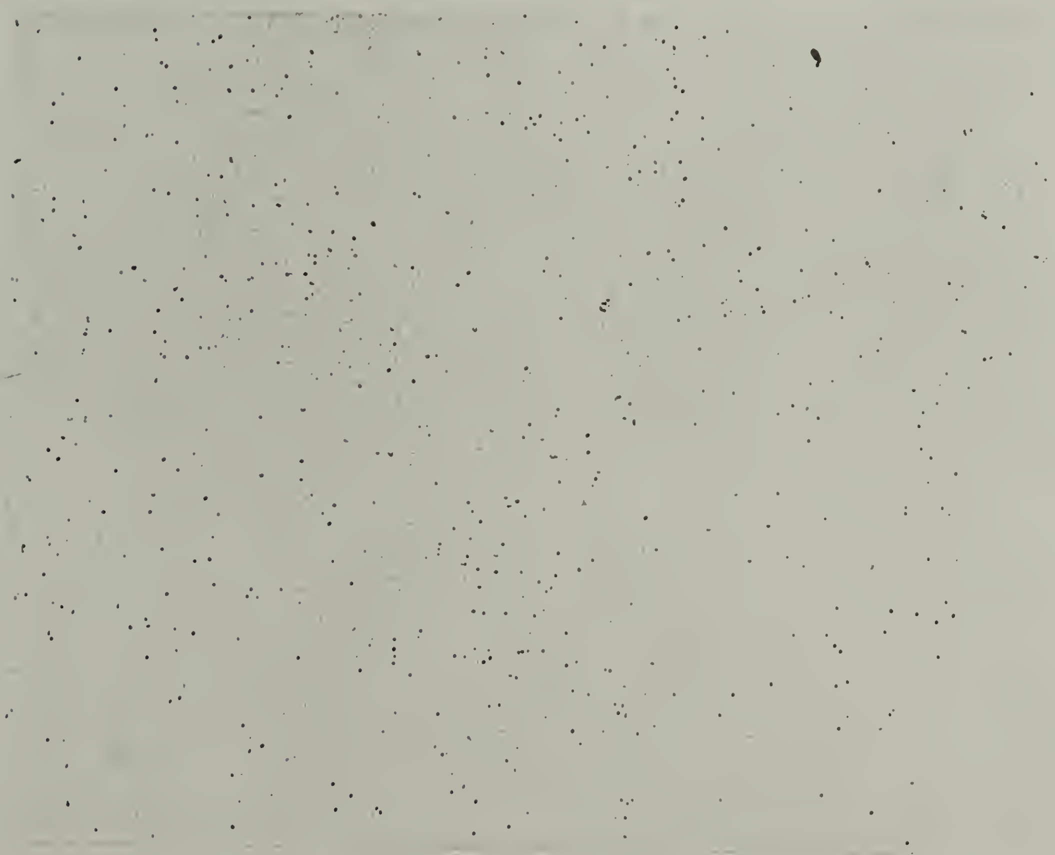


Figure 1. Typical microstructure for bolts from lot 1. Microstructure is tempered martensite with no metallographic evidence of delta ferrite. Etched with Kalling's reagent. X500.



a

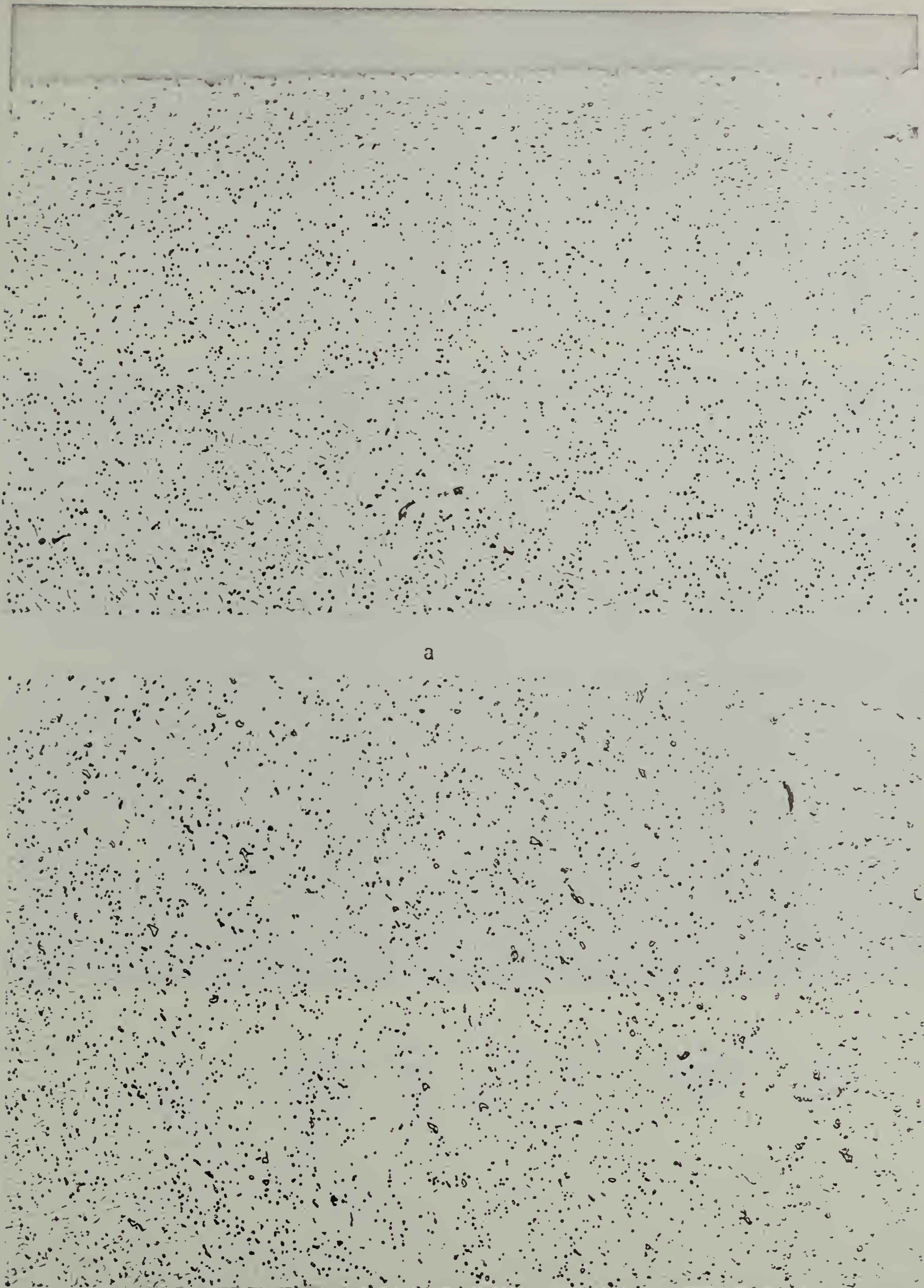


b

Figure 2. Typical Carbide distribution in T-bolts from Lot 1. Etched, electrolytically in 10% NaCN. X500.

a. Note abundance of carbides adjacent to bolt periphery. Concentration appears to diminish toward center.

b. Carbide concentration at center of T-bolt.



a

b

Figure 3. Typical Carbide distribution in bolts from lots 2 and 3. Etched electrolytically in 10% NaCN. X500.
a. Concentration adjacent to bolt periphery.
b. Concentration at center.

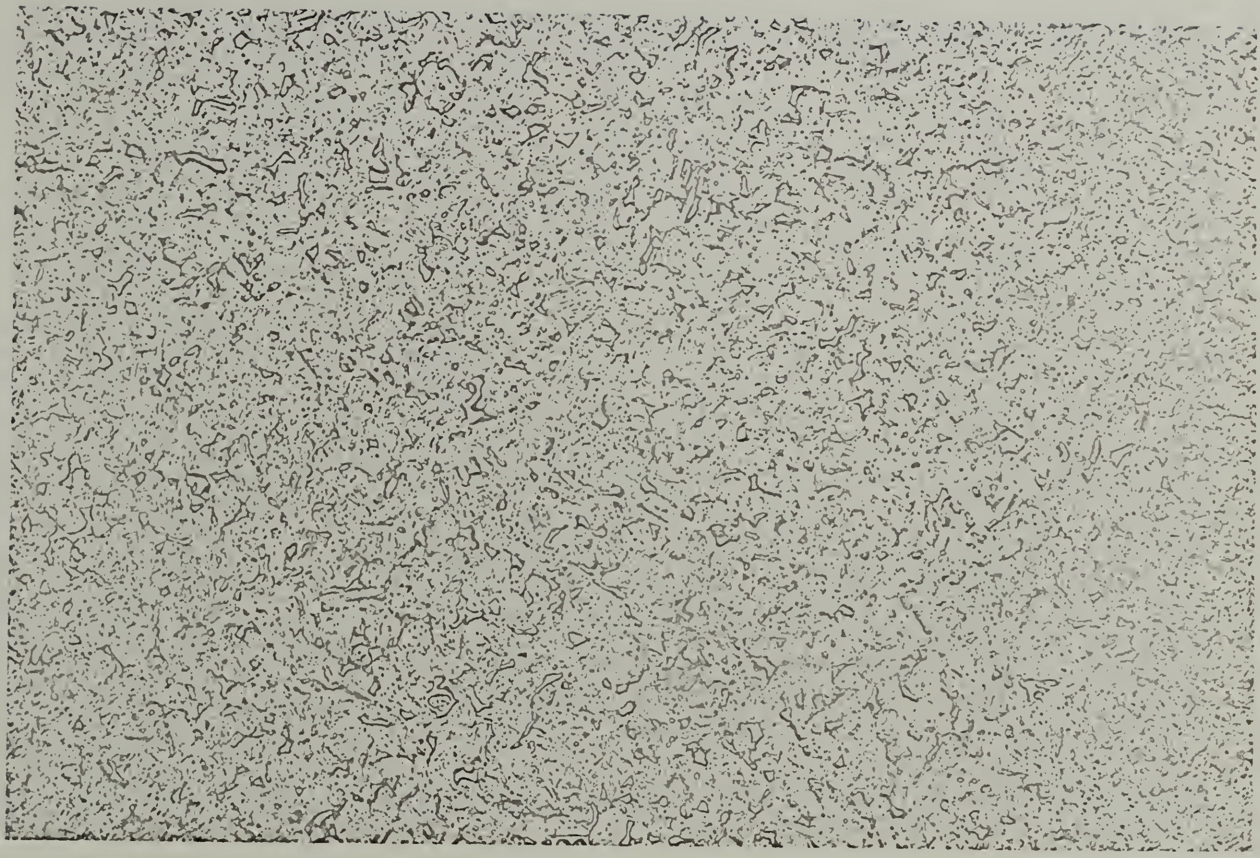


Figure 4. Typical Microstructure in bolts from lots 2 and 3. Microstructure is tempered martensite with delta ferrite. Etched, with Kalling's reagent. X500.

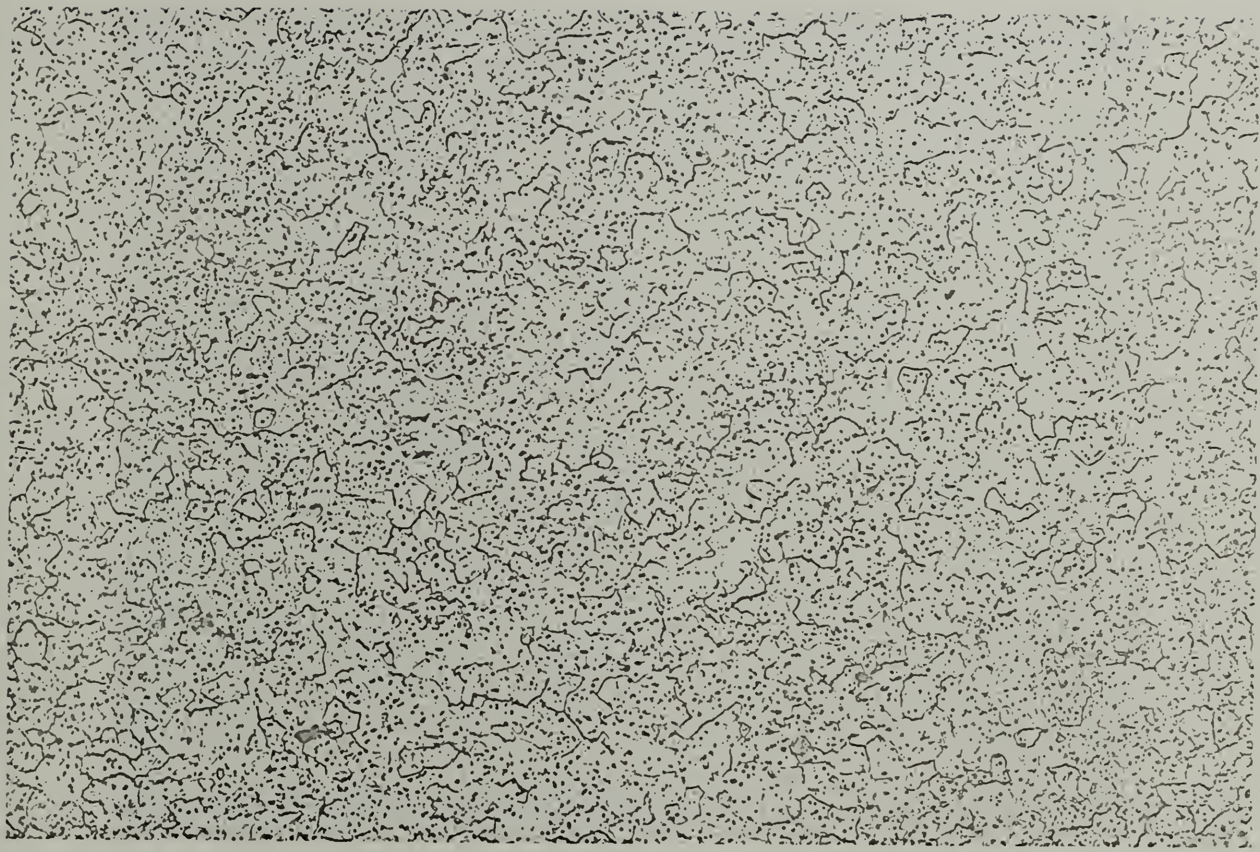


Figure 5. Microstructure of lot 4 T-bolt that failed to meet the minimum tensile and hardness requirements. Microstructure is similar to that of annealed material. Etched with Kalling's reagent. X500.

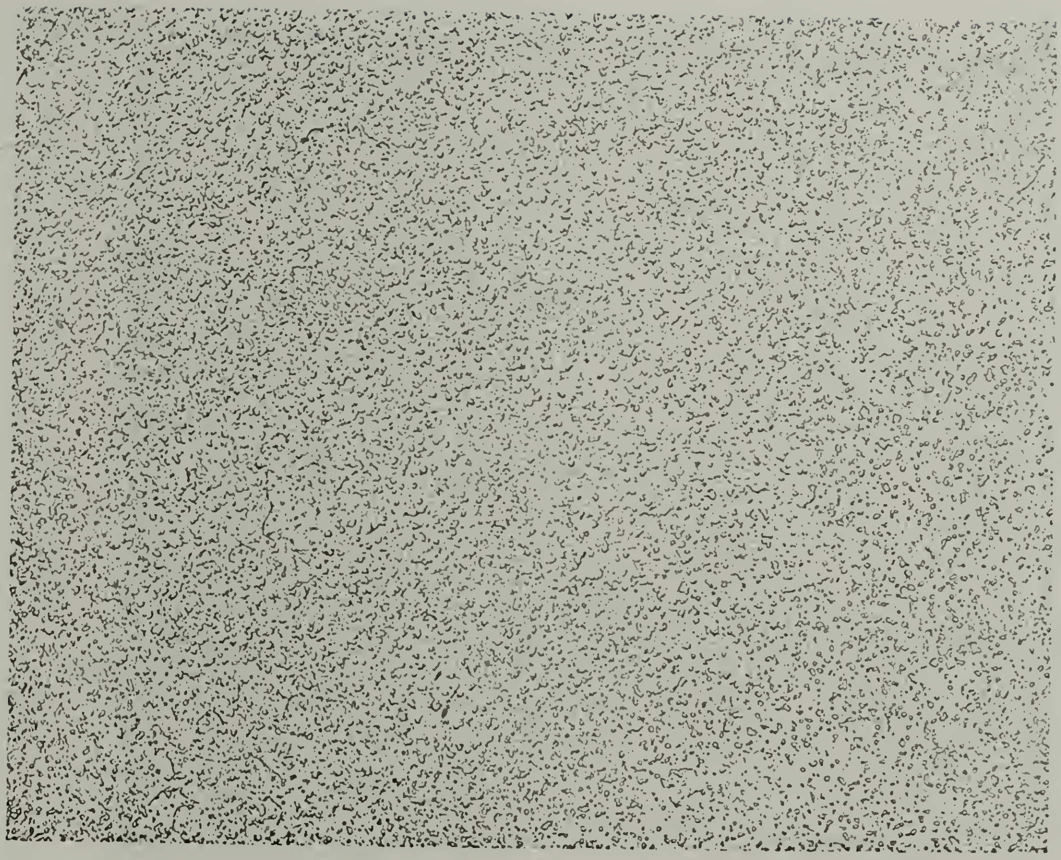
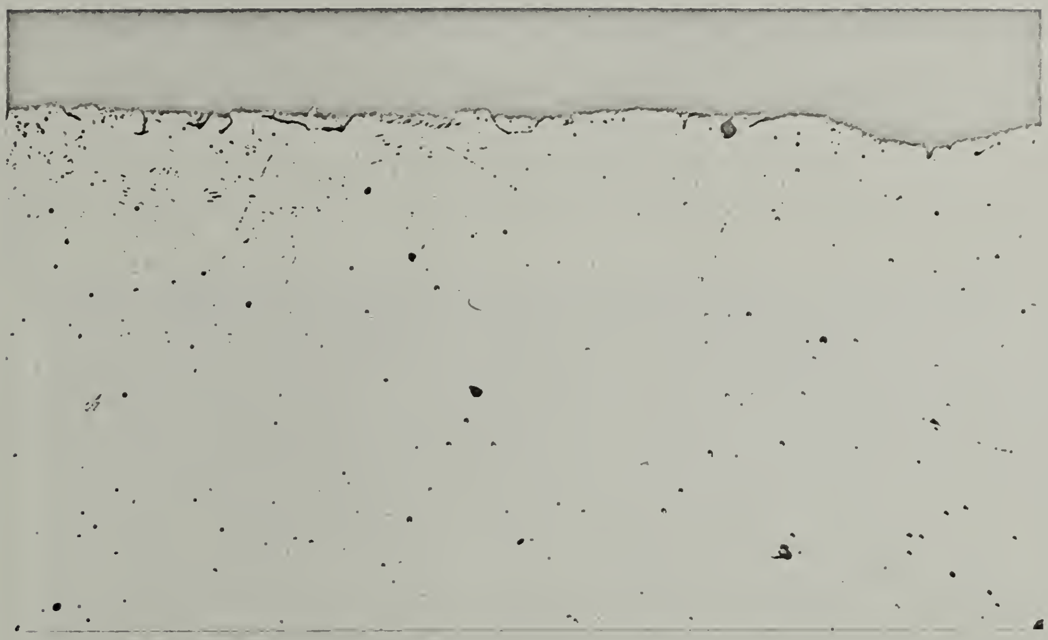


Figure 6. Photomicrograph of annealed material from lot 6, item 1, presented here for comparison with the annealed microstructure shown in Figure 5. Etched with Kalling's reagent. X500.

Figure 7. Photomicrograph of a portion of the section of a lot 5 bolt that failed to meet the minimum tensile and hardness requirements for a 180 ksi bolt. Microstructure is tempered martensite with no metallographic evidence of delta ferrite. Etched with Kalling's reagent. X500.



a

b

Figure 8. Typical carbide distribution in lot 6, items 5 and 6 bolts. Etched electrolytically in 10% NaCN. X500.
a. Concentration adjacent to the periphery.
b. Concentration at the center.

Figure 9. Photomicrograph of typical structure in bolts from lot 6, item 5 and 6. Microstructure is tempered martensite with delta ferrite. Note that some grain growth occurred. Etched with Kalling's reagent. X500.

Figure 10. Microstructure in a bolt from lot 8. Note the presence of an abundance of free ferrite in the tempered martensite matrix. Etched with Vilella's reagent. X500.