LAB IV

Effects of Heat Treatment on Steel, Aluminum and Brass Alloys - Microstructure and Properties

PRE LAB PREPARATION (required!)

1. Using the ASM metal handbooks or other resources find and print/copy the following or as close as you can get. For example 4140 for 4340, if 4340 not available. Included in this lab are several pages from ASM handbooks that may be helpful.
   a. The chemical composition ranges for Steel 4340, 1018 (A36), Aluminum alloy 2024 and 70-30 (260) brass
   b. Microstructures of 4340 and 1018 (A36) steel in the normalized, quenched and tempered conditions
   c. Microstructure of aluminum alloy 2024 in the slow cooled, solutionized & and solutionized and aged conditions
   d. Phase diagrams for the alloys systems of interest.
   e. Time-Temperature-Transformation diagrams for each alloy, if possible. If not try to find heat treatment information for each alloy, e.g. hardness vs. time, etc.

2. In terms of heat treatment and the development of microstructure, what are two major limitations of the iron-iron carbide phase diagram?

3. Consider the Iron-Carbon Phase Diagram shown in your textbook. For steel alloys 1018 and 4340 which have been slowly cooled from the austenite region (1100^{o}C) to room temperature, calculate the relative amounts and compositions of the phases present at room temperature. Draw the microstructure, which would result in each case.

4. What is the minimum temperature (for each alloy) to heat Steel 4340, 1018 (A36), Al 2024 and 70-30 (260) brass in order to form a single phase material?

5. Please answer the following questions using the TTT diagrams and phase diagrams of alloys: Steel 4340, 1018 (A36), Al 2024 and 70-30 (260) brass

   a. Predict what phases will form from the following heat treatments Assume linear cooling rates:
      i. 4340 and 1018 (A36) cooled from 900C to below 500 C in 1 sec and room temp in less than 5 secs
      ii. 4340 and 1018 (A36) cooled from 900C to below 500 C in 20 sec and room temp in 200 secs
      iii. Al 2024 and Brass 70-30 (260) cooled from 550 C to room temp in less than 1 sec
      iv. Al 2024 and brass 70-30 (260) cooled from 550C to room temp in 200 secs.
   b. Why does martensite not appear on the Fe-C phase diagram?

6. What does the "T#" signify after Al2024-TO, Al2024-T3, Al2024-T6?

Purpose:

- Understand the effect of cooling rates and reheating on microstructure and properties of steel, aluminum and brass alloys.
- To observe the heat treatment process for a 4340 and a 1018 (A36) steel sample and effect on properties.
- To observe the heat treatment process for a 2024 aluminum sample and effect on properties.
- To observe the effect of heat treatment on 260 Brass sample and effect on properties.
- Relate microstructure to mechanical properties

Heat treatment

Each lab group will receive four alloys to test. We will be using 4340 and 1018 steel, 2024 aluminum and 70-30 (260) brass... The steel samples will be austenitized at 900 degrees C for 30 minutes. The aluminum and brass samples will be heated to 550 C for 30 minutes. The samples will then be cooled in two manners. The first will be a slow air- cooling, which should result in a piece approximately in equilibrium. The second piece will be quenched in water resulting in a non-equilibrium sample. A subset of these samples will then be reheated to temperature that will allow limited diffusion for 30 minutes.

Procedures:

1. Wrap a piece of wire approximately 6 inches long around all samples. This will be used to place and remove samples from furnaces.
2. Heat the steel samples up to 900 °C in furnace A. Heat the Aluminum and Brass samples to 550 C in furnace B. Allow samples to equilibrate for approximately 30 minutes
3. Cool the samples:
   a. Take the first two samples of EACH alloy and quench them in water. They must be removed from furnace and placed in the water very quickly, approximately 1-2 seconds, so everything has to be ready.
   b. Remove second set of samples of each alloy and place in to bucket of vermiculite (an insulating material to slow cooling rate).
4. Take 1 sample from each alloy and cooling rate and place in Furnace C for steel and Furnace D for Aluminum and Brass samples. Steels will be reheated to 300 C and aluminum and brass to 200 C for 30 minutes.

	Steel 1018 (A36)	Steel 4340	Aluminum 2024	70-30 (260) Brass
Sample 1	Heat to 900 Quench in H_2O	Heat to 900 Quench in H_2O	Heat to 550 C Quench in H_2O	Heat to 550 C Quench in H_2O
Sample 2	Heat to 900 Quench in H_2O Reheat at 300 C	Heat to 900 Quench in H_2O Reheat at 300 C	Heat to 550C Quench in H_2O Reheat at 200 C	Heat to 550C Quench in H_2O Reheat at 200 C
Sample 3	Heat to 900 Cool slowly	Heat to 900 Cool slowly	Heat to 550 Cool slowly	Heat to 550 Cool slowly
Sample 4	Heat to 900 Cool slowly Reheat to 300 C	Heat to 900 Cool slowly Reheat to 300 C	Heat to 550 Cool slowly Reheat to 200C	Heat to 550 Cool slowly Reheat to 200C

5. Once the samples are cool they may have to be ground to remove the oxide layer (Steels!!). Do this using the belt sanders with water cooling.
6. Take the hardness measurements using Rockwell C and/or Rockwell B scales. Take at least 3 measurements on each sample and average the value. Be careful not to place indents too close together as it may affect the results.
7. Look at the microstructures of ALL samples at each of the four heat treatments. Polished and etched samples of each type will be provided by the TA's. These samples were polished to a 1 micron finish and then chemically etched to reveal the grain boundaries. View each of the samples, comment on the microstructures in your lab report and include microstructures at all heat treatments in your report. Compare the properties (hardness) of ALL alloys at after all heat treatments and explain in term of the phase transformations, resulting microstructure and easy of dislocation motion.

Questions:

1. What is the difference in 4340 steel vs 1018 (A36) steel.
2. Which steel sample was harder, the air-cooled or water quenched? Why was it harder?
3. Which steel alloy was harder? Why was it harder?
4. How did the different cooling rate affect the microstructure of each steel? Do these microstructures agree with what would be predicted from the TTT diagrams?
5. What did reheating do to the steels (4340 and 1018 (A36)) microstructure and properties? Why?

6. Compare the TTT diagram for 1018 (A36) with that of 4340. What are the major differences? Why does the decomposition of austenite take longer in 4340 than 1018 (A36)?
7. What would be the effect of quenching in oil instead of water?
8. What was the effect of reheating the samples:on microstructure and properties?
9. What would happen to the microstructure and hardness if the samples were reheated to 600C for 30 minutes and then quenched?
10. For aluminum alloys, what do T0, T3 and T6 refer to? Did you treat Al 2024 to any of those conditions?
11. Compare the hardness values you measured for each alloy in each condition with values from the literature. If there are any significant deviations from expected values, provide likely causes for this and how could it be corrected.

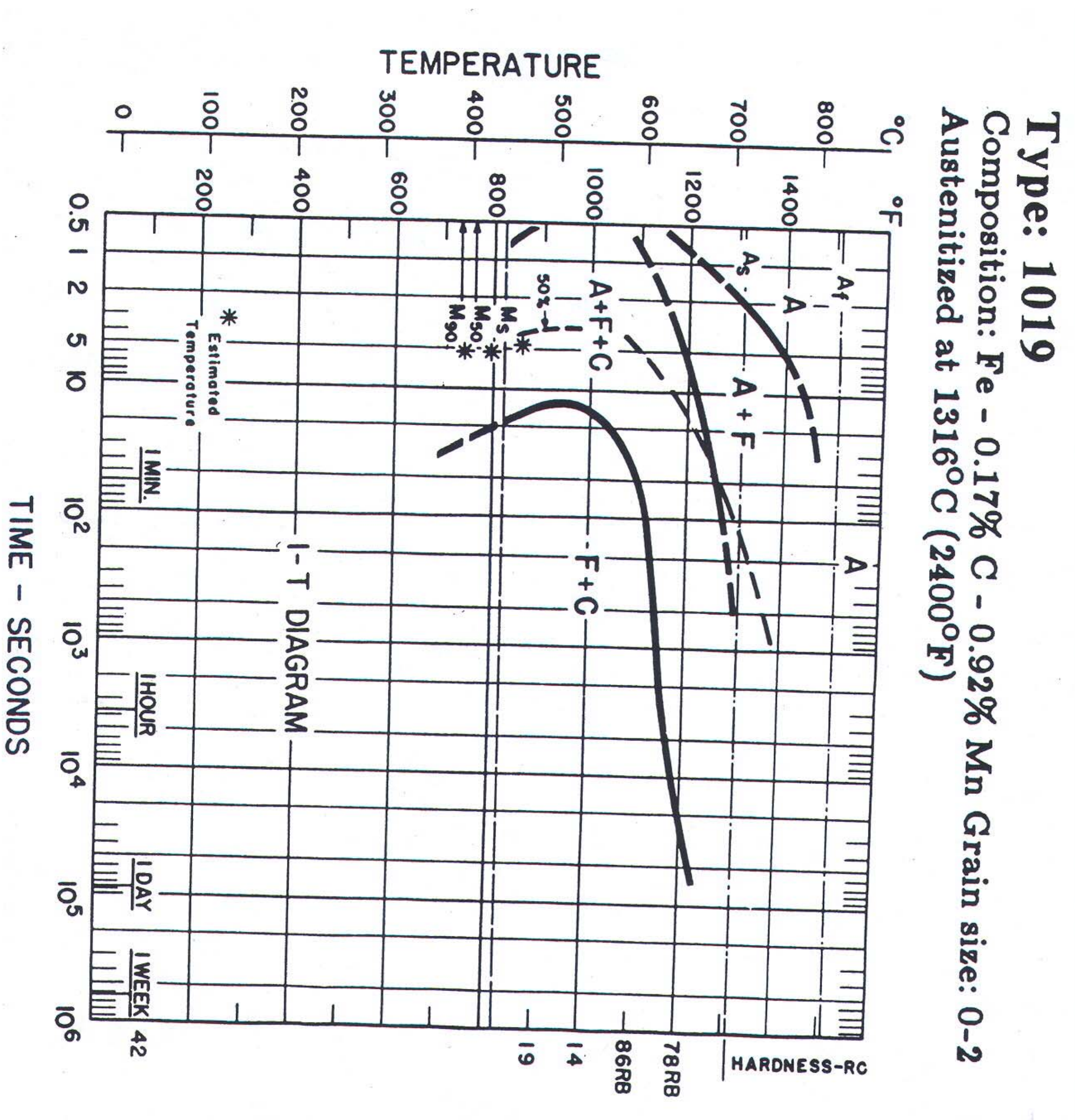
Lab Report

The lab report should address all the questions above but should not consist only of these questions. Please follow the procedures outlined on the homepage and in the lab. Look under lab handouts and report formats *(How to write a lab report)* for point distribution and requirements. U

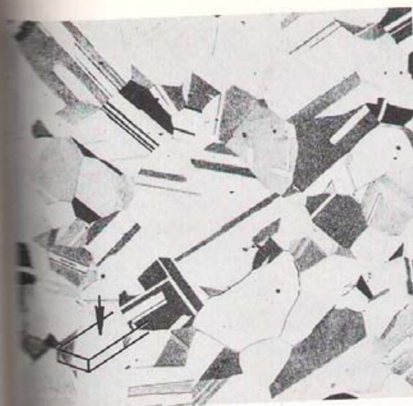
References:

1. William D. Callister, Jr., “Materials Science and Engineering an Introduction”, 6th Edition, John Wiley and Sons, New York. (2000), chap. 10-11.
2. E.C. Subbarao, et al., "Experiments in Materials Science," McGraw-Hill, New Your, (1972).
3. George L. Kehl, "The Principles of Metallographic Laboratory Practice," 3rd ed., McGraw-Hill, New York (1949) 232-240.
4. L. Van Vlack, "Elements of Material Science and Engineering," 6th ed., Addison Wesley, Reading, MA (1986) pp. 257-262, 292-304.
5. R.E. Smallman, "Modern Physical Metallurgy," 4th ed., Butterworths, London, (1985) 335-379.
6. ASM Metals Handbooks

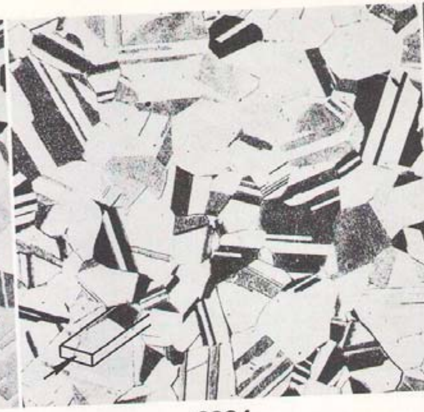
APPENDIX: Possibly useful diagrams and microstructures from Metals Handbook 8th edition, vol. 7, **Atlas of time-temperature diagrams for nonferrous alloys / edited by George F. Vander Voort**: ASM International, c1991 and **Atlas of time-temperature diagrams for irons and steels / edited by George F. Vander Voort**: ASM International, c1991



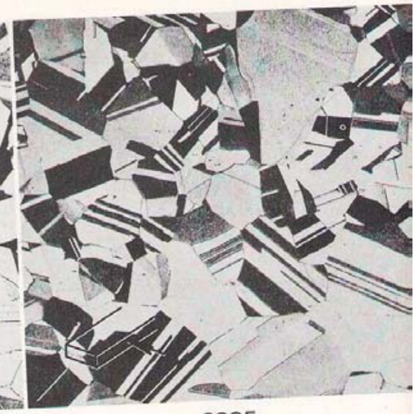
Effect of Reduction by Cold Rolling of Alloy 260 (Cartridge Brass, 70%), at 75×



2333

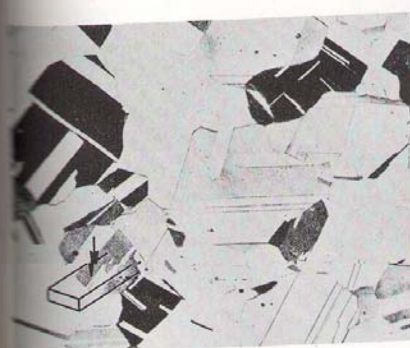


2334

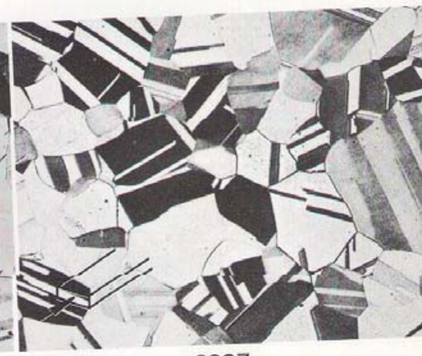


2335

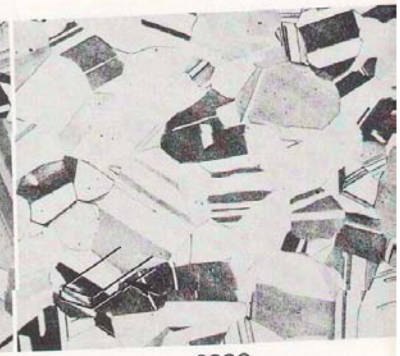
Annealed sheet, 0.239 in. thick, processed as described below. Grain size, 0.120 mm. Nominal tensile strength, 43,000 psi.



2336

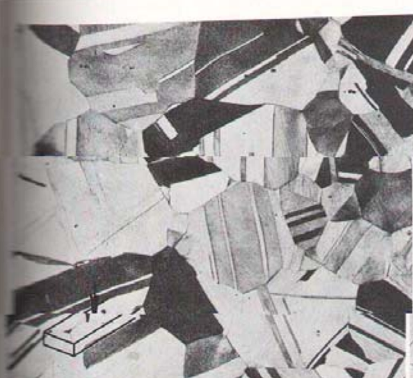


2337

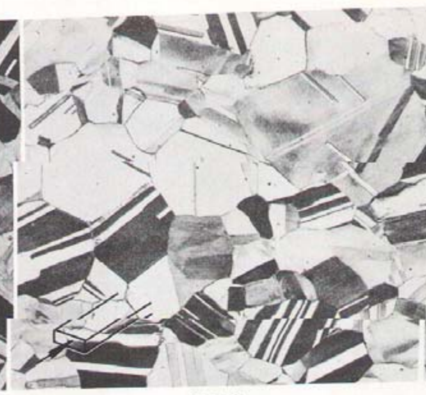


2338

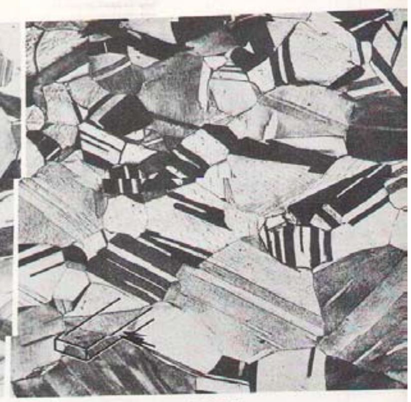
Reduced 6% by cold rolling from 0.239 to 0.225 in. thick. **Eighth-hard temper** (½ B&S gage number hard). Nominal tensile strength, 49,000 psi.



2339



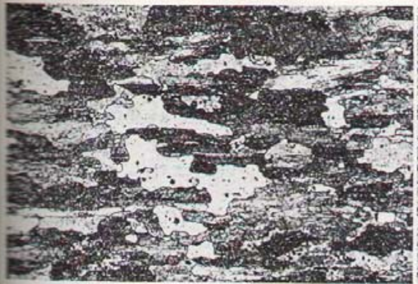
2340



2341

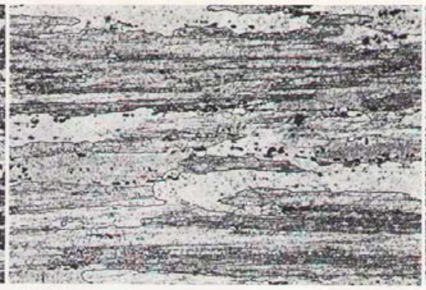
Reduced 11% by cold rolling from 0.239 to 0.213 in. thick. **Quarter-hard temper** (1 B&S gage number hard). Nominal tensile strength, 54,000 psi.

The micrographs on this and the next two pages are of alloy 260 (cartridge brass, 70%) sheet. All specimens received the same preliminary processing: slab was hot rolled to a thickness of 0.400 in., annealed to a grain size of 0.015 mm, cold rolled 40% to a thickness of 0.239 in., and annealed to a grain size of 0.120 mm. All specimens were etched in a mixture of ammonium hydroxide and hydrogen peroxide. Diagram at lower left in each micrograph indicates the orientation of the view with respect to the rolling plane of the sheet.



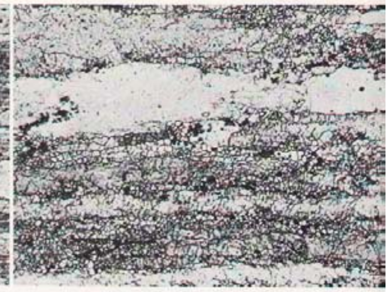
Keller's reagent 200×

2031 Alloy 2024-T851 plate, 6 in. thick, cold rolled, solution heat treated, stretched and artificially aged. Section was taken in the rolling plane (long transverse) from an area near the surface showing elongated grains.



Keller's reagent 200×

2032 Same alloy and condition as for 2031, but a longitudinal section showing the edge view of an area near the surface of the plate. Grains are flattened and elongated in the direction of rolling. See micrograph 2033.

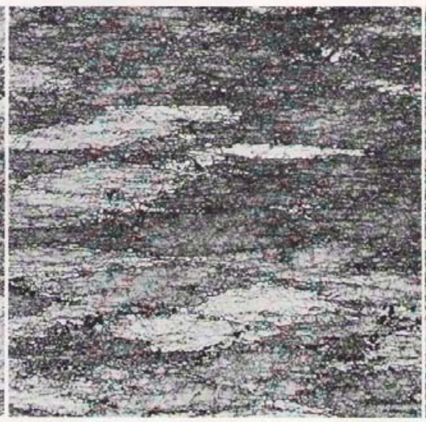


Keller's reagent 2

2033 Same alloy and condition as for 2 but a short transverse section show the end view of an area near the surface of plate. Grains are flattened, but are not as e gated as grains in micrograph 2032.

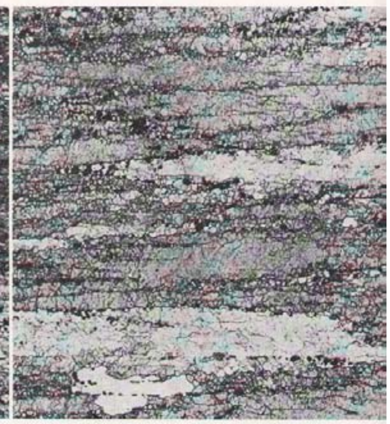
Keller's reagent 200×

2034 Same alloy, condition and orientation as for 2031, but specimen was from the center of the plate thickness, which received less cold working than the surface.



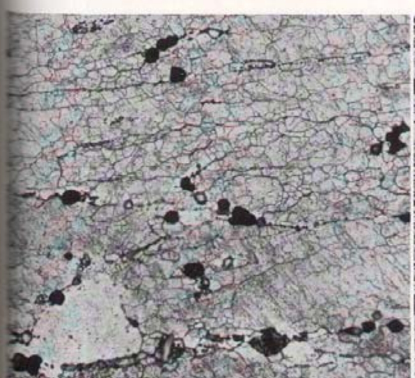
Keller's reagent 200×

2035 Same alloy, condition and orientation as for 2032, but specimen was from the center of the plate thickness. There is less flattening and elongation of the grains.



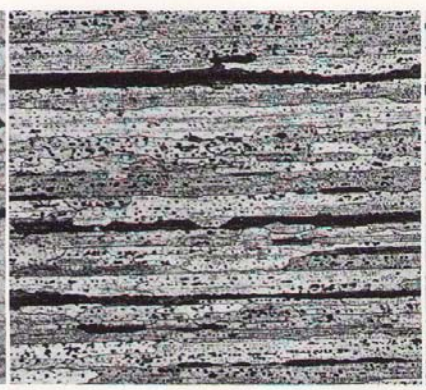
Keller's reagent 2

2036 Same alloy, condition and orienta as for 2033, but specimen was from center of the plate thickness. Less cold work has resulted in less deformation.



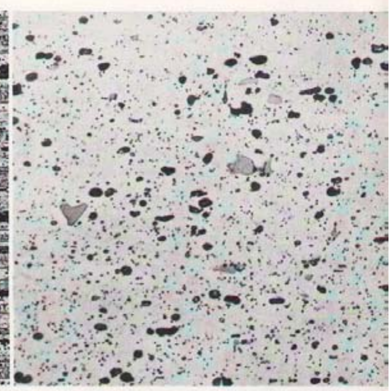
10% phosphoric acid 500×

2037 Alloy 2024-T851 plate, 4 in. thick, hot rolled, solution heat treated, stretched and artificially aged. Fragmented grain structure; one small recrystallized grain. High rolling temperature limited strain and recrystallization.



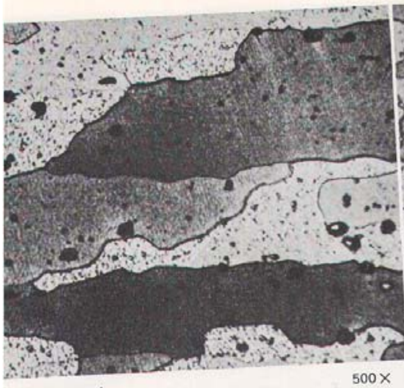
Potassium permanganate, sodium carbonate 100×

2038 Alloy 2024-O plate, ½ in. thick, hot rolled and annealed. Longitudinal section. Elongated recrystallized grains and unrecrystallized stringers resulting from polygonization that occurred during the hot working.



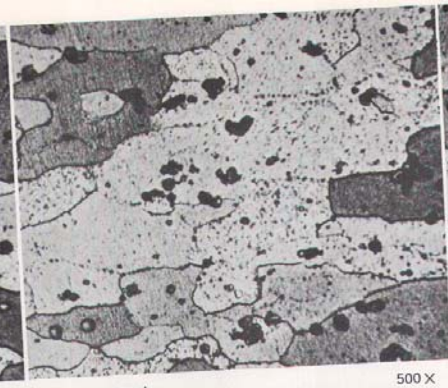
25% nitric acid 5

2039 Alloy 2024-O sheet. Structure cons of light gray particles of insol $(Cu,Fe,Mn)Al_6$, large black particles of un solved $CuMgAl_2$, and fine particles of CuM that precipitated during annealing.



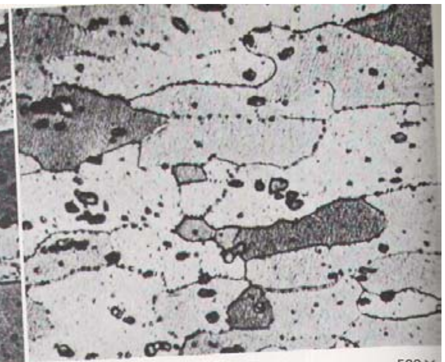
eller's reagent 500×

2022 Alloy 2024-T3 sheet, solution heat treated at 920 F (493 C) and quenched n cold water. Longitudinal section. Dark paricles are $CuMgAl_2$, Cu_2MnAl_{20} and Cu_2FeAl_7.



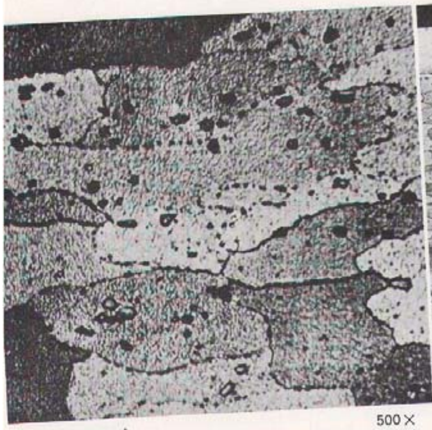
Keller's reagent 500×

2023 Same alloy and solution heat treatment as for 2022, but quenched in boiling water. The lower quenching rate resulted in precipitation of $CuMgAl_2$ at grain boundaries.



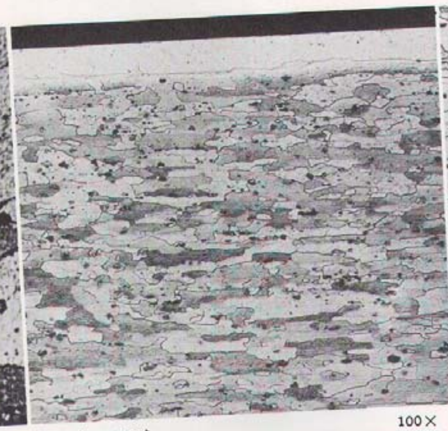
Keller's reagent 500×

2024 Same alloy and solution heat treatment as for 2022, but cooled in an air blast. The lower cooling rate resulted in increased precipitation of $CuMgAl_2$ at grain boundaries.



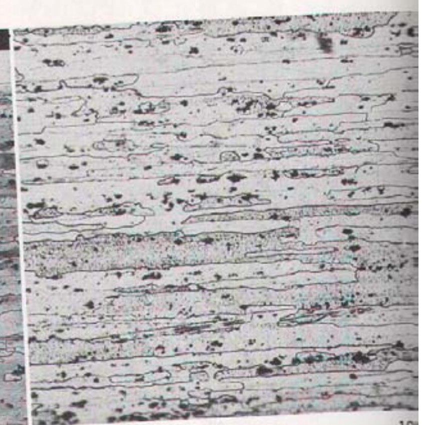
Keller's reagent 500×

2025 Same alloy and solution heat treatment as for 2022, but cooled in still air. The slow cooling resulted in intragranular and grain-boundary precipitation of $CuMgAl_2$.



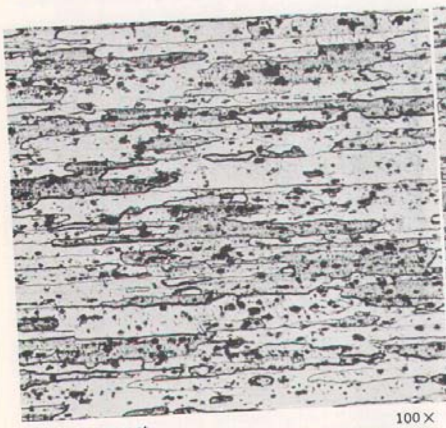
Keller's reagent 100×

2026 Alloy 2024-T3 sheet clad with alloy 1230 (5% per side), solution heat treated. Normal amount of copper and magnesium diffusion from base metal into cladding (top).



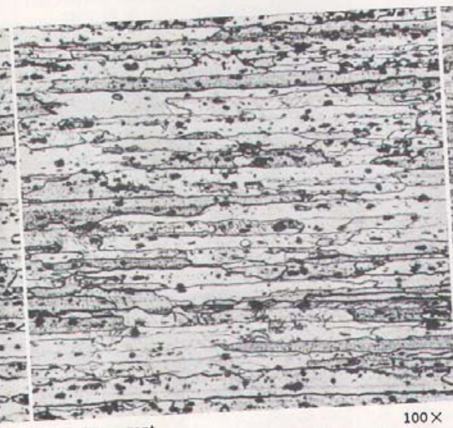
Keller's reagent 10

2027 2024-T6 sheet, ¼ in. thick (redu from 16-in.-thick ingot), stretched 2 Longitudinal section. Note absence of str lines in structure. Compare with 2028 to 2



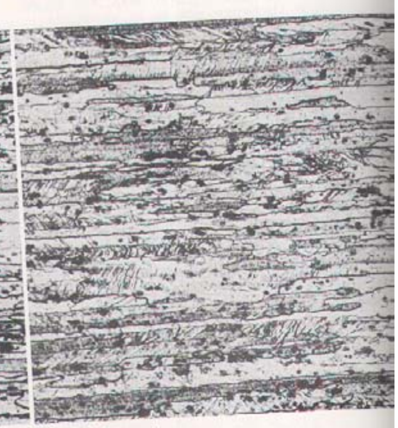
Keller's reagent 100×

2028 Same as 2027, but stretched 6%. Longitudinal section. Some faint strain lines have formed (compare with 2029, 2030).



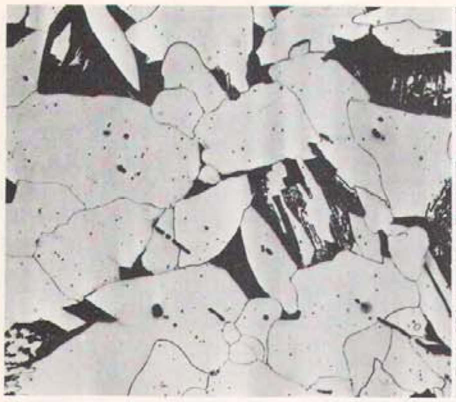
Keller's reagent 100×

2029 Same as 2027, but stretched 12%. Longitudinal section. More strain lines have formed than in 2028. Compare with 2030.



Keller's reagent

2030 Same as 2027, but stretched 20% gitudinal section. A great many lines have formed (compare with 2028, 20



Picral 500×

215 1025 steel that was normalized by austenitizing at 2000 F (1093 C) and air cooling. Coarse-grain structure consisting of pearlite (black constituent) in a matrix of ferrite (white constituent). See micrograph 216.

Picral 500×

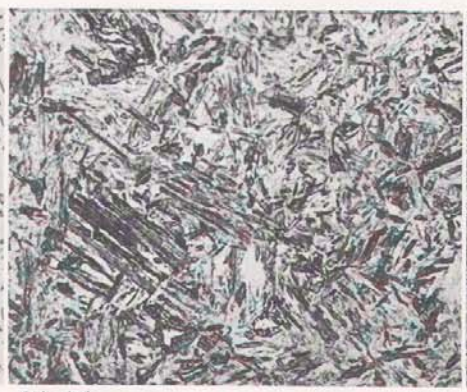
216 Same as 215 except the steel was normalized by austenitizing at 1700 F (927 C) and air cooling. The lower austenitizing temperature is responsible for the finer grain size of the normalized steel.

Picral

217 1030 steel aus
for 1 hr, then
40 min, held at 130
isothermal transform
quenched. Ferrite an

Picral 1000×

218 1030 steel austenitized at 1475 F (802 C) for 40 min, held at 1300 F (704 C) for 15 min for isothermal transformation, then heated to 1305 F (707 C) and held 192 hr. Partly spheroidized pearlite in a ferrite matrix.

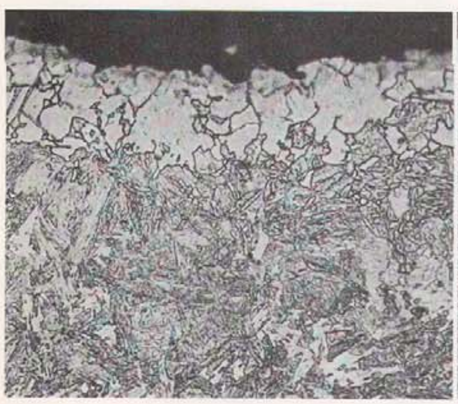


1% nital 550×

219 10B35 steel austenitized at 1560 F (849 C) 1 hr, quenched in still water, tempered at 350 F (177 C) 1 hr. Ferrite (small, white areas) and lower bainite (dark acicular areas) in a matrix of tempered martensite.

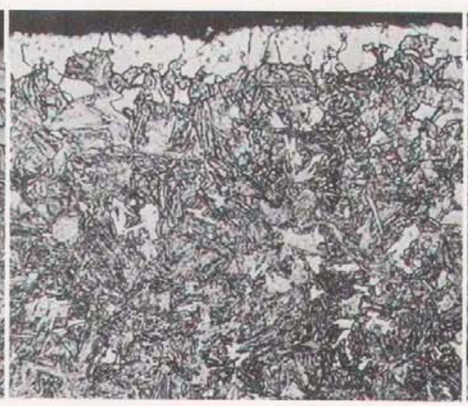
1% nital

220 10B35 steel au
as 219, but qu
and tempered at 450
severe quench suppr
and bainite. Structur



1% nital 500×

221 10B35 steel austenitized at 1600 F (871 C) 1 hr, water quenched, tempered at 450 F (232 C) 1 hr. Core is tempered martensite; surface of specimen (ferrite) is severely decarburized (white area near top).

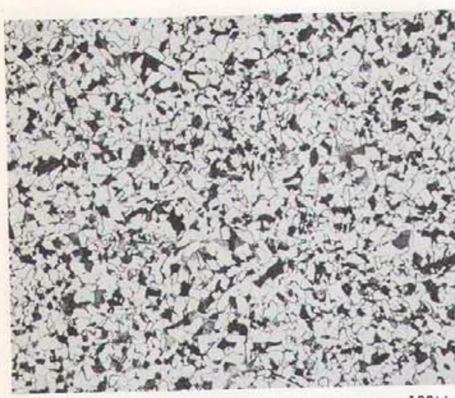


1% nital 550×

222 Same steel and heat treatment as for 221 except austenitizing was done in an atmosphere that had a carbon potential that more nearly matched that of the steel, resulting in less decarburization at surface (top).

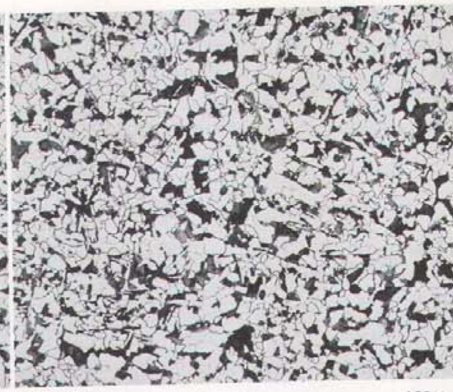
1% nital

223 Same steel a
221 and 222
350 F (177 C) for 1
in an atmosphere of
note absence of decar



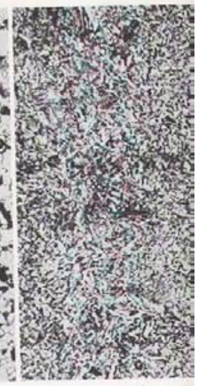
2% nital 100×

152 ASTM A537, grade A, steel plate, 2 in. thick. Normalized by austenitizing at 1670 F (910 C) and cooling in air. Specimen was taken near the plate surface. Light areas are ferrite; dark areas are pearlite.



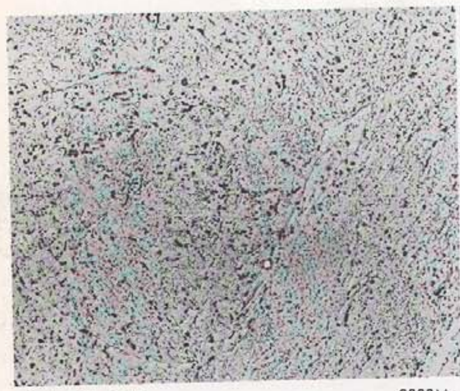
2% nital 100×

153 Same steel and heat treatment as for 152, but the specimen was taken from the center of the plate. Note that the grains are larger than those shown in the specimen taken from near the plate surface (see 152).



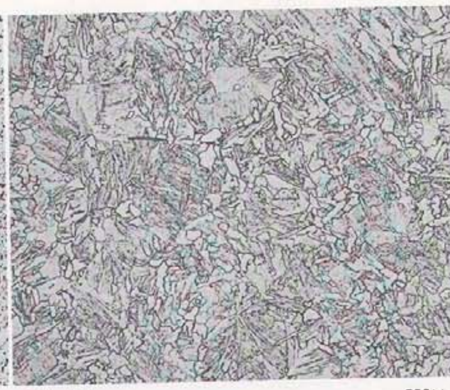
Saturated picral

154 ASTM A537 thick, quenc ized at 1650 F (899 tempered at 1100 F is carbide particles



Saturated picral 3000×

155 Same steel and heat treatment as for 154, but shown by a replica transmission electron micrograph. The carbide particles now appear as small black dots. The matrix (gray) is tempered martensite.



2% nital 500×

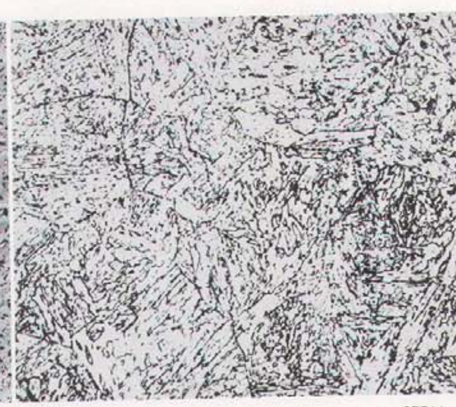
156 ASTM A537, grade B, steel plate, ¾ in. thick, quenched and tempered. Austenitized at 1700 F (927 C), water quenched, tempered at 1180 F (638 C). The structure consists of tempered martensite.

Saturated picral

157 ASTM A5 thick, quen ized at 1750 F (pered at 1250 F probably tempere

Saturated picral 3600×

158 Same steel and heat treatment as for 157, but a replica electron micrograph that resolves a general distribution of fine carbide particles (black and white; see 147 for explanation). Matrix, probably tempered bainite.

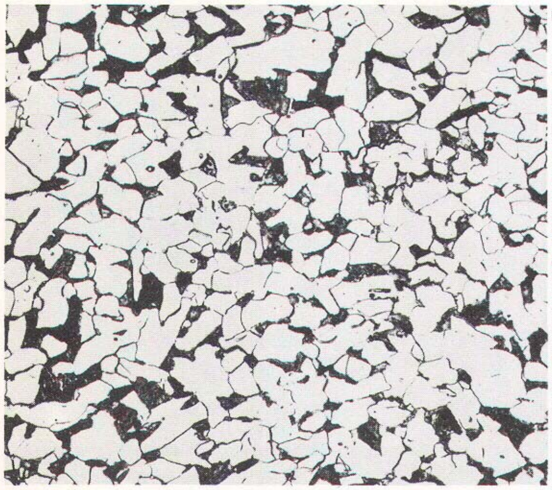


Nital 275×

159 ASTM A542, class 2, steel plate, 4.575 in. thick, austenitized 4 hr at 1750 F (954 C), quenched in agitated brine, tempered 4 hr at 1050 F (566 C). Specimen from midthickness. Structure is tempered bainite.

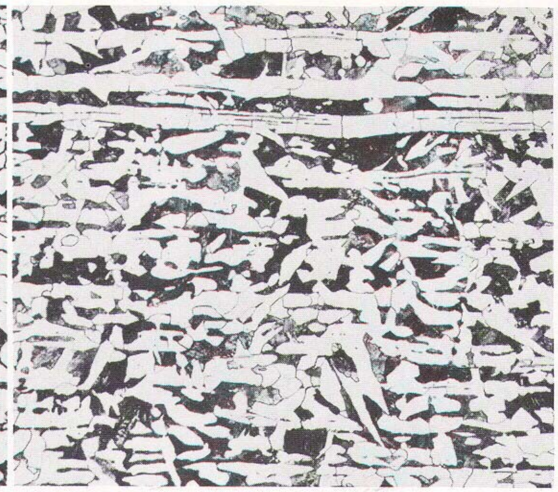
1% nital

160 ASTM A5 in. thick, tenitized at 147 quenched, temper and cooled in ai



1% nital 250×

116 ASTM A36 steel plate, ⅜ in. thick, as rolled. Structure consists of equiaxed ferrite (white areas) and pearlite (black areas).



2% nital 100×

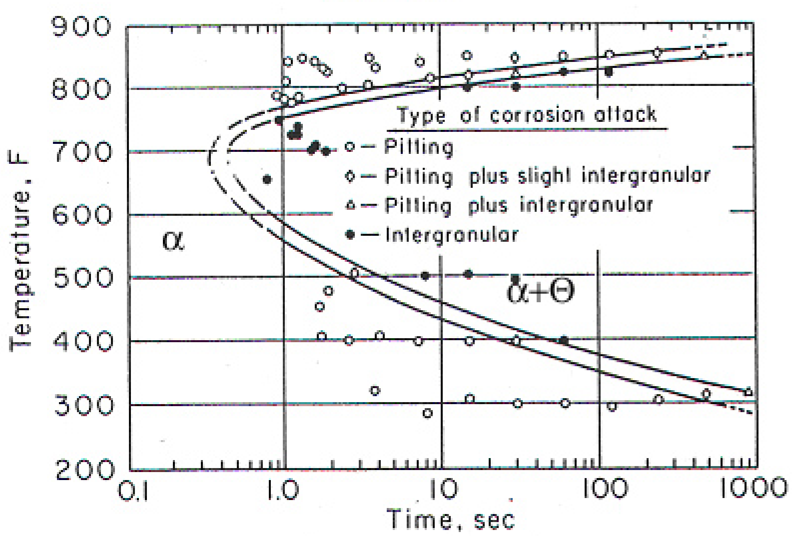
117 ASTM A36 steel plate, 1 in. thick, as rolled. Pearlite (black), and ferrite (white) with small nonmetallic inclusions.

4%

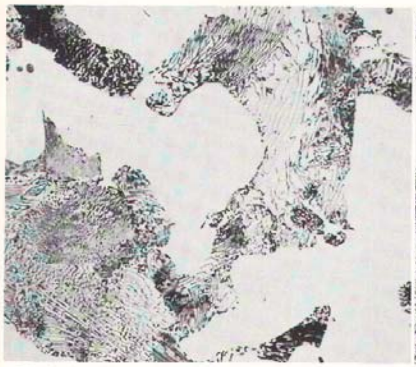
11

(see

2024 Alloy

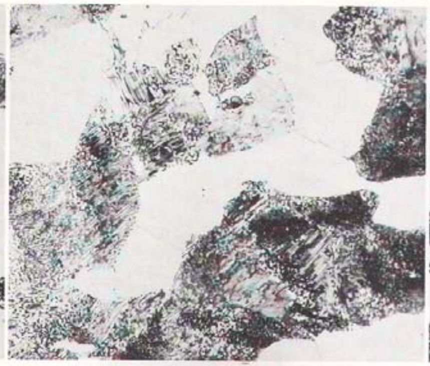


Time-temperature-corrosion diagram
Effect of temperature and time in interrupted-quenching experiments on type of corrosion attack developed in 2024-T4 sheet by an accelerated corrosion test



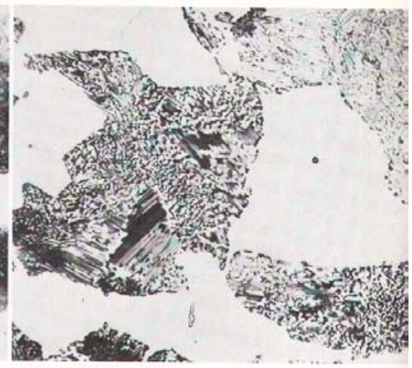
2% nital 750×

287 4130 hot rolled steel bar, 1-in. diam, austenitized at 1550 F (843 C) for 1 hr, cooled to 1250 F (677 C) and held for 2 hr, and air cooled. Partly spheroidized pearlite (dark) in a matrix of ferrite (white).



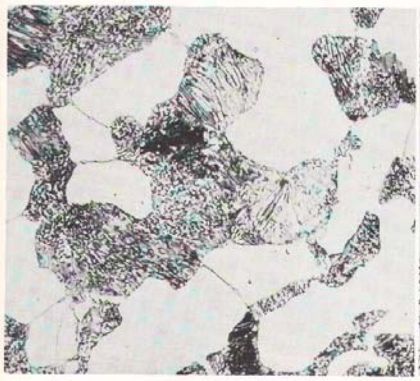
2% nital 750×

288 Same as 287 except that the time at 1250 F (677 C) was increased to 4 hr. Structure is essentially the same as that of the specimen shown in micrograph 287, but the degree of spheroidization of the pearlite is greater.



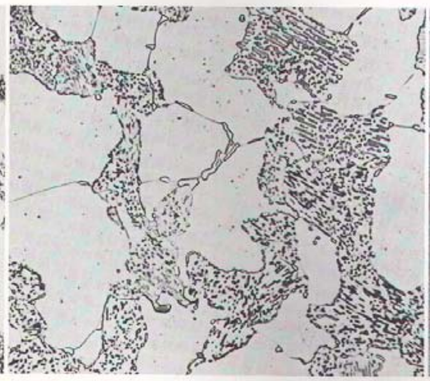
2% nital 750×

289 Same as 287 and 288 except that the tim at 1250 F (677 C) was increased to 8 h Structure is similar to those shown in 287 an 288, but the degree of spheroidization of th pearlite has further increased.



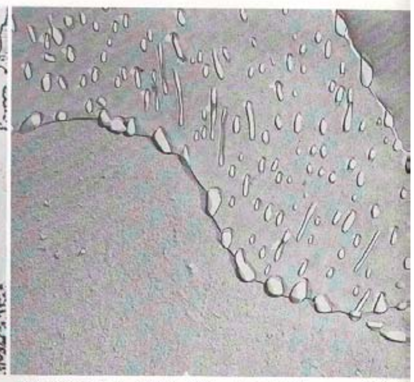
2% nital 750×

290 Same as 287, 288 and 289 except that the time at 1250 F (677 C) was increased to 16 hr. Note that the degree of spheroidization of pearlite is greater than that in 289.



2% nital 750×

291 Same as 287, 288, 289 and 290 except that the time at 1250 F (677 C) was increased to 112 hr. Spheroidization of the pearlite is now nearly complete.

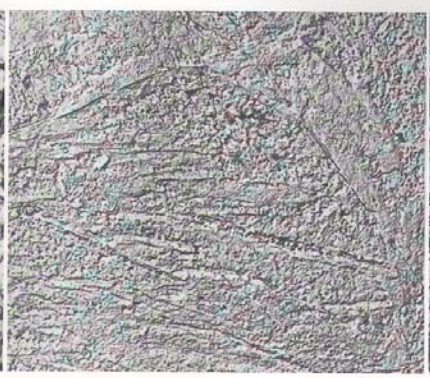


5% picric acid, 2½% HNO_3, in ethanol 5000×

292 Same as 291. Electron micrograph of a platinum-carbon-shadowed two-stage carbon replica. Spheroidized pearlite (middle) and ferrite (upper right and lower left).

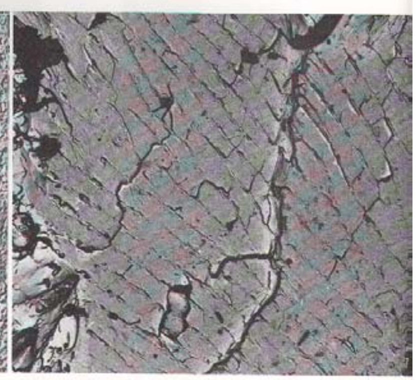
2% nital 750×

293 4130 hot rolled steel bar, 1-in. diam, austenitized at 1600 F (871 C) for 1 hr and water quenched. Untempered martensite.



5% picric acid, 2½% HNO_3, in ethanol 11,000×

294 Same as 293, but an electron micrograph of a platinum-carbon-shadowed two-stage carbon replica. Untempered martensite.

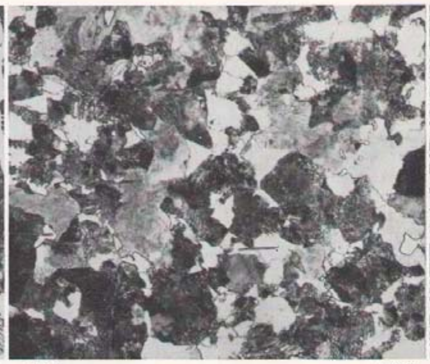


Not polished, not etched 8600×

295 4130 steel in the annealed condition. A replica electron fractograph. Note fatigue striations, resolved only at high magnification.

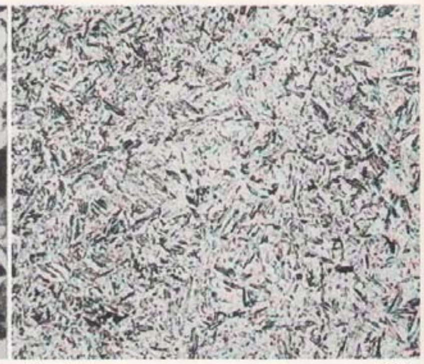
2% nital 825×

296 Resulfurized 4140 steel forging normalized by austenitizing at 1650 F (899 C) hr, air cooling; annealed by heating at 1500 F (816 C) 1 hr, furnace cooling to 1000 F (538 C), air cooling. Blocky ferrite and fine-to-coarse lamellar pearlite. Black dots are sulfide.



Nital 500×

297 4140 steel bar, 1-in. diam, austenitized at 1550 F (843 C) 1 hr, cooled to 1200 F (649 C) and held 1 hr for isothermal transformation, then air cooled to room temperature. White areas, ferrite; gray and black areas, pearlite with fine and coarse lamellar spacing.

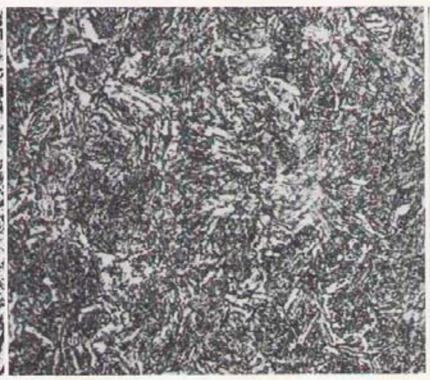


2% nital 500×

298 4140 hot rolled steel round bar, 1 in. in diameter, austenitized at 1550 F (843 C) for 1 hr and water quenched. Structure consists entirely of fine, homogeneous, untempered martensite. Tempering at 300 F (149 C) would result in a darker-etching structure.

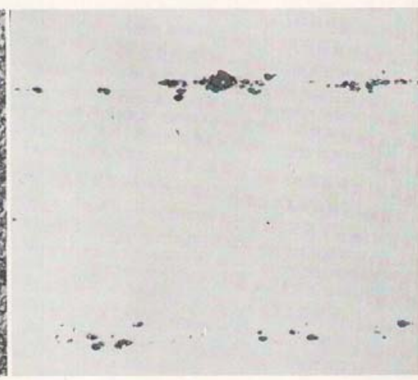
2% nital 500×

299 Same as 298 except the steel was quenched in oil instead of water, resulting in the presence of bainite (black constituent) along with the martensite (light).



2% nital 750×

300 4140 steel bar austenitized at 1550 F (843 C), oil quenched to 150 F (66 C), and tempered 2 hr at 1150 F (621 C). Tempered martensite; some ferrite (small, white areas).

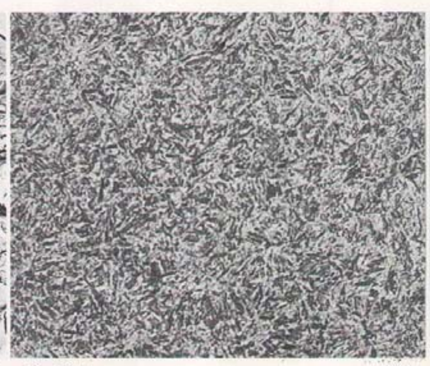


As polished (not etched) 200×

301 Oxide inclusions (stringers) in a 4140 steel bar, 1 in. in diameter. The stringers are parallel to the direction of rolling on the as-polished surface of the bar.

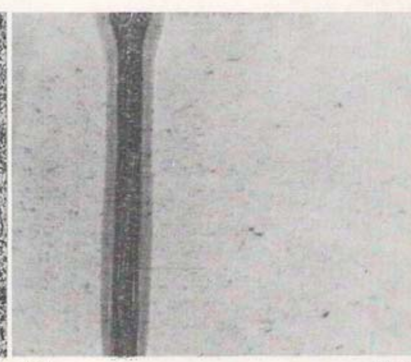
Not polished, not etched 8600×

302 4140 steel. Replica electron fractograph showing the dimpled structure that is typical of the overstress mode of failure.



2% nital 500×

303 4340 steel quenched in oil from 1550 F (843 C) and tempered at 600 F (316 C). Structure is tempered martensite.



Nital 2¾×

304 Electron beam weld in 4340 steel that had been quenched, and double tempered at 500 F (260 C), before electron beam welding.