MSE170
3/03/08

Week 6 TA Meeting

Agenda:
Lab IV theory
Go over Lab IV procedure
If time- go over prelab
If time- go over grading
Anything else?

I) Opening

Check Lab notebooks- if students made effort to complete every question, give them full credit.
Tell students, if time will review prelab at end

II) Lab IV: Heat Treatment
Each lab section will do one complete set of materials. This means your whole lab section needs:
4- 1018 Samples
4- 4340 Samples
4- Aluminum 2024 Samples
4- 70-30 Brass Samples

* Quench after annealing
* 30 minutes for each heat treatment

	Steel 1018	Steel 4340	Aluminum 2024	70-30 Brass
Sample 1 Quench	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 Quench, Anneal	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 Slow cool	Heat to 900 Cool slowly	Heat to 900 Cool slowly	Heat to 550 Cool slowly	Heat to 550 Cool slowly
Sample 4 Slow cool, anneal	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

☆ Go over SAFE furnace operating procedure and discuss how early TAs need to arrive to turn furnaces on before their section

4 quadrants
suggest how to group samples for initial heat treatment — separated by temperature and speed of cooling

One person from each group monitor the furnace temperature
One person from each group keep track of time.

Remember safety. Don't rush. Wear goggles, gloves, face shield.
Quench in water right by the furnace. Slow cool in vermiculite. Slow cool after annealing in air.
Check samples to make sure they are cold before removing.

This is a large source of error →
☆☆☆ Sand sample down before measuring hardness — remove oxide layer on ALL samples
Brass, Al 2024: Use HRB Scale — only surface that will be tested
~~Steel 4340: Use HRC Scale~~ — 240 grit SiC
4340 + Steel 1018 Quenched, Quenched Anneal: Use HRC scale
4340 + Steel 1018 Slow cool, Slow cool anneal: Use HRB scale

III) Review Lab IV theory and lab report
Students can see course web site to see our grading sheet, and the format.
This is a full length lab report
Micrographs are on the course web site. They need to be cited in the report
Review data on board
Review theory. It is OK to give them "the answers." This is a difficult lab report

~~**IV) Next Week**~~
Lab IV: Heat Tr~~eatment Lab report Due~~ — depends on quarter
~~Print out Lab V: Mechanical Testing answer prelab questions in lab notebook~~

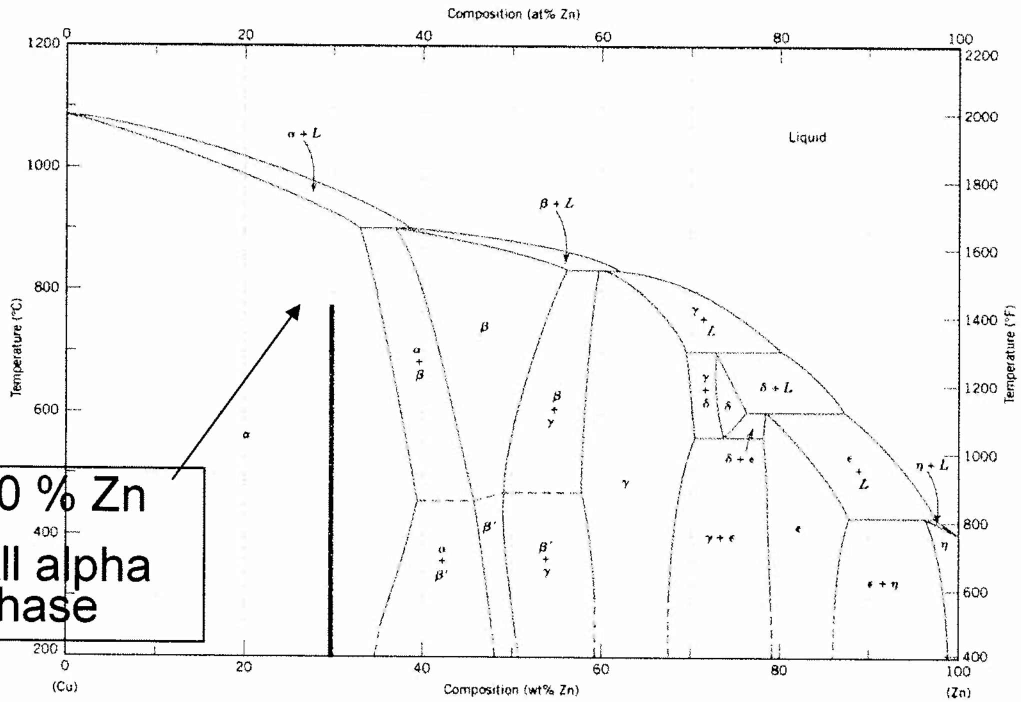
Lab IV: Phase Transformations Sample Data

	Brass 360	Aluminum 2024	Steel 4340	Steel 1018
Quench	Soft 58 HRB	Soft off-scale low HRB no precipitates, saturated alloy solution	Hardest 43 HRC Martensite	Hardest 38 HRC martensite or bainite
Quench + Anneal		Hardest 70 HRB Optimum large number and small size of precipitates	Hard 40 HRC tempered martensite	Hard 32 HRC tempered martentsite or tempered bainite
Slow Cool		Soft off-scale low HRB Overaged	Soft 94 HRB pearlite	Soft 90 HRB pearlite
Slow Cool + Anneal		Soft off-scale low HRB Even more overaged	Soft 88 HRB tempered pearlite	Soft 74 HRB tempered pearlite

*All hardness values are from a previous quarter and should not be expected to match your data exactly, but your numbers should be in the same relative order (hardest to softest) for each material – example: for the Quenched 4340 sample, you shouldn't expect to get exactly 43 HRC, but that sample should be the hardest of the rest of your 4340 samples

Brass 360

70% Cu
30% Zn

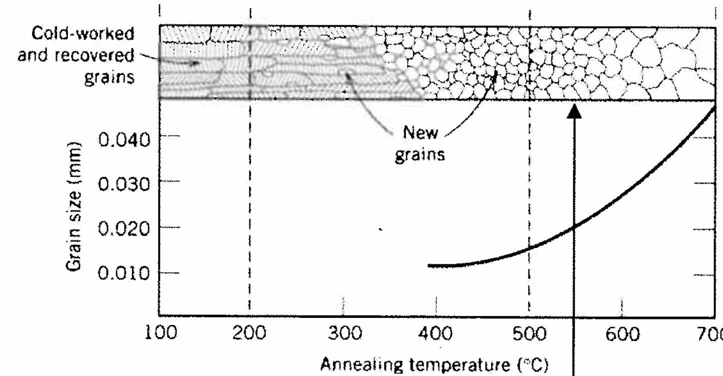


30 % Zn
All alpha phase

(e)

Medium Grains

Note: With no heat treatment Brass 360 is hard [74 HRB]. Heat treatment brings as received samples through recrystalization and grain growth. Must mean that samples were received cold worked



550° C
Medium Grain size

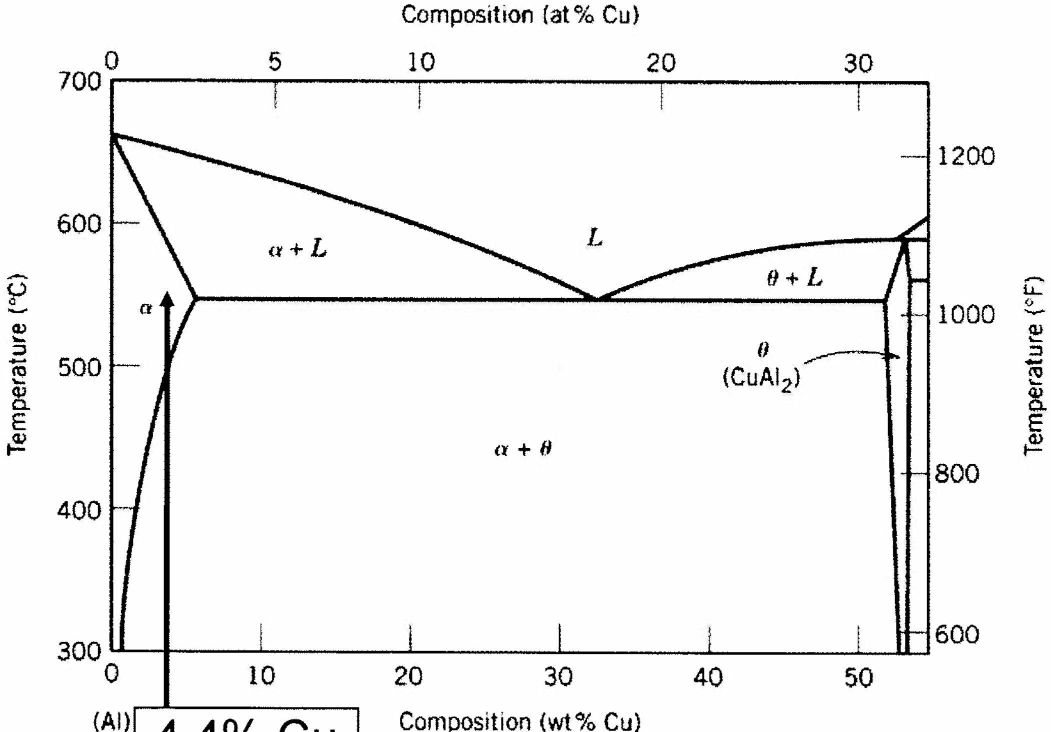
Quench	Soft 58 HRB
Quench and Anneal	Soft 58 HRB
Slow Cool	Soft 58 HRB
Slow Cool and Anneal	Soft 58 HRB

Hardness may slighting increase with longer time at high temp.
Small increase in grain size

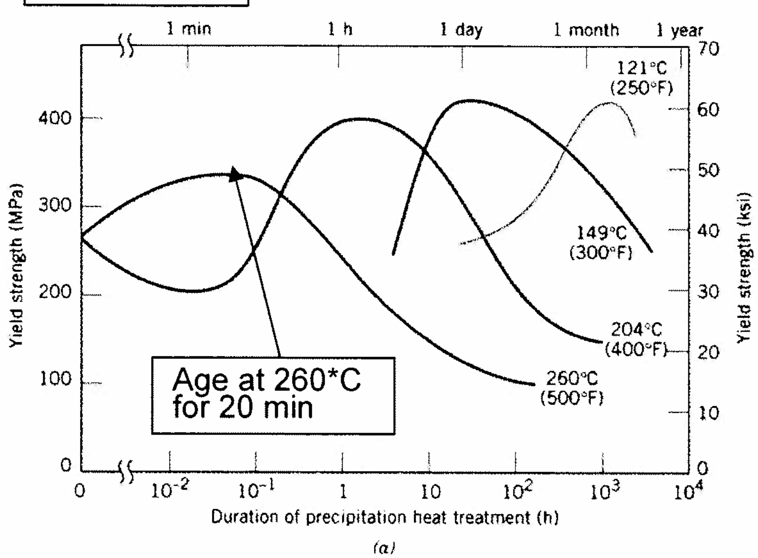
Callister sections 7.10-7.13

Aluminum 2024

4.4% Cu
1.5% Mg
0.6% Mn

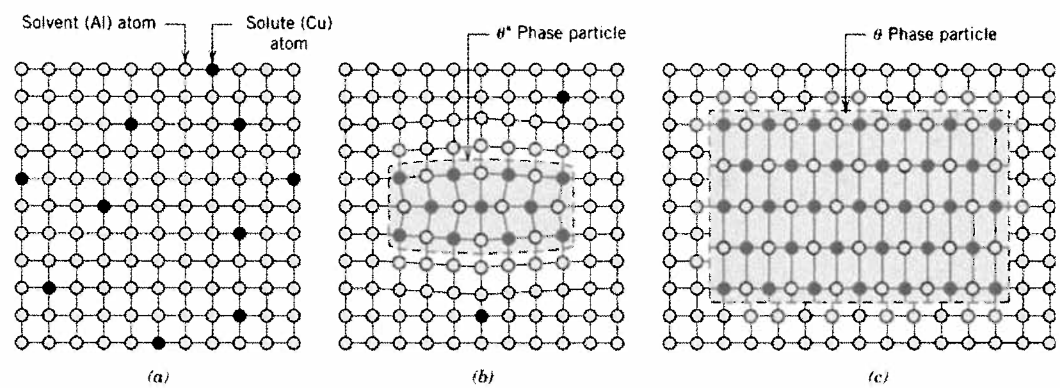


4.4% Cu



Age at 260*C for 20 min

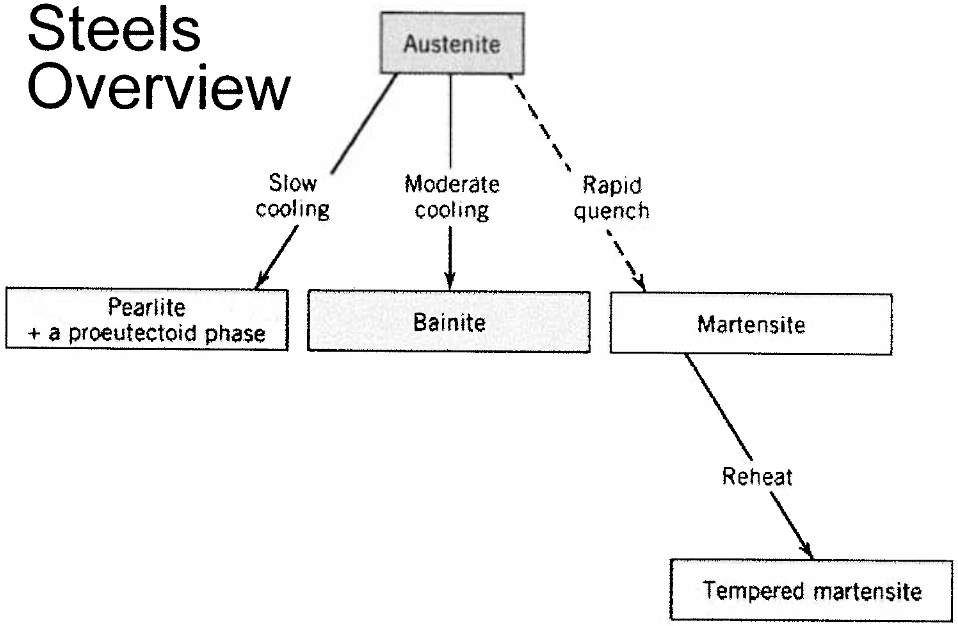
Quench	**Soft off-scale low** Few, if any precipitates form. Supersaturated alloy solution
Quench and Anneal	**Hardest 70 HRB** Optimum large number and small size of precipitates
Slow Cool	**Soft off-scale low** Fewer number and larger precipitates - OVERAGED
Slow Cool and Anneal	**Soft off-scale low** Even Fewer number and larger precipitates – even more OVERAGED

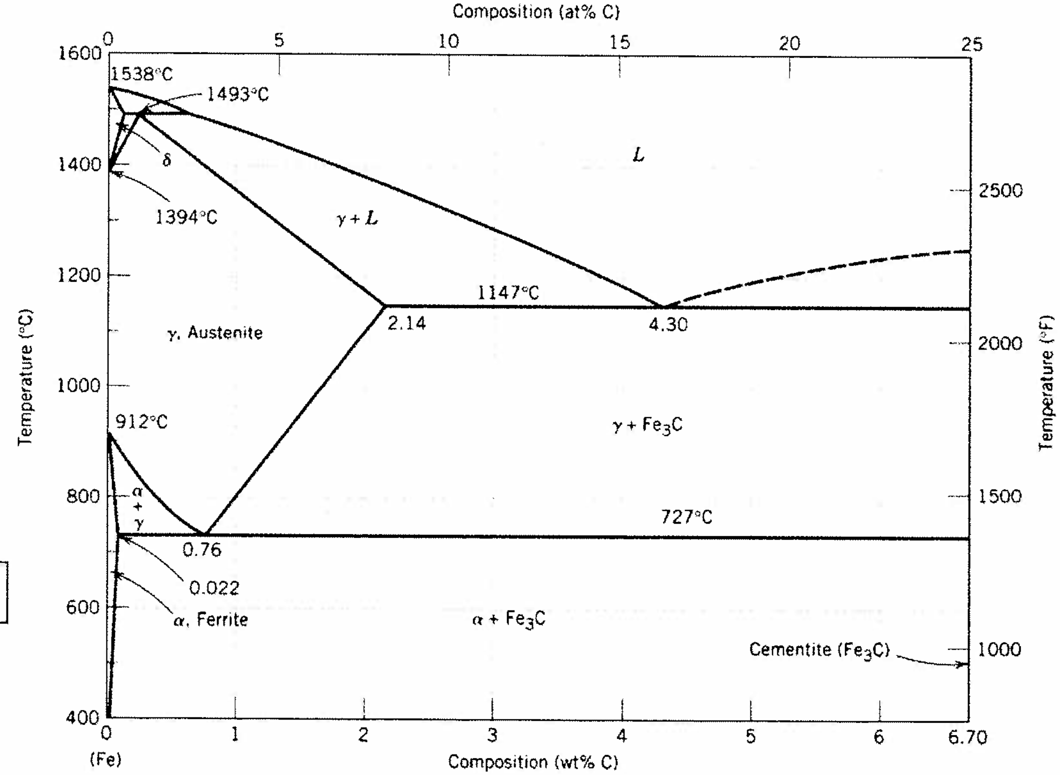


Precipitates and lattice strain impedes dislocation motion

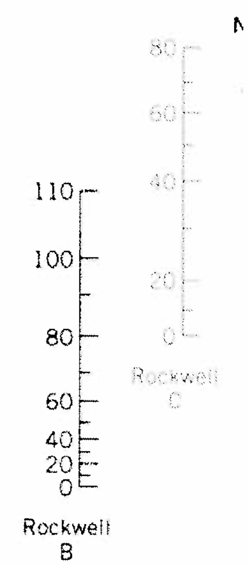
Callister p402

Steels Overview





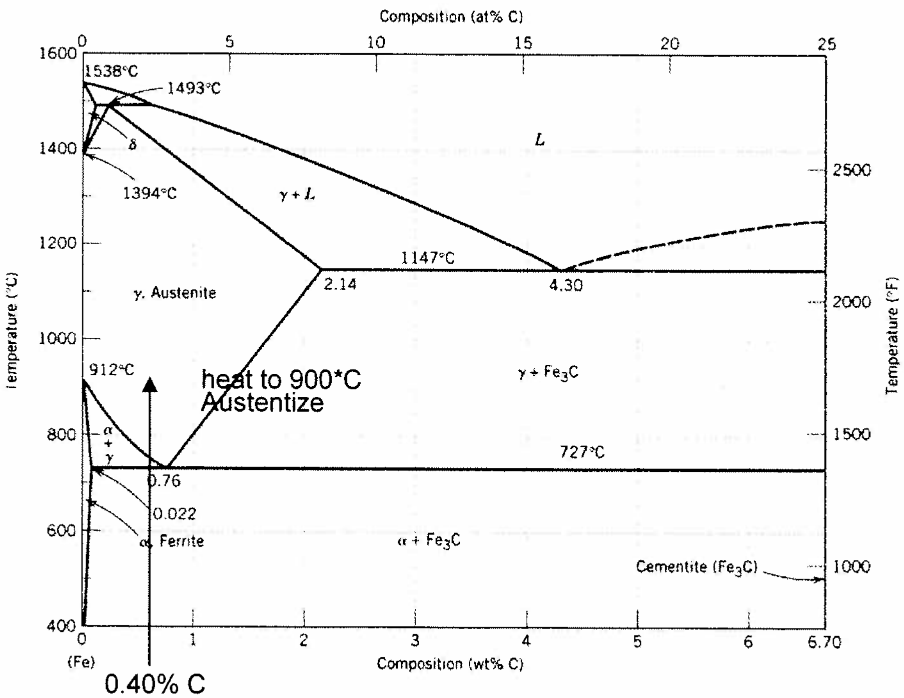
Microconstituent	Phases Present	Arrangement of Phases	Mechanical Properties (Relative)
Spheroidite	α Ferrite + Fe_3C	Relatively small Fe_3C sphere-like particles in an α-ferrite matrix	Soft and ductile
Coarse pearlite	α Ferrite + Fe_3C	Alternating layers of α ferrite and Fe_3C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α Ferrite + Fe_3C	Alternating layers of α ferrite and Fe_3C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α Ferrite + Fe_3C	Very fine and elongated particles of Fe_3C in an α-ferrite matrix	Hardness and strength greater than fine pearlite; hardness less than martensite; ductility greater than martensite
Tempered martensite	α Ferrite + Fe_3C	Very small Fe_3C sphere-like particles in an α-ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered tetragonal, single phase	Needle-shaped grains	Very hard and very brittle

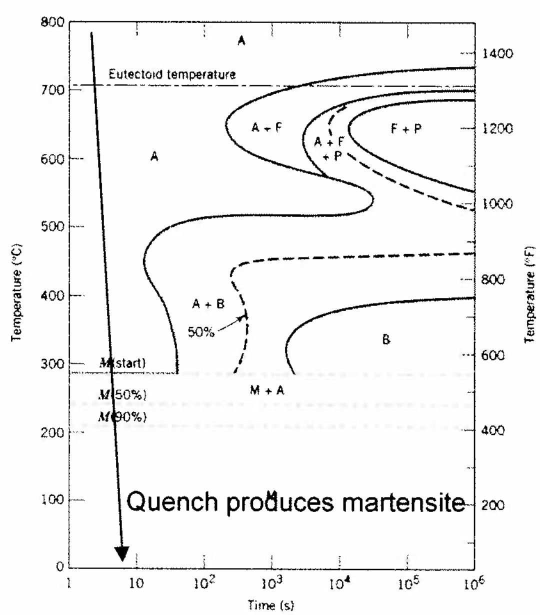


Hardness Scale Comparison Callister p159

Steel 4340

0.40% C
and Cr, Mo, Mn



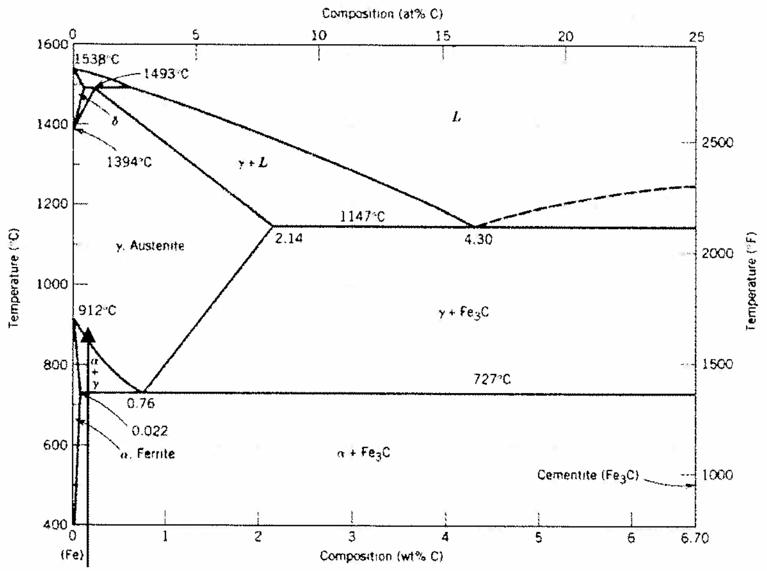


Quench	Hardest 43HRC Martensite
Quench and Anneal	Hard 40 HRC Tempered Martensite
Slow Cool	Soft 94 HRB pearlite and proeutectoid ferrite
Slow Cool and Anneal	Soft 88 HRB tempered pearlite and proeutectoid ferrite

Higher Carbon content in 4340 produces more lattice distortion in martentsite phase

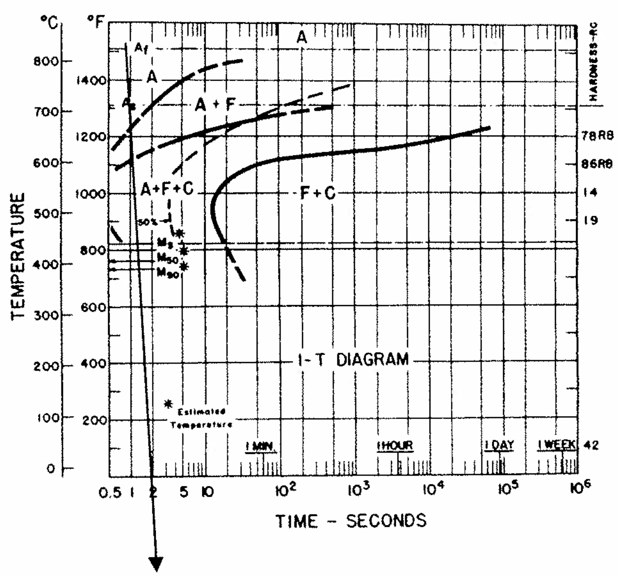
Steel 1018

0.18% C
and Mn



0.18% C

Type: 1019
Composition: Fe - 0.17% C - 0.92% Mn Grain size: 0-2
Austenitized at 1316°C (2400°F)

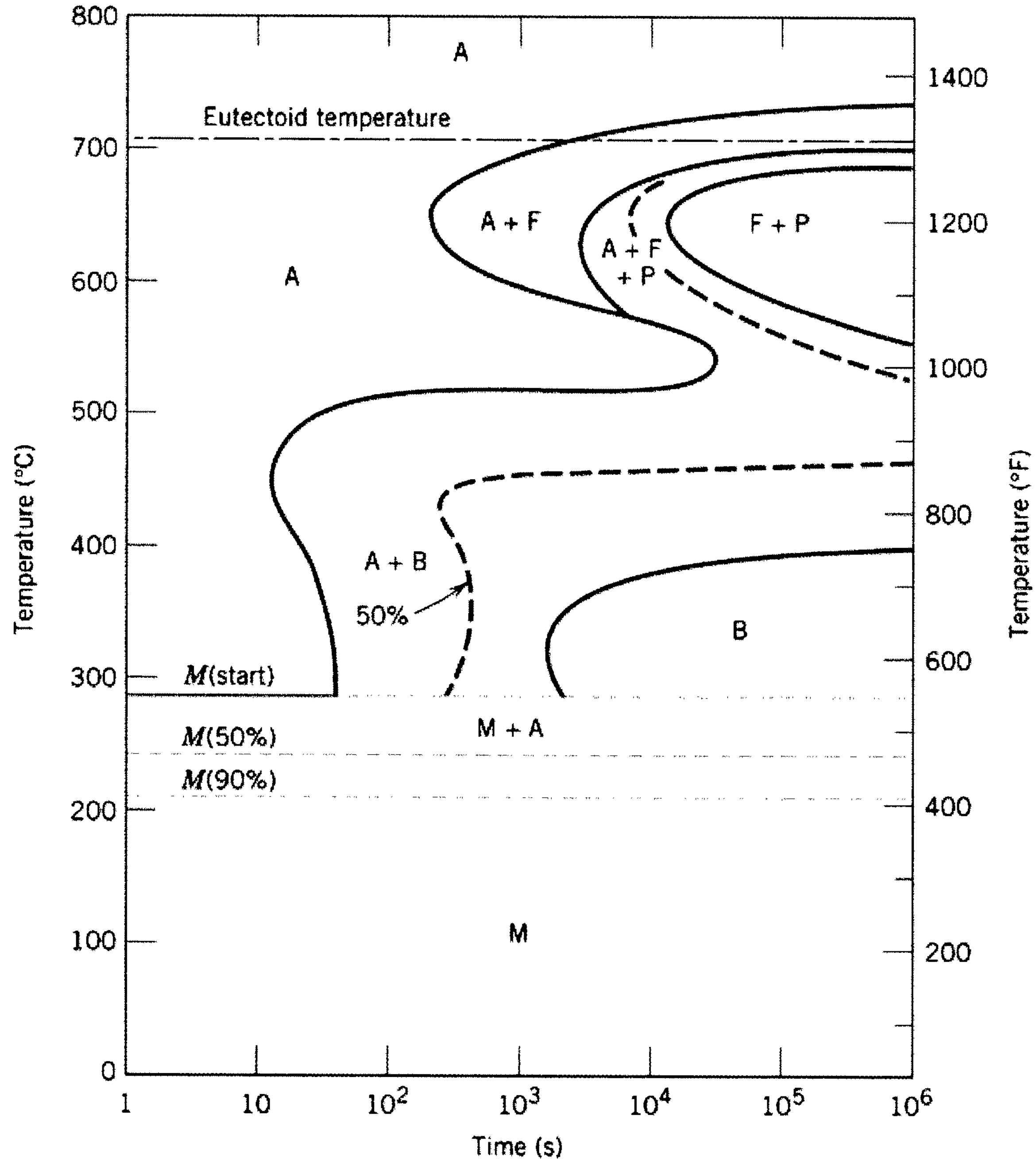


Quench produces martensite

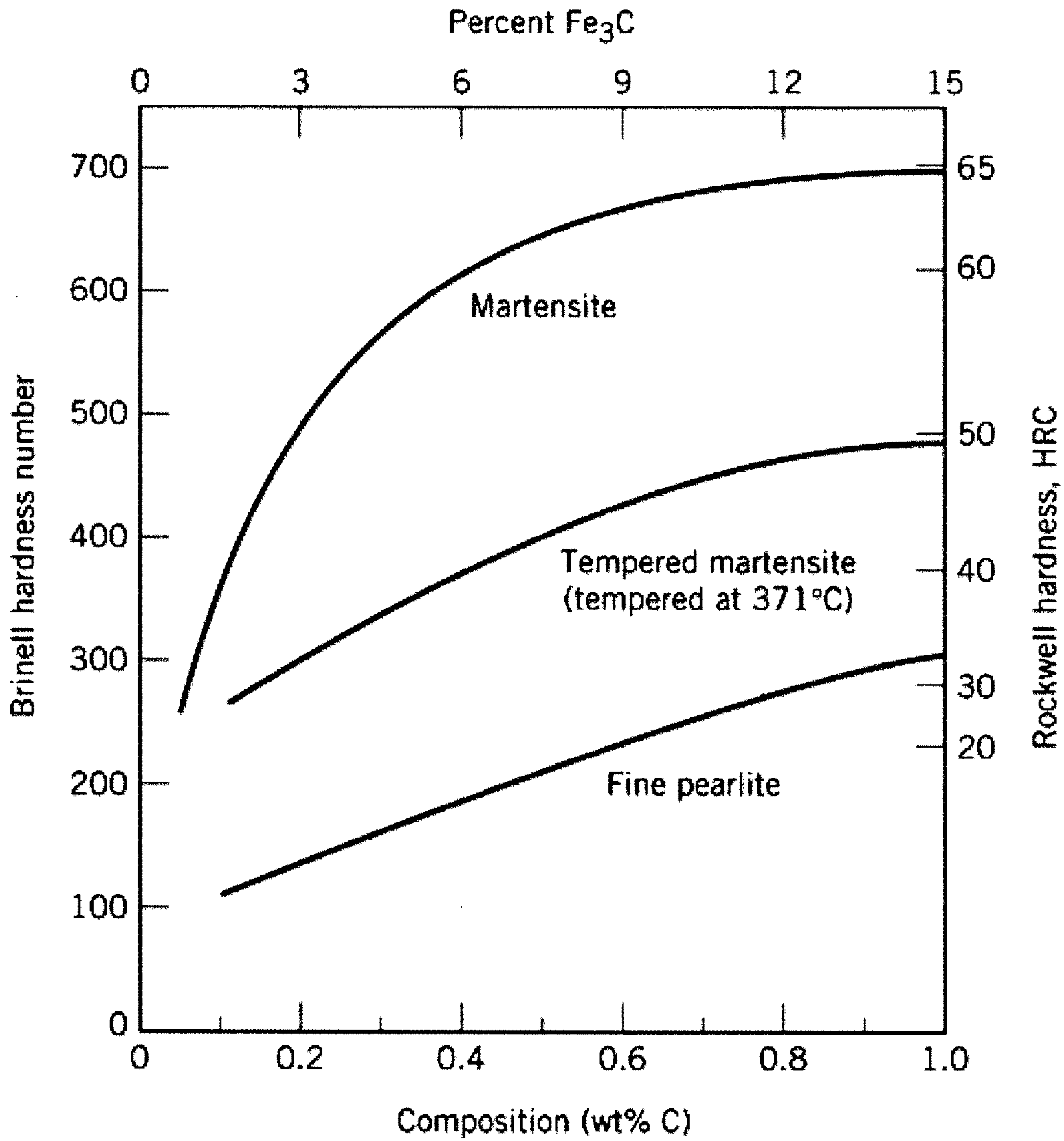
Quench	Hardest 38 HRC Martensite
Quench and Anneal	Hard 32 HRC Tempered Martensite
Slow Cool	Soft 90 HRB pearlite and proeutectoid ferrite
Slow Cool and Anneal	Soft 74 HRB tempered pearlite and proeutectoid ferrite

Included in back of lab handout – use 1019 to approximate 1018 TTT behavior

Microconstituent	*Phases Present*	*Arrangement of Phases*	*Mechanical Properties (Relative)*
Spheroidite	α Ferrite + Fe_3C	Relatively small Fe_3C sphere-like particles in an α-ferrite matrix	Soft and ductile
Coarse pearlite	α Ferrite + Fe_3C	Alternating layers of α ferrite and Fe_3C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α Ferrite + Fe_3C	Alternating layers of α ferrite and Fe_3C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α Ferrite + Fe_3C	Very fine and elongated particles of Fe_3C in an α-ferrite matrix	Hardness and strength greater than fine pearlite; hardness less than martensite; ductility greater than martensite
Tempered martensite	α Ferrite + Fe_3C	Very small Fe_3C sphere-like particles in an α-ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered tetragonal, single phase	Needle-shaped grains	Very hard and very brittle



Steel 4340 Isothermal transformation diagram Callister p333



Callister p343

Prelab Question answers for Lab IV:

1.

   a. Accept anything close; Ch. 11 holds a little less information than Appendix B. Don't worry about info in brackets below.

      1018 steel: Fe + 0.18 % C [and Mn?]

      4340 steel: Fe + 0.40 % C [and Cr, Mo, Mn]

      70-30 (260) brass: Cu + 30 % Zn [and Pb, Fe]

      Al 2024: Al + 4.4 % Cu, 1.5 % Mg, 0.6 % Mn

   b and c. The microstructures for the different phases are on the course web site. They can paste these into their lab reports, but they must be cited. In some cases there may be more than one acceptable answer, and there is usually extra information in the pictures that is irrelevant for our purposes.

   d. Equalibrium Phase diagrams, for 1018 and 4340 steels, Brass, and Al 2024 are given in the book.

   e. TTT diagrams or hardness vs. time: For steel 1018: use 1019 graph attached to lab IV, steel 4340 and Al 2024 are given in the book, brass is not given, it's ok if they couldn't find any.

2. In equalibriam phase diagrams there is no information on time or the associated metastable microstructures.

3. These are both hypoeutectoid steels.

   a. 1018: 2 phases: % pearlite = (.18-.022) / (.76-.022) * 100 = 21.4 %; the rest, 78.6%, is proeutectoid α-ferrite. picture is given in the book.

   b. 4340: 2 phases: % pearlite = (.40-.022) / (.76-.022) * 100 = 51.2 %; the rest, 48.8%, is proeutectoid α-ferrite. picture is given in the book.

4. Lowest temperature in the phase diagrams: Steels: 727 °C; Al 2024: ~650 °C; Brass <= 200 °C

5. a

      i. 1018, 4340: martensite

      ii. 1018: pearlite [plain carbon steels don't form bainite]; 4340, a mix of bainite and martensite

      iii. Al 2024, alpha and theta phases; brass, alpha

      iv. Al 2024, alpha and theta phases; brass, alpha (same)

   b. Phase diagrams represent (approximate) thermodynamic equilibrium, and martensite is not ultimately thermodynamically stable

6. TO: annealed, T3: solution heat treated, cold worked, then naturally aged; T6: solution heat treated, then artificially aged.

Fundamentals of Materials Science

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 the solutionized & 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°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 900°C to below 500°C in 1 second and room temp in less than 5 seconds

ii. 4340 and 1018 (A36) cooled from 900°C to below 500°C in 20 seconds and room temp in 200 seconds
iii. Al 2024 and Brass 70-30 (260) cooled from 550°C to room temp in less than 1 second
iv. Al 2024 and brass 70-30 (260) cooled from 550°C to room temp in 200 seconds

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?

I. 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

II. 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°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 sample experiencing approximately equilibrium cooling. The second piece will be quenched in water resulting in a sample with non-equilibrium cooling. A subset of these samples will then be reheated to a temperature that will allow limited diffusion for 30 minutes.

III. Experimental Procedure

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.

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

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 hardness measurements using Rockwell C and/or Rockwell B scales. Take at least 3 measurements on each sample and average the values. Be careful not to place hardness indentations 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.

IV. Analysis

1. What is the difference between 4340 steel and 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)) microstructures 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 600°C 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 the deviations could be corrected.

V. Formal Lab Report

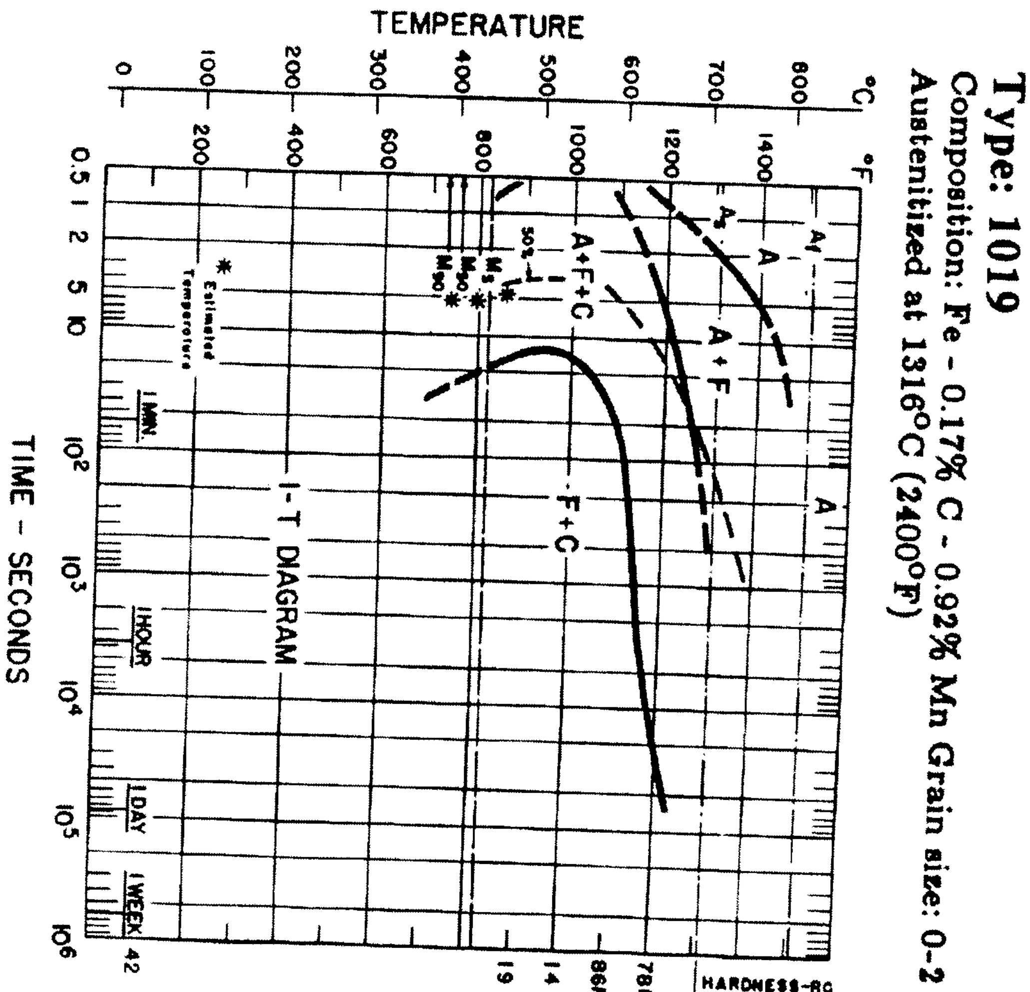
The formal lab report should address all the questions above but should not consist only of these questions. Please follow the procedures outlined on the homepage and in the lab. Look under lab handouts and report formats *(How to write a lab report)* for point distribution and requirements.

VI. 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 York, (1972).
3. George L. Kehl, **The Principles of Metallographic Laboratory Practice, 3rd Ed.** *McGraw-Hill*, New York (1949), pp. 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), pp. 335-379.
6. ASM Metals Handbooks

APPENDIX

Possibly useful diagrams and microstructures from **Metals <u>Handbook 8th Edition, Vol. 7: Atlas of Time-Temperature Diagrams for Nonferrous Alloys / edited by George F. Vander Voort.</u>** *ASM International*, ©1991 and **<u>Atlas of Time-Temperature Diagrams for Irons and Steels / edited by George F. Vander Voort.</u>** *ASM International*, ©1991.



Lab IV: Heat Treatment
Grading Criteria

MSE 170

COVER PAGE (5 points)
Laboratory title, course name and #
Needs to be a seperate page
Student name(s) incl. group members
Instructor's name, TA's name
Date report due
Abstract

ABSTRACT (10 points)
Purpose: Brief introduction to the experiment.
Procedure: Identifies experimental approach (materials, variables, equip, etc.).
Experimental results are given (numeric when possible).
Significant conclusions are reported.
Needs to be concise

PROCEDURE (10 points)
This should be written in paragraph form.
Be as specific as possible
Someone should be able to complete the same experiment by reading your procedure.

RESULTS (15 points)
Figures and tables are descriptively captioned (figure 1: Hardness values...).
Computations are complete and correct (sample calculations cited).
Data and calculated results are presented in tabular or graphical form (% difference, %error, etc.).
Same data does not appear in both tables and graphs (unless in Appendix).
Good comprehension of the relative meaning and importance of the results is shown (trends are cited, averages, extremes, % change, etc.).

DISCUSSION (30 points) Order of presentation is logical.
Discussion concerns experiment results and correlation with analysis, not comments on experiment technique or lost data. Data is interpreted correctly, related to micro-structure.
Comparisons are made between materials and treatments. Results related to micro-strucutre.
Error analysis is performed; deviation from expected results is discussed.
Lab questions to be answered are incorporated within the body of the report.

CONCLUSIONS (15 points)
Most important conclusions are given first.
Conclusions are drawn only from the body of the report.
Micro-structure to property relationships are reinforced

REFERENCES (5 points) References are cited in the text (superscript # or [#] end of sentence)
References are presented in a numbered list in the order of citation
Proper format is used for each reference
All micro graphs and phase diagrams are cited.

WORKUP (10 points) General arrangement of ideas is logical, clear, and consistent
Grammar, sentence, and paragraph structure are good
Spelling errors are absent, paper has been proof-read
Page composition is appropriate, neat, and pleasing
Units defined on sample calculations, tables, graphs, etc.

TOTAL SCORING (100 points)

Grading Scheme for labIV: TTT

These are suggestions for how to award points specifically for this lab using the general grading criteria found on the course website

COVER PAGE (10)

- Separate cover page (5)
- Laboratory title, course name and # (1)
- Student name(s) including group members (1)
- Date report due (1)
- Abstract (1)

ABSTRACT (10)

- Introduction (2.5)
- Procedure (2.5)
- Results (2.5)
- Conclusions (2.5)

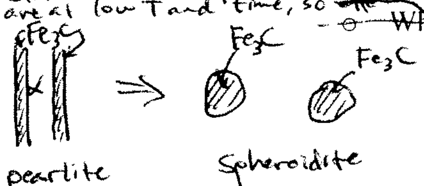
PROCEDURE (5)

- Paragraph, not bulleted list

RESULTS AND DISCUSSION (35)

- Separate Results and Discussion **(2)**
- Error Analysis **(3)**
- All figures and tables referred to in text **(1)**
- Lab questions are included in body of report, not numbered **(2)**
- Compare hardness results to literature values (2)
- Effect of heat treatments on hardness AND microstructure
    - Brass **(3)**
        - Solutionizing takes as-received material through recovery, recrystallization, and grain growth, decreasing hardness
        - Quenching vs. slow cooling shouldn't make much of a difference to microstructure
        - Annealing might provide further grain growth, further reducing hardness
    - Aluminum **(5)**
        - Al-Cu precipitates block dislocation motion, increasing hardness
        - Small precipitates are more effective than large precipitates due to coarsening – average distance between precipitates increases with increasing precipitate size – small precipitates have lattice mismatch = strain, large precipitates don't → strain blocks dislocation motion
        - Hardness should go as follows As-Quenched<Slow Cooled+Annealed<Slow Cooled<Quenched+Annealed
    - 4130 and 1018 Steel **(8)**
        - Quenching forms metastable phase martensite – hard because BCT has few slip systems ← w/ Carbon interstitial
        - Annealing the as-quenched sample forms tempered martensite – softer because BCC α + Fe_3C precipitates that coarsen with more tempering and weaken material
        - Slow cooling forms equilibrium phases proeutectic ferrite and pearlite
        - ~~Annealing after slow cooling allows pearlite structure to coarsen~~
        - Relative hardness ~~coarse pearlite~~ tempered pearlite<~~fine pearlite~~ pearlite<tempered martensite<martensite
    - Why is 4130 martensite harder than 1018 martensite? **(2)**
        - Compositions of steels tells us 4130 has higher carbon content
        - Hardness vs. wt%C says hardness increases with wt%C
        - Higher wt%C provides more lattice distortion for martensitic phase transition from FCC austenite to BCT martensite
    - ~~Why does the decomposition of austenite take longer in 4340 than 1018? (1)~~

1) cooling rate determines lamellae thickness
2) lamellae thickness do not change with annealing – need to go back up to austenite to change thickness
3) tempering/annealing pearlite starts to form spheroidite – we are at low T and time, so ~~the~~ → we can't see the physical effects of the tempering yet



        - Substitutional alloying additions (Cr, Mo) make diffusion harder
  - Did they use figures from text/other sources such as TTT diagrams, hardness vs. wt%C, phase diagrams (ex. Al-Cu), etc., to explain results **(3)**
  - Did they point out physical make-up of microstructures in the micrographs? **(2)**
    - Ex. in Figure 1, the white phase is ferrite and the black phase corresponds to pearlite, lamellar structure is too fine to distinguish ferrite and cementite at this magnification
  - Effect of quenching in oil instead of water **(1)**
    - Slower cooling rate (can prevent cracking in materials susceptible to cracking during water quenching)
  - For aluminum, what does T0, T3, and T6 refer to? **(1)**
    - T0 = annealed
    - T3 = solution heat treated, cold worked, then neutrally aged
    - T6 = solution heat treated, then artificially aged
    - We did T6 in this lab

CONCLUSIONS (15)

- Most important conclusions are given first
- No new information; conclusions are drawn only from body of report

TABLES AND FIGURES (10)

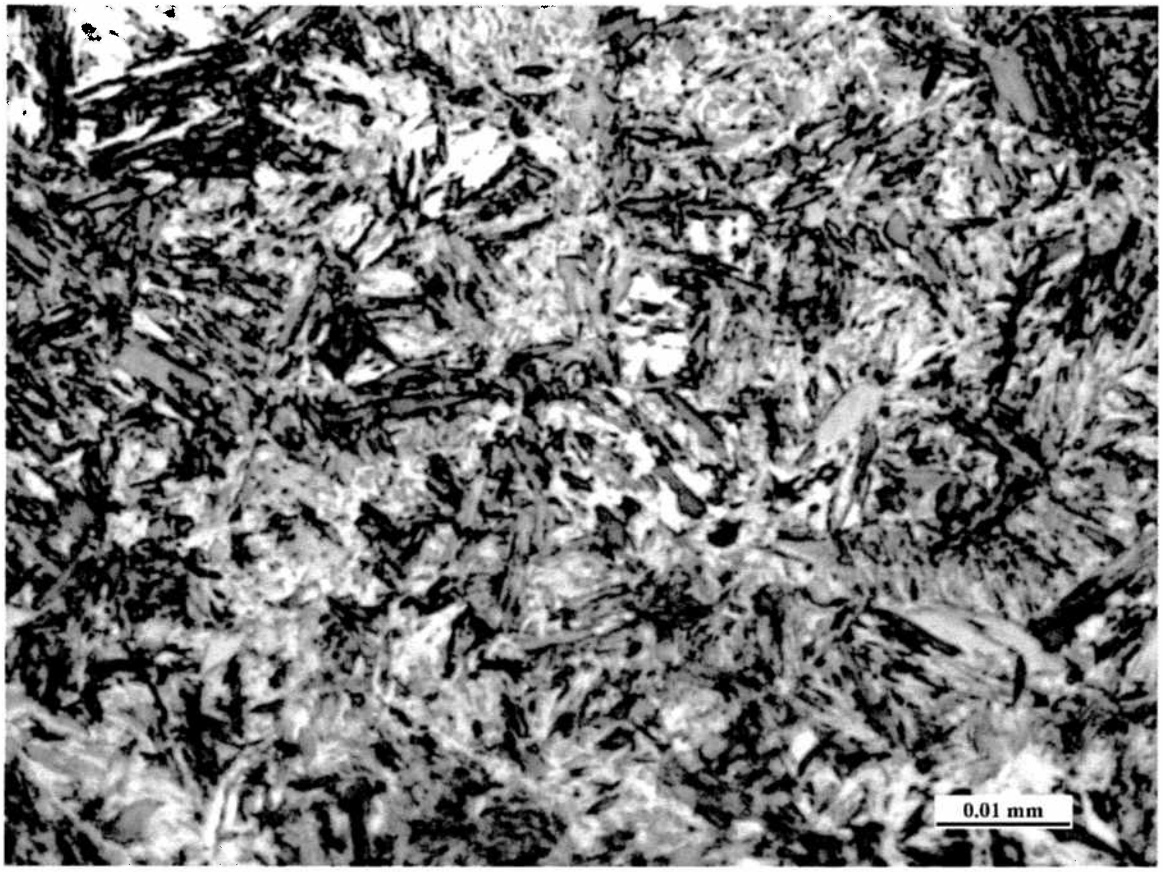
- standard deviation for hardness data (or error bars on graphs) (1)
- Graph with Labeled axes (2)
- Labels ("Figure 1", "Table 1") (1)
- Caption – descriptive and informative (2)
- All Figures and tables are in order (2)
- Microstructure Pictures (2)
  - They don't have to include the microstructure pictures from the lab handout, but they do have to refer to them so you know which micrograph they're talking about (ASM Figure # is a good way)

REFERENCES (5)

- do they have one (2.5)
- do they cite these references in the report and are they numbered and listed in the same order as they are listed in the references section (2.5)

WORKUP (10)

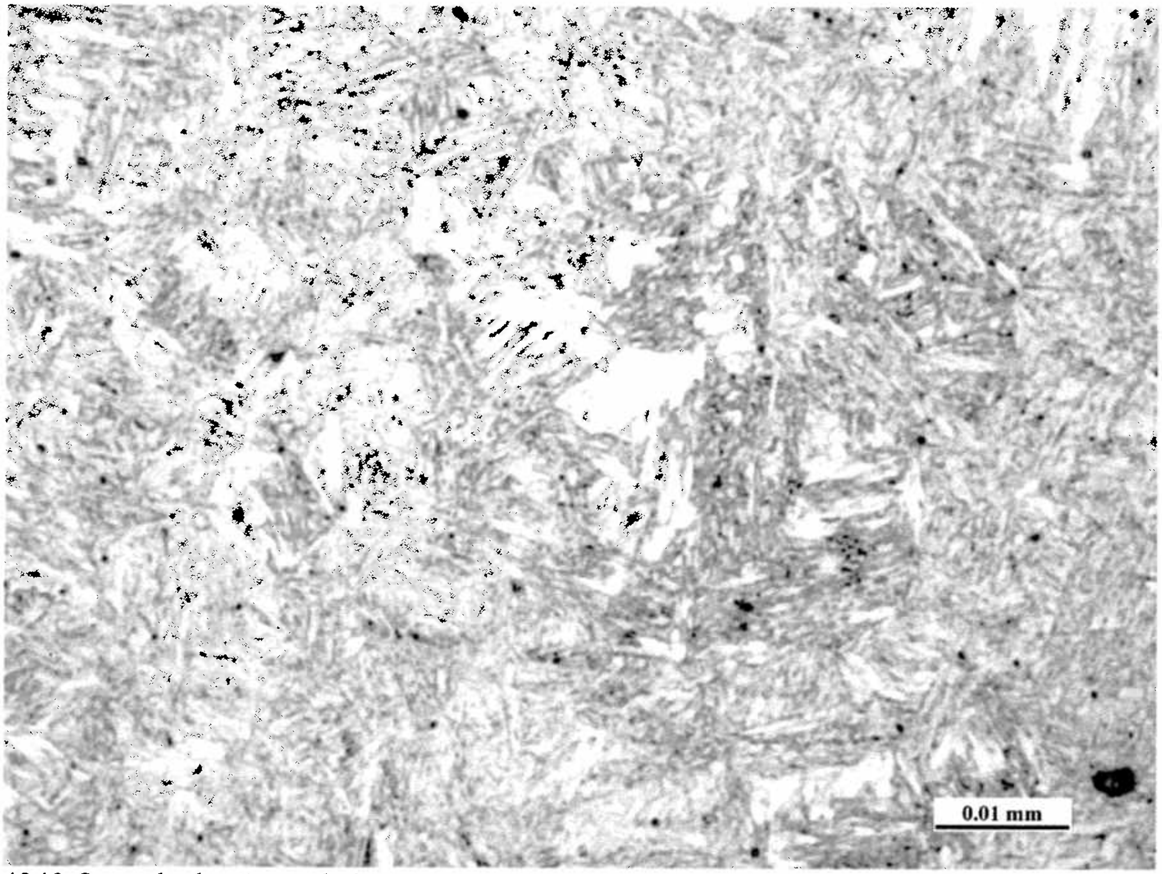
- general impression of effort and attention to detail – be nice



4340 Quenched

(1) Martensite - compare to martensite picture from Callister - same needle-like microstructure

(2) Same for 1018 Quenched



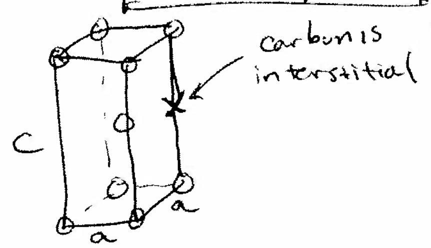
4340 Quenched + Annealed

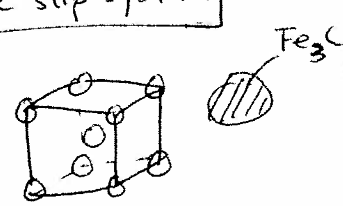
① Tempered martensite – looks same as martensite because tempering has physical changes that are much smaller – picture of tempered martensite in Callister is at much higher magnification – within 1 of the needles on the above picture

② why hardness decrease from martensite → tempered martensite

martensite (BCT) ⟶ (BCC) α-ferrite + Fe_3C precipitates

few slip systems | more slip systems

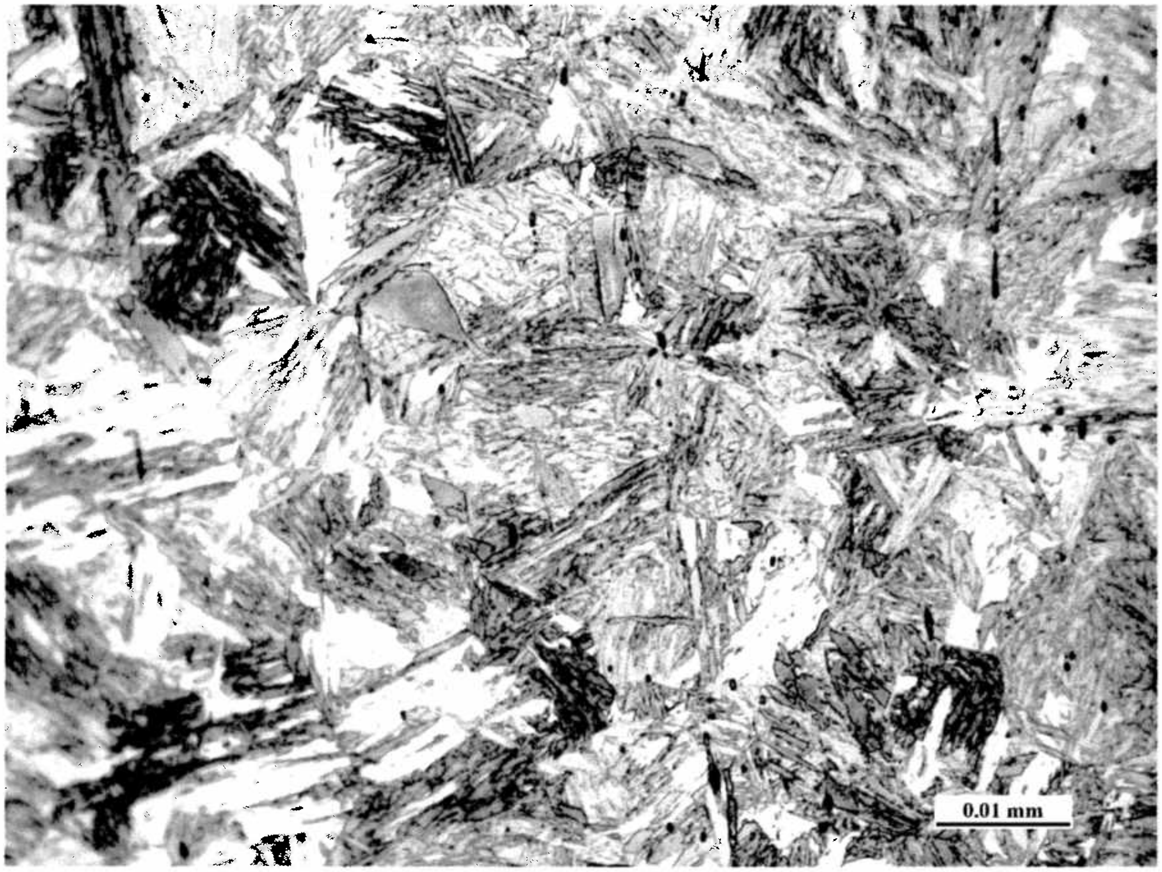




carbon is not interstitial, forms Fe_3C precipitates

* precipitates coarsen with increased aging time, increasing spacing between precipitates, hardness/strength ↓, ductility ↑

③ same for 1018

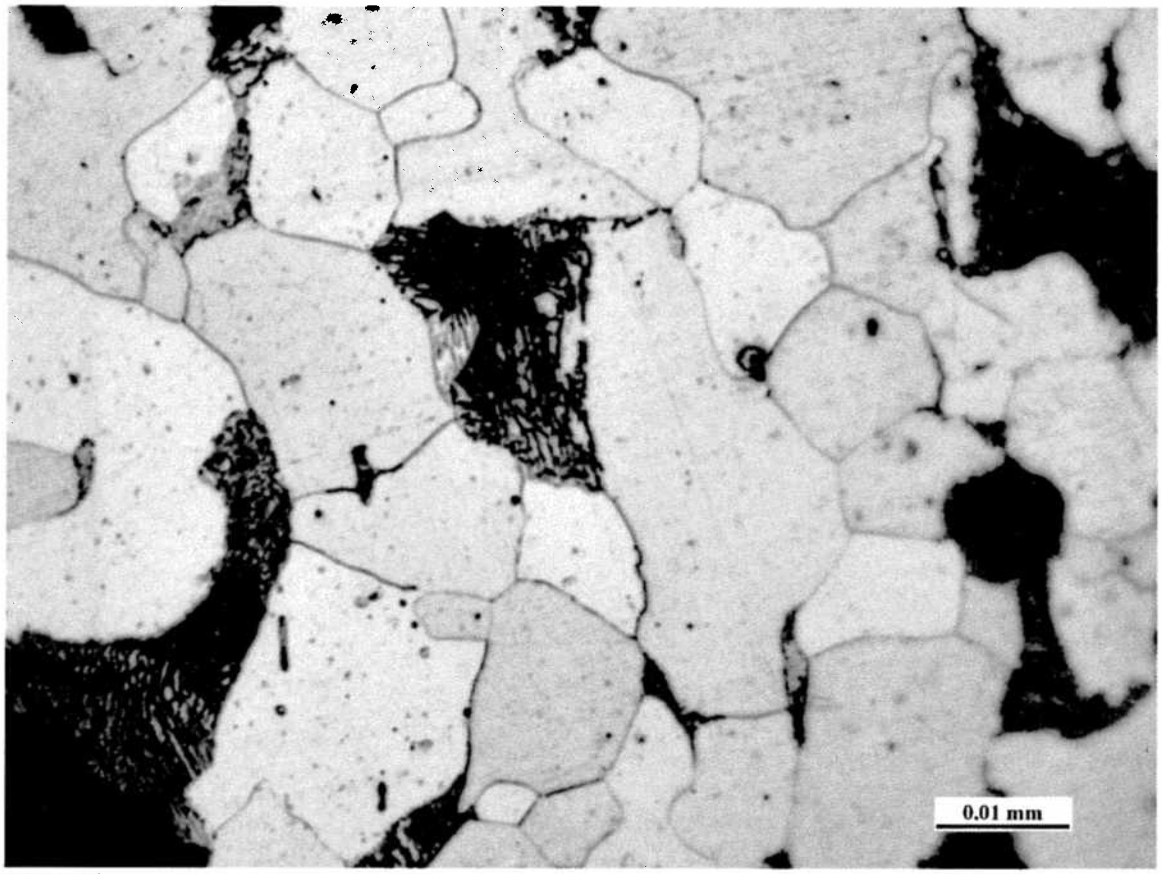


1018 Quenched

(1) Martensite

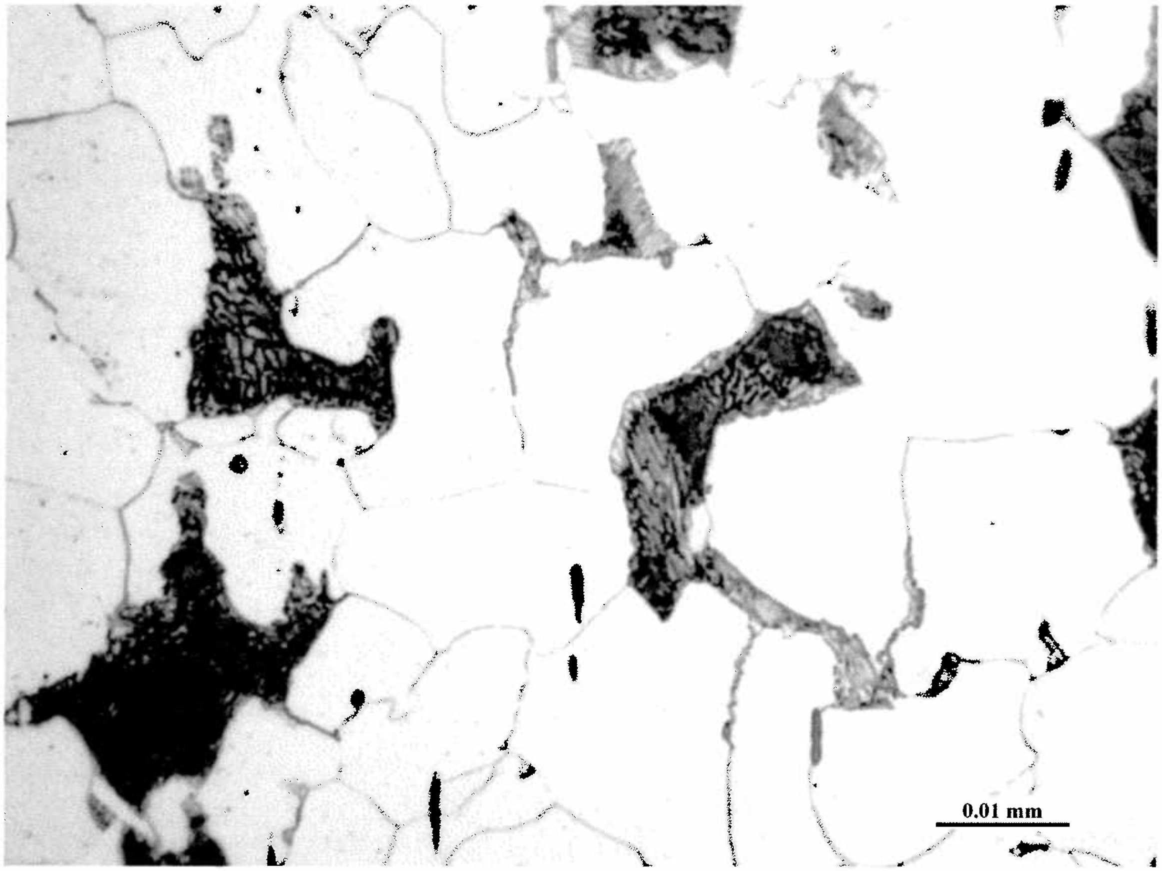
1018 Quenched + Annealed

(1) Tempered Martensite



1018 Slow Cooled

(1) Proeutectoid Ferrite (white) + Pearlite (darker, striped areas)

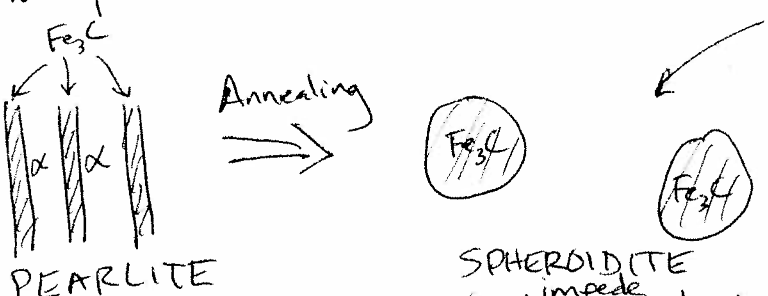


1018 Slow Cooled + Annealed

(1) Proeutectoid Ferrite (white) + Pearlite (darker, striped areas)

(2) Pearlite does not look any coarser after annealing
BECAUSE only ~~a~~ cooling rate from ~~above~~ austenite region affects coarseness (thickness) of α and Fe_3C in pearlite

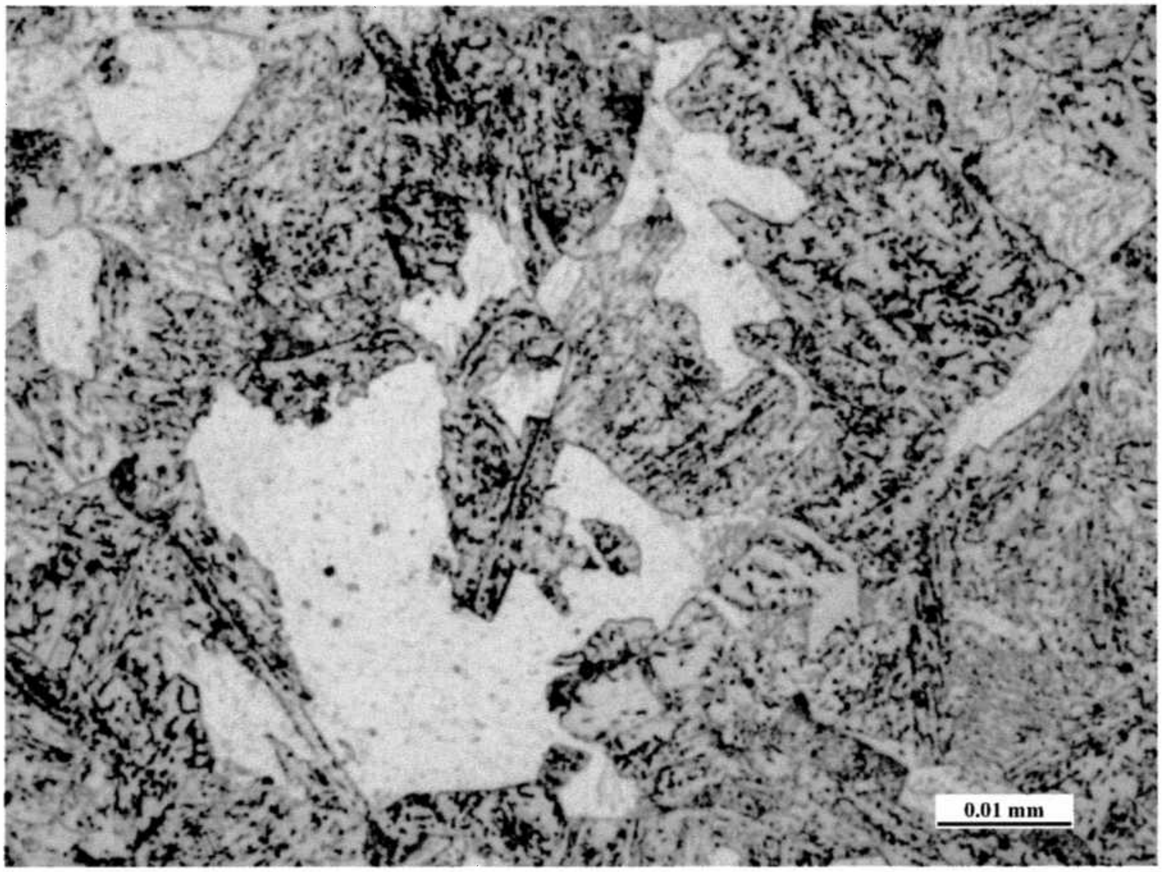
(3) Annealing ~~..~~ (or Tempering, synonymous) Pearlite starts to form Spheroidite



the reason our microstructure looks like this is because of our relatively low T (300°C) and time (30 min) compared to a normal spheroidizing treatment (600°C, 24 hrs.)

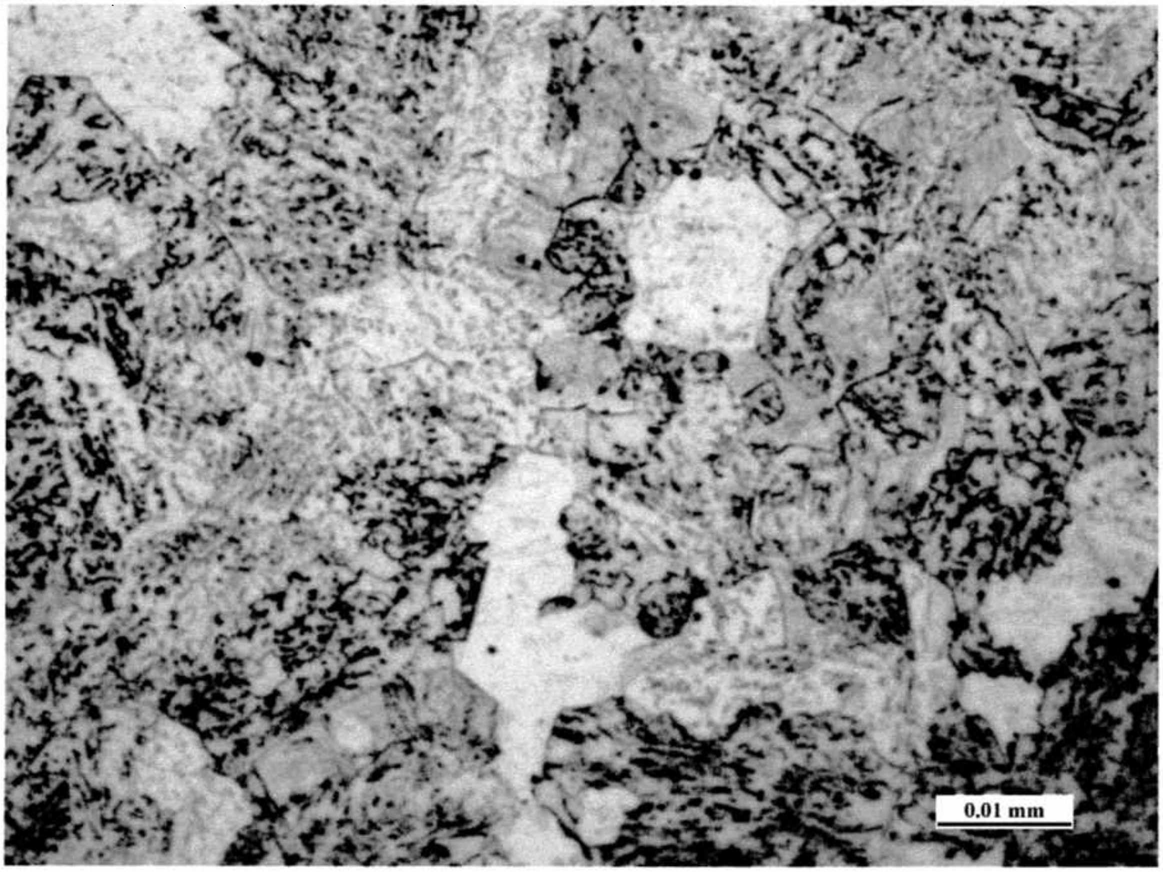
* phase boundaries serve to ~~block~~ impede dislocation motion, as you spheroidize, you decrease the surface area of phase boundary, so you decrease strength and hardness and increase ductility

(4) same for 4340, except 4340 has more pearlite because it has a higher ~~fraction of pearlite~~ carbon concentration – you can phase



4340 Slow Cooled

(1) Proeutectoid ferrite + Pearlite



4340 Slow Cooled + Annealed

(1) Proeutectoid ferrite + Pearlite (slightly tempered)