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EGR 221 Materials Science
Assignment 11, Fall 2015

1) A) Based on the color alone, which could be considered "bright red" – how hot would you estimate the samurai sword was just prior to the final quench? Was it likely austenite or not? Briefly justify your answer.

ANS: from Wikipedia (search for incandescence) when an object glows "red" due to heat, it is in the range of about 650 to 900°C. Bright red is on the higher end of that – so somewhere above 800°C. From the Fe – Fe_3C phase diagram, the steel with carbon content between about 0.4% to 1.3% will be fully austenitized at 800°C. Regardless of carbon content, steels will be at least partially austenitized above 727°C.

B) In order to determine the microstructures that may form when a samurai sword is removed from glowing red charcoal fire into water, which curve would be more appropriate to use and why: time-temperature-transformation (TTT) curve (aka isothermal transformation diagram) or a continuous cooling transformation (CCT) curve? Briefly, why?

ANS: The continuous cooling transformation curve would be appropriate since quenching in water would result in a continuous cooling. The TTT diagram is applicable for cooling to a specific temperature and then dwelling at the temperature for a period of time.

C) In order to determine the microstructures that may form during a Jominy end-quench test, which curve would be more appropriate to use and why: time-temperature-transformation (TTT) curve or a continuous cooling transformation (CCT) curve? Briefly, why?

ANS: The continuous cooling transformation curve would be appropriate since quenching one end in water would result in a continuous cooling. The TTT diagram is applicable for cooling to a specific temperature and then dwelling at the temperature for a period of time.

2) A) Plain carbon steels (steels that contain only iron and carbon as alloy elements) are designated by both SAE (Society of Automotive Engineers) and AISI (American Iron and Steel Institute) with a four-digit number system. The first two digits are used to specify the alloy elements and the last two digits are the amount of carbon present. For example AISI 1080 (aka SAE 1080) steel --- the first two digits, "10", tell us that it is a plain carbon steel. The last two digits "80" tell us that there is 0.80wt% carbon. The eutectoid composition of plain carbon steel is about 0.76wt%C, therefore, AISI 1080 is generally considered to be eutectoid (close enough to 0.76%). Can bainite be produced in AISI 1080 by continuous cooling? If the samurai sword was made from AISI 1080 steel, would it possibly contain bainite?

ANS: bainite cannot be produced in plain carbon steel, such as AISI 1080 by continuous cooling. To produce bainite in plain carbon steel, the steel must be austenitized and quickly cooled to a temperature between about 550°C and 230°C and held at that temperature sufficiently long to allow the transformation from austenite to α *and* Fe_3C *to be completed.*

B) What are the alloying elements in AISI/SAE 4340? What is the range of the allowable carbon content (hint, nominally there is 0.40wt%, but 0.40 is not a range)? What are its principal design features (what's it particularly good for)? Can bainite be produced in AISI 4340 by continuous cooling? If the samurai sword was made from AISI 4340 steel, would it possibly contain bainite?

ANS: from http://www.azom.com/article.aspx?ArticleID=6772

Nickel, Ni	1.65 - 2.00
Chromium, Cr	0.700 - 0.900
Manganese, Mn	0.600 - 0.800
Carbon, C	**0.370 - 0.430**
Molybdenum, Mo	0.200 - 0.300
Silicon, Si	0.150 - 0.300

Its high strength/hardness and high toughness allow it to be used effectively in such applications as gears.

Yes, from the TTT diagram for AISI 4340, bainite can be formed by continuous cooling, and therefore, if the samurai sword was made from 4340 it is possible that the quenching rate could result in bainite formation.

3) A) Briefly define hardness and hardenability – and distinguish between them (how are they different?)

ANS: hardness is the resistance to local deformation. Hardenability is the ease of which martensite may be formed. If a steel can be slow cooled and still result in martensite, it is highly hardenable.

B) How/why do certain alloying elements increase hardenability? In other words, why can a highly hardenable steel be more slowly quenched than a less hardenable steel and still result in martensite

ANS: the presence of such elements as chromium slows the diffusion rate of carbon in iron. If the diffusion rate is slow, the steel does not need to be cooled quickly to form martensite.

4) A) Using hardenability curves (such as Fig 13-21 in the textbook) that compare AISI 4340 and AISI 1050, what do you conclude about the role of carbon in regards to hardness and hardenability?

ANS: carbon content directly affects hardness; the more carbon, the harder the steel can be (but the effect of carbon on hardness plateaus at around 1% carbon). Other than that, it does not affect hardenability, per se.

B) Using hardenability curves, what do you conclude about the role of alloying elements such as chromium and molybdenum in regards to hardness and hardenability?

ANS: they do not have a significant effect on maximum hardness, but they do affect hardenability.

5) For AISI 1080 steel (or if you prefer, AISI 1076) what microstructures would likely result for each of the following (use the TTT (isothermal transformation) diagram attached, mark on it appropriately):

   a) Hold at 740°C sufficiently long to achieve austenitic structure, then cool rapidly to 700°C, hold for 10 seconds, then rapidly quench to room temperature.

   b) Hold at 740°C sufficiently long to achieve austenitic structure, then cool rapidly to 600°C, hold for 10 seconds, then rapidly quench to room temperature.

   c) Hold at 740°C sufficiently long to achieve austenitic structure, then cool rapidly to 500°C, hold for 10 seconds, then rapidly quench to room temperature.

   d) Hold at 740°C sufficiently long to achieve austenitic structure, then cool rapidly to 400°C, hold for 10 seconds, then rapidly quench to room temperature.

   e) Hold at 740°C sufficiently long to achieve austenitic structure, then cool rapidly to 300°C, hold for 10 seconds, then rapidly quench to room temperature.

   f) Hold at 740°C sufficiently long to achieve austenitic structure, then rapidly quench to room temperature.

ANSWERS:

a) 100% martensite. Austenite, which will still exist while being at 700C for 10 seconds, transforms into martensite when quickly quenched.
b) 100% pearlite
c) 100% bainite
d) After 10 seconds, the transformation from austenite into bainite has begun but not completed. It looks like it may be about 25% complete --- so the answer is about 25% bainite, 75% martensite.
e) 100% martensite
f) 100% martensite

6) What is marquenching (aka martempering) and why is it done? What may possibly happen if rather than marquenching, the hot (austenite) steel is rapidly quenched directly to room temperature? Which of the conditions in question 5 could be considered marquenching?

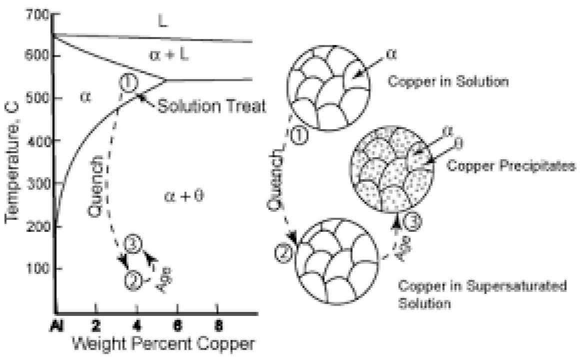
ANS: marquenching is to quickly cool austenitized steel to just above the martensitic transformation temperature, hold it at that temperature for as long as possible before transformation begins, then quench to form martensite. This is done to allow the part to more closely reach uniform temperature so that the thermal gradients are minimized before forming martensite. If there are significant thermal gradients present when martensite forms, the martensite may crack (referred to as quench cracking). Condition (5e) most closely resembles marquenching.

Now onto something besides steel….let's talk about aluminum alloys. Obviously, aluminum is very different stuff than steel, but also has similarities. It is about one-third the density and about one-third the elastic stiffness of steel (E_{alum} ~ 1/3 E_{steel}). Some aluminum alloys have strength that competes with many commonly used steels (but no aluminum alloys compete in strength with high strength steels). The designation for aluminum alloys looks very similar to the AISI designation for steels – however, looks may be deceiving. With aluminum alloys, there are four digits but all of the digits are "codes", similar to the first two digits for steel (43xx, the 43 is a code – it does not represent the quantity "43" of anything). For aluminum alloys, the first digit is a code indicating the primary alloy elements. 6000 series aluminum alloys are magnesium and silicone. In 2000 series, copper is the primary alloying element. The next three digits are codes regarding specific alloy elements and their quantities.

There are two general classes of aluminum alloys: heat treatable and non-heat treatable. Non-heat treatable alloys are alloys for which heat treating has no significant effect on properties. Heat treatable alloys are heat treated in various ways to create desired properties. They are more interesting to talk about right now…

7) How would you form martensite, pearlite, bainite, or spheroidite in an aluminum alloy? HINT: this is a trick question – please please don't fall for the trick! *ANS: You can't, I can't, no one can. These terms have no application with aluminum alloys.*

8) A) 2024 is a heat treatable aluminum alloy (one of many "2000 series" alloys). It contains approximately 4wt% copper. Briefly describe age hardening (aka precipitation hardening) and include a sketch of the microstructures resulting from the three steps (similar to figure 12-9 – okay, exactly similar).



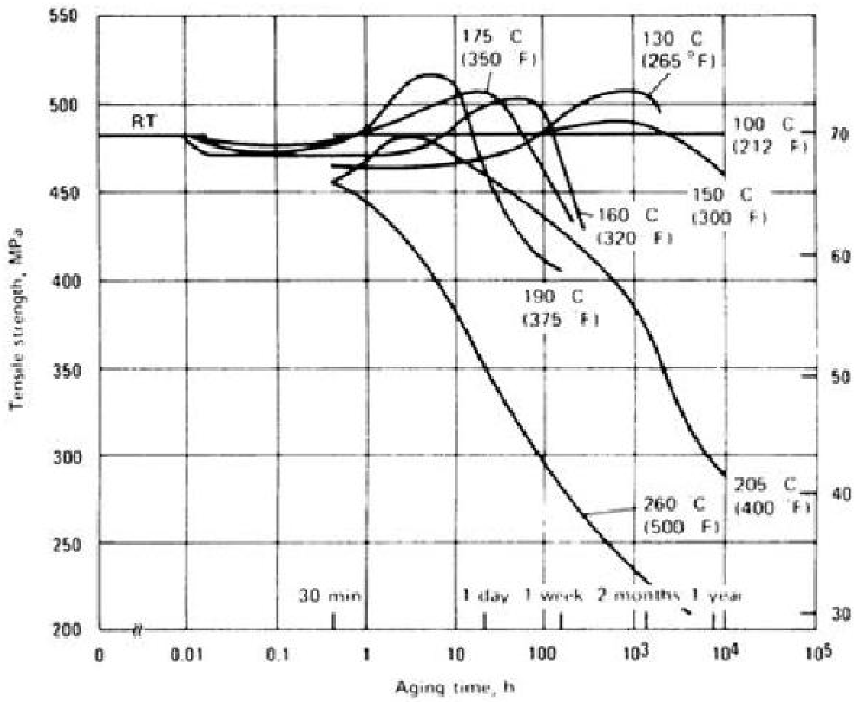
ANS: Step 1 – solution heat treat. Heat to form a single solid solution (~550C).
Step 2 – quench to room temperature or colder. This will trap the copper in solution (super cooled phase) and theta will not form.
Step 3 – allow time and temperature to do its thing – copper will diffuse forming theta phase ($CuAl_2$). If done correctly, the precipitates will form within the alpha matrix (not at the grain boundaries) resulting in hard and strong alloy. In alloys such as 2024, room temperature is sufficiently warm – but it will take a few days for the alloy to be aged.

B) Why is the alloy (2024) quickly quenched from solution heat treat temperature? What would likely result if 2024 aluminum was not quenched in water but rather slow cooled in air immediately following solution heat treating? Sketch the likely resulting microstructure.

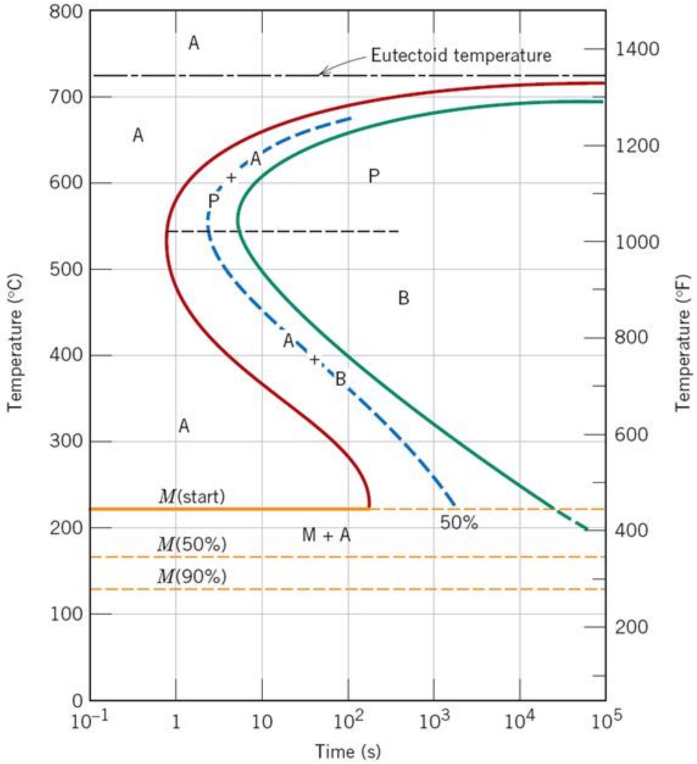
ANS: slow cooling from solution heat treat would likely result in the second phase (theta) forming at the grain boundaries. This would allow dislocations to slip through the grains with ease – a soft, weak alloy will result.

9) What is meant by over-aging? Would it be possible for an airplane made from 2024 aluminum alloy to overage if it flew too close to the sun --- assuming by flying too close it actually got too warm? How warm would it have to get to overage? What could be the result if it did overage?

ANS: over-aging occurs when an heat treatable aluminum alloy is held at elevated temperatures too long. The warmer the temperature, the faster over-aging occurs. The chart below (from ASM handbook) shows the relationship between strength, temperature and time. From the curve, it appears that any temperature below 100C will not result in over-aging in 2024 aluminum.



175 C
(350 F)
130 C
(265 °F)
RT
100 C
(212 F)
150 C
(300 F)
160 C
(320 F)
190 C
(375 F)
205 C
(400 F)
260 C
(500 F)
30 min
1 day
1 week
2 months
1 year
Tensile strength, MPa
Tensile strength, ksi
Aging time, h



Eutectoid temperature
A
P
B
A + P
A + B
M(start)
M(50%)
M(90%)
M + A
50%
Temperature (°C)
Temperature (°F)
Time (s)