University of Anbar/ Faculty of Engineering

Department of Mechanical Engineering

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Lecture # 16

Kinetics and Heat Treatments in Metals

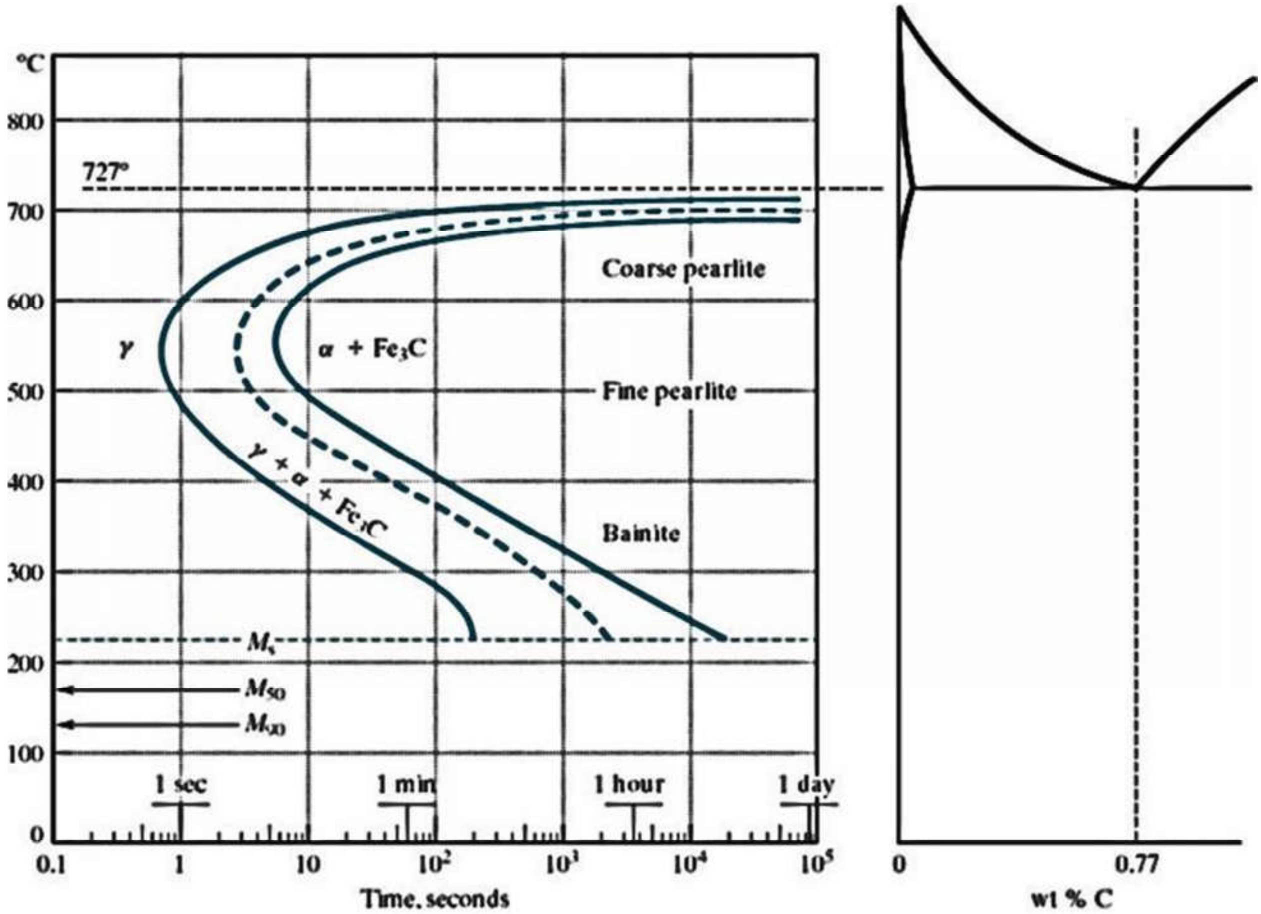
Phase Diagrams are limited in their usefulness because they can only predict the microstructure that will result for equilibrium conditions, i.e. very very slow cooling. Non-equilibrium cooling will result in different microstructures hence altered properties.
Let's investigate what non-equilibrium cooling do to the microstructure and properties of metals. These non-equilibrium cooling processes are also called heat treatments or thermal processing. They are the temperature vs. time history.

Kinetics is the field of study that takes into account the time dependent aspect of a transformation. TTT diagrams are the tools that we can use to take into account the kinetics of the transformation. They show the relationship between time, temperature and (percent) transformation. There are two types of TTT diagrams:

1. isothermal transformation (IT) TTT diagrams
2. continuous cooling transformation (CCT) TTT diagrams

The IT TTT diagram for eutectoid steel

Eutectoid reaction is: γ (0.76wt% C) $\rightarrow$ α (0.022wt% C) + Fe_3C (6.7wt%C)



<u>The presence of other alloying elements other than carbon (Cr, Mo, Ni, W, Mn, Si) may cause significant changes in the IT TTT. These include</u>:

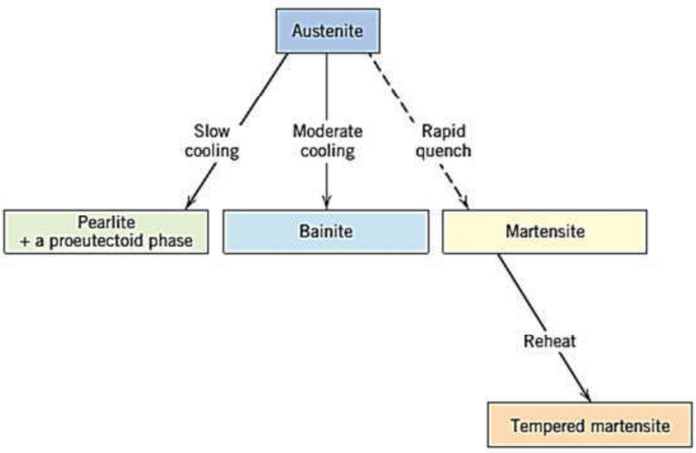
1. shifting the nose to the right (longer times for the transformation to complete.)
2. forming a separate banite nose
3. shifting the Temperature up or down.

Note that each TTT diagram is for a particular composition of steel.

Phase Transformations: involving

- diffusionless transformation:
  at Rapid quench (γ ⟶ Martensite)

- diffusion transformation: at slow or moderate cooling.
  At slow cooling:
  (γ ⟶ Pearlite + proeutectic phase)
  At Moderate cooling:
  (γ ⟶ Bainite)



See **Figure** shows that

<u>Microstructures of Steel</u>:

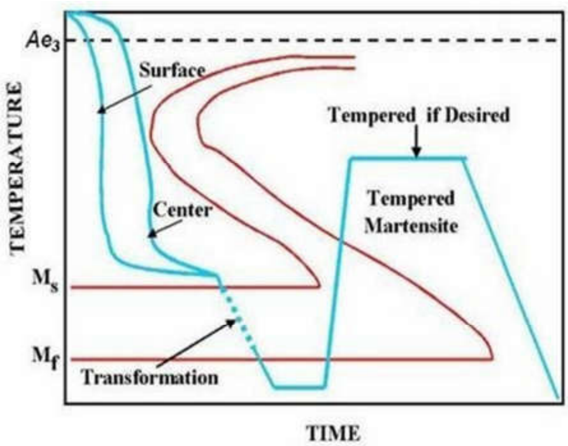
1. **Austenite** – the fcc phase of Fe that can have up to 2.14% C in interstitial solid solution.

2. **Pearlite** – <u>the eutectoid microstructure of ferrite and cementite</u>. There is coarse pearlite and fine pearlite.

3. **Bainite** – another eutectoid microstructure of ferrite and cementite. It has a different grain morphology than Pearlite. There is upper bainite and lower bainite that differs in the grain morphology as well. As you would expect, lower bainite is a finer grained material.

4. **Martensite** – a metastable (non-equilibrium) single phase, supersaturated, interstitial solid solution of C in Fe. It can be bct or bcc depending on the amount of C. It is the result of a diffusionless transformation (time independent, instantaneous). Martensite is extremely hard and extremely brittle. It is not really a practical material. It needs to be made more ductile in order to be able to use it. The microstructure of martensite will depend on the amount of C. In general martensite is acicular or needlelike grains which is why it is so brittle.

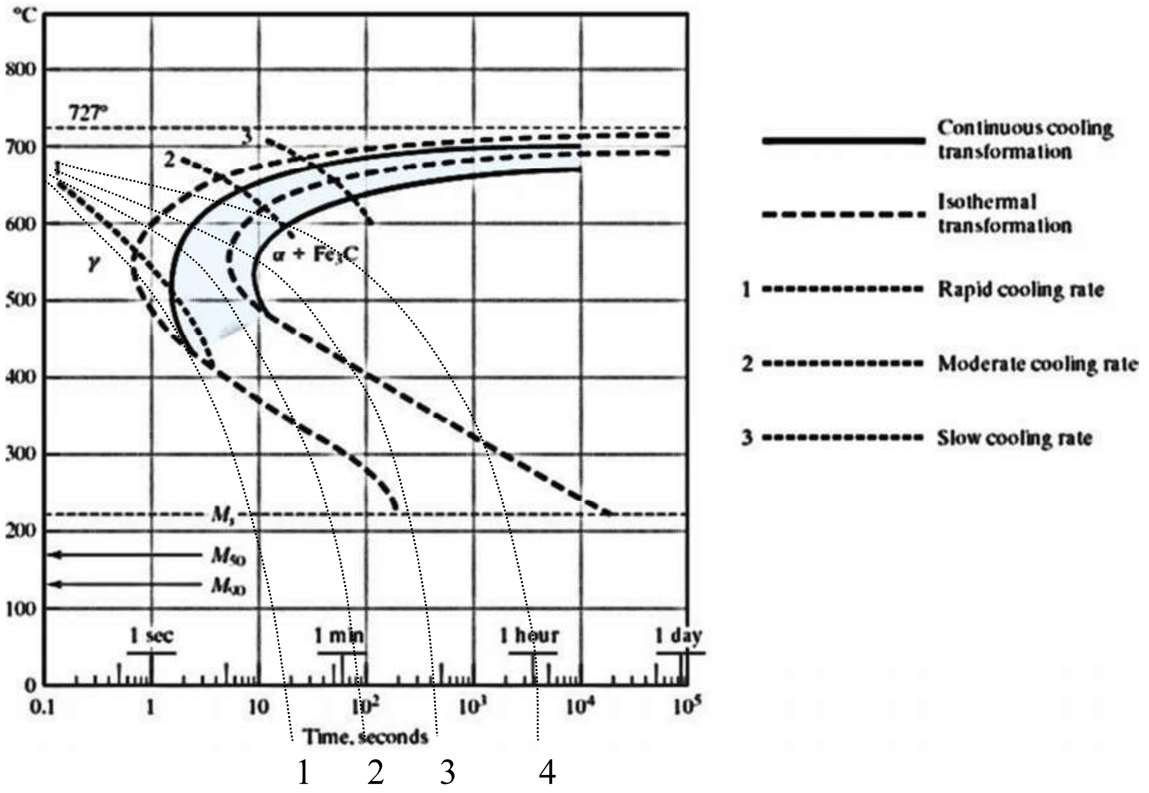
5. **Tempered Martensite** – martensite that is given a heat treatment (Tempering) to increase the ductility. It is heated to a temperature below the eutectoid temperature for a period of time. The microstructure of tempered martensite is small and uniform cementite in a continuous ferrite matrix.
   Be careful: Some alloying elements in steel like (Mg, Mi, Cr, An, P, Ar, Sn) will result in lower ductilities with a tempering treatment. These shift the ductile to brittle transition temperature to a higher temperature. This is called <u>temper embrittlement</u>.



Martempering

6. **Spheroidite** – another structure of ferrite and cementite. It is formed by reheating pearlite or bainite to just below the eutectoid temperature to get a softer and more ductile material. The cementite becomes sphere-like particles in a continuous ferrite matrix.

The CCT TTT diagram for eutectoid steel



Solved Question: Consider the cooling rates 1-4. What will be the resulting microstructures?
Answer:

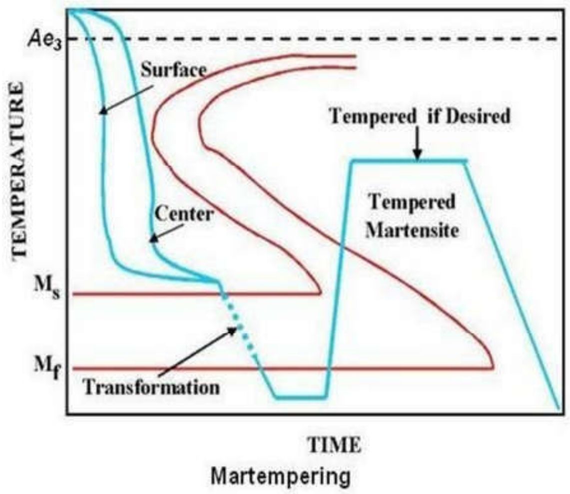
1. 100% martensite (This is called the critical cooling rate. It is the slowest cooling rate that will produce 100% martensite.)
2. ½ martensite, ½ pearlite (This is called a split transformation.)
3. fine pearlite
4. coarse pearlite

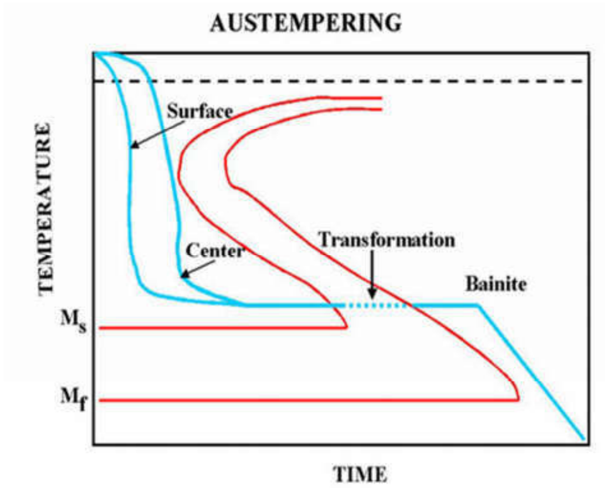
Note: there will be no bainite with a CCT.

Martempering and Austempering

1. **Martempering** involves an isothermal hold in the quenching operation.
2. **It gives** martensite structure as extremely hard and brittle.
3. More quenching cracks.
4. Martensite structure require tempering to increase ductility; the final structure formed is tempered martensite.
5. Used for small sections.

1. **Austempering** involves an isothermal hold in the quenching operation.
2. **It gives** bainite structure, as hard and tough,
3. Less quenching cracks.
4. Not require further tempering.
5. Used for complex sections.





In General, we want the steel microstructure to result in Martensite!

This is because martensite is very hard and strong. To get Martensite, of course you must first austenitize and then quench. But to what extent are you assured of a Martensitic microstructure throughout?

The factors that determine Martensite formation in a steel specimen:

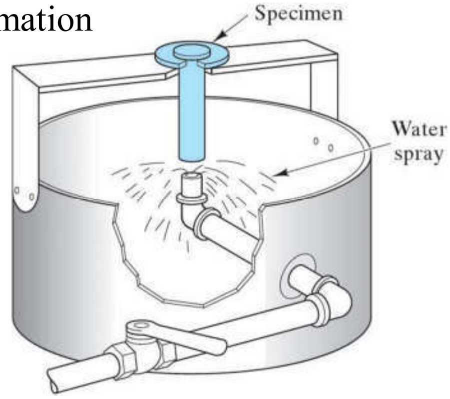
1) composition
2) quench rate (furnace, air, water, oil)
3) geometry
4) size

Hardenability

It is the relative ability of steel to be hardened by quenching. It is essentially a measure of the cooling rate at which martensite will form. The **Jominy End Quench test** is used to obtain Hardenability.

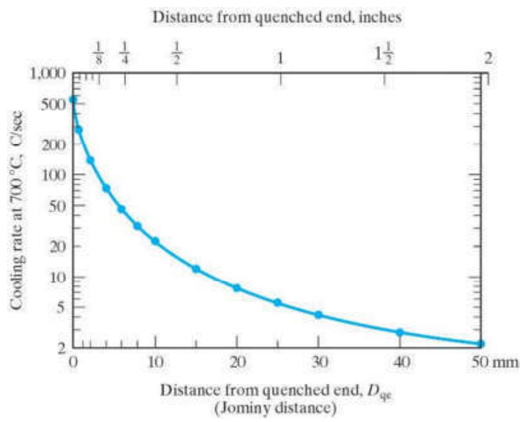
H.W. What is the difference between Hardenability and Hardness?

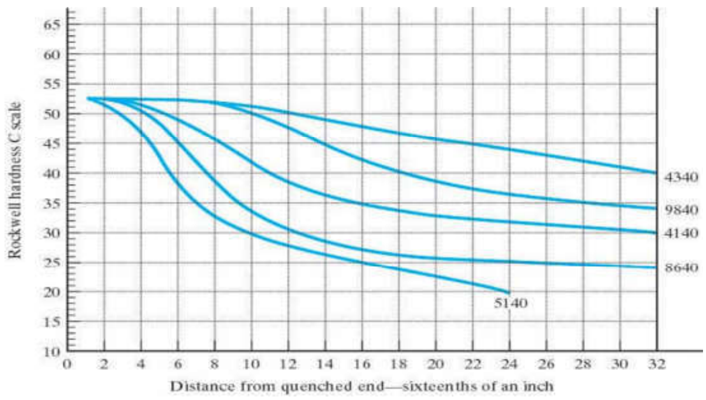
Answer: **Hardenability**: it is the relative ability of steel to be hardened by quenching. It is essentially a measure of the cooling rate at which martensite will form. **Hardness**: a measure of the resistance of a material to plastic (permanent) deformation



The Jominy End Quench test is used to obtain Hardenability Curves

A Hardenability Curve for a particular steel will give the hardness as a function of cooling rate. (Cooling rate is correlated to distance from the quenched end, d_{qe}.)





There are plots in the literature that you can use that will give you the cooling rates experienced for any point in a steel specimen of a particular size, geometry and quench. (The standard quenches are water or oil. Once the cooling rate is known, the hardness can be determined from the Hardenability curve.

Note: the larger the surface area to mass ratio of the specimen, the faster the cooling rates will be inside. So irregular shapes may have high hardenabilities.