Heat treatments of Steel

- Quenching and Tempering Steel (Basic, more complete discussion later)
- Spheroidizing
- Full Annealing
- Normalizing
- Hardenability (More on the quenching and tempering process.)

Steels

Low Alloy
- low carbon <0.25 wt% C
- Med carbon 0.25-0.6 wt% C
- high carbon 0.6-1.4 wt% C

High Alloy

	Low Alloy						High Alloy
	low carbon <0.25 wt% C		Med carbon 0.25-0.6 wt% C		high carbon 0.6-1.4 wt% C		
Name	plain	HSLA	plain	heat treatable	plain	tool	austenitic stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	4310	1040	4340	1095	4190	304
Hardenability	0	+	+	++	++	+++	0
TS	-	0	+	++	+	++	0
EL	+	+	0	-	-	--	++
Uses	auto struc. sheet	bridges towers press. vessels	crank shafts bolts hammers blades	pistons gears wear applic.	wear applic.	drills saws dies	high T applic. turbines furnaces V. corros. resistant

→ increasing strength, cost, decreasing ductility

Based on data provided in Tables 11.1(b), 11.2(b), 11.3, and 11.4, *Callister 7e*.

Quenching and Tempering

- We have found that Martensite (M) is very hard, strong, and brittle. It sees little use as an end product.
- But, if we reheat to below 727, (250-650) and leave the M there for a while, it changes into something with real usefulness. Tempered Martensite. (TM)
- TM is ferrite, with an extremely fine dispersion of roughly spherical particles of Fe_3C. Extremely strong, but has ductility and toughness. This is the primo stuff, as far as steel goes.

A Typical Q&T Steel

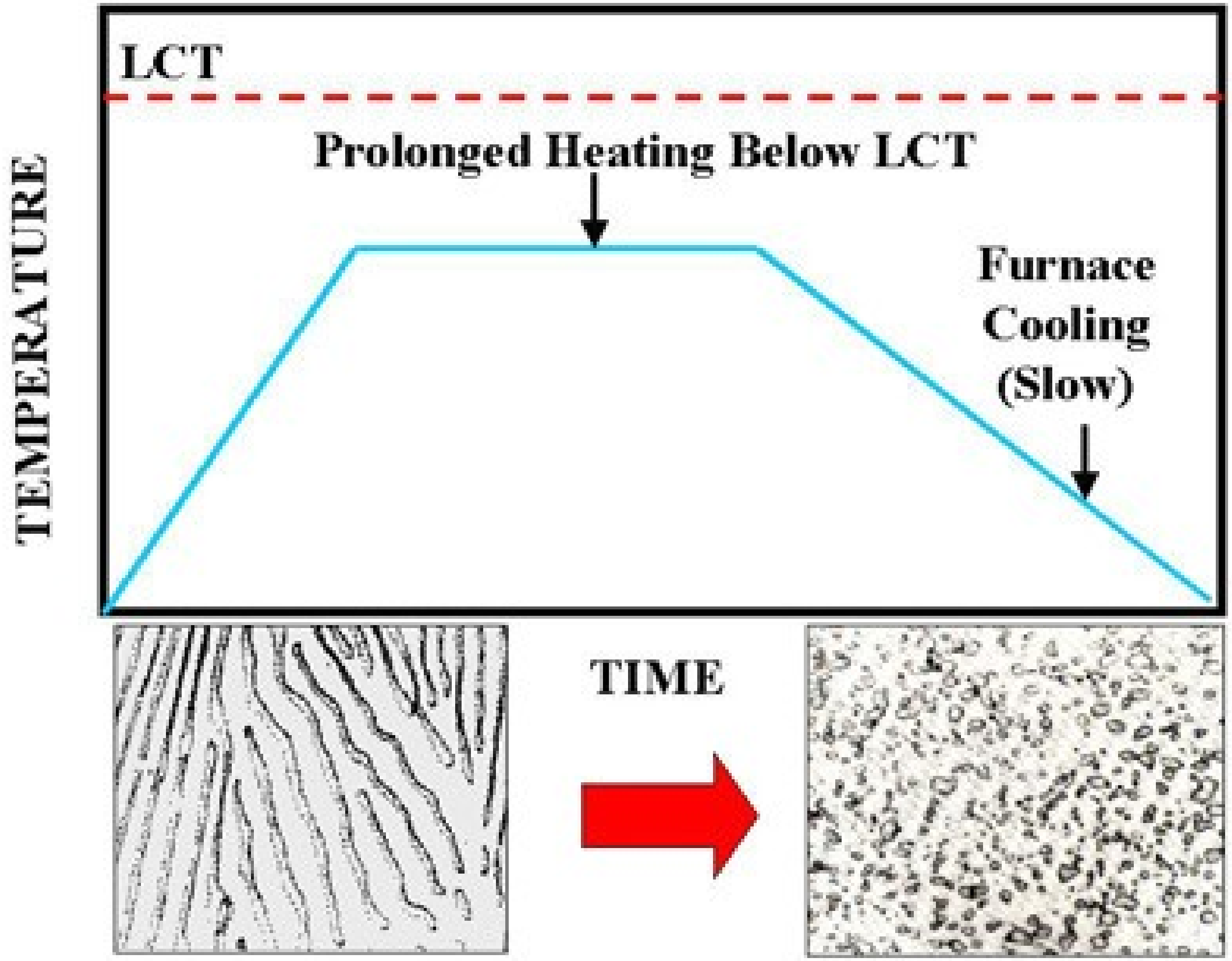
- We will use Matweb to look over a couple of steels.
- Note the differences in strength and ductility in a 1060 Steel.   The annealed steel with have very coarse pearlite. The Q&T steel will have very finely distributed cementite.

Process	UTS	Yield	%EL	Hardness
Annealed	90.6 ksi	53.7 ksi	22	88
Q & T	148.7 ksi	98.2	15	99

Spheroidizing

- Strangely, sometimes we would like the steel to be just as soft and ductile as absolutely possible.
- Why, do you think?
- Pearlite is not the lowest energy arrangement possible between ferrite and cementite. If heated to just below the eutectoid temperature, and left for an extended time, the pearlite layers break down, and spherical clumps of cementite are found.
- These spherical clumps are hundreds or even thousands of times larger that those in TM, and spaced much further apart. → Softest, most duct.

SPHEROIDIZING



http://info.lu.farmingdale.edu/depts/met/met205/ANNEALING.html

More on Spheroidite

- You have to spend a lot of energy cooking steel. Spheroidizing is not really used with low carbon steels, since they are already soft and ductile enough.
- Spheroidizing is done with the higher carbon steels, so they will be as ductile as possible for shaping.
- Spheroidizing is done to improve the machineability of high carbon steels. Having the massive cementite regions enhances chip formation.

Full Anneal

- The idea is to get the soft metal and relieve stresses. We contrast this anneal with the "process anneal" associated with CW.
- In the full anneal, we must fully austenitize the steel. This is followed by a furnace cool, the slowest cooling rate possible.
- The result is coarse Pearlite mixed with primary phase. This steel will be close to spheroidite in its softness and ductility.

Normalizing Steel

- **Here we austenitize the steel and then air cool as opposed to furnace cooling.**
- **The result is a uniform microstructure, very uniformly spaced pearlite in equal sized grains throughout.**
- **It is stronger and somewhat less ductile than full anneal.**
- **Often done after forging to normalize the grain structure.**

Thermal Processing of Metals

Annealing: Heat to T_{anneal}, then cool slowly.

Types of Annealing

- **Stress Relief**: Reduce stress caused by:
  - -plastic deformation
  - -nonuniform cooling
  - -phase transform.

- **Spheroidize** (steels): Make very soft steels for good machining. Heat just below T_E & hold for 15-25 h.

- **Full Anneal** (steels): Make soft steels for good forming by heating to get γ, then cool in furnace to get coarse *P*.

- **Process Anneal**: Negate effect of cold working by (recovery/ recrystallization)

- **Normalize** (steels): Deform steel with large grains, then normalize to make grains small.

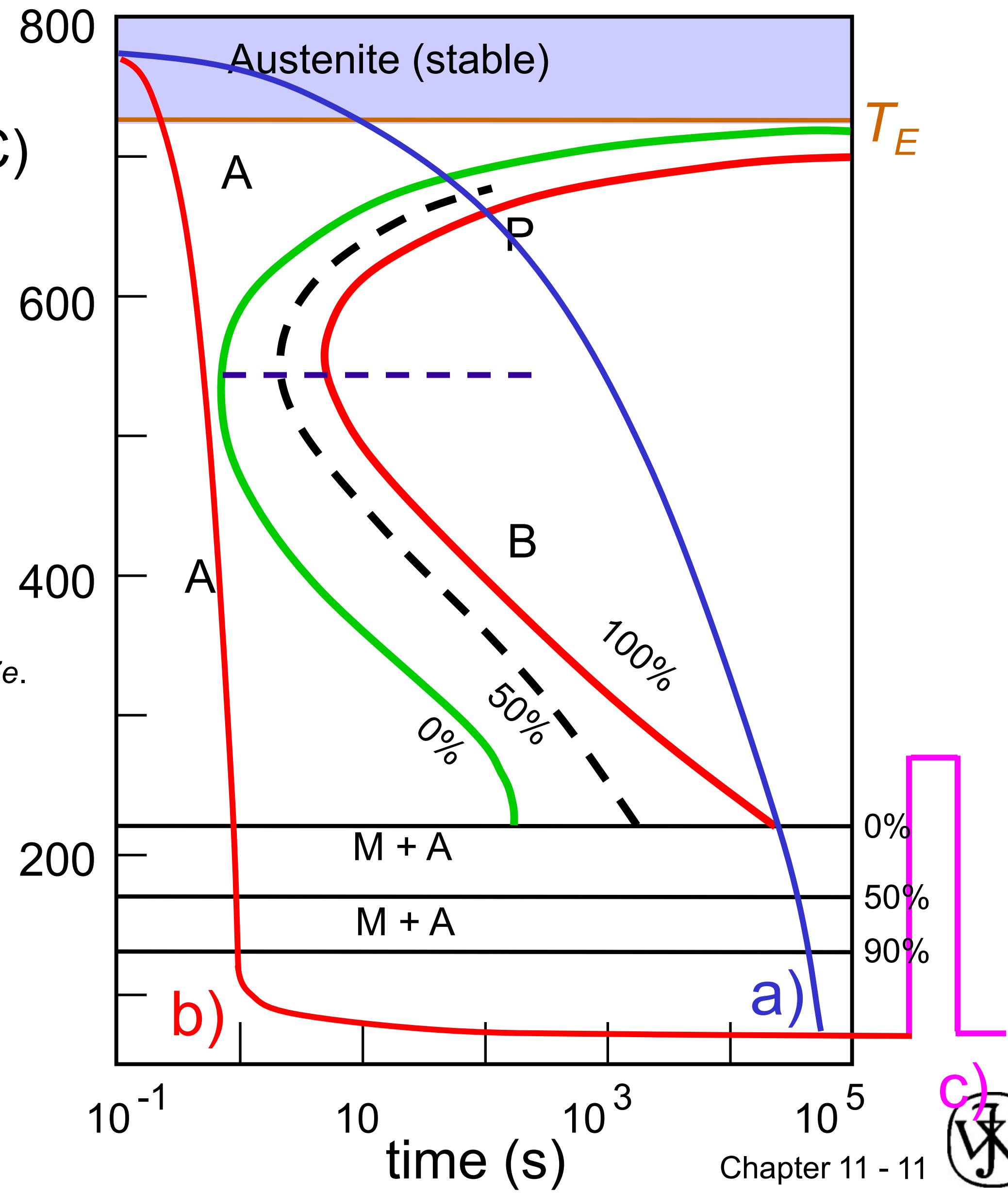
Based on discussion in Section 11.7, *Callister 7e*.

Heat Treatments

a) Annealing

b) Quenching

c) Tempered Martensite



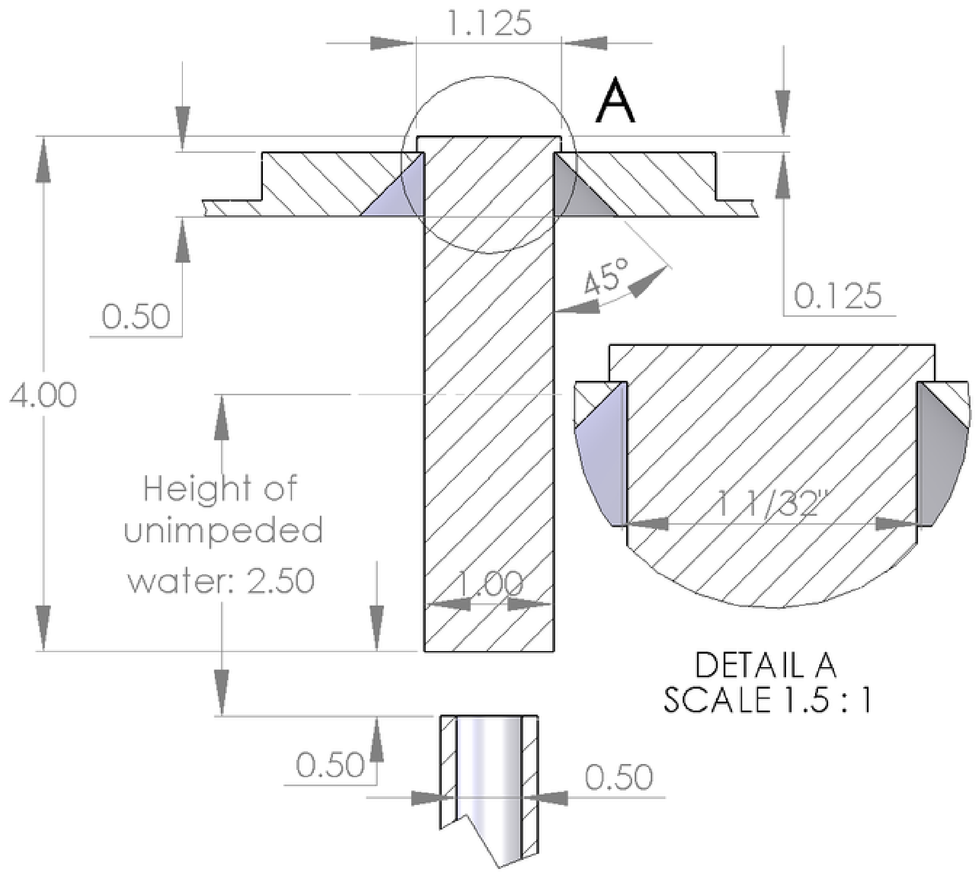
Adapted from Fig. 10.22, *Callister 7e*.

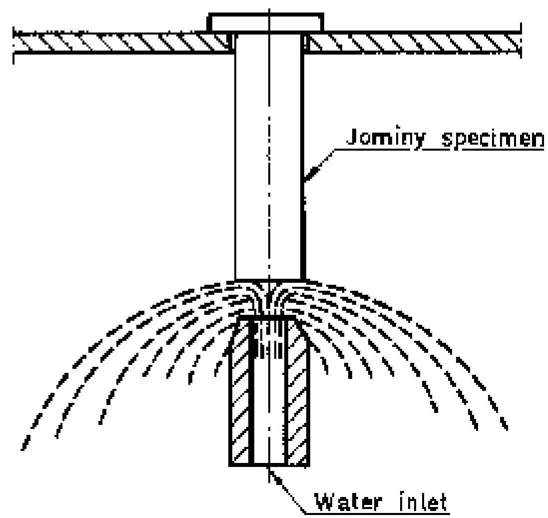
Hardenability

- **We have seen the advantage of getting martensite, M. We can temper it, getting TM with the best combination of ductility and strength.**
- **But the problem is this: getting M in depth, instead of just on the surface. We want a steel where Pearlite formation is relatively sluggish so we can get it to the cooler regions where M forms.**
- **The ability to get M in depth for low cooling rates is called hardenability.**
- **Plain carbon steels have poor hardenability.**

Jominy Test for Hardenability

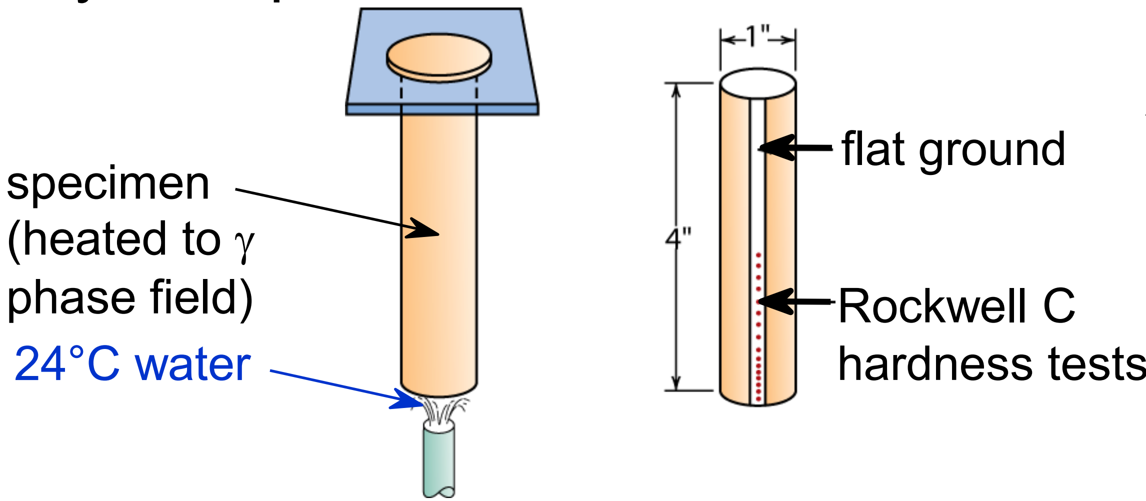
- **Hardenability not the same as hardness!**





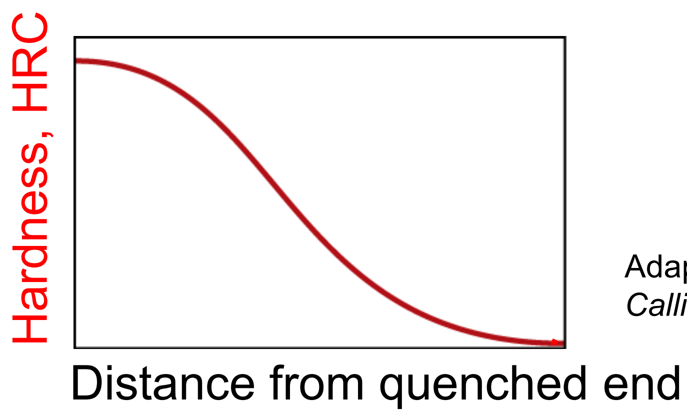
Hardenability--Steels

- Ability to form martensite
- Jominy end quench test to measure hardenability.



Adapted from Fig. 11.11, *Callister 7e*. (Fig. 11.11 adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

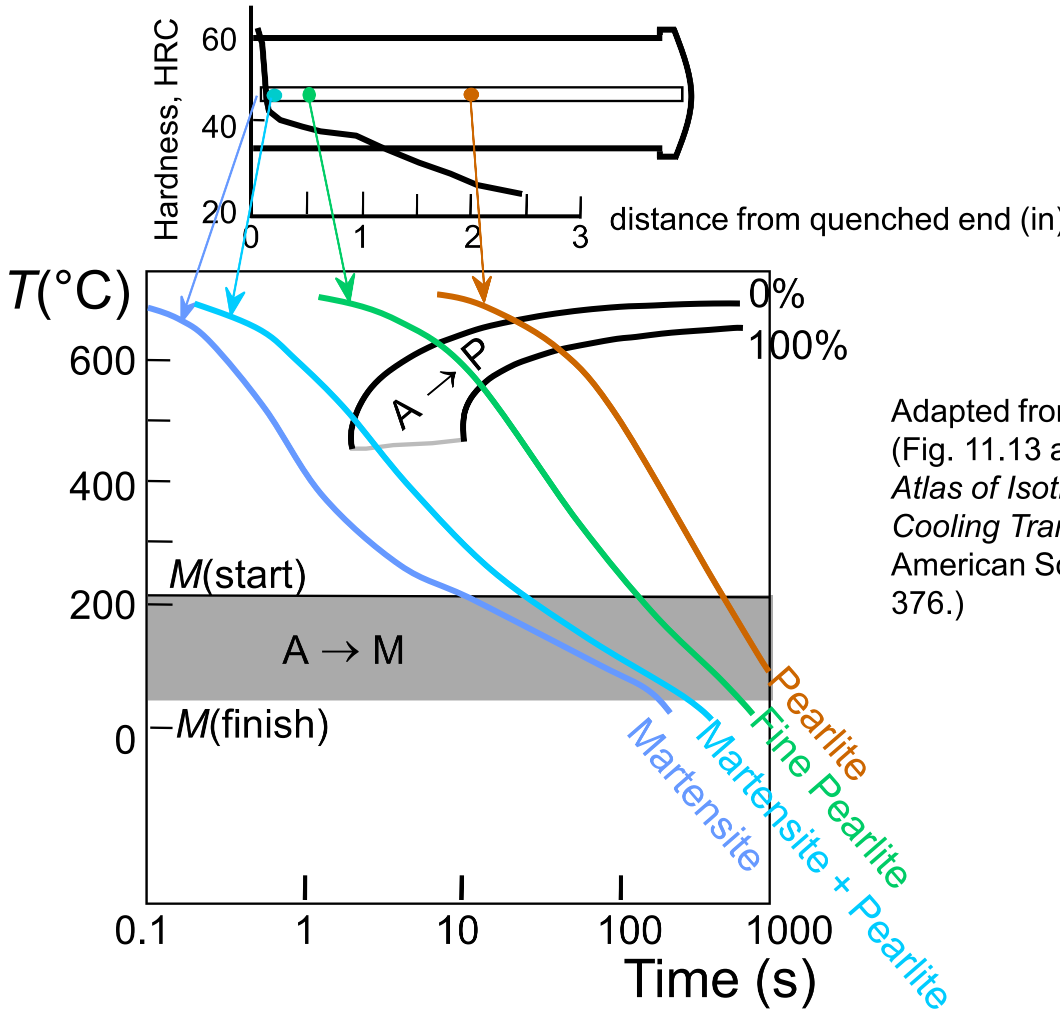
- Hardness versus distance from the quenched end.



Adapted from Fig. 11.12, *Callister 7e*.

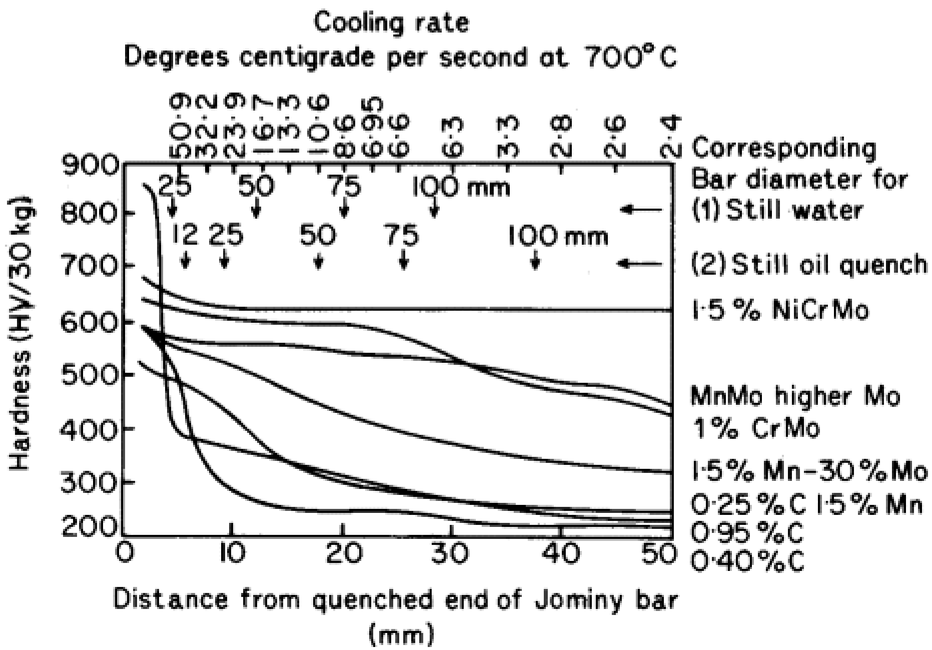
Why Hardness Changes W/Position

- The cooling rate varies with position.



Adapted from Fig. 11.13, *Callister 7e*. (Fig. 11.13 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1977, p. 376.)

The Result is Presented in a Curve



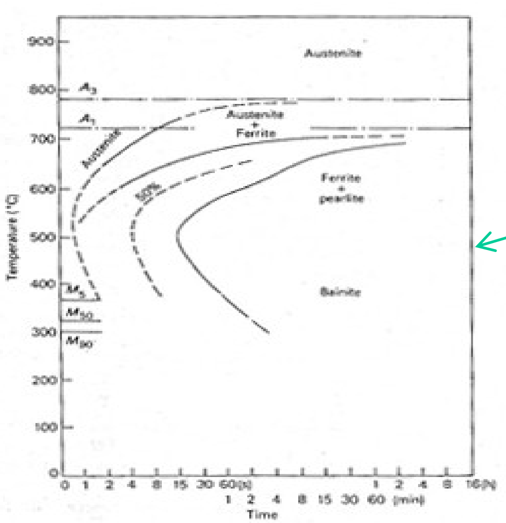
Rank steels in order of hardenability.

Note:

1. Distance from quenched end corresponds to a cooling rate, and a bar diameter
2. Notice that some steels drop off more than others at low cooling rates. Less hardenability!

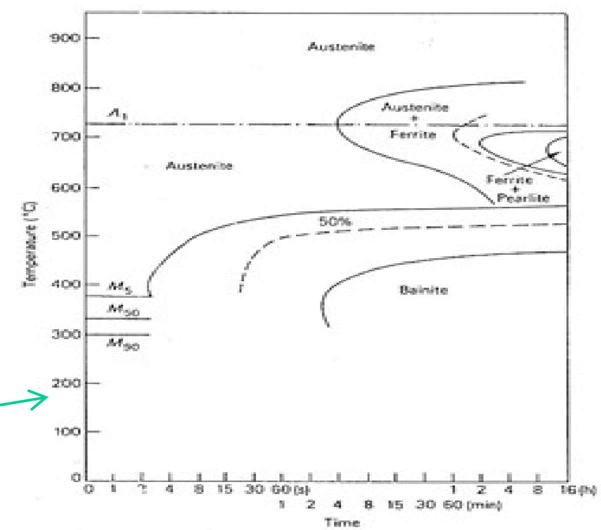
Factors Which Improve Hardenability

- 1. Austenitic Grain size. The Pearlite will have an easier time forming if there is a lot of g.b. area. Hence, having a large austenitic grain size improves hardenability.
- 2. Adding alloys of various kinds. This impedes the $\gamma \rightarrow$ P reaction.



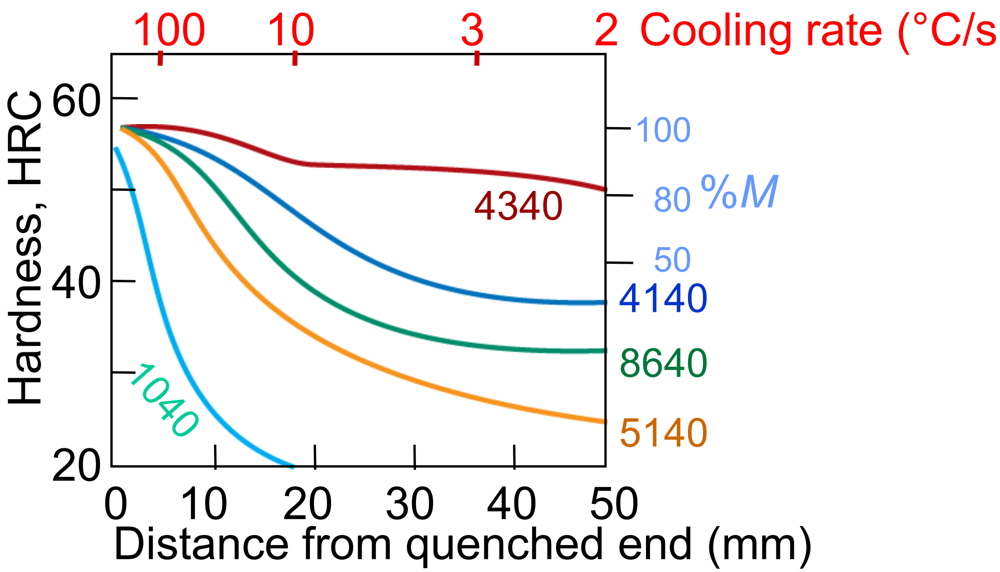
TTT diagram of a molybdenum steel 0.4C 0.2Mo

After Adding 2.0% Mo



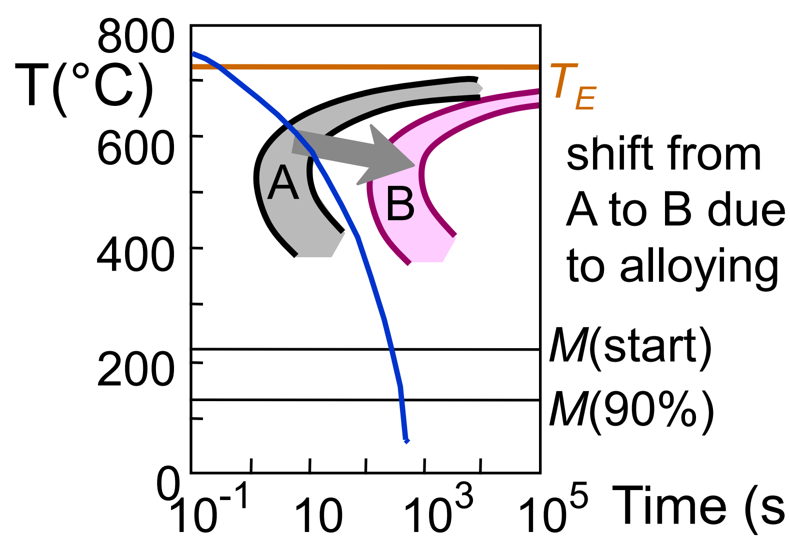
Hardenability vs Alloy Composition

- Jominy end quench results, C = 0.4 wt% C



Adapted from Fig. 11.14, *Callister 7e*. (Fig. 11.14 adapted from figure furnished courtesy Republic Steel Corporation.)

- "Alloy Steels" (4140, 4340, 5140, 8640)
  --contain Ni, Cr, Mo (0.2 to 2wt%)
  --these elements shift the "nose".
  --martensite is easier to form.



Quenching Medium & Geometry

- Effect of quenching medium:

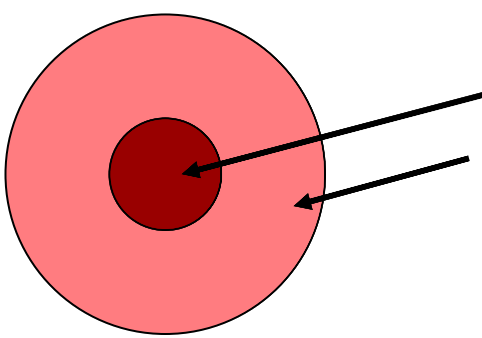
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of geometry:

When surface-to-volume ratio increases:

--cooling rate increases

--hardness increases



Position	Cooling rate	Hardness
center	low	low
surface	high	high

Ferrous Alloys

Iron containing – Steels - cast irons

Nomenclature AISI & SAE

- 10xx Plain Carbon Steels
- 11xx Plain Carbon Steels (resulfurized for machinability)
- 15xx Mn (10 ~ 20%)
- 40xx Mo (0.20 ~ 0.30%)
- 43xx Ni (1.65 - 2.00%), Cr (0.4 - 0.90%), Mo (0.2 - 0.3%)
- 44xx Mo (0.5%)

where xx is wt% C x 100

example: 1060 steel – plain carbon steel with 0.60 wt% C

Stainless Steel -- >11% Cr