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.
- The ability to get M in depth for low cooling rates is called hardenability.

Hardenability

Hardenability is the ability of Fe-C alloy to harden by forming martensite

Hardenability (not "hardness"): Qualitative measure of rate at which hardness decreases with distance from surface due to decreased martensite content

High hardenability means the ability of the alloy to produce a high martensite content throughout the volume of specimen

Application of Hardenability

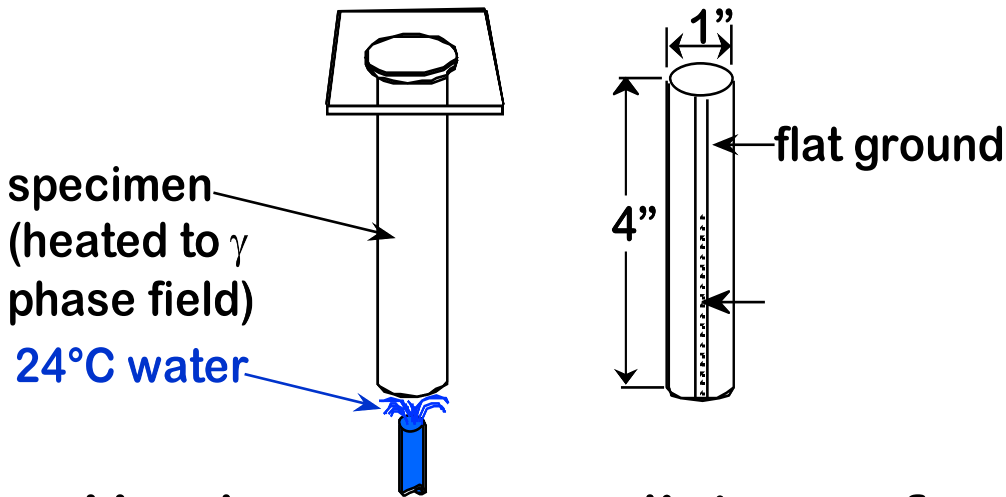
- Jominy test –Hardenability measured by Jominy end-quench test performed for standard cylindrical specimen, standard austenitization conditions, and standard quenching conditions (jet of water at specific flow rate and temperature).

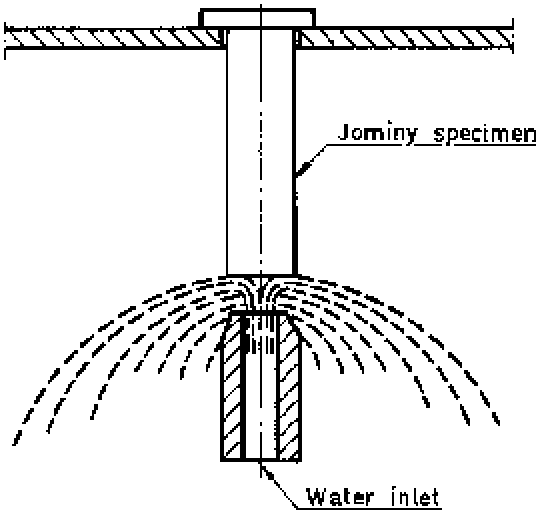
The test used to evaluate hardenability. An austenitized steel bar is quenched at one end only, thus producing a range of cooling rates along the bar.

- Hardenability curves - Graphs showing the effect of the cooling rate on the hardness of as-quenched steel.
- Jominy distance - The distance from the quenched end of a Jominy bar. The Jominy distance is related to the cooling rate.

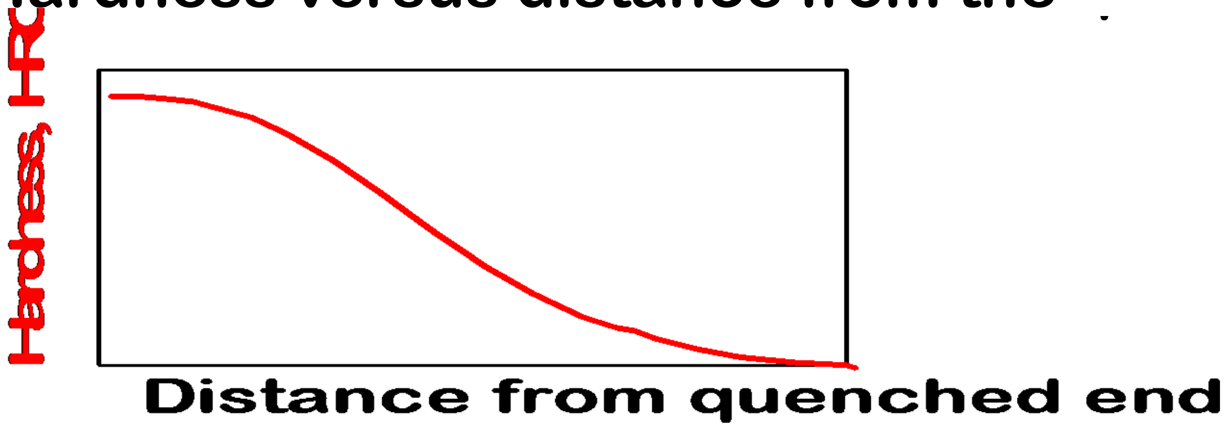
Hardenability -Steels

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



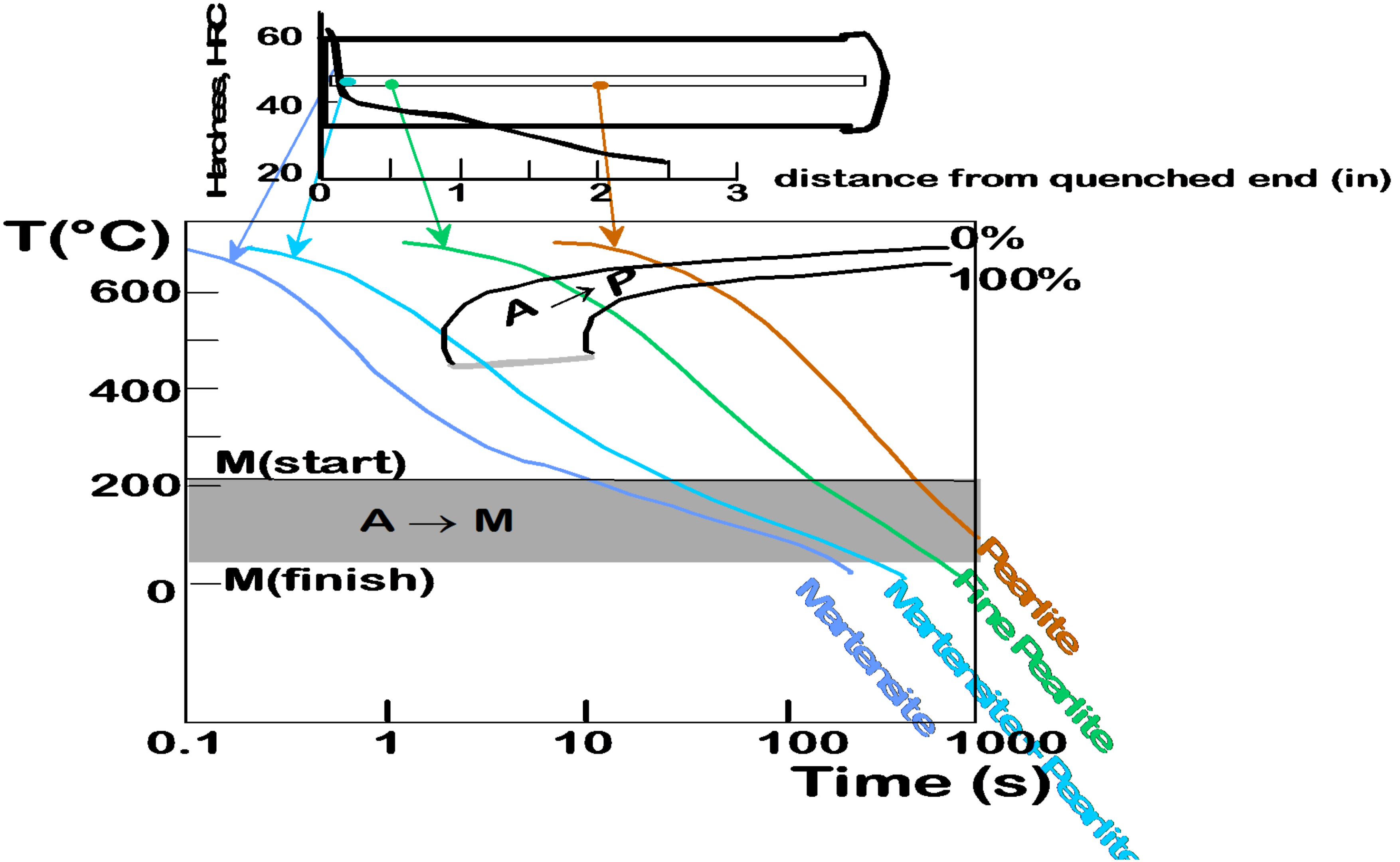


- **Hardness versus distance from the**



WHY HARDNESS CHANGES W/POSITION

- The cooling rate varies with position.



Isothermal Transformation and Cooling Transformation Diagrams,

Influence of Quenching Medium, Specimen Size, and Geometry on Hardenability

- Quenching medium: Cools faster in water than air or oil. Fast cooling → warping and cracks, since it is accompanied by large thermal gradients
- Shape and size: Cooling rate depends upon extraction of heat to surface. Greater the ratio of surface area to volume, deeper the hardening effect

Spheres cool slowest, irregular objects fastest.

Quenching Medium & Geometry

- **Effect of quenching medium:**

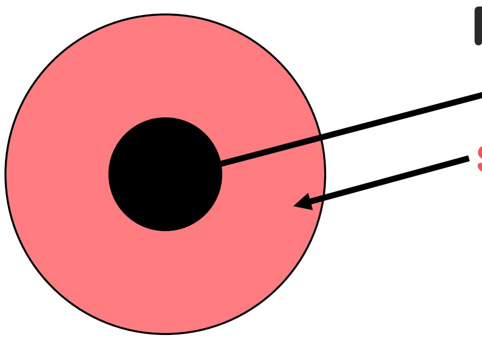
Medium	Severity of Quench	Hardness
air	small	small
oil	moderate	moderate
water	large	large

- **Effect of geometry:**

When surface-to-volume ratio increases:

--cooling rate increases

--hardness increases



Position	Cooling rate	Hardness
center	small	small
surface	large	large

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. After Adding 2.0% Mo

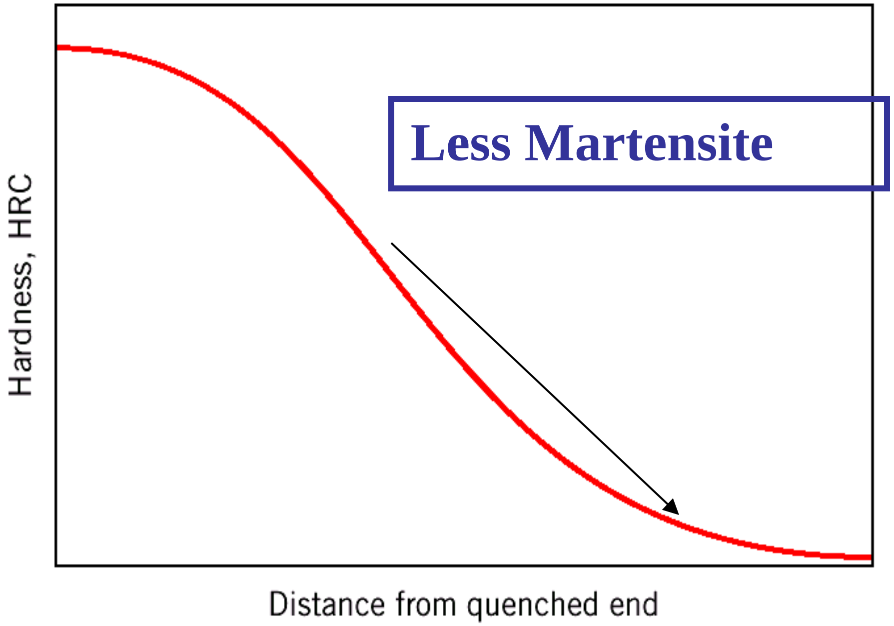
The hardenability of a steel depends on

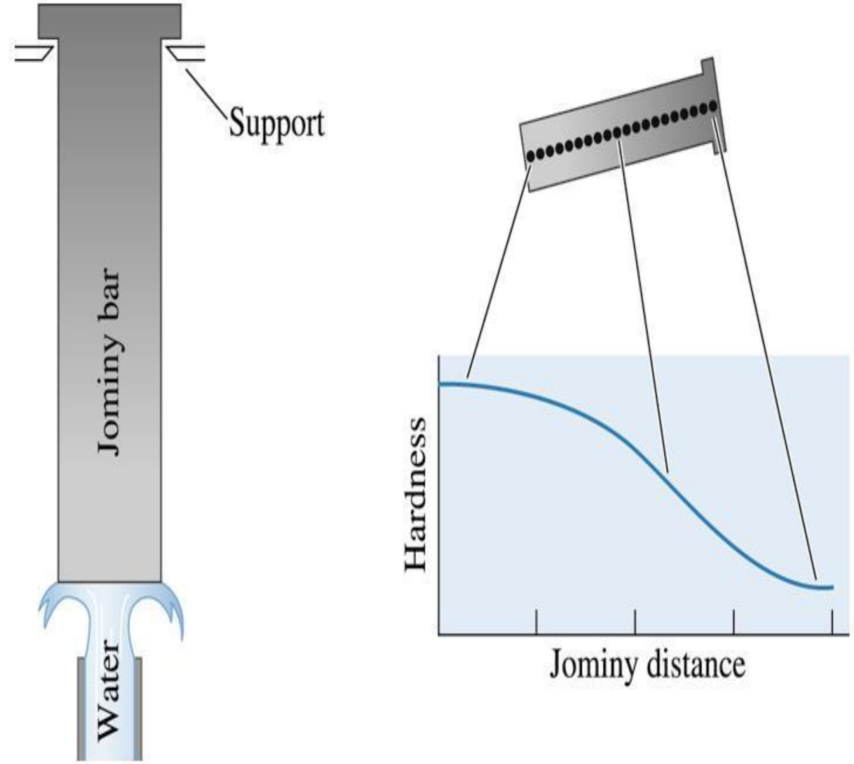
(1) the composition of the steel,

(2) the austenitic grain size, and

(3) the structure of the steel before quenching.

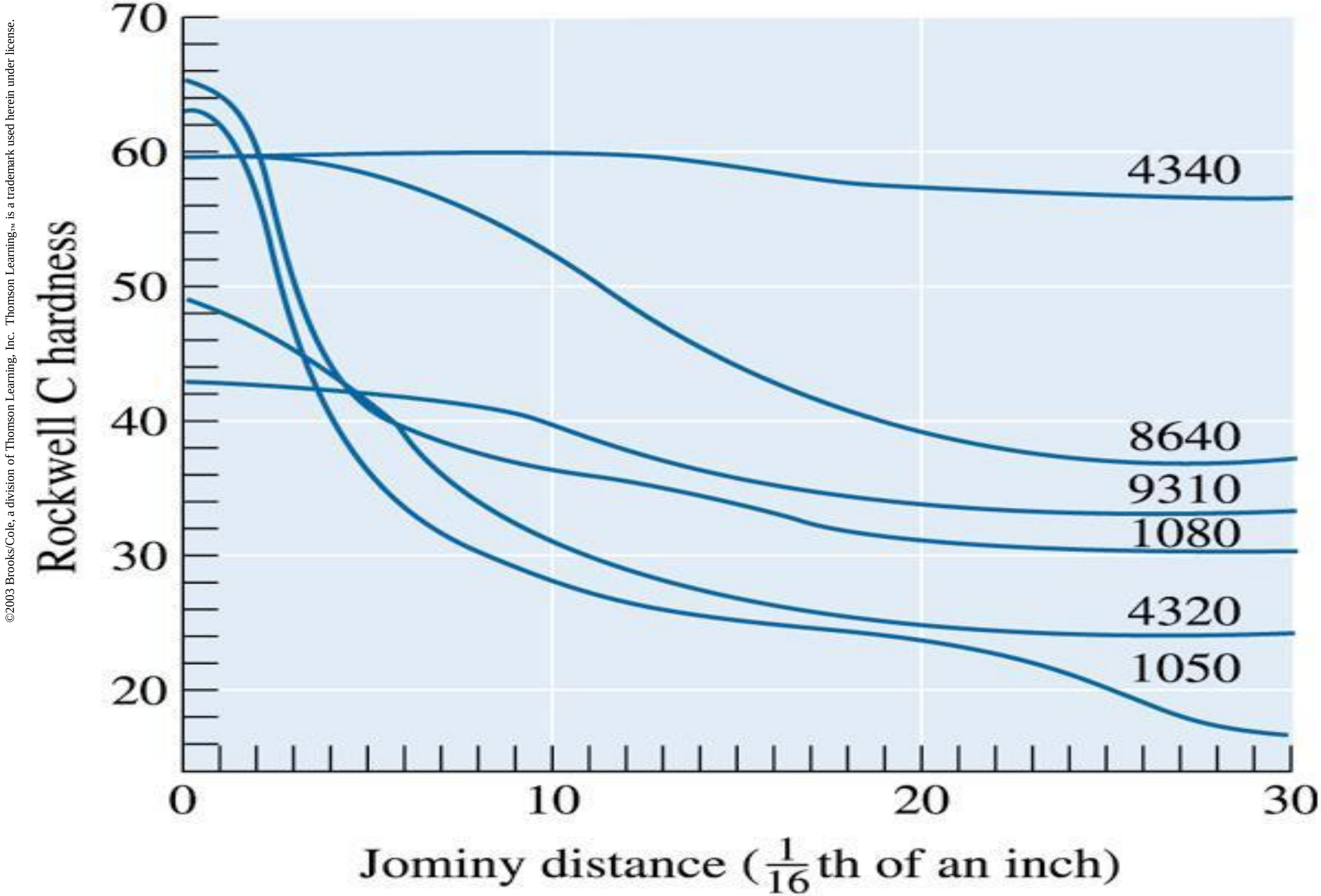
Hardenability Curve





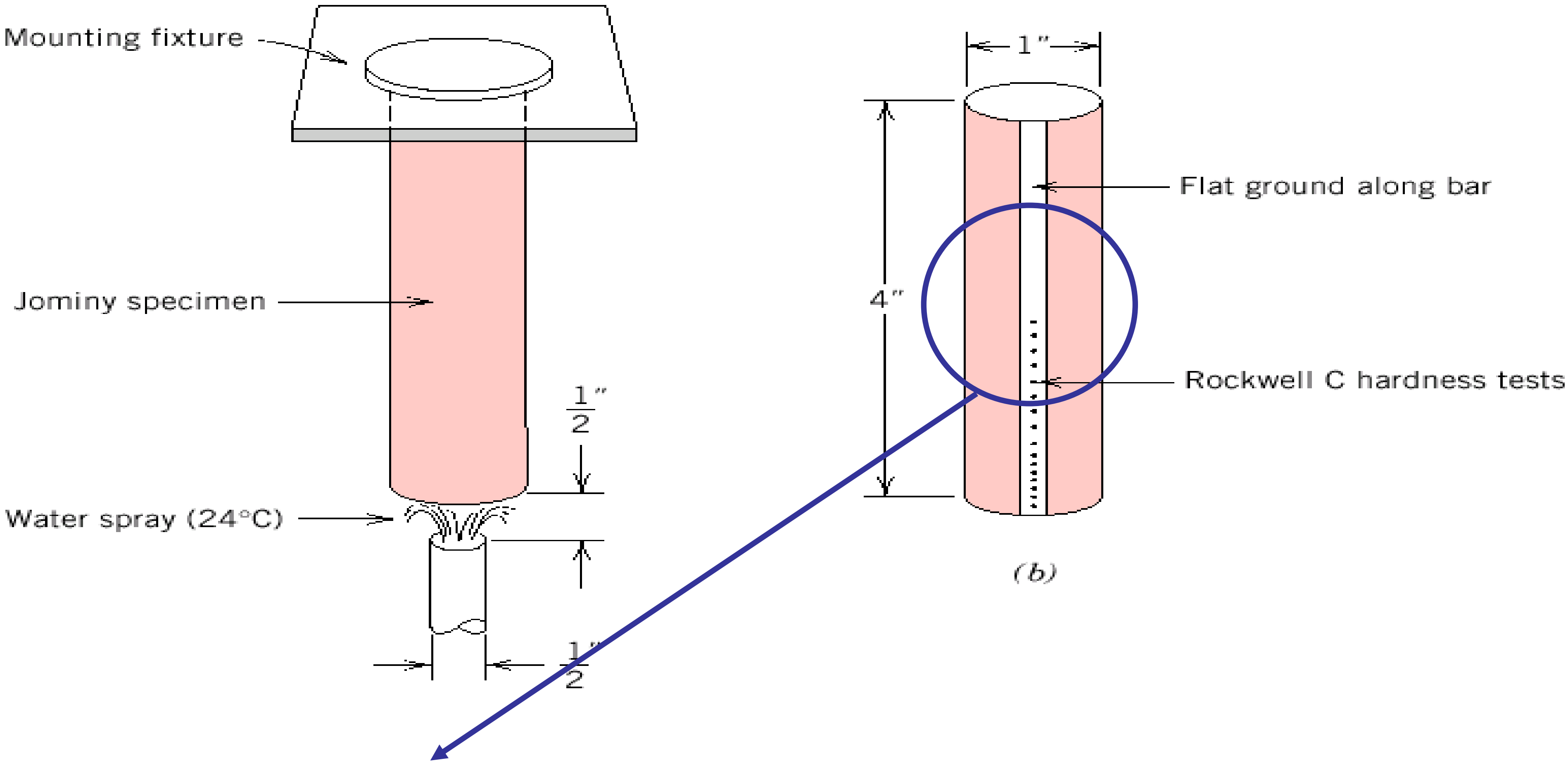
Quenched end cools most rapidly, contains most martensite

Cooling rate decreases with distance from quenched end: greater C diffusion, more pearlite/bainite, lower hardness



The hardenability curves for several steels.

Jominy end-quench test of Hardenability



Hardenability curve is the dependence of hardness on distance from the quenched end.

TABLE 12-3 ■ *The relationship between cooling rate and Jominy distance*

Jominy Distance (in.)	Cooling Rate (°C/s)
$\frac{1}{16}$	315
$\frac{2}{16}$	110
$\frac{3}{16}$	50
$\frac{4}{16}$	36
$\frac{5}{16}$	28
$\frac{6}{16}$	22
$\frac{7}{16}$	17
$\frac{8}{16}$	15
$\frac{10}{16}$	10
$\frac{12}{16}$	8
$\frac{16}{16}$	5
$\frac{20}{16}$	3
$\frac{24}{16}$	2.8
$\frac{28}{16}$	2.5
$\frac{36}{16}$	2.2