Hardenability of Steels

Introduction to Hardenability

Hardenability refers to the ability of steel to harden in depth when cooled from the austenitizing temperature. It is not a measure of maximum achievable hardness, but rather the capacity to form martensite through the cross-section.

Hardness vs. Hardenability

• Hardness: Resistance to deformation; depends on microstructure (e.g., martensite).
• Hardenability: Ability to form martensite upon quenching; depends on composition and cooling rate.

Jominy End-Quench Test

The Jominy test is a standard method to measure hardenability. A steel sample is austenitized, then one end is quenched. The resulting hardness profile from the quenched end to the opposite end indicates hardenability depth.

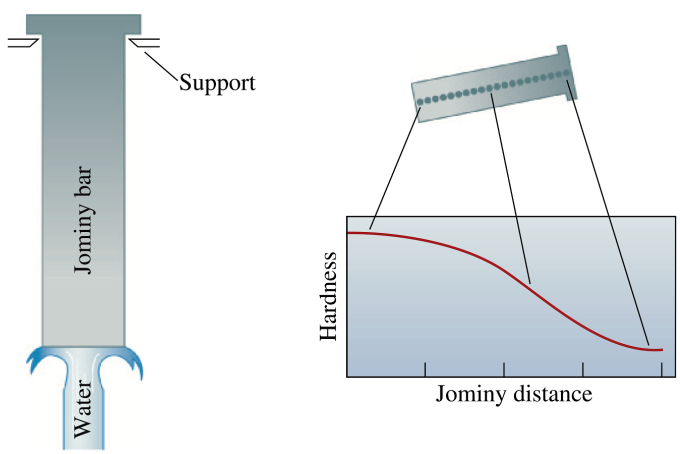

Figure 1. The setup for the Jominy test used for determining the hardenability of a steel.

Factors Influencing Hardenability

- • Alloying elements (Cr, Mn, Mo, Ni) increase hardenability by slowing transformation kinetics.
- • Grain size: Coarser grains increase hardenability.
- • Cooling rate: Faster cooling increases hardness but can cause distortion or cracking.
- • Section size: Larger sections cool slower at the core; require higher hardenability to ensure full hardness.

Engineering Application of Hardenability

Hardenability data is critical in selecting steels for thick components or complex geometries. By matching hardenability with quenching conditions, engineers can avoid insufficient hardness or excessive residual stress.

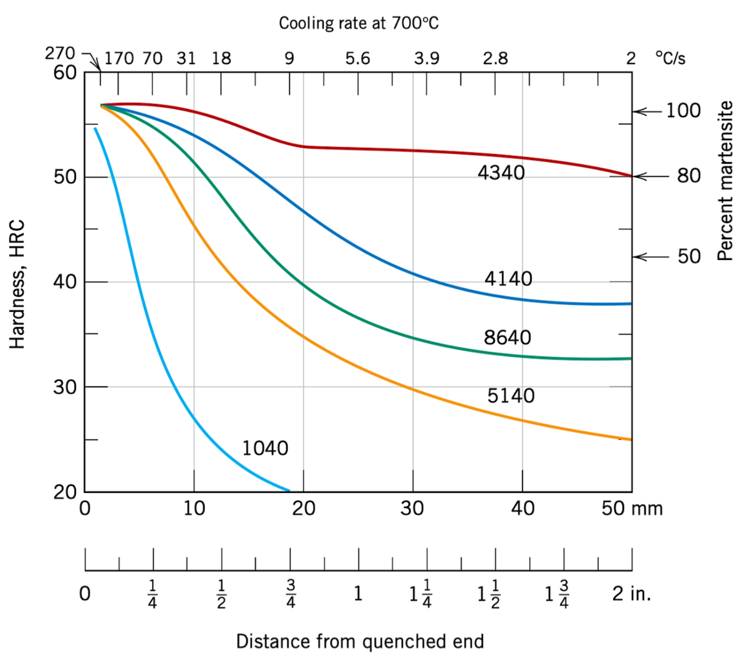

Figure 2. Hardenability curves forfive different steel alloys, each containing 0.4 wt% C. (Adapted from callister, 2014).

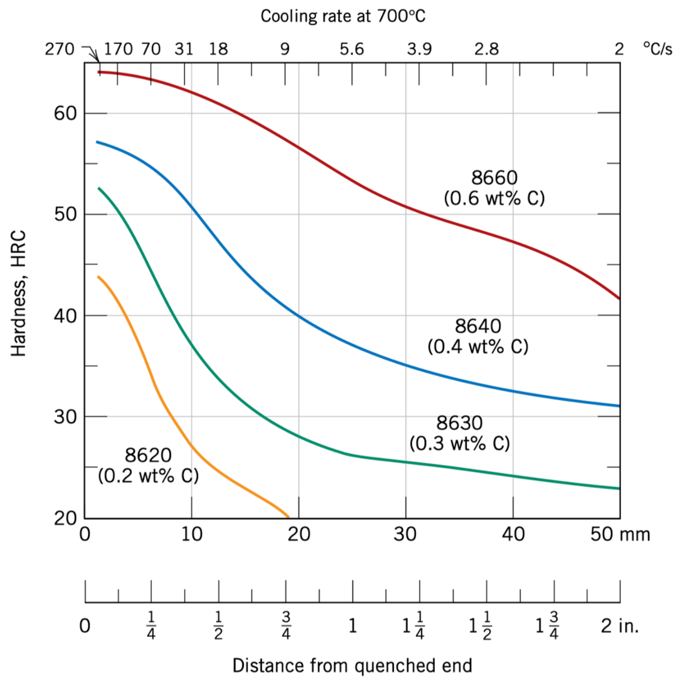

Figure 3. Hardenability curves for four 8600 series alloys of indicated carbon content. (Adapted from callister, 2014).

Example *Design of a Wear-Resistant Gear*

A gear made from 9310 steel, which has an as-quenched hardness at a critical location of HRC 40, wears at an excessive rate. Tests have shown that an as-quenched hardness of at least HRC 50 is required at that critical location. Design a steel that would be appropriate.

SOLUTION

We know that if different steels of the same size are quenched under identical conditions, their cooling rates or Jominy distances are the same. From Figure 13-21, a hardness of HRC 40 in a 9310 steel corresponds to a Jominy distance of 10/16 in. (10°C/s). If we assume the same Jominy distance, the other steels shown in Figure 13-21 have the following hardnesses at the critical location:

1050 HRC 28
1080 HRC 36
4320 HRC 31
8640 HRC 52
4340 HRC 60

Both the 8640 and 4340 steels are appropriate. The 4320 steel has too low a carbon content to ever reach HRC 50; the 1050 and 1080 have enough carbon, but the hardenability is too low. In Table 13-1, we find that the 86xx steels contain less alloying elements than the 43xx steels; thus the 8640 steel is probably less expensive than the 4340 steel and might be our best choice. We must also consider other factors such as durability.

Example Problems

1. A steel rod is subjected to a Jominy end-quench test. The hardness at 5 mm from the quenched end is 62 HRC, and at 25 mm it drops to 32 HRC. Based on this, discuss the steel's hardenability and whether it is suitable for a 30 mm thick gear.
2. Using the Jominy curve of a 4140 steel, estimate the hardness at 20 mm from the quenched end and identify the expected microstructure.
3. A plain carbon steel and an alloy steel are quenched in oil. The plain carbon steel shows pearlite in the center, while the alloy steel forms martensite throughout. Explain why this occurs using CCT diagram behavior.
4. For a given alloy steel, the critical diameter in oil is 38 mm and in water is 57 mm. What does this say about the steel's hardenability?
5. Draw and explain a schematic Jominy end-quench curve comparing high- and low-hardenability steels.

Industrial Case Study: Large components failing strength specifications

Case: Thick steel components hardened unevenly.

Cause: Low hardenability steel used for large cross-sections.

Lesson: Hardenability, not hardness, determines through-section performance.