

Surface Hardening of Steels

Introduction to Surface Hardening

Surface hardening involves treating the outer layer of steel to achieve high hardness while retaining a tough and ductile core. It enhances wear resistance, fatigue strength, and surface durability, making it ideal for components such as gears, shafts, and cams.

Diffusional Surface Hardening

These methods rely on the diffusion of carbon or nitrogen atoms into the steel surface at elevated temperatures.

- **Carburizing**
 - Methods: Pack, gas, vacuum carburizing
 - Temperature: 900–950°C
 - Followed by quenching to form a high-carbon martensitic case
 - Case depth: up to 2 mm
 - Applications: gears, pins, camshafts

Procedure

Carburising is carried out on steel containing carbon less than 0.2%. It involves increasing the carbon contents on the surface layers upto 0.7 to 0.8%. A high carbon content is produced at the surface due to rapid diffusion and the high solubility of carbon in austenite. When the steel is then quenched and tempered, the surface becomes a high-carbon tempered martensite, while the ferritic center remains soft and ductile.

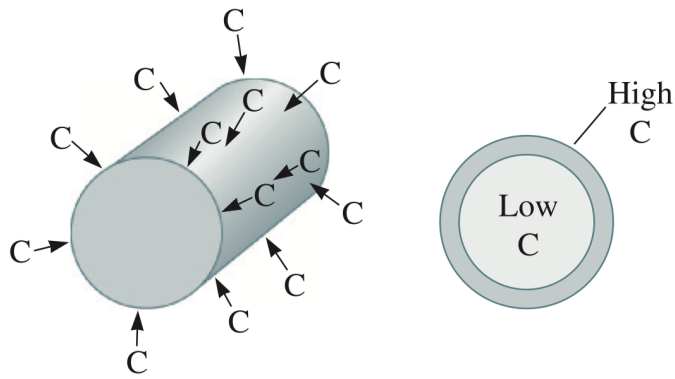


Figure 1. Carburizing of a low-carbon steel to produce a high-carbon, wear-resistant surface.

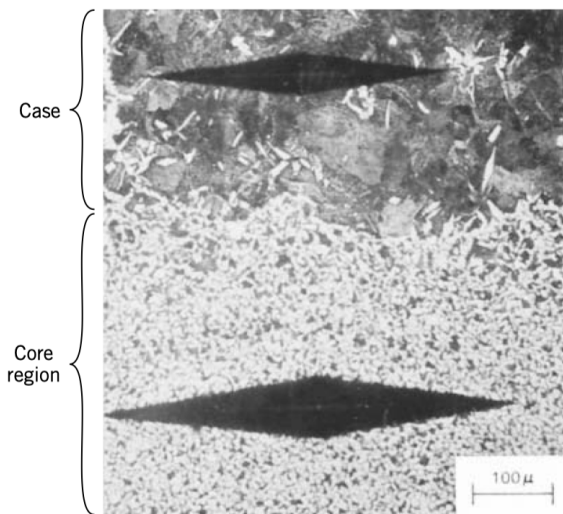


Figure 2. Photomicrograph showing both core (bottom) and carburized outer case (top) regions of a case-hardened steel. The case is harder, as attested by the smaller microhardness indentation. 100 \times . (Adapted from Callister, 2014).

- **Nitriding**

Nitriding involves diffusion of nitrogen into the product to form nitrides.

- Methods: Gas, plasma, ion.
- Temperature: 500–550°C, no quenching needed
- Requires alloy steels (Cr, Mo, Al).
- Produces compound (stable nitrides) and diffusion zones
- Low distortion

- **Carbonitriding**

- Simultaneous diffusion of carbon and nitrogen
- Temperature: 750–900°C
- Used for small, inexpensive components
- Case depth: up to 0.75 mm

Non-Diffusional Surface Hardening

- **Flame Hardening**

- Heating source: Oxy-acetylene or oxy-propane flame.
- Applicable to medium and high-carbon steels (>0.35% C).
- Rapid heating to austenitizing temperature (A_3), followed by immediate quenching.
- Depth of hardening: 1 to 6 mm, depending on flame intensity and exposure time.
- Used for large components such as rails, gears, and shafts.

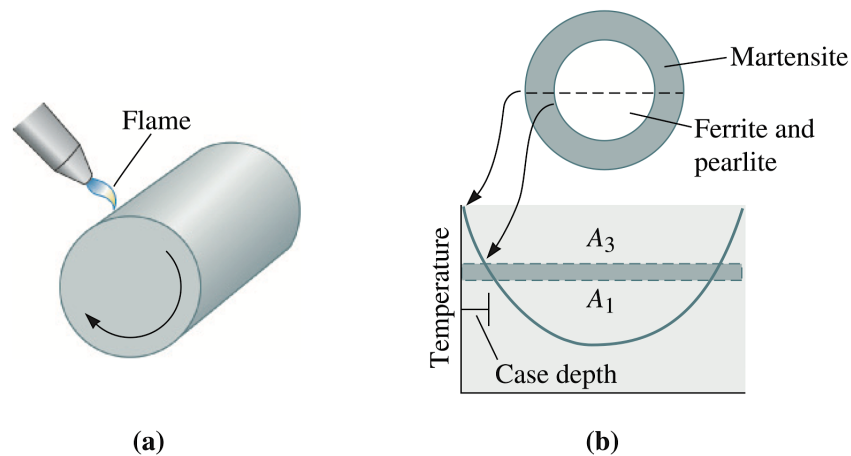


Figure 3. (a) Surface hardening by localized heating. (b) Only the surface heats above the A_1 temperature and is quenched to martensite. (Adapted from Askelan, 2016).

- **Induction Hardening**

- Heating by electromagnetic induction from a copper coil.
- Heating is fast and localized, reducing distortion.
- Frequency (kHz to MHz) controls the depth of penetration:
 - High frequency: shallow depth (0.5–1 mm)
 - Low frequency: deeper case (up to 5 mm)

Materials: medium/high-carbon steels, or low-carbon steels pre-carburized.

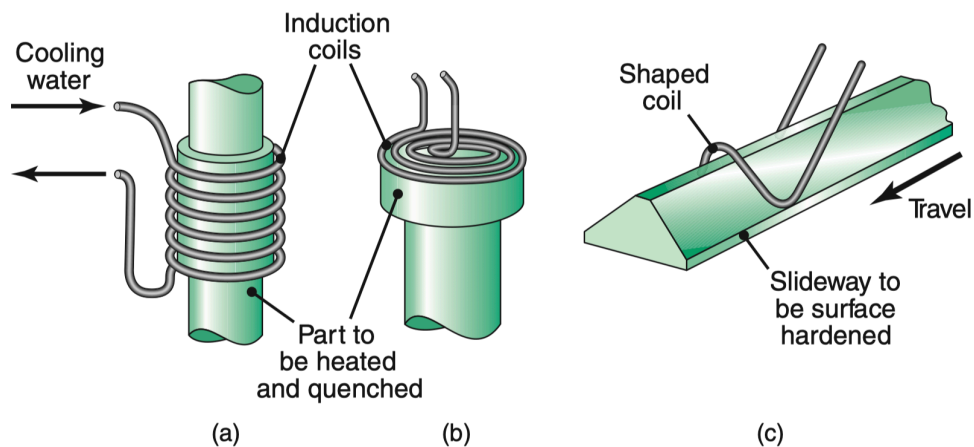


Figure 4. Types of coils used in the induction heating of various surfaces of parts.

Industrial Applications

Surface hardening is essential in automotive, aerospace, and tool industries. It helps to reduce wear, pitting, and improve fatigue resistance.

Example

Design of Surface-Hardening Treatments for a Drive Train

Design the materials and heat treatments for an automobile axle and drive gear (Figure 5).

SOLUTION

Both parts require good fatigue resistance. The gear also should have a good hardness to avoid wear, and the axle should have good overall strength to withstand bending and torsional loads. Both parts should have good toughness. Finally, since millions of these parts will be made, they should be inexpensive.

Quenched and tempered alloy steels might provide the required combination of strength and toughness; however, the alloy steels are expensive. An alternative approach for each part is described below.

The axle might be made from a forged 1050 steel containing a matrix of ferrite and pearlite. The axle could be surface-hardened, perhaps by moving the axle through an induction coil to selectively heat the surface of the steel above the A_3 temperature (about 770°C). After the coil passes any particular location of the axle,

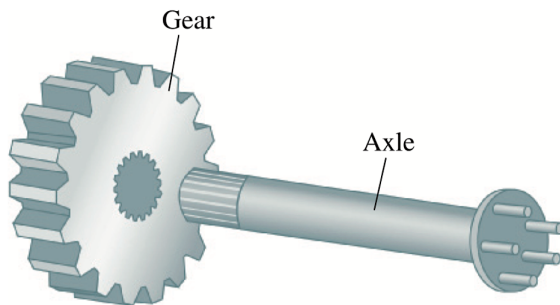


Figure 5

Sketch of axle and gear assembly
(for Example 13-7).

the cold interior quenches the surface to martensite. Tempering then softens the martensite to improve ductility. This combination of carbon content and heat treatment meets our requirements. The plain carbon steel is inexpensive; the core of ferrite and pearlite produces good toughness and strength; and the hardened surface provides good fatigue and wear resistance.

The gear is subject to more severe loading conditions, for which the 1050 steel does not provide sufficient toughness, hardness, and wear resistance. Instead, we might carburize a 1010 steel for the gear. The original steel contains mostly ferrite, providing good ductility and toughness. By performing a gas carburizing process above the A_3 temperature (about 860°C), we introduce about 1.0% C in a very thin case at the surface of the gear teeth. This high-carbon case, which transforms to martensite during quenching, is tempered to control the hardness. Now we obtain toughness due to the low-carbon ferrite core, wear resistance due to the high-carbon surface, and fatigue resistance due to the high-strength surface containing compressive residual stresses introduced during carburizing. In addition, the plain carbon 1010 steel is an inexpensive starting material that is easily forged into a near-net shape prior to heat treatment.