Carburizing cannot be done in ferrite phase as it has very low solid solubility for carbon at room temperature. It is done in the Austenite region above 727°C in carbon rich atmosphere.

Types of carburizing

i. Pack carburizing
ii. Gas carburizing
iii. Liquid carburizing

For iron or steel with low carbon content, which has poor to no hardenability of its own, the case hardening process involves infusing additional carbon into the case.

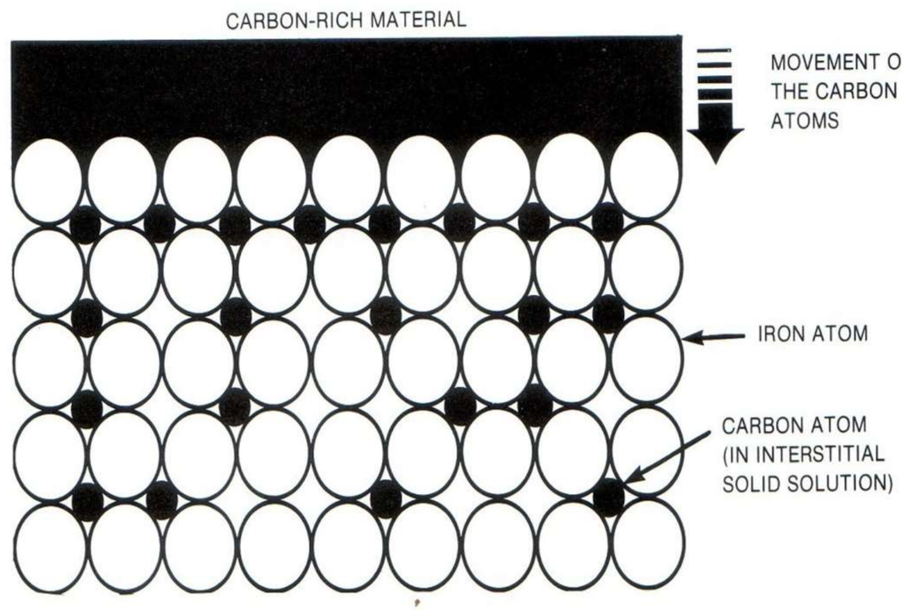
Case hardening is usually done after the part has been formed into its final shape, but can also be done to increase the hardening element content of bars to be used.

Because hardened metal is usually more brittle than softer metal, through-hardening (that is, hardening the metal uniformly throughout the piece) is not always a suitable choice for applications where the metal part is subject to certain kinds of stress.

In such applications, case hardening can provide a part that will not fracture (because of the soft core that can absorb stresses without cracking) but also provides adequate wear resistance on the surface.

Pack carburizing

- The component is packed surrounded by a carbon-rich compound and placed in the furnace at 900 degrees.
- Over a period of time carbon will diffuse into the surface of the metal.
- The longer left in the furnace, the greater the depth of hard carbon skin. Grain refining is necessary in order to prevent cracking.



A major limitation of pack carburizing is poor control over temperature & carburization depth.
On completion of the process the steel parts are cooled slowly. Direct quenching is not possible as the job is surrounded by carburizing mixture packed in a sealed box having high thermal mass.

This can be overcome by using gaseous or liquid carburizing medium.

- **Salt bath carburizing.** A molten salt bath (sodium cyanide, sodium carbonate and sodium chloride) has the object immersed at 900 degrees for an hour giving a thin carbon case when quenched.

- **Gas carburizing.** The object is placed in a sealed furnace with carbon monoxide allowing for fine control of the process.

- Gas carburization is done by keeping the samples at the carburizing temperature for a specified time in a furnace having a mixture of carburizing and neutral gas. CH_4 and CO are the most commonly used carburizing gas.

- It is usually mixed with de-carburizing (H_2 and CO_2) and neutral gases (N_2).

- This helps maintain a close control over carbon potential. It should be enough to maintain %C at in the range 1.0-1.2% at the surface.

- In the presence of Fe the carburizing gases decompose to produce nascent carbon that diffuses into steel.
  $CH_4 = C\ (Fe) + 2H_2$
  $2CO = C\ (Fe) + CO_2$

- It provides excellent control over the furnace temperature and atmosphere (carbon potential).

- Samples after carburization can be directly quenched.

Liquid carburization

It is done by keeping the job in a salt bath consisting of 8% NaCN + 82 $BaCl_2$ + 10 NaCl.

It allows precise temperature control and rapid heat transfer. Carburization takes place due to the formation of nascent carbon.

The chemical reactions that occur in the presence of Fe are as follows:

$$BaCl_2 + NaCN = Ba(CN)_2 + NaCl$$

$$Ba(CN)_2 = C\,(Fe) + BaCN_2$$

What is the chemical CN?

A cyanide is a **chemical** compound that contains the group C≡N. This group, known as the cyano group, consists of a carbon atom triple-bonded to a nitrogen atom.

The sample can be quenched immediately after carburization.

Nitriding

Nitrides are formed on a metal surface in a furnace with ammonia gas circulating at 500 degrees over a long period of time (100 hours). It is used for finished components.

If steel is heated in an environment of cracked ammonia it picks up nitrogen.

Nitrogen like carbon forms interstitial solid solution with iron. If it is present in excess it forms nitride (Fe_4N). It is extremely hard and brittle

Nascent nitrogen that forms at the surface of steel as ammonia comes in contact with Fe.

This diffuses into iron lattice and form nitride as and when the amount of nitrogen in steel exceeds its solubility limit.

The presence of alloying elements having high affinity for nitrogen increases nitrogen pick up.

The formation of nitride within the matrix results in a substantial increase in the hardness of steel.

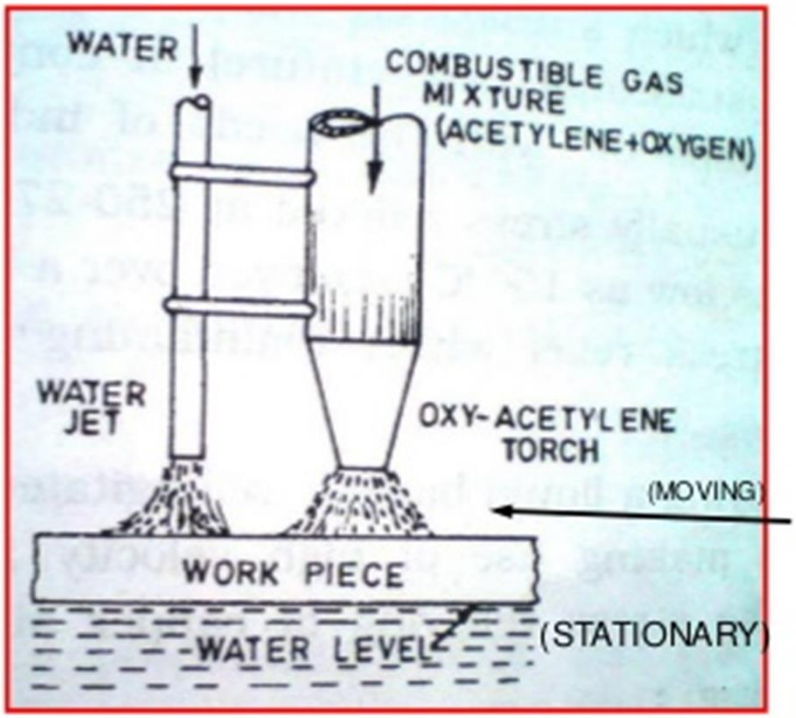
The preferred thickness of the hardened layer is around 20 micro meter.

The hardness of the nitride layer is usually in the range of 1000-2000Hv.

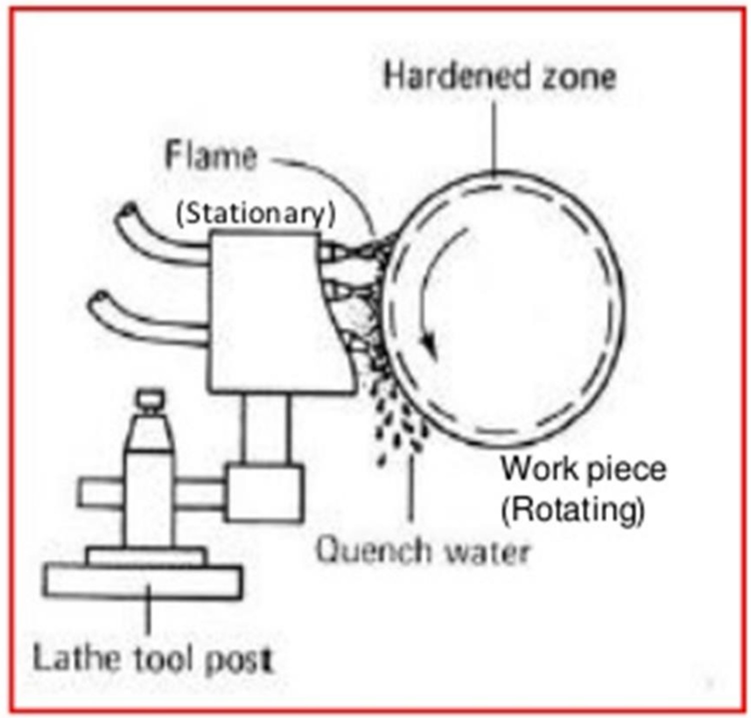
Nitriding of steel is carried out only after it has been hardened and tempered. It is the last heat treatment given to steel.

Flame Hardening

- A high intensity oxy-acetylene flame is applied to the selective region. The temperature is raised high enough to be in the region of Austenite transformation.
- The "right" temperature is determined by the operator based on experience by watching the color of the steel.



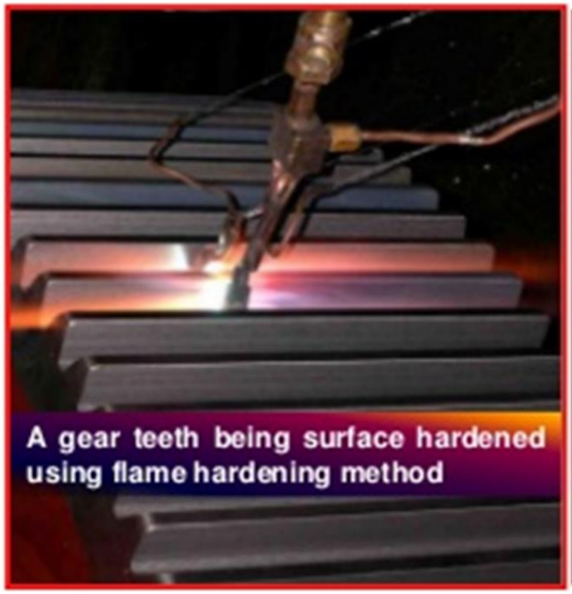
Flame hardening of a flat cross section work piece

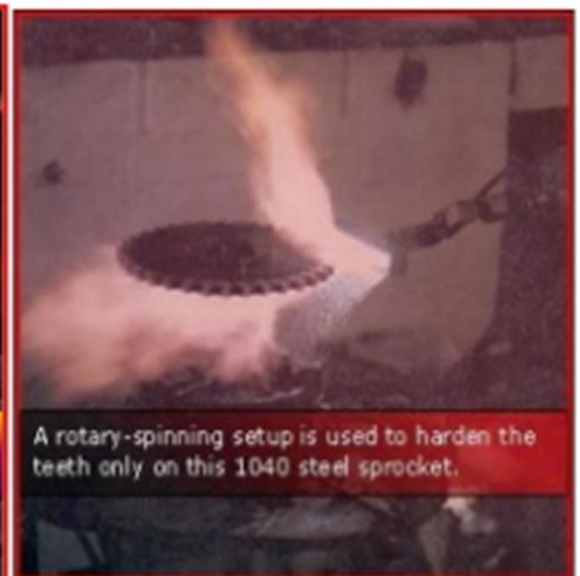


Flame hardening of a circular cross section work piece using lathe

Flame Hardening

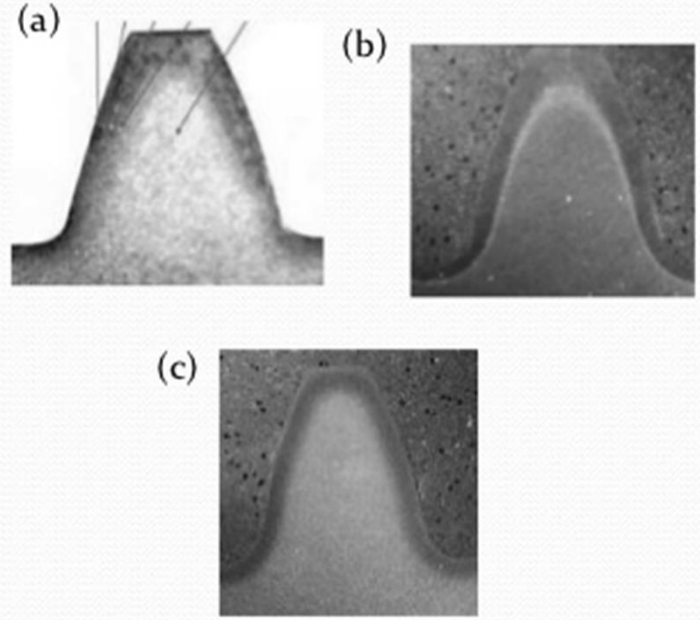
- The overall heat transfer is limited by the torch and thus the interior never reaches the high temperature.
- The heated region is quenched to achieve the desired hardness.
- Tempering can be done to eliminate brittleness.
- The depth of hardening can be increased by increasing the heating time.
- Maximum 6 mm of depth can be achieved.


A gear teeth being surface hardened using flame hardening method


A rotary-spinning setup is used to harden the teeth only on this 1040 steel sprocket.

Review of Surface Hardening *

- Induction hardening (~67 HRC)
  - Can be used on any type of steel
  - Utilizes localized heating
  - Has clean transition pattern
  - Process takes less than 1 minute
- Nitriding (~69 HRC)
  - Uses ammonia or cyanide salt baths
  - Depth of 1 mm
  - Roughly 4 hours per work piece
- Carburizing (~50 HRC)
  - Used on low carbon content steel (<0.2%C)
  - Depth up to 6 mm
  - Typically 12-72 hrs. per work piece



Images of gear teeth hardened by (a) nitriding (b) carburizing and (c) induction hardening found at http://www.gearsolutions.com/media//uploads/assets//PDF/Articles/Jan_10/0110_Boeing.pdf

*Davis, et. al, Surface Engineering of Cast Irons, *Surface Engineering*, ASM Handbook [5] 683-700 (1994)