Objectives of Heat Treatments

To increase strength, hardness and wear resistance (*bulk hardening, surface hardening*)

To increase ductility and softness (*Tempering, Recrystallization Annealing*)

To increase toughness (*Tempering, Recrystallization annealing*)

To obtain fine grain size (*Recrystallization annealing, Full annealing, Normalizing*)

To remove internal stresses induced by differential deformation by cold working, non-uniform cooling from high temperature during casting and welding (*Stress relief annealing*)

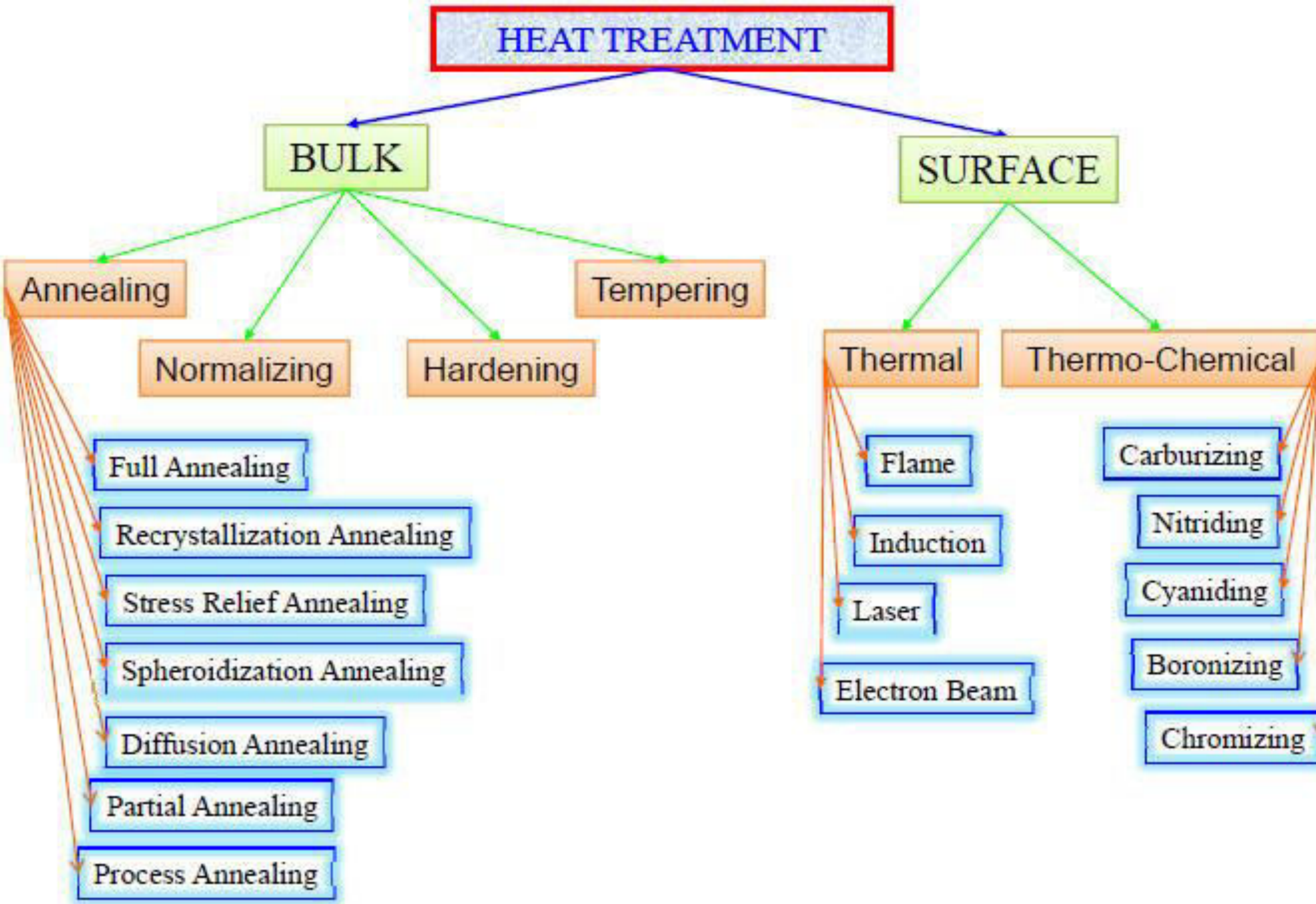
To improve machinability (*Full annealing and Normalizing*)

To improve cutting properties of tool steels (*Hardening and Tempering*)

To improve surface properties (*surface hardening, high temperature resistance-precipitation hardening, surface treatment*)

To improve electrical properties (*Recrystallization, Tempering, Age hardening*)

To improve magnetic properties (*Hardening, Phase transformation*)


HEAT TREATMENT
BULK
SURFACE
Annealing
Normalizing
Hardening
Tempering
Thermal
Thermo-Chemical
Full Annealing
Recrystallization Annealing
Stress Relief Annealing
Spheroidization Annealing
Diffusion Annealing
Partial Annealing
Process Annealing
Flame
Induction
Laser
Electron Beam
Carburizing
Nitriding
Cyaniding
Boronizing
Chromizing

Full Annealing

- The steel is heated above A_3 (for hypo-eutectoid steels) | A_1 (for hyper-eutectoid steels) →(hold) →then the steel is furnace cooled to obtain Coarse Pearlite
- Coarse Pearlite has ↓ Hardness, ↑ Ductility
- Not above A_{cm} →to avoid a continuous network of proeutectoid cementite along grain boundaries (→path for crack propagation)

Recrystallization Annealing

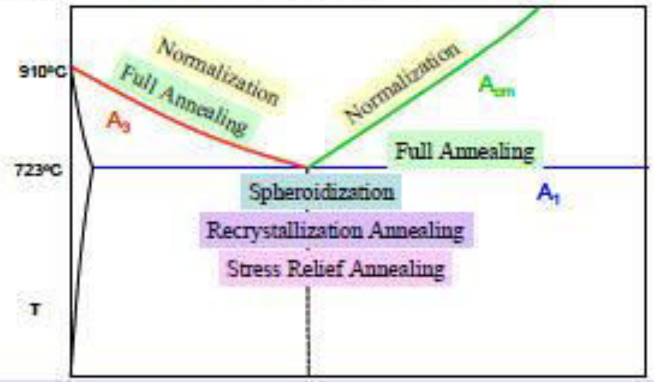
- The Heat below A_1 → Sufficient time → Recrystallization ↘ Cold worked grains → New stress free grains
- Used in between processing steps (e.g. Sheet Rolling)

Normalizing

Heat above A_3 | A_{cm} → Austenization → Air cooling → Fine Pearlite (Higher hardness)

Purposes

- Refine grain structure prior to hardening
- To harden the steel slightly
- To reduce segregation in casting or forgings



Hardening

Heat above A_3 | A_{cm} → Austenization → Quench (higher than critical cooling rate)

- Certain applications demand high tensile strength and hardness values so that the components may be successfully used for heavy duty purposes. High tensile strength and hardness values can be obtained by a processes known as Hardening.
- hardening process consists of four steps. The first step involves heating the steel to above A_3 temperature for hypoeutectoid steels and above A_1 temperature for hypereutectoid steels by 50^0C.
- The second step involves holding the steel components for sufficient socking time for homogeneous austenization.
- The third step involves cooling of hot steel components at a rate just exceeding the critical cooling rate of the steel to room temperature or below room temperature.
- The final step involves the tempering of the martensite to achieve the desired hardness. Detailed explanation about tempering is given in the subsequent sections. In this hardening process, the austenite transforms to martensite. This martensite structure improves the hardness.

Retained Austenite

Advantages

- Ductility of austenite can help to relieve some internal stresses developed due to hardening, to reduce danger of distortion and cracks. 10% retained austenite along with martensite is desirable.
- The presence of 30-40% retained austenite makes straightening operation of the components possible after hardening. Straightening increases the hardness slightly.
- Non-distorting steels owe their existence to retained austenite. Here enough austenite is retained to balance the transformational contracting during heating, on the formation of austenite from ferrite carbide aggregate on the one hand, and the expansion corresponding to the formation of martensite during cooling, on the other, Here, the basis of dimensional stability of non-distorting steels is the presence of retained austenite.

disadvantages

- The soft austenite if present, in large amounts, decreases the hardness of hardened steels.
- As retained austenite may transform to lower bainite, or to martensite, there takes place increase in dimensions of the part. Not only it creates problems in precision gauges, or dies, the neighboring parts may be put under stress by it. In the component itself, stresses may be created to cause distortion or cracking.
- Retained austenite decreases the magnetic properties of the steel.

Sub-Zero treatment

The retained austenite is generally undesirable, sub-zero treatment is one of the method to eliminate retained austenite.

As the room temperature lies between M_s and M_f temperatures of steel, quenching to room temperature results in retained austenite.

Subzero treatment consists in cooling the hardened steel to a temperature below 0°C. The temperature of the sub zero treatment depends on the position of M_f temperature of the steel.

A steel can be cooled much below the M_f temperature, but it, evidently achieves nothing, because it cannot bring about any additional increase of hardness, or any additional increase of martensite, because the Martensitic transformation ends at M_f temperature.

Sub-zero treatment is more effective, if it is carried out immediately after quenching operation. Any lapse of time between hardening and the cold treatment causes the stabilization of austenite, makes the retained austenite resistant to further transformation.

Most steels can be cooled by subzero treatment in a low cooling unit with one of the mediums as given in table (next page) .

The low-cooling unit consists of two vessels, the interior one of copper, where the parts or tools to be deep frozen, are placed and the exterior one of steel provided with a good heat insulation.

Tempering

The hardened steel is not readily suitable for engineering applications. It possesses following three drawbacks.

- ✓ Martensite obtained after hardening is extremely brittle and will result in failure of engineering components by cracking.
- ✓ Formation of martensite from austenite by quenching produces high internal stresses in the hardened steel.

Determination of Hardenability

Hardenability of steel is determined by the following methods

- ✓ Grossman's critical diameter method
- ✓ Jominy end quench test
- ✓ Estimation of hardenability from chemical composition
- ✓ Fracture test

Quenching Processes

Previously it was shown that the cooling rate and the shape of the cooling curve influence the course of phase transformations, residual stresses and distortion.

In quench hardening, fast cooling rates, depending on the chemical composition of the steel and its section size, are frequently applied to prevent diffusion controlled transformations in the pearlite range and to obtain a structure consisting mainly of martensite and bainite.

However, the reduction of undesirable thermal and transformational stresses due to volume changes usually requires slower cooling rates.

Quenching processes therefore require the selection of cooling rates that are fast enough to permit the desired micro structure to form but slow enough to minimize residual stresses and distortion.

These considerations have resulted in different quenching methods such as

- Direct quenching,
- Interrupted quenching (Mar-quenching, Austempering, Isothermal Annealing)
- Spray quenching,
- Gas quenching
- Fog quenching.

The time temperature cycles that can be obtained with different quenching methods are shown in Figure (next page) for the center and surface of the quenched part together with the time temperature transformation diagram.

Surface Hardening

Flame Hardening

Flame hardening is the simplest form of surface hardening heat treatment.

This process consists of heating the large work-piece, such as crank shaft, axle, large gear, cam, bending roller, or any other complicated cross-section, by an oxy-acetylene, or oxy-fuel blow pipe, followed by spraying of jet of water as coolant.

After hardening, reheating of the parts is carried out in furnace or oil bath at about 180-200 °C for stress relieving.

Normally, case depth up to 3mm can be achieved.

Induction Hardening

Induction hardening may be used for local surface heat treatment. Generally, it is used to surface harden crank shafts, cam shafts, gears, crank pins and axles. In this process, heating of the component is achieved by electromagnetic induction.

Here, an alternating current of high frequency passes through an induction coil enclosing the steel part to be heat treated. The induced emf heats the steel. the depth up to which the heat penetrates and rises the temperature above Ac_3 is inversely proportional to the square root of the AC frequency.