CHAPTER 4

SURFACE HARDENING PROCESSES

4.1 INTRODUCTION

This chapter deals with the objectives and principles of the various surface hardening processes. A thorough knowledge of surface hardening processes helps an engineer in deciding the type of process to be undertaken for the smooth and efficient working of the components and structures.

4.2 FLAME HARDENING PROCESS

This method involves rapidly heating the surface of the steel or cast iron to a temperature above its upper critical temperature by using an oxyacetylene flame torch, followed by water spray quenching or by immersing the component into a quenching medium in order to transform austenite to martensite. Steel used in flame hardening may be hardenable, i.e., it should have sufficient carbon percentage suitable alloying elements.

Also it is important to note that in this process there is no alteration in the chemical composition, i.e., there is no inward diffusion of carbon or nitrogen in order to increase the surface hardness of steel.

There are three methods of flame hardening such as Spot method, Spinning method and Progressive method.
In spot hardening, a particular region or spot on the component is heated by one or more flames and is quenched. It consists of locally heating selected areas with a suitable flame head and subsequently quenching. The heating head may be of either single-orifice or multiple-orifice design, depending on the extent of the area to be hardened. The heat input must be balanced to obtain a uniform temperature over the entire selected area. After being heated, the parts are usually immersion quenched; however, in some mechanized operations, a spray quench may be used (Figure 4.1).

The spinning method is applied to round or semi-round parts such as wheels, cams, or gears. In its simplest form, the method uses a mechanism for rotating or spinning the work-piece, in either a horizontal or a vertical plane, while the surface is being heated by the flame head. One or more water-cooled heating heads equal in width to the surface to be heated are employed (Figure 4.2).

In progressive method the heating and quenching devices are fitted in single equipment which is moved over the surface of the component which is quenched by water spray or quenched in a water bath. It is used to harden large areas that are beyond the scope of the spot method. The size and shape of the work-piece, as well as the volume of oxygen and fuel gas is required to heat the specified area, are factors in the selection of this method (Figure 4.3). In progressive hardening, the flame head is usually of the multiple-orifice type and quenching facilities may be either integrated with the flame head or separate from it. The flame head progressively quenched a narrow band that is subsequently quenched as the head and quench traverse the work-piece (Thomas Ruglic 1995).

By suitably controlling the various parameters, the case depth of the hardened layer can be varied. Normally a case depth up to 3 mm can be achieved. The carbon content required for flame hardening of steels varies from 0.3 % to 0.6%. This process can also harden high carbon steels, but care should be taken to avoid cracking. The flame hardened components are tempered at low temperature to relieve internal residual stresses. The same flame torch can also perform tempering.
Figure 4.1 Spot method of flame hardening a rocker arm and the internal lobes of a cam

Figure 4.2 Spinning methods of flame hardening, (the methods shown at left and center, the part rotates. In the method at right, the flame head rotates)

Figure 4.3 Progressive hardening method
In flame hardening there is less distortion than conventional hardening, also there is less scaling (oxidation) and decarburization since the heating and cooling rate are very fast, also the core remains unaffected.

4.3 INDUCTION HARDENING PROCESS

Heating steel or cast iron by means of high frequency electric current is induction hardening. The principle of induction is that when a component is placed in a varying magnetic field an eddy current is induced in it. This eddy current produced is used to heat the component. The component heated by induction is then quenched (Sharma 2000).

A thin hardened layer is formed on the surface of hardenable steel or cast iron that is induction hardened. The time taken to heat the component by induction is very short. It ranges from two to five minutes. With in this short time period the surface layer reaches the upper critical temperature.

When the current density is more, the induced eddy current is unevenly distributed with the distance from the surface. This phenomenon is termed as electromagnetic surface effect or skin effect. The higher the frequency of varying magnetic field the more uneven will be the distribution of eddy currents in the cross section of the object being heated (Figure 4.4).

The skin layer through which the induced current flows is inversely proportional to the square root of induced current frequency. Controlling the frequency of supply voltage can control the depth of hardening or hardened skin layer. The frequency usually ranges from 1000 Hz to 100000 Hz and the depth of hardness ranges from 0.5 to 6 mm.
After the component reaches the upper critical temperature (i.e., it reaches the austenite temperature), it is quenched by spraying water. Since the heating rate is very rapid and the heating time is also very less, the austenitic grain size is very fine.

The structure obtained after quenching has a very fine martensite structure with the same austenitic grain size. After quenching, the component is tempered at low temperature in the range of 150°C to 200°C in order to relieve any stress caused by induction hardening due to rapid heating and cooling of the surface. If a harder core is required then the component should be suitably heat treated before induction hardening in order to obtain the desired properties in the core.
Steel with carbon percentage ranging from 0.4 to 0.5% are suitable for induction hardening. The hardening temperature for plain carbon steel is about 760°C and for alloy steels higher hardening temperatures are required. This process may harden components such as pulleys, crankshafts, gears, boring bars, crankpins, axles and brake drums.

4.4 ELECTRON BEAM HARDENING PROCESS

Electron beam hardening process is a short surface hardening procedure for martensitically hardenable ferrous materials. Austenizing occurs through the energy transferred by electron beams. Precise application of the energy with respect to work-piece location and elapsed time using a focused and deflectable electron beam makes it the process of choice, especially for the partial hardening of highly stressed surface regions in components. The austenizing process advances from the surface towards the inner core regions of the component via heat conduction, thus allowing for a defined adjustment of the hardness penetration by selecting a suitable energy transfer duration. Typical hardening depths obtained by the electron beam hardening process range from 0.1 to 1.5mm (0.004 to 0.006 in.) The rapid cooling of the austenite required for martensite formation occurs through a self-quenching process that is dependent on the thermal conductivity and starts after the energy transfer has ceased. Depending on the material selected, the work-piece thickness required should be at least 5 to 10 times the austenizing depth (Schiller et al 1995).

This technique has only recently found practical application in the metals industry. Because it offers the advantages of extremely low hardening distortion and relatively low energy consumption, electron beam hardening provides the metallurgist with an additional option to conventional hardening techniques.
4.4.1 Principle of energy absorption and heat conduction

The electrons of the beam hit the component surface and penetrate into the metal surface is shown in Figure 4.5. Because of the intense interaction between the beam of electrons and the atoms of the material being bombarded by the beam, the electrons lose their energy rapidly. The majority of the energy lost by the electrons is transformed into heat in the absorption volume. Approximately 75% of the power generated by an electron beam is converted to heat when the beam is incident perpendicular to a steel surface.

Substantial energy losses are incurred chiefly by the back scattering of incompletely decelerated electrons. The efficiency of this energy conversion is independent of the optical properties of the work-piece surface and the temperature of the material. When the incident beam is inclined to the steel surface, energy losses are increased because of enhanced electron back scattering.

![Energy absorption zone and heat conduction zone generated by an electron beam on the surface of a work-piece](image)

Figure 4.5 Energy absorption zone and heat conduction zone generated by an electron beam on the surface of a work-piece
4.5 LASER SURFACE HARDENING PROCESS

Laser surface hardening of ferrous materials is an established process used to enhance the mechanical properties of highly stressed machine parts, such as gears and bearings. Surface hardening increases the wear resistance of the material and under favourable circumstances, increases the fatigue strength caused by residual stresses that are induced in the work-piece surface by the transformation hardening process. The surface hardening process is not fundamentally different from conventional through hardening of ferrous materials. In both processes, increased hardness and strength are obtained by quenching the material from the austenite region to form hard martensite. Surface hardening differs from conventional through hardening in that only a thin surface layer is heated to austenization temperatures prior to quenching, leaving the interior of the work-piece essentially unaffected (Ole and Sandvan 1995).

Because ferrous materials are fairly good heat conductors, it is necessary to use very intense heat fluxes to heat the surface layer to austenization temperatures without unduly affecting the bulk temperature of the work-piece. The heat input is commonly obtained by the use of very hot flames or by high frequency induction heating. By selectively heating the work-piece surface to austenization temperatures, desired surface hardening is obtained by application of a quench medium to the hot surface, or by self-quenching. Self-quenching occurs when the cold interior of the work-piece constitutes a sufficiently large heat sink to quench the hot surface by heat conduction to the interior at a rate high enough to allow martensite to form at the surface.

In recent years, industrial lasers have become available for metalworking uses, including surface hardening. A laser can generate very intense energy fluxes at the work-piece surface and the resulting temperature profiles in the work-piece usually can be made steep enough to negate the need for external quench media. The laser
beam is a beam of light, which is essentially independent of the work-piece, easily controlled, requires no vacuum and generates no combustion products. However, laser surface hardening also has some disadvantages that might limit its practical use in a heat-treatment shop.

4.5.1 Principles of laser surface hardening

When a laser beam impinges on a surface, part of its energy is absorbed as heat at the surface. If the power density of the laser beam (usually given in watts per square centimeter) is sufficiently high, heat will be generated at the surface at a rate higher than heat conduction and the temperature in the surface layer will increase rapidly. In a very short time, a thin surface layer will have reached austenitizing temperatures, whereas the interior of the work-piece is still cool. Even with a relatively moderate power density of 500 W/cm², temperature gradients of 500°C/mm can be obtained. By moving the laser beam over the work-piece surface (Figure 4.6), a point on the surface within the path of the beam is rapidly heated as the beam passes. This area is subsequently cooled rapidly by heat conduction to the interior after the

Figure 4.6 Square laser beam with uniform power density on a flat plate
beam has passed. By selecting the correct power density and speed of the laser spot, the material will harden to the desired depth. The resulting depth of case will depend on the hardening response of the material, but it will rarely be more than 2.5 mm (0.1 in.). For steel with low hardenability, such as low and medium carbon steel, the depth of case obtainable is much smaller, varying from perhaps 0.25 mm (0.1 in.) in mild steels to 1.3 mm (0.05 in.) in a medium carbon steel. Because of the very high heating and cooling rates obtainable, it is possible to harden steels not normally considered hardenable. For the same reason, the hardness obtainable by the laser hardening process can, in some instances, be slightly higher than that considered possible with conventional methods.

4.6 SALT BATH HARDENING PROCESS

Salt baths are used in a wide variety of commercial heat-treating operations including neutral hardening, liquid carburizing, liquid nitriding, austempering, martempering and tempering applications. Salt bath hardening process is well adapted to heat treatment of ferrous and nonferrous alloys (James Laird 1995).

Parts that are heated in molten salt baths are heated by conduction; the molten salt bath provides a ready source of heat as required. Although materials being heated come in contact with heat through their surfaces, the core of a part rises in temperature at approximately the same rate as its surface. Heat is quickly drawn to the core from the surface and salt baths provide heat at an equal rate over the total part.

Neither convection nor radiation heating methods are able to maintain the rate of heating required to reach equilibrium with the rate of heat absorption. The ability of a molten salt bath to supply heat at a rapid rate accounts for the uniform, high quality of parts heat treated in salt baths. Heat-treating times are also shortened, for example, a 25 mm (1 in.) diameter bar can be heated to temperature equilibrium
in 4 minutes in a salt bath, whereas 20 to 30 minutes would be required to obtain the same properties in either convection or radiation furnaces (Figure 4.7).

Salt baths are very efficient methods of heat treating; about 93 to 97% of the electric power consumed with a covered salt bath operation goes directly into heating of the parts. In atmosphere furnaces, 60% of the energy goes for heating and the remaining 40% is released up the furnace stack as waste. Steels that are heat treated in molten salts typically are processed in ceramic-lined furnaces with submerged or immersed electrodes containing chloride-based salts.

![Figure 4.7 Externally heated salt bath furnaces for liquid carburizing](image)

(a) Gas fired or oil fired,  
(b) Resistance heated

4.6.1 Surface protection

Parts immersed in a molten salt bath develop a thin cocoon of solidified salt, which can be easily washed from the surface after treatment. This surface protection afforded by salt baths can eliminate the formation of damaging oxide scales. Moreover, because salt baths do not contain the oxygen, carbon dioxide and vapour levels found in most non-vacuum furnaces, immersed parts are protected further from scale formation. Decarburization of steel parts from contact with oxygen and carbon dioxide are also eliminated by the use of molten salts. Vacuum furnaces provide similar advantages in surface protection.
4.6.2 Control of distortion

Salt baths offer a way to minimize the bad effects of nonuniform heating, lack of support and poor quenching that may cause size and shape distortion. Unlike parts in an atmosphere or vacuum furnace, parts immersed in molten salts are supported by the density of the medium. Due to its buoyancy, sagging or bending of the parts is minimized in a molten salt bath.

Heating in molten salts is also very uniform. The temperature uniformity in a molten salt bath averages ±3 °C throughout the bath, depending on furnace design. The layer of solidified salt around a part can also protect the part from rapid initial heating and the resulting thermal shock. As the cocoon of salt melts, the part is gradually and uniformly heated, minimizing distortion and preventing cracking.

4.6.3 Selecting a salt for a given application

Information concerning the various salts suitable for heat-treating furnaces is available from many sources, such as the many competent salt companies. Also, military specification MIL-10699 describes the salts in detail. When selecting a salt for a given application, the following must be considered:

- The salt must have the proper working range to meet the operating temperature requirements.
- The salt must have the proper melting point to avoid prolonged heat-up times for heavy loads.
- The salt must be compatible with other salts and oil used in the same heat-treating line.
- The versatility of the salts application.
- The ease with which the salt is washed from the work after heat treatment and affinity of the salt for moisture.