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Chemical Heat Treatment of Steels

INTRODUCTION

Chemical heat treatment is the process used to achieve different properties in core and steel components. There are situations in which the requirement is such that the outer surface should be hard and wear resistant and the inner core more ductile and tougher. Such a combination of properties ensures that the component has sufficient wear resistance to give long service life and at the same time has sufficient toughness to withstand shock loads. Such combination can basically be achieved by two different methods.

The first method is known as thermochemical treatment because the surface composition of the steel changes by diffusion of carbon and/or nitrogen (as in carburizing and nitriding) and sometimes by other elements. The second method involves phase transformation by rapid heating and cooling of the outer surface (flame hardening, induction hardening and electron beam and laser hardening). The aim of both methods is the same.

Components which are surface hardened include ball and tapered bearings, gears, bushings, rock drill bits, dies, gun barrels, cam shafts, crank pins, valve rocker shafts and axles. In this chapter, various thermochemical treatments are considered. Chapter 9 summarizes important surface hardening treatments which do not involve any change in chemical composition.

8.1 CARBURIZING

This is the most widely used process for surface hardening of steels. It is carried out on low carbon steels which contain from 0.10% to 0.25% carbon and are known as carburizing steels. Examples of such steel grades are AISI 1018, 1117, 4023, 4118, 5015 and 8620.

Generally, carburizing is carried out in the temperature range 900–930°C, and the surface layer is enriched with carbon up to 0.7–0.9 percent. In this process, carbon is diffused into steel by heating above the transformation temperature and holding the steel in contact with a carbonaceous material which may be a solid medium, a liquid or a gas. Under such conditions, carbon is absorbed in solid solution in austenite. As the solubility of carbon is more in austenitic state than in ferritic state, fully austenitic state is essential for carburizing. The surface hardness depends on the relationship of hardness (VPN) with carbon content which differs slightly for different grades of steels, as shown in Figure 8.1. Carburizing can be

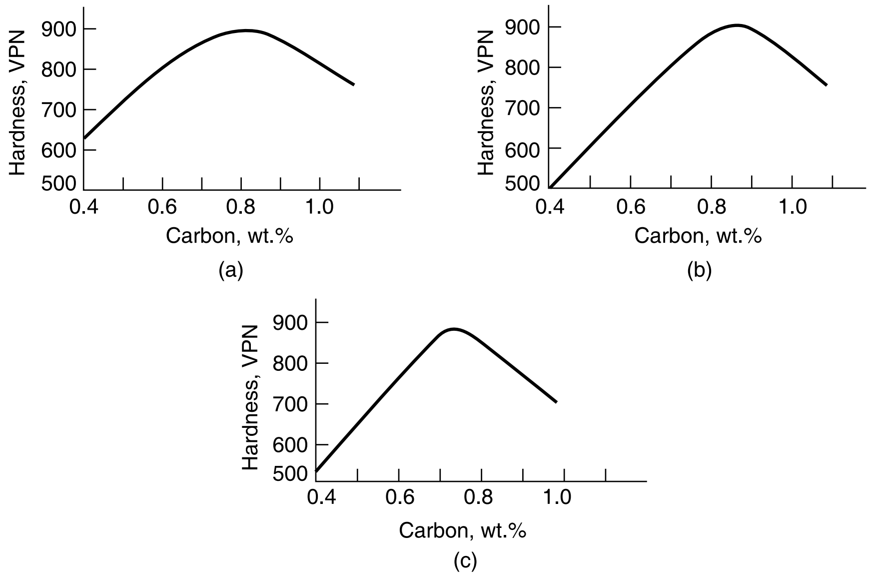

Figure 8.1 Relationship between hardness and carbon content for carburized steels in quenched condition. (a) plain carbon steel (En 32). (b) C-Mn steel (En 201). (c) Ni-Cr steel (En 351).

divided into three categories according to the carbonaceous material used: pack carburizing, liquid carburizing, and gas carburizing, which we now discuss.

8.1.1 Pack Carburizing

This method of carburizing is also known as solid carburizing. It is the oldest method of carburizing steel components. In this process, steel components to be heat treated are packed with 80 percent granular coal and 20 percent $BaCO_3$ as energizer in heat resistant boxes and heated at 930°C in furnace for a specific period of time which depends on the case depth required. Such a high temperature in furnace helps in absorption of carbon at the outer layer. The following reactions take place:

(i) Energizer decomposes to give CO gas to the steel surface:

$$BaCO_3 \rightarrow BaO + CO_2$$
$$CO_2 + C \rightarrow 2CO$$

(ii) Carbon monoxide reacts with the surface of steel:

$$2CO + Fe \rightarrow Fe(C) + CO_2$$

(iii) Diffusion of carbon into steel.

(iv) CO_2 formed in step (ii) reacts with "C" in the coal:

$$CO_2 + C \rightleftharpoons 2CO$$

For a given steel at a given temperature, the depth of penetration is dependent on diffusion and can be related to the time t by the equation

$$\text{Case depth} = k \sqrt{t}$$

where k is a constant.

Generally, carburizing time varies from 6 hours to 8 hours, and case depth obtained varies from 1 mm to 2 mm. In this process, the results depend on the quality of coal. So, there is some element of uncertainty. Here, temperature and case depth control are less than in liquid and gas carburizing.

8.1.2 Liquid Carburizing

Liquid carburizing is also popularly known as salt bath carburizing. In this process, carburizing occurs through molten cyanide (CN) in low carbon steel cast pot type furnace heated by oil or gas. Bath temperature is maintained between 815°C and 900°C. The life of pot depends on quality of material, operating temperature and mode of operation, viz. whether it is continuous or intermittent. Continuous and automatic processes give good end results. The bath surface is covered with graphite or coal to reduce radiation losses and excessive decomposition of cyanide.

Different salt mixtures used in this process are named according to their carbon potential activity. Besides sodium or potassium cyanide, the bath contains (i) sodium and potassium chlorides, and (ii) barium chloride which acts as an activator.

The reactions in cyanide salt bath are as follows:

$$BaCl_2 + 2NaCN \rightarrow Ba(CN)_2 + 2NaCl$$
$$Ba(CN)_2 + Fe \rightarrow Fe(C) + BaCN_2$$

Some beneficial nitrogen diffusion may also take place through oxidation of CN to CNO.

In liquid carburizing, heating time is short and heat transfer is rapid. There is complete uniformity of the carburized layer in the component. This process gives a thin and clean hardened layer (0.08 mm thick). However, extensive safety precautions are required to avoid explosions.

8.1.3 Gas Carburizing

This is the most widely used method of carburizing. It is carried out in retort type, sealed quench type, or continuous pusher type furnaces. These furnaces are either gas fired or are heated electrically. Gas carburizing temperature varies from 870°C to 950°C.

Gas atmosphere for carburizing is produced from liquid (methanol, isopropanol) or gaseous hydrocarbons (propane and methane). An endothermic gas generator is used to supply endothermic gas. A mixture of propane or methane with air is cracked in hot retort of an endogas generator to form carrier gas, whose dew point is adjusted at about +4°C by proper gas/air ratio. The approximate composition of this gas is as follows:

Nitrogen	40%
Hydrogen	40%
Carbon monoxide	20%
Carbon dioxide	0.3%
Methane	0.5%
Water vapour	0.8%
Oxygen	in traces

Such a gas acts as a 'carrier gas' for the process. Furnace chamber is purged with this gas to maintain a slightly positive pressure. This in turn prevents infiltration of air from atmosphere. This gas also prevents oxidation of the steel during heating. When the material reaches carburizing temperatures, propane or methane is introduced to maintain a specific carbon potential. Carbon potential is computed by measuring the dew point or carbon dioxide, by infra-red absorptiometry or oxygen, by an electrolytic potential technique using a zirconia probe.

During gas carburizing, the following reactions take place:

(i) $C_3H_8 \rightarrow 2CH_4 + C$ (cracking of hydrocarbon)
(ii) $CH_4 + Fe \rightarrow Fe(C) + 2H_2$
(iii) $CH_4 + CO_2 \rightarrow 2CO + 2H_2$
(iv) $2CO + Fe \rightarrow Fe(C) + CO_2$

Carburizing occurs mainly due to conversion of CO to CO_2 through reaction (iv). Hydrogen reacts with CO_2 and increases CO concentration by the reaction

$$H_2 + CO_2 \rightarrow CO + H_2O$$

Traces of O_2 are also present due to the following reactions:

$$2CO_2 \rightarrow 2CO + O_2$$
$$CO_2 + Fe \rightarrow Fe(C) + O_2$$

Average concentrations of CO_2, H_2O, and O_2 are 0.2 percent, 0.5 percent, and 10^{-14} ppm, respectively.

One of the recent developments in the gas carburizing technique is the use of nitrogen as a carrier gas. Normally, nitrogen gas is used with some minor additives. Carbon potential is controlled by adjusting the level of oxidizing constituents. Currently, the cost of equipment for this modified process is high. Also, skilled and well trained operators are required for successful operation of the process. Small and medium industries cannot afford to have such high investment for this process. Therefore, these industries produce carburizing atmosphere *in situ* by supplying liquid hydrocarbons into the furnace above 700°C. The carbon potential is controlled by regulating liquid flow rates.

8.2 VACUUM CARBURIZING

The first commercial application of vacuum carburizing started in the early 1970s. Vacuum carburizing is a process of carburizing, carried out either in vacuum or in reduced pressure. The main advantage of the process lies in the tremendous energy saving associated with it.

Carburizing in vacuum or reduced pressure is carried out in two stages. In the first stage, carbon is made available to the steel for absorption. In the second stage, diffusion of the carbon takes place within the steel piece and results in appropriate concentration of carbon and depth of carburizing. In vacuum carburizing, there is accurate control on the amount of carbon absorbed. Also, as the process takes place at a relatively higher temperature, carbon absorption is quite rapid.

To start the process, the job is introduced into the furnace which is then evacuated. After achieving the required degree of vacuum, the furnace is heated up to a carburizing temperature