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Evaluation and Diffusion Assessment for Surface Hardening Processes

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Abstract

The ability of heat is to change or modify the physical and mechanical characteristics of metals is an important aspect of manufacturing. The heat treatment processes is generally adapted to the processing of carbon steels in the production field. The content of carbon in mild steel is less than 0.3% and it requires sufficient hardness on surface of a component. Because of the lack of carbon, the metals to be processed under the carburizing Process. The carburizing process is diffuses carbon in to the surface of heat treated components in an atmosphere controlled furnace. The purpose of carburizing is to increases the surface carbon content, on the surface region or case depth/layer. Fick's law describes the instantaneous flow of diffusing atoms in the case layer. This case depth is controlled by the diffusion of carbon atoms through the surface layers of the work piece and achieves maximum hardness during subsequent quench hardening in the surface hardening. The major types of surface hardening processes are: carburizing, carbo-nitriding and induction hardening. The objective is to improve the surface properties of a component, mainly in the hardness on the surface. These surface/case hardening operations are quite important also to static and dynamic strength with wear and seizure properties. In this article focused to an evaluation of surface hardening and the effects of diffusion layer formation during the heat treatment process are to be studied and analyzed.

Keywords: Heat treatment processes; Carburizing; Surface hardening

Introduction

Steel is an alloy of two major constituents iron and carbon. Carbon steel (plain-low) is graded by its carbon content as 0.1 % to 0.3% it's called mild steel, it cannot be hardened by direct heat treatment because of low strength of carbon content. Thermo chemical carburizing-case hardening and heat treatments of atoms in metals and alloys and a corresponding marked variation in physical, chemical and mechanical properties. Among the more important of these treatments are heat treatment processes such immersion hardening, induction hardening and case carburizing. Carburizing and case hardening are "thermo chemical" treatments, usually conducted at temperatures in the range 800-940°C in the first stage of "case-hardening". Quenching is followed by a low-tempering.

Carbon Steels and Characteristics

Carbon steels in general are easy to work [1] with exhibiting excellent mach inability and weld ability. Though as the carbon content increases, the ease of manufacture decreases. Low carbon has carbon content less than 0.3%, usually called mild steel. Its requiring low strength cannot be hardened by heat treatment. The added carbon changes the behaviour of the material at high temperature and therefore needing a more refined process. The ability of heat to change or modify the physical characteristics [2-6] of matter is an important aspect of manufacturing, since the characteristics of matter can be improved by treating them with heat in various ways. Different kinds of traditional develop great hardness, another type can be used to develop softness, and then another improves the mechanical properties such as tensile strength, yield strength, corrosion resistance and creep rupture. The quality most often sought is strength. Although the idea of heat-treating is straight forward, determining the correct combination of temperature, time atmosphere, cooling rate and cooling media (Figure 1).

Surface Engineering

The utilization of surface engineered materials in various engineering fields has undergone a tremendous increase in recent years. Surface engineering is a complex process in itself, as a number of variables affect the success of the process and quality of the components. One industrial survey indicates that there is a rejection of 10%-12% of case hardened components due to various defects. Quality control is one way to minimize the percentage rejection [7]. Surface treatment of a component is a widely employed method of enhancing resistance to fatigue failure and a number of approaches are possible. Surface

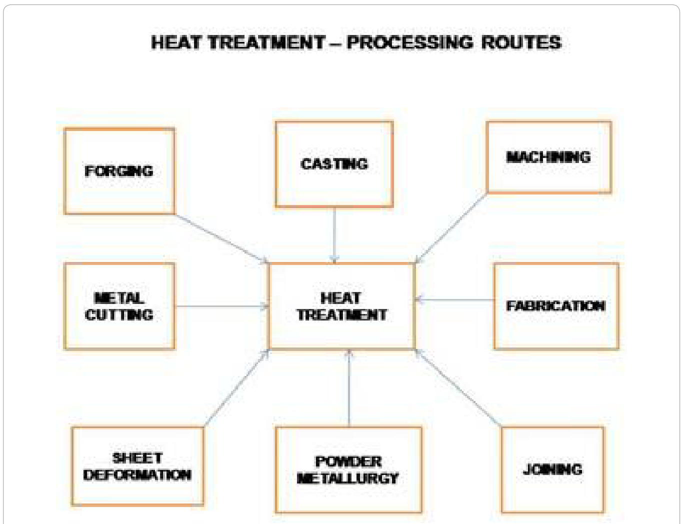

Figure 1: Heat Treatment-Processing Routes.

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hardening can be employed to inhibit fatigue: this can be affected in several ways. In steels, surface hardening can be achieved by changing the surface composition by diffusion heat-treatment of the component.

Carburizing

In a carburizing process, carbon is diffused in the surface layer of a component in a high temperature environment under a controlled atmosphere. The objective is to improve the surface properties such as the hardness of the component. It is critical to control the carbon content of the furnace atmosphere in order to maintain the final carbon concentration at the surface of the part, at a specified value. Important process variables include furnace temperature, furnace atmosphere composition carburizing time and the carbon potential of the atmosphere. In order for carburizing to occur, the carbon potential of the atmosphere must be greater than the carbon potential of the component's' surface. The carburizing diffuses carbon into the surface of heat-treated components in an atmosphere controlled furnace followed by directly quenching.

Case Hardening Operations

In order to cause carbon to diffuse in to a steel surface, the steel is heated to the austenite region in a carbon containing gas, such as carbon monoxide. It may also be heated in a carbon containing fused salt, such as sodium cyanide mixed with sodium carbonate and sodium chloride. These treatments are known as "case hardening". Case hardening operations [8] are quite important to introduce hardness, static and dynamic strength with wear and seizure properties. Because to properties of simple quench and hardened steel are not sufficient to withstand bending , and rotating stress and friction , varieties of surface hardening processes are applied to produce automotive components. Case hardness is increased by diffusion of carbon and or nitrogen and quenches hardening processes such as carburizing, nit riding and induction hardening etc.

Carbon Potential Control in Gas Carburizing Processes

Control of heat treatment atmosphere is quite important to produce quality products .However, the Carbon Potential (CP) control of protective atmosphere is not done well in spite of long history for quenching, and carbon nit riding that requires precise atmospheric controls to prevent the occurrence of de-carburization [9]. Over carburizing and to introduce optimum compressive residual stresses. The diffusion depth and hardened case depth are influenced by the carbon potential of the atmosphere. CP is influenced by various factors such as furnace insulator materials, the state of shooting condition, gas composition, pressure, operating temperature, etc., and is not stable at any moment of the carburizing process as believed. Appropriate CP Control enables the reduction of treating time and ensures the surface carbon concentration and diffusion pattern, which directly affect the state of the introduced micro structure; hardness and strength of treated components.

Diffusional Processes

Diffusion Surface modification processes rely on diffusion of new atoms in to the work piece to alter the mechanical properties of the surface region. Diffusion is the spontaneous movement of atoms to new sites within the metallic crystal structure. When controlled appropriately, diffusion can create a net flux of atomic movement. Although new atoms move in to the work piece, there is no intentional build-up or increase in the work piece dimensions. Carburizing Classified in to 1. Pack Carburizing 2. Gas Carburizing 3. Liquid Carburizing

Types of Carburizing

Pack carburizing

The parts to be carburized are packed on metal surrounded by a suitable compound which is rich in carbon. Among the ingredients combined in different percentages some are, powered charred leather wood charcoal and horn. The boxes are sealed with clay to exclude air, are placed in an oven or furnace. When they are heated to a temperature between 900°C to 920°C, depending on the composition of steel. The carbon from the carburizing compound soaks in to the surface of the hot steel to depth which depends on the time that the boxes are left in the furnace, so that the low carbon steel is converted in to high carbon steel in the form of thin case. The result being a piece of steel with a dual structure. The steel can be recovered from the box and once again heated to a temperature just above its critical point or approximately 915°C-925°C for fine grain steel, followed by quenching in water, brine or oil .In order to improve the ductility and impact resistance of the core and case, the second heat treatment is given to a steel at about 760°C-780°C.

Vacuum carburizing

Vacuum carburizing technology has advanced considerer ably. Continuous measurement of the carburizing condition under reduced pressure becomes possible through the emergence of newly developed in gas sampling methods (much the same as gas carburizing) and enables precise control of the carburizing process. Diffusion speed of carbon is directly affected by heat treatment temperature with higher temperatures increasing diffusion speed. The high temperature carburizing condition usually results in grain growth during treatment and necessitates the use of improved of excessive grain growth to some extent. New vacuum carburizing grade steels containing about less than 0.1 percent of Ti and Nb increase the temperature limits of grain growth up to 1050°C.

Liquid carburiz ing

This consists of molten salt (such as sodium cyanide) filled container, would be heated by a gas burner or electrical immersion elements. The parts may be quenched immediately after removal from the salt bath. Best results can be obtained when specimen is reheated up to 760°C and quench them again.

Gas carburizing

In this method by heating the specimen in a furnace in to which a gas which is rich in some gases such as methane, propane. etc is introduced. Low carbon steel (0.2%) is placed in an atmosphere, which contains substantial amount of carbon monoxide. For several hours, the usual carburizing temperature is 927°C. Usually the high carbon steel surface is hardened by quenching from above austenite temperature. It is a surface hardening method in which the surface of the components is saturated with carbon in a gaseous atmosphere containing carbon. To accomplish this, the components are first heated in a neutral atmosphere to a predetermined temperature in the range of 870°C to 940°C.Then the furnace is loaded with a suitable gas such as propane, butane, methane. Finally, the components are held at this temperature to allow for the diffusion of carbon in to the case. After the carburizing treatment is completed, the components are quenched to obtain the required hardness, wear resistance and fatigue resistance on the surface, supported by a tougher core.

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Diffusion Mechanism

The atoms or molecules of a material are associated with specific lattice sites in its structure. However, atoms are not static. They vibrate around their equilibrium positions. The vibration energy is the heat energy of the material. A crystal containing N atoms vibrates in 3N ways or modes. Thus each atom may be considered as vibrating in three ways. The frequency of vibration, V, of a mode is essentially constant, but the amplitude of the vibration increases with increase in the energy of the vibration. The energy with which an atom may vibrate in a mode is quantized, and is given by (1/2+n) hr, where h is the Planck's constant and n is an integer having values between zero to infinity. These permissible energies are known as the energy levels .There are many possible mechanisms by which atoms may migrate. Therefore, an atom near a vacant lattice site can move to the vacant lattice site simply by squeezing through the nearby atoms as shown in figure for the movement of the atom at A to the vacancy at B. Atoms in the high vibration energy levels have sufficient energy to move to site A-B. This mechanism is known as the vacancy mechanism of diffusion (Table 1).

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Diffusional Flow during Carburizing

The case depth is controlled by the diffusion of carbon atoms through the surface layers of the work piece. Carbon from the surrounding atmosphere or pack quickly saturates the surface layer after the start of the case hardening process. The carbon saturation concentration [10,11] at the surface is the maximum carbon content that can be absorbed in the austenite phase. This surface layer remains saturated at the same carbon concentration throughout the case hardening treatment, while carbon diffuses inward to form the case.

Diffusion Flux

Let the concentration of the solute in a material vary in the x-direction as shown in figure. The net diffusion flux of the solute atoms in the x=direction across a plane perpendicular to the x-direction per unit area of the plane per unit time is given by the following phenomenological equation ,which is popularly known as the Fick's first law of diffusion = -D[dc/dx], Where, J=diffusion flux in amount of solute (atoms , or grams , or moles) per unit area per unit time., C=concentration of solute in amount (atoms , or moles , or grams) per unit time., x=distance., [dc/dx] =concentration gradient across the plane., D= The diffusion co-efficient in ($length^2$) unit time. When c is in $atoms/cm^3$, x is in cm, and D is in cm^2/s, the flux, J, is equal to the number of atoms moving across the plane at x is the x-direction per cm^2 of the plane per second.

Carburized Case Depth

The plot of example is clearly indicates that the carbon concentration varies as a function of depth. However, to characterize the carburized layer, a case depth is defined as the depth corresponding to a carbon concentration that is the average of the initial and saturation carbon concentrations. Thus the carbon concentration at the case depth is, $C=(x_p)\ c_s+c_o/2$, Where c_s = is the carbon surface saturation concentration ,c_o = is the initial carbon content of the steel $c\ (x_p)$ = is the carbon concentration at the case depth. By substituting equation $c(x_{p)} = c_s+c_o/2$ in to the equation for the carbon concentration $[c(x,t)=c_s+(c_{o-}c_s)$ ert{x/2 √Dt } and realizing from below:

X= 0	0.01	0.05	0.1	0.2	0.3
C(x)=1.3	1.18	0.76	0.38	0.124	0.1

That erf (0.5), the case depth is approximated as $x_p= \sqrt{Dt}$. The square root form of the distance is often referred to as the Einstein equation and is common many mass transport phenomena. Equation $x_p = \sqrt{Dt}$ is a useful approximation because it provides an easy method of determining the case depth for a particular furnace temperature, which in turn determines the value of the diffusion constant from equation $D=D_O=\exp\{-Q/RT\}$ (Table 2)

Case Study

Carbon profile after carburizing

A Piece of SAE 1010 Steel (0.1% carbon) is carburized at 900°C

Process	Temp	Case Depth (mm)	Hardns (Rc)	Comments
Carburizing-Pack	815-1090	0.125– 1.5	50- 63	Low equipment cost, Poor control
Carburizing-Gas	815-1090	0.075- 1.5	50- 63	Accurate case depth, Gas safety
Carburizing-Liquid	815-1090	0.05- 1.5	50-65	Faster, Salt disposal problems

Table 1: Summary of Diffusional Surface Modification Processes.

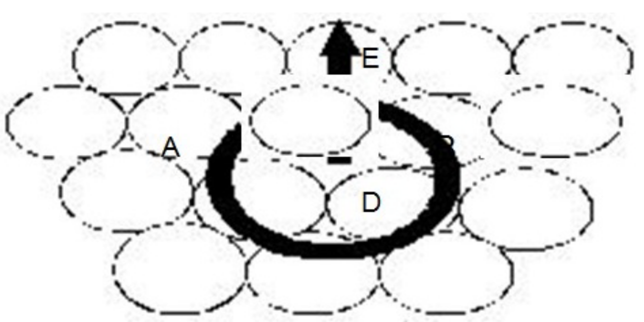

Figure 2: Atomic Movement: The atomic Process Consisting of transfer of an atom from Position A to Position B.

Diffusing Atom	Host Atom	Frequency Factor D_o(cm²/s)	Activation Energy Q(KJ/mol)
Carbon	Iron (bcc)	0.0079	76
Carbon	Iron (fcc)	0.21	142
Nitrogen	Iron (bcc)	0.014	71
Iron(bcc)	Iron (bcc)	0.01	289

Table 2: Frequency Factors and Activation Energies for Diffusional Systems.

for 10h.Calculate the carbon concentration in the case after the 10h carburizing operation. And calculate the case depth; also find, if the conditions are repeated but the carburizing temperature is increased to 1000°C, What carburizing would result in the sure case depth. For example: t=19h = 3.6 x 10^4 Second, c_0=0.1 % carbon , T=900°C = 1173k, For carbon diffusing in austenite (fcc iron) Q=142 KJ/mol, D_0= 0.21 cm²/s, R= 8.314 J/mol, Using the Fe- c phase diagram at 900^{0}c the maximum solubility of carbon in iron (austenite) is about 1.3 % ., so *cs*=1.3%., D=D0*exp*{-*Q*/*RT*} = 0.21*cm*²*sxexp*{- 142.000 *J*.*mol*/8.314 J.*molx*1173*K*}: D = 1.0 X 10-7cm²/s.

To calculate carbon concentration for various depths:

[*c*(*x*,*t*) = *cs* + (*co*-*cs*) *ert*{*x*/2 *Dt* }*c*(*x*)=1.3-1.2 *erf* {*x*/2 [√1x10-7*cm*²/*sx*3.6*x*104*s*; c(x)=1.3-1.2 *erf* (8.3*x*)]

To calculate the case depth:

xp=√*Dt* = √1*x*10-7*cm*²/*sx*3.6*x*104*s* =0.06*cm*.

The case depth of 0.06cm is in agreement with the carbon concentration profile. To achieve the same case penetration depth the product Dt must remain constant.

Dt=1*x*10-7cm²/*sx*3.6*x*104*s* =3.6x10-3cm².

From

$$D = D_0 \exp\left\{-\frac{Q}{RT}\right\} = 0.21cm^2 sxexp$$

$$\left\{-142.000\,J.\frac{mol}{8.314}J.molx1173K\right\} = 3.1\frac{x107cm^2}{s}$$

So the carburizing time is

t = 3.6*x*10-3cm²/3.1 *x*107*cm*²/*s* = 1.16*x*104s.

Note: A relatively small change in the carburizing temperature (about 10%) causes a large change in the carburizing time (decreased by a factor of about 3).This is characteristics of thermally activated processes.

Conclusion

Carbon is diffused in the surface layer of a component in a high temperature environment under a controlled atmosphere. The case depth is controlled by the diffusion of carbon atoms through the surface layers of the work piece. The case depth is defined as the depth corresponding to a carbon concentration that is the average of the initial and saturation carbon concentrations. The net diffusion flux of the solute atoms in the x=direction across a plane perpendicular to the x-direction per unit area of the plane per unit time. Diffusion Surface modification processes rely on diffusion of new atoms in to the work piece to alter the mechanical properties of the surface region.

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