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Recent Advances in Metal Surface Treating Technology-Review

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Abstract: **-- New materials like micro-alloy steels, titanium-nitride or vanadium nitride inserts, super alloys, composite materials, magnetic materials, electric and electronic materials, hard and wear resistant tool steels etc. have been developed in the last fifty years. Development of these and many more new materials have necessitated the development of new heat treatment technologies which are more efficient, environment-friendly and commercially viable. In the beginning, metallic components were being treated using conventional heat treating technics like annealing, normalizing, hardening, tempering, surface hardening by carburizing, nitriding, flame hardening, induction hardening etc. Over the years heat treating technologies have been evolved to modern and more efficient, more accurate and more environmentally friendly and commercially viable techniques. This paper gives a brief review of the conventionally used surface hardening heat treating techniques along with the newly developed techniques such as laser beam hardening, electron beam hardening, ion implantation, plasma heat treatments, aqueous plasma heat treatments etc. Instrumentation and process control have contributed remarkably in taking the heat treating technology to a higher level and some light is thrown on this aspect too.**

Key words**: Hardening, carburizing, plasma heat treatment, aqueous plasma, etc.**

I. INTRODUCTION

Surface hardening, a process that includes a wide variety of techniques, is used to improve the wear resistance of parts without affecting the softer, tough interior of the part. This combination of hard surface and resistance to breakage upon impact is useful in parts such as a cam or ring gear, bearings or shafts, turbine applications, and automotive components that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation. Most surface treatments result in compressive residual stresses at the surface that reduce the probability of crack initiation and help arrest crack propagation at the case-core interface. Further, the surface hardening of steel can have an advantage over through hardening because less expensive low-carbon and medium carbon steels can be surface hardened with minimal problems of distortion and cracking associated with the through hardening of thick sections. Surface hardening can be achieved through the techniques such as hard facing, electroplating, surface coatings in which new layer or new material is added on the surface of the component to be surface hardened. Coatings and overlays can be effective in some applications. With tool steels, for example, TiN and Al_2O_3 coatings are effective not only because of their hardness but also because their chemical inertness reduces crater wear and the welding of chips to the tool. Some overlays can impart corrosion-resistant properties. These techniques are associated with limitation of fatigue strength.

Other methods of surface hardening includes compositional; modification at the surface so that it can result into hard and wear resistant surface. Compositional modification is done by addition of alloying elements such as carbon, nitrogen, boron and titanium. Surface hardening treatments making use of these alloy additions are Carburizing, Nitriding, Carbonitriding, Nitrocarburizing, Boriding, Titanium-carbon diffusion.

In another heat treatment method, hardening is achieved through microstructural change at the surface of the component. This is achieved by martensite structure formation upon quench hardening of steel. This technique demands adequate carbon concentration at the surface which is achieved via carburizing. From such components, after heat treatment yields tough core but hard and wear resistant surface. Same techniques can also be employed for selective hardening in which only localized areas of the component can be surface hardened.

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Carburizing and carbonitriding:
Carburizing involves diffusion of carbon into steel surface at a high temperature. Carburizing temperature varies from 850-980 0C. Steel attains austenite crystal structure at this temperature. Carbon diffuses into austenite and forms solid solution with it. Carbon concentration diffused into steel surface is time and temperature dependent. It also depends upon the carbon potential at the steel surface. When adequate carbon concentration is built up into the surface layers, steel is quenched to achieve martensite transformation. Presence of martensite in surface leads to increase in hardness and wear resistance. The hardened depth or the case depth is given by
Case depth = K(t)1/2
Where K is a diffusivity constant which depends upon the temperature, material composition and carbon concentration gradient and t is the time of carburizing. Surface hardness is the function of its carbon content and increases max. up to 0.65%C. Any more carbon addition beyond this limit begins to develop carbide network in the structure which then makes the steel brittle. Normally, 0.2%C steels in a killed condition are suitable for carburizing. Killed steels can resist grain growth at carburizing temperature. Generally the carbon content at the surface of the carburized steels is maintained below 0.9%. Higher carbon concentration adversely affects the microstructure. Case depth is controlled by controlling the time, temperature and the carbon potential at the steel surface. Quenching practice involves the use of water, oil or high pressure gas as the quenching media. Choice depends upon the level of distortion that can be permitted. Oil quenching or high pressure gas quenching is recommended for the applications such as gears and bearings where distortion should be minimized.

Carburizing methods:
1. Pack carburizing
2. Gas carburizing
3. Liquid carburizing

In its earliest application, parts were simply placed in a suitable container and covered with a thick layer of carbon powder (pack carburizing). Although effective in introducing carbon, this method was exceedingly slow and as the production demand grew, a new method using a gaseous atmosphere was developed. In gas carburizing, the parts are surrounded by a carbon-bearing atmosphere that can be continuously replenished so that a high carbon potential can be maintained. Rate of carburizing is substantially increased in the gaseous atmosphere. Gas carburizing has become the most effective and widely used method for carburizing steel parts in high volume. However this method involves complexities because of multicomponent furnace atmosphere. This problem is mitigated in vacuum carburizing where oxygen free furnace atmosphere can be maintained. However it becomes a costly technique. Also there is a risk of nonuniform case depth as the vacuum carburizing is done at a very low pressure.
To summarize, carburizing methods include:
1. Gas carburizing
2. Vacuum carburizing or low-pressure carburizing.
3. Plasma carburizing
4. Salt bath carburizing
5. Pack carburizing

These conventional methods introduce carbon by the use of gas (atmospheric gas, plasma, and vacuum carburizing), liquids (salt bath carburizing), or solid compounds (pack carburizing). All of these methods have limitations and advantages, but gas carburizing is used most often for high-volume production because it can be accurately controlled and requires minimal special handling. Carburizing may also be performed in a vacuum furnace. In this arrangement, the part may be placed in a vacuum chamber, which is then evacuated. The part is heated to a desired temperature and a carburizing gas may be supplied to the vacuum chamber. While this method may produce surfaces with uniform hardness values, it is still costly and time-consuming to establish and maintain the required vacuum environment during a carburizing process. Vacuum carburizing and plasma carburizing have found applications because the absence of oxygen in the furnace atmosphere thus eliminates grain-boundary oxidation. Salt bath and pack carburizing are still done occasionally but have relatively little commercial importance today. Carburizing has also been performed by exposing the part to a plasma containing carbon. While plasma carburizing methods may offer potential increases in heating rates over traditional furnace carburizing methods, these plasma carburizing methods involve the use of costly vacuum equipment to provide the necessary vacuum environments. Further, generation of the carburizing plasma usually requires the application of several hundred volts of DC between the work piece and the cathode (e.g., chamber) Plasma carburizing takes much less time as compared to the gas carburizing. It results into the uniform case depths for the intricate shaped parts. This happens because of the quick attainment of the carbon potential and the close plasma envelope on the surface of the metal being carburized [1, 2].
New plasma assisted carburizing has been developed in which carbon containing paste is applied on the surface to be carburized. The plasma produced on this surface caused quick melting at surface and subsequent mixing of carbon with the melt resulting into carbon enriched surface leading to rise in hardness and wear resistance. Selective

carburizing treatment has been developed to carburize only the localized areas of the components. In turn it becomes possible to prevent carburizing in some parts of the components. This is achieved by masking or copper plating or applying some compounds on the areas where carburizing is to be prevented. For example, thin areas and the areas to be machined are prevented from carburizing. Thin sections if carburized become brittle [3].

Carbonitriding:

Carbonitriding treatment involves addition of carbon and nitrogen to the steel surface at austenite temperature. Presence of carbon and nitrogen into the steel surface increases hardeness and wear resistance of the steel. More importently nitrogen increases hardenability and therefore carbonitrided parts can be quenched directly without the danger of distortion and quench cracking. Nitrogen is a austenite stabilizer. Hence increase in nitrogen content increases retained austenite after quenching. Presence of retained austenite can be reduced by controlling the flow rate of ammonia throughout the treatment or by reducing it in the lateral stages of the treatment..

Case carburizing by Laser treatment:

The concept of laser carburizing was initially realized through the use of graphite coatings during laser surface hardening of steels, which served as an efficient way to increase the coupling of radiation with the steel substrate, which for the case of the CO2 laser far infrared radiation (wavelength 10.6 µm) is extremely low[4]. It was then observed that substantial amounts of carbon could be introduced to steel surfaces in that manner[5]. Ever since, studies have been reported on the laser carburizing of commercially pure iron , plain-carbon and low-alloy steels.

Laser carburizing can be achieved by two different mechanisms: a. laser surface alloying, which involves melting of a surface layer while carbon enters the liquid phase; and b. solid state diffusion of carbon, activated by laser heating. Laser surface alloying has been carried out experimentally for a variety of sub-strates and alloying elements [6].

Electron beam hardening:

Electron beam (EB) hardening, like laser treatment, is used to harden the surfaces of steels. The EB heat treating process uses a concentrated beam of high-velocity electrons as an energy source to heat selected surface areas of ferrous parts. Electrons are accelerated and are formed into a directed beam by an EB gun. After exiting the gun, the beam passes through a focus coil, which precisely controls beam density levels (spot size) at the work piece surface and then passes through a deflection coil. To produce an electron beam, a high vacuum of 10-5 torr (1.3 * 10-3 Pa) is needed in the region where the electrons are emitted and accelerated.

Carburizing by PES techniques:

In this technique of heat treatment electrolyte plasma is struck at the specimen. As a result of which specimen temperature quickly rises to the carburizing temperature at which carbon from the carburizing electrolyte diffuses into the specimen surface enriching its carbon content.

USE OF COMPUTERS IN HEAT TREATMENT

Computer usage in heat treatment processing has made a significant impact in recent years. It is thought, that in the future, computers are going to exert a still greater influence on heat treatment technology. The areas of heat treatment technology in which computers are being used regularly are:

1) Storage and retrieval of databases
2) Modelling of transformation processes
3) Prediction of microstructures and properties
4) Process analysis and optimization
5) On-line process monitoring and control

Through the development of computer-based storage and retrieval systems for material composition, material properties, the effect of processing variables on material properties, CCT and I 1 1 informations for various alloys etc., heat treatment technologist can assess the effect of material selection on heat treatment and its final properties very easily. Thus an assessment of the material and processing alternatives available can be readily made and executed. Using computers, it is now possible to model a heat-treatment process accurately enough so that the effect of the processing variables can be analysed. Therefore, it may not be necessary to perform costly and lengthy experiments in order to study the effect of clrocessing variables and instead a computer-based optimization of the process can be performed. Computers have been extensively used for on-line process monitoring and control during heat treatment. This has largely been brought about by the development of solid state transducers. On-line heat treatment softwares are particularly suitable for monitoring energy consumption, which is an important issue nowadays.

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