Engineering Materials

The selection of a specific material for a particular use is a very complex process. However, one can simplify the choice if the details about (i) Use parameters, (ii) manufacturing processes, (iii) functional requirements, and (iv) cost considerations are known. While selecting materials for engineering purposes, properties such as impact strength, tensile strength, and hardness indicate the suitability for selection.

Mechanical properties of Engineering Materials

Tensile Strength: This enables the material to resist the application of a tensile force. The internal structure of the material provides the internal resistance to withstand the tensile force. Ultimate strength is the unit stress; measures in kgf per square millimeter, developed in the material by the maximum slowly applied a load that material can withstand withoutrupturing in a tensile test.

Shear Strength:

It is the ability of a material to resist the shear force applied to the material.

Compressive Strength:

It is the ability of a material to withstand pressures acting on a given plane.

Elasticity:

It is the property of material due to which it returns to its original shape and size after releasing the load. Any material that is subjected to an external load is distorted or strained. Elastically stressed materials return to their original dimensions when the load is released.

Hardness:

It is the degree of resistance to indentation, scratching, abrasion, and wear. Alloying techniques and heat treatment help to achieve the same.

Ductility:

This is the property of a metal by virtue of which it can be drawn into wires or elongated before rupture takes place. It depends upon the grain size of the metal crystals.

Malleability:

It is the property of a metal to be deformed or compressed permanently into the sheet without fracture. It shows the ability of the material to be rolled or hammered into thin sheets.

Impact Strength:

It is the energy required per unit cross-sectional area to fracture a specimen, i.e., it is a measure of the response of a material to shock loading.

Toughness:

It is the ability of the material to absorb energy before fracture or rupture. It may be presented as impact strength of the material.

Brittleness:

The term “brittleness” implies sudden failure. It is the property of breaking without warning, i.e., without visible permanent deformation.

Wear Resistance:

The ability of a material to resist friction wear under particular conditions, i.e.,to maintain its physical dimensions when in sliding or rolling contact with a second member.

Corrosion Resistance:

Those metals and alloys which can withstand the corrosive action of a medium, i.e., corrosion processes proceed in them at a relatively low rate that are termed as corrosion-resistant.

Density:

This is an important factor of a material where weight and thus the mass is critical, i.e., aircraft components.

Classification of Engineering Materials

(i) Metals (ferrous and non-ferrous) and alloys

(ii) Ceramics

(iii) Organic polymers

(iv) Composites

(v) Semi-conductors

(vi) Biomaterials

(vii) Advanced materials

Ferrous Metals

In ferrous materials, the main alloying element is carbon (C). Depending on the amount of carbon present, these alloys will have different properties, especially when the carbon content is either less/higher than 1.5%

Low Carbon Steel:

It contains up to 0.3% carbon and 1% manganese. Since its microstructure consists of ferrite and pearlite so it is relatively softer than the other carbon steel.It has good ductility and toughness. Mildsteel (Carbon % 0.15–0.3) due to its good strength, high machinability, and weldabilityproperty is an extensively used engineering material. It is used as different structural sections (channel, angles, etc.), sheets, automobile components, etc.

Medium Carbon Steels:

These contain carbon between 0.3% and 0.6%. The strength of these materials is high but their weldability is comparatively less. Due to higher C%,it can be heat treated to get higher hardness. It is used as railway track andwheels, crankshafts, gears, etc.

High Carbon Steels:

These contain carbon varying from 0.65% to 1.5%. These materials get hard and tough by heat treatment and their weldability is poor. The steel formed in which carbon content is up to 1.5%, silica up to 0.5%, and manganese up to 1.5% along with traces of other elements is called plain carbon steel.

Cast Irons:

The carbon content in these substances vary between 2% and 4%. The costof production of these substances is quite low and these are used as ferrous casting alloys.

Gray Cast Iron:

These alloys consists carbon in form graphite flakes, which are surrounded by either ferrite or pearlite. Because of the presence of graphite, fractured surface of these alloys look grayish and so is the name for them. The alloying addition of Si (1–3 wt%) is responsible for decomposition of cementite, and also high fluidity. Thus castings of intricate shapes can be easily made. Due to graphite flakes, gray cast irons are weak and brittle.However, they possess good damping properties, and thus typical applications include:base structures, bed for heavy machines, etc. they also show high resistance to wear.

White Cast Iron:

When Si content is low (<1%) in combination with faster cooling rates,there is no time left for cementite to get decomposed, thus most of the brittle cementite retains. Because of the presence of cementite, the fractured surface appears white, hence the name. They are very brittle and extremely difficult to machine. Hence their use is limited to wear resistant applications such as rollers in rolling mills. Usually, white cast iron is heat treated to produce malleable iron.

Nodular (or Ductile) Cast Iron:

Alloying additions are of prime importance in producing these materials. Small additions of Mg/Ce to the gray cast iron melt before casting can result in graphite to form nodules or sphere-like particles. Matrix surrounding these particles can be either ferrite or pearlite depending on the heat treatment. These are stronger and ductile than gray cast irons. Typical applications include pump bodies, crankshafts,automotive components, etc.

Malleable Cast Iron:

These formed after heat treating white cast iron. Heat treatments involve heating the material up to 800–900°C, and keep it for long hours, before cooling it to room temperature. High temperature incubation causes cementite to decompose and form ferrite and graphite. Thus these materials are stronger with appreciable amount of ductility. Typical applications include: railroad, connecting rods, marine, and other heavy duty service

Alloy Steel

The common alloying elements are Chromium, Nickel, Molybdenum, Tungsten, Cobalt, Copper, Manganese, Silicon, and Sulfur, Phosphorous, etc. Depending on the percentage of alloying elements, mechanical properties like strength, hardness corrosion, etc. changes under different operating conditions.

Effect of Alloying Elements

Manganese (Mn) –

When Manganese percentage exceeds a normal percentage (1.65%) in steel, then the steel is known as Manganese steel. Manganese up to 1.95% improves hardness, tensile strength, and hot working property.

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Silicon (Si) –

The steel having more than 0.6% Si is known as Silicon steel. It acts as deoxidizer and graphitizer. As it dissolves in ferrite so it is not carbide former. It has high magneticpermeability but very low hysteresis loss. It is extensively used in electrical industries. Steel with 0.5% C and 3–4% Si is used to make a motor, transformer cores. This is known as transformer steel..

Phosphorus (P) –

Small amount (about 0.05%) is present in normal steel. If it is increased to 0.12% in low carbon steel then it improves strength, hardness, corrosion resistance, machine ability, etc.

Nickel (Ni) –

When added up to 5% it improves static and impact load bearing properties.Higher % of Nickel addition improves corrosion resistance. Steels with 1.5–3% Ni are suitable for loco boilers, railway axles, etc.

Chromium (Cr) –

Chromium addition in plain carbon steel improves hardenability, strength,wear resistance, corrosion, and red hot resistance if added more than 4% it improves corrosion resistance. Chromium improves hardenability It is widely used in tool steel.

Tungsten (W) –

The steel retains its hardness at a higher temperature with addition of tungsten as an alloy. It is a strong carbide former. Tungsten carbide is extremely hard and stable.It improves wear and abrasive resistance in steel. It retards softening of Martensite during tempering and gives hot hardness. So is commonly added to make tool and hot-working diesteel. In High-Speed Steel (HSS), it is added up to 18%.

Molybdenum (Mo) –

The steel becomes more wear resistant with the addition of Molybdenum.Its red hot hardness is high as compared to Carbon steel as Molybdenum Carbide can withstand higher temperature as compared to iron carbide. It is used to make aircraft components, pressure vessels, and springs. 5% Mo is added in some HSS steel.

Vanadiun (V) –

It improves red hot hardness, fatigue resistance and wear resistance property.Vanadium carbide has the highest hardness and wear resistance property amongst alloying elements added to steel. 2% Vanadium is added in some HSS.

Non-Ferrous Metals

Aluminum Alloys:

Aluminum alloys have high thermal and electrical conductivity and good corrosion resistant characteristics. As Al has FCC crystal structure, these alloys are ductile even at low temperatures and can be formed easily. However, the great limitation of these alloys is their low melting point (6600C), which restricts their use at elevated tem peratures.Chief alloying elements include Cu, Si, Mn, Mg, Zn. Recently, alloys of Al and other low-density metals like Li, Mg, Ti gained much attention as there is much concern about vehicle weight reduction. Al-Li alloys enjoy much more attention especially as they are very useful in aircraft and aerospace industries. Common applications of Al alloys include beverage cans, automotive parts, bus bodies, aircraft structures, etc

Copper Alloys: One special feature of most of these alloys is their corrosion resistant in diverse atmospheres.**Brass, alloys** of Cu and Zn where Zn is substitution addition (e.g., yellow brass, cartridge brass, Muntz metal, gilding metal);**Bronze, alloys** of Cu and other alloying additions like Sn, Al, Si, and Ni. Bronzes are stronger and more corrosion resistant than brasses. Mention has to be made about berylliumcoppers who possess a combination of relatively high strength, excellent electrical and corrosion properties, wear resistance, Applications of Cu alloys include costume jewellery, coins, musical instruments, electronics, springs,bushes, surgical and dental instruments, radiators, etc.

Magnesium Alloys:
The most sticking property of Mg is its low density among all structuralmetals. Mg has HCP structure, thus Mg alloys are difficult to form at room temperatures.Hence Mg alloys are usually fabricated by casting or hot working.Major alloying additions areAl, Zn, Mn, and rare earth. Common applications of Mg alloys include hand-held devices like saws, tools, automotive parts like steering wheels, seat frames, electronics like casing for laptops, camcorders, cell phones, etc.
Titanium Alloys:
Ti and its alloys are of relatively low density, high strength and have a very high melting point. At the same time, they are easy to machine and forge. However, the major limitation is Ti's chemical reactivity at high temperatures, which necessitated special techniques to extract. Thus these alloys are expensive. They also possess excellent corrosion resistance in diverse atmospheres and wear properties. Common applications include space vehicles, airplane structures, surgical implants, and petroleum and chemical industries.
Refractory Metals:
These are metals of very high melting points. For example Nb, Mo, W,and Ta. They also possess high strength and high elastic modulus. Common applications include space vehicles, X-ray tubes, welding electrodes, and where there is a need for corrosion resistance.

Plastics

Common organic materials are plastics and synthetic rubbers, which are termed as organic polymers. Other examples of organic materials are wood, many types of waxes and petroleum derivatives. Organic polymers are prepared by polymerization reactions, in which simple molecules are chemically combined into long chain molecules or three-dimensional structures. Organic polymers are solids composed of long molecular chains. These materials have low specific gravity and good strength. The two important classes of organic polymers are:
Thermoplastics:
On heating, these materials become soft and hardened again upon cooling, e.g., nylon, polyethene, etc.
Thermosetting Plastics:
These materials cannot be resoftened after polymerization, e.g.urea-formaldehyde, phenol formaldehyde, etc. Due to cross-linking, these materials arehard, tough, non-swelling and brittle. These materials are ideal for molding and castinginto components.The excellent resistance to corrosion, ease of fabrication into desired shape and size, fine lustre, light weight, strength,rigidity have established the polymeric materials and these materials are fast replacing many metallic components. PVC (Polyvinyl Chloride) and polycarbonate polymers are widely used for glazing, roofing, and cladding of buildings. Plastics are also used for reducing the weight of mobile objects, e.g., cars, aircraft, and rockets. Polypropylenes and polyethene are used in pipes and manufacturing of tanks.
Thermoplastic films are widely used as lining to avoid seepage of water in canals and lagoons. To protect the metal structure from corrosion, plastics are used as surface coatings. Plastics are also used as main ingredients of adhesives. The lower hardness of plastic

materials compared with other materials makes them subjective to attack by insects and rodents. Because of the presence of carbon, plastics are combustible. The maximum service temperature is of the order of 100°C.These materials are used as thermal insulators because of lower thermal conductivity. Rubber materials are widely used for tire of automobiles, insulation of metal components, toys and other rubber products.

Abrasive Materials

Abrasives are hard, non-metallic, sharp-edged and irregular shaped materials used to remove a small amount of materials by cutting action. It may be used in bonded form or as free particles. It is employed in grinding, polishing, super finishing, buffing, honing operations. Commonly used abrasives are alumina (Al2O3), Silicon carbide (SiC), Cubic boron nitride (CBN), and diamond.

Ceramics

Ceramics are compound of metallic and nonmetallic materials. It has properties of high compressive strength, low thermal expansion, high elasticity, high hardness, high wear esistance, and low electrical and thermal conductivity. Ceramics are used for tiles, pottery, sanitary wares (Porcelain). The raw materials used for ceramics are clay having a fine sheet like structure, Kaolin (silicate of aluminum) used as clay, flint, and feldspar.

Silica

It is available in abundance in nature in the form of quartz. Most of the glasses contain more that 50% of silica. It is also used in electric materials to increase the magnetic permeability of the materials. It may be used in the form of silicates of various materials as clay, asbestos, mica, glasses, etc.

Glasses

It is a super cooled amorphous material. It consists of more than 50% silica and other additives such as oxides of aluminum, sodium, calcium, magnesium, titanium, lithium, lead, and potassium. It has applications is windows, containers, lighting instruments, cookware, etc. The availability of various types of glasses is soda-lime glass, lead alkali glass, borosilicate glass, etc

Heat Treatment

Heat treatment is a process to control the mechanical properties of engineering materials by heating, cooling and alloying the metal as per requirement. It deals with change in properties by alloying different elements to the metal at various temperatures. The various mechanical properties such as hardness, toughness, ductility, machinability, and grain refinement are controlled by heat treatment process.

TTT (time–temperature–transformation) diagram

The time-temperature-transformation curves correspond to the start and finish of transfor mations which extend into the range of temperatures where austenite transforms to pearlite. Above 550°C, austenite transforms completely to pearlite. Below 550°C, both pearlite and bainite are formed and below 450°C, only bainite is formed and half the austenite to pearlite.

Annealing

The purposes of annealing are:
(a) to soften the metal for easy machining,
(b) to remove internal stress caused by working,
(c) to increase ductility, to refine grain size,
(d) to modify electrical and magnetic properties.
Normalized steel is less ductile and has more yield point and tensile strength than the annealed steel.
There are two types of annealing :—
Process annealing
Full annealing.

Process Annealing:

This is a process of heating the metal below or very close to lower critical temperature, i.e., 650oC for steel and slow cooling to form new grain structure.
The purposes of the process are:
(a) to increase the ductility of cold worked metal
(b) to remove internal stress.
This is frequently used in wire drawing to increase the plasticity of the metal.

Full Annealing:

The purposes of full annealing are:
(a) to soften the steel,
(b) to refine grain
The structure above the upper critical limit by 20 to 30°C for 0.9% C-steel and by the same amount below the critical point for high carbon steel. Carbon-steel is cooled 100o to 200oC per hour. It is essential that the steel should not hold less than 4 to 8 min for heating. To prevent the steel for carburization and oxidization workpiece is closed in a metal box and

put into the furnace. Austenite changes to pearlite and mixture of pearlite and ferrite.

Spheroidizing

Spherodizing is used to improve the machinability of steel. The workpiece is heated to 730–770°C, slightly above the lower critical temperature, and cooled 25-30°C per hour

Hardening

The purposes of hardening are:

(a) to harden the steel to resist wear,

(b) to enable it to cut other metal.

The metal is heated 30–50°C above the upper critical temperature for hypoeutectoid steel and above the same amount above the lower critical temperature for hypereutectoid steel. It is left for soaking for considered time. Quenching of high carbon steel heated to 1100–1300°C is done in a current of air. Quenching 150–200°C per sec in solution 3–10% caustic soda and 5-15% salt is more rapid than the quenching effect in water at 20oC and 32–42°C for oil quenching.

Tempering

Tempering is a process of reheating of hardened steel below critical range and cooled at the decreased rate (approximately 4 to 5 minutes for each mm of the section). There is the partial transformation of martensite to secondary constituent troosite and sorbite.

The purposes of tempering are:

(a) to reduce some amount of hardness produced during hardening and increase the ductility

(b) to remove strain produced during heating.

Low-temperature Tempering: Steel is heated to 150–250°C and cooled down. This is used to remove internal stress, reduce hardness, and increase ductility without changing the steel structure.

Medium-temperature Tempering: Steel is heated to 350–450°C and cooled down. Martensite is changed is changed to secondary troosite. It results in a reduction in strength and hardness,and increase in ductility. It is used for the part which is to be used in impact loadings such as chisel, hammer, spring, and spring plates.

High-temperature Tempering: Steel is heated to 500–600°C and cooled down. Martensite is changed to sorbite. Internal stress is relieved completely. This is used for the part subjected to high impact and stress such as gear wheels, shafts, and connecting rod, etc.

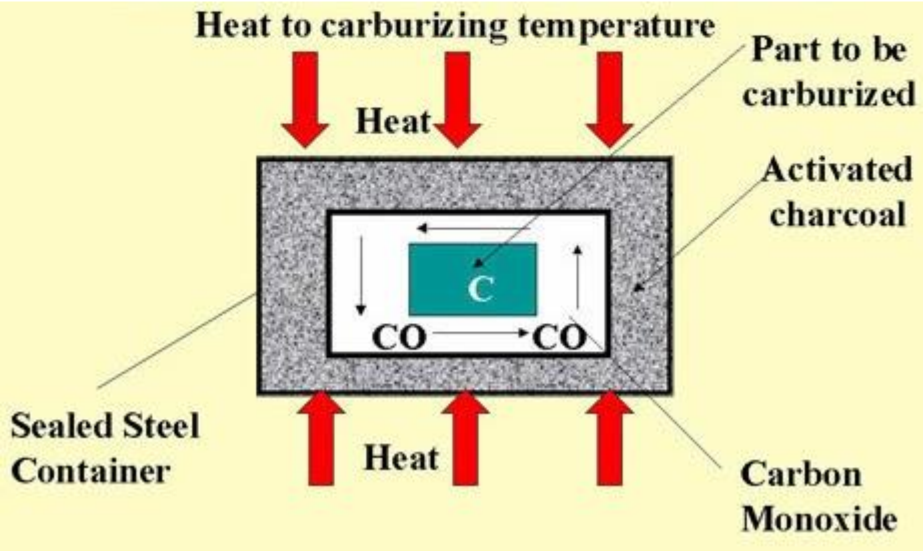
Carburizing

Carburizing is a heat treatment process in which iron or steel absorbs carbon liberated when the metal is heated in the presence of a carbon rich atmosphere, such as charcoal or carbon monoxide, with the intent of making the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures lead to greater carbon diffusion into the part as well as increased depth of carbon diffusion. When the iron or steel is quenched, the higher carbon content on the outer surface becomes hard via the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure. It is applied to low-carbon workpieces are in contact with a high-carbon gas, liquid or solid it produces a hard workpiece surface; workpiece cores largely retain their toughness and ductility, and it produces case hardness depths of up to 6.4 mm.

Gas Carburizing:

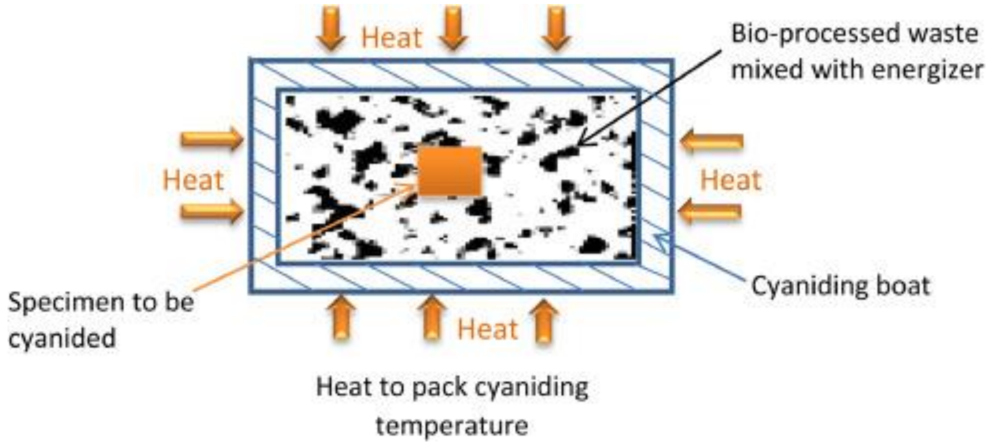
It is a heat treatment process, which improves the case depth hardness of a component by diffusing carbon into the surface layer to improve wear and fatigue resistance. The workpieces are pre-heated and then held for a period of time at an elevated temperature in the austenitic region of the specific alloy, typically between 820 and 940°C. During the thermal cycle the components are subject to an enriched carbon atmosphere such that nascent species of carbon can diffuse into the surface layers of the component.

The rate of diffusion is dependent on the alloy and carbon potential of the atmosphere. Care must be taken to ensure that only sufficient carbon is available in the atmosphere at any one time to satisfy the take-up rate of the alloy to accept the carbon atoms.Pack Carburizing: It is a heat treatment process in which carbon monoxide derived from a solid compound decomposes at the metal surface into nascent carbon and carbon dioxide.The nascent carbon is absorbed into the metal, and the carbon dioxide immediately reacts with carbonaceous material present in the solid carburizing compound to produce fresh carbon monoxide. The formation of carbon monoxide is enhanced by energizers or catalysts,such as barium carbonate, calcium carbonate, potassium carbonate, and sodium carbonate that are present in the carburizing compound. These energizers facilitate the reduction of carbon dioxide with carbon to form carbon monoxide. Thus, in a closed system, the amount of energizer does not change. Carburizing continues as long as enough carbon is present to react with the excess carbon dioxide.



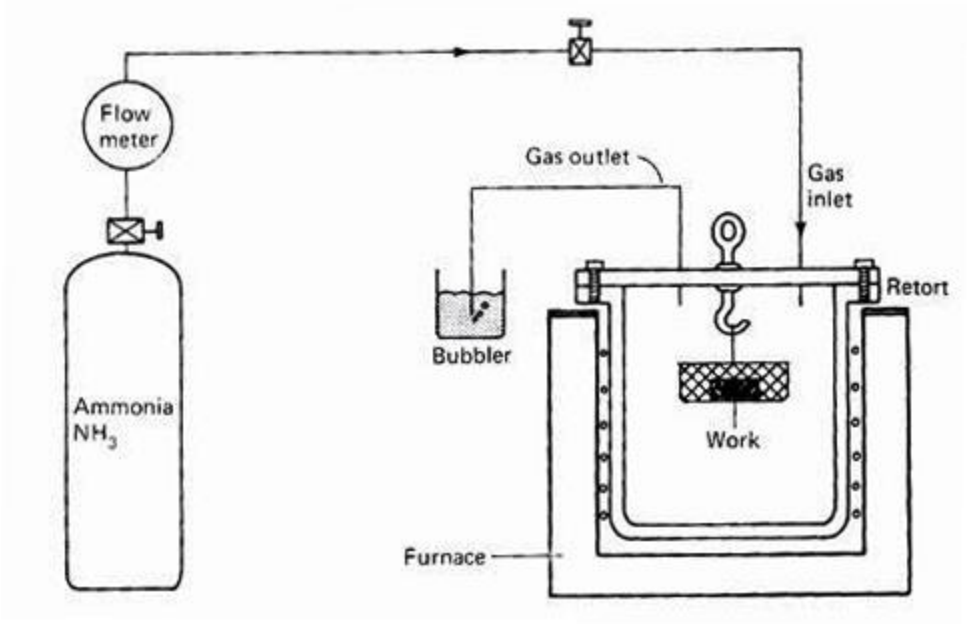
Cyaniding

Steel parts may be surface-hardened by heating in contact with a cyanide salt, followed by quenching. Only a thin case is obtained by this method. Cyaniding is, however, a rapid and economical method of case hardening, and may be used in some instances for relatively unimportant parts. The work to be hardened is immersed in a bath of molten sodium or potassium cyanide from 30 to 60 minutes. The cyanide bath should be mainlined at a temperature to 760 to 899°C. Immediately, after removal from the bath, the parts are quenched in water. The case obtained in this manner is due principally to the formation of carbides and nitrides on the surface of the steel. The use of a closed pot and ventilating hood are required for cyaniding, as cyanide vapors are extremely poisonous.



Nitriding

This method is advantageous due to the fact that a harder case is obtained than by carburizing. Many engine parts such as cylinder barrels and gears may be treated in this way. Nitriding is generally applied to certain special steel alloys, one of the essential constituents of which is aluminum. The process involves the exposing of the parts to ammonia gas or other nitrogenous materials for 20 to 100 h at 500–650°C. The container in which the work and Ammonia gas are brought into contact must be airtight and capable of maintaining good circulation and even temperature throughout. The depth of case obtained by nitriding is about 0.2 to 0.4 mm if heated for 50 h. The nitriding process does not affect the physical state of the core if the preceding tempering temperature was 500°C or over.



Induction hardening

This process involves heating applied rapidly and locally to the steel component followed by quenching. High-frequency electric fields quickly heat the surface of the component via induction coils, which is then quenched using water. This results in a localized hardened layer at the surface. Different shaped inductor coils are available and can be made to suit. Induction Hardening offers a cost effective low distortion surface hardening treatment to steels, particularly large components where an increase in surface hardness is required whilst maintaining core properties.