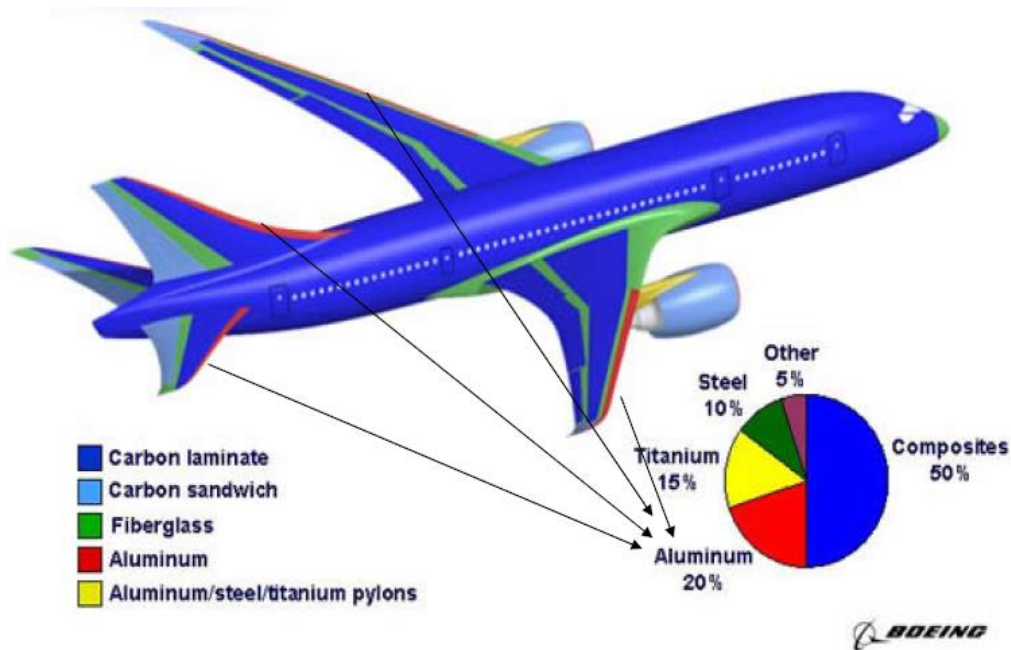


Machining

Level I

Based On March 2022, Curriculum Version 1



**Module Title: -Test and Identify Properties
Of Metals**

Module Code: - IND MAC1 M 02 0322

Nominal Duration: 29 Hour

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Acronym

AIST-American Iron and Steel Institute

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Au-Gold
 Ag-Silver
 C-Carbon
 Cr-Chromium
 Cu-Copper
 DT-Destructive Testing
 F-Force
 Fe-Iron
 Hv-Vickers Hardness
 Mg-Magnesium
 Maps-Mega Pascal
 Mn-Manganese
 NDT-Non-Destructive Testing
 Ni-Nickel
 P-Phosphorus
 Pb-Lead
 Pt-Platinum
 OHS-Occupational Health and Safety
 S-Sulfur
 SAE-Society of Automotive Engineering
 Si-Silicon

Introduction to the Module

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In machining field; the Testing and Identifying Properties of Metals project helps to know the classification common ferrous and non-ferrous metals; to management of OHS in the workplace; to Test basic applications and methods for manufacturing; to perform basic common metal tests ;to define common heat treatment outcomes and applications; Assess quality of test and complete documentation .

This module is designed to meet the industry requirement under the machining occupational standard, particularly for the unit of competency: **Testing and Identifying Properties of Metals.**

This module covers the units:

- ferrous , non-ferrous and alloy metals
- Test methods for manufacturing
- metal tests
- heat treatment

Learning Objective of the Module

- Classify ferrous and non-ferrous metals
- To know applications and methods for manufacturing of metal property
- Perform Test a metal property and type
- Define common heat treatment outcomes and applications

Module Instruction

For effective use this modules trainees are expected to follow the following module instruction:

1. Read the information written in each unit
2. Accomplish the Self-checks at the end of each unit
3. Perform Operation Sheets which were provided at the end of units
4. Do the “LAP test” giver at the end of each unit and
5. Read the identified reference book for Examples and exercise

Unit one: Classify common ferrous and non-ferrous metals

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Classification of metals
- metal properties

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Identify types of metal and their application.
- Identify property of metal.

1.1. Classification of Ferrous, Non-Ferrous and Alloys Metals

1.1.1. Introduction to Metals:

Because of the widespread use and necessity for metals in agriculture, building, automotive, airplane and different usage it is important for the worker to have a basic understanding of metals and metallurgy when fabricating and making repairs on metals. Steelworkers need to know the two basic types of metal and be able to provide initial identification. While they primarily work with the ferrous metals of iron and steel, they also need to be able to identify and become familiar with the nonferrous metals coming into more use each day.

Metal-Metal is an element.

There are over 118 known elements, and about 75 percent of them are classified as metals.

Alloy is a mixture of two or more metals or of metals and one or more non-metals

The elements added to a metal to form an alloy may be either metal or non-metal. In most cases alloys have more desirable properties and are less expensive than pure metals.

Classification of metal

These metals can be broken down into four groups and classified as follows:

- ✓ Ferrous Metals
- ✓ Non-ferrous metals
- ✓ Ferrous Alloys
- ✓ Non-ferrous Alloys

1.1.2. Ferrous metals

Metals whose chief ingredient is iron. Pig iron, cast iron, wrought iron, and steel are examples of ferrous metals.

Pig iron or cured iron. It is iron ore changed to pig iron by a blast furnace.

Cast iron:-It is a product of pig iron and contains a considerable amount of carbon and some impurities.

It is brittle and granular in structure. It is formed by pouring into special castings.

The basic principal raw material for all ferrous metals is pig iron which is obtained by melting iron ore, coke and limestone, in the blast furnace.

I. Pig Iron

Pig iron was originated in the early days by reduction of iron ores in blast furnace and when the total output of the blast furnace was sand cast into pigs which is a mass of iron roughly resembling a reclining pig.

It is produced in a blast furnace and is the first product in the process of converting iron ore into useful ferrous metal. The iron ore becomes pig iron when the impurities are burnt out in a blast furnace.

The charge in the blast furnace for manufacturing pig iron is

- (a) Ore - Consisting of iron oxide or carbonate associated with earth impurities.
- (b) Coke - A fuel
- (c) Limestone - A flux

In addition to iron, pig iron contains various other constituents in varying form of impurity such as carbon, silicon, sulphur, manganese and phosphorus etc. It has the following approximate composition which is as given as under.

Carbon — 4 to 4.5% Phosphorus — 0.1 to 2.0%

Silicon — 0.4 to 2.0% Sulphur — 0.4 to 1.0%

Manganese — 0.2 to 1.5 % Iron — Remaining %

Pig iron is the raw material for all iron and steel products. It is of great importance in the foundry and in steel making process.

Carbon exists in iron in free form (graphite) and/or in combined form (cementite and pearlite). Pig iron is classified on the basis of contents of free and combined carbon as follows.

These classifications are also termed as grades.

i. Grey pig iron (Grades 1, 2 and 3)

Grey pig iron contains about 3% carbon in free form (i.e., graphite form) and about 1% carbon in combined form. This is a soft type of pig iron.

ii. White pig iron (Grades 4)

White pig iron is hard and strong. It contains almost all of the carbon in the combined form.

iii. Mottled pig iron (Grade 5)

This type of pig iron is in between the grey and white variety. It has an average hardness and mottled appearance. The free and combined forms of carbon are in almost equal proportion in mottled pig iron.

II. Cast iron

Cast iron is basically an alloy of iron and carbon and is obtained by re-melting pig iron with coke, limestone and steel scrap in a furnace known as cupola. The carbon content in cast iron varies from 1.7% to 6.67%. It also contains small amounts of silicon, manganese, phosphorus and sulphur in form of impurities elements.

General properties of cast iron

- Cast irons are difficult to weld.
- Cast iron is very brittle and weak in tension and therefore it cannot be used for making bolts and machine parts which are liable to tension.
- It has low cost, good casting characteristics, high compressive strength, high wear resistance and excellent machinability.
- Its tensile strength varies from 100 to 200 MPa, compressive strength from 400 to 1000 MPa and shear strength is 120 MPa.
- The compressive strength of cast iron is much greater than the tensile strength.

There are four kinds of cast iron

- ❖ Grey cast iron
- ❖ White cast iron
- ❖ Malleable cast iron, and
- ❖ Nodular cast iron

i. Gray cast iron

Gray cast iron is grey in color which is due to the carbon being principally in the form of graphite (C in free form in iron).

It contains:-

$$\begin{array}{ll} \text{C} = 2.5 \text{ to } 3.8\% & \text{Mn} = 0.4 \text{ to } 1.0\% \\ \text{Si} = 1.1 \text{ to } 2.8\% & \text{P} = \text{less than } 0.15\% \quad \text{S} = \text{less than } 0.1\% \end{array}$$

It is produced in cupola furnace by refining or pig iron.

Properties of gray cast iron

- When fractured it gives gray color.
- It can be easily cast.
- It has lowest melting point.
- It can be easily machined and possesses machinability better than steel.
- It possesses lowest melting of ferrous alloys.
- It has high resistance to wear.

- It possesses high compressive strength.
- It has a low tensile strength.
- It has very low ductility and low impact strength as compared with steel.

Applications of gray cast iron

The grey iron castings are mainly used for machine tool bodies, automotive cylinder blocks, pipes and pipe fittings and agricultural implements. The other applications involved are

- ✓ Machine tool structures such as bed, frames, column etc.
- ✓ Household appliances etc.
- ✓ Gas or water pipes for underground purposes.
- ✓ Piston rings.
- ✓ Rolling mill and general machinery parts.
- ✓ Blocks and heads for engines.
- ✓ Frames of electric motor.

ii. White cast iron

It has a white appearance due to the form in which the carbon is present in the iron.

White iron is usually cast in metal moulds which permit a rapid cooling rate so that the carbon remains in solution with the iron.

White iron is used for such purposes as chilled iron castings of rollers for rolling mills used in the production of steel plate.

It is extremely difficult to machine and the main purpose of white cast iron is to produce malleable iron.

$$\begin{aligned} C &= 3.2 \text{ to } 3.6\% & Mg &= 0.1 \text{ to } 0.4\% \\ Si &= 0.4 \text{ to } 1.1\% & P &= \text{less than } 0.3\% & S &= \text{less than } 0.2\% \end{aligned}$$

Properties White cast iron

- ✓ Its name is due to the fact that its freshly broken surface shows a bright white fracture.
- ✓ It is very hard due to carbon chemically bonded with iron as iron carbide (Fe_3C), which is brittle also.
- ✓ It possesses excellent abrasive wear resistance.
- ✓ Since it is extremely hard, therefore it is very difficult to machine.
- ✓ Its solidification range is $2650-2065^\circ F$.
- ✓ The white cast iron has a high tensile strength and a low compressive strength.

Applications White cast iron

- ✓ For producing malleable iron castings.
- ✓ For manufacturing those component or parts which require a hard, and abrasion resistant surface such as rim of car.
- ✓ Railway brake blocks.

Grey cast iron & white cast iron are:-

- ✓ Low in cost
- ✓ They are very brittle, however
- ✓ They cannot hammer or formed.

iii. Malleable iron

Malleable iron is produced by placing white iron castings in an annealing furnace and subjecting them to temperatures above 870°.

The ordinary cast iron is very hard and brittle. Malleable cast iron is unsuitable for articles which are thin, light and subjected to shock.

It can be flattened under pressure by forging and rolling

Typical uses for malleable iron are for pipe fittings & plumbing fixtures.

Properties

- ✓ Malleable cast iron is like steel than cast iron.
- ✓ It is costly than grey cast iron and cheaper than softer steel.

Applications of malleable iron

Malleable cast iron are generally used to form automobile parts, agriculture implementation, hinges, door keys, spanners mountings of all sorts, seat wheels, cranks, levers thin, waned components of sewing machines and textiles machine parts.

iv. Ductile cast iron (Nodular)

Nodular iron is produced by adding elements such as nickel and molybdenum to the molten metal.

Nodular iron is:-

- ✓ Very high strength
- ✓ Good machinability and
- ✓ Good Resistance to wear

This type of iron is used for high quality castings such as lathe and machine tool beds and where hard wearing and resistance to shock qualities are required.

Silicon is also used as an alloying element since it has no effect on size and distribution of carbon content. The magnesium controls the formation of graphite. But it has little influence

on the matrix structure. Nickel and manganese impart strength and ductility. Ductile cast iron has high fluidity, excellent cast ability, strength, high toughness, excellent wear resistance, pressure tightness, weldability and higher machinability in comparison to grey cast iron.

v. Wrought iron

Wrought iron is mechanical mixture of very pure iron and a silicate slag.

It can also be said as a ferrous material, aggregated from a solidifying mass of pasty particles of highly refined metallic iron with which a uniformly distributed quantity of slag is incorporated without subsequent fusion. This iron is produced from pig iron by re-melting it in the puddling furnace. Wrought iron is very ductile; forges well, can easily bend hot or cold, and can be welded.

It has a tensile strength of about 275 M Pa and it is high cost.

Properties Wrought iron

- ✓ The wrought iron can be easily shaped by hammering, pressing, forging, etc.
- ✓ It is never cast and it can be easily bent when cold.
- ✓ It is tough and it has high ductility and plasticity with which it can be forged and welded easily.
- ✓ It possesses a high resistance towards corrosion.
- ✓ It can accommodate sudden and excessive shocks loads without permanent injury.
- ✓ It has a high resistance towards fatigue.
- ✓ It can be elongated considerably by cold working.
- ✓ It has high electrical conductivity. The melting point of wrought iron is about 1530°C.
- ✓ It has elongation 20% in 200 mm in longitudinal direction and 2–5 % in transverse direction.

Applications Wrought iron

It is used for making chains, crane hooks, railway couplings, and water and steam pipes.

It has application in the form of plates, sheets, bars, structural works, rivets, and a wide range of tubular products including pipe, tubing and casing, electrical conduit, cold drawn tubing, welding fittings, bridge railings.

III. Steels

Steel is an alloy of iron and carbon with carbon content maximum up to 1.7%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel.

Plain carbon steels

Plain carbon steel is an alloy of iron and carbon. It has good machine ability and malleability. Plain carbon steels are classified by the amount of carbon they contain.

i. Low carbon steel, often called mild or soft steel, it contain 0.1 up to 0.3 per cent carbon.

Low carbon steels is

- ✓ Have a lower tensile strength and hardness.
- ✓ It is easy welded, machined, and formed.
- ✓ It is used for most bench metal

ii. Medium carbon steel

It contains 0.3 up to 0.6 percent carbon. Medium carbon steels are used where strength and ductility are required. It is used for many standard machine parts & for projects like hammer heads and clamp parts.

iii. High carbon

It contains 0.3 up to 0.6 percent carbon. High carbon steels have a higher tensile strength, hardness, and wear resistance but are low in ductility and have poor machinability.

It is used for making small tools.

1.1.3. Non-ferrous metals

Non-ferrous metals are those which have no iron and are made up of a single element. These are aluminum, copper, lead, magnesium, nickel, tin, tungsten, zinc, silver, and gold.

The most common non-ferrous metals and alloys are: aluminum alloys, copper, brass, nickel, and tin, zinc, lead, and magnesium alloys.

a) Aluminum

It is a white metal produced by electrical process from the oxide (Alumina), which is prepared from a clay mineral called Bauxite. Bauxite is hydrated aluminum oxide. The chief impurities are oxide, silica, clay and titanium oxide.

Properties of Aluminum

- Light weight
- Good electrical conductivity
- Malleability and ductility
- High thermal conductivity
- Resistance to corrosion
- Non-magnetic properties
- Most elements alloying aluminum are Cu, Cr, Ni, Mn, Si, and Mg.

Uses of Aluminum

- It is mainly used in aircraft and automobile parts where saving of weight is an advantage.
- It is used for reflectors, mirrors and telescopes.
- It is a useful metal for cooking apparatus.
- It is a cheap and very important nonferrous metal used for making cooking utensils.

b) Copper

Copper is one of the most widely used non-ferrous metals in industry. It is extracted from ores of copper such as copper glance, copper pyrites, malachite and azurite. Copper is a corrosion resistant metal of an attractive reddish brown color.

Properties of copper

- Good resistance to corrosion.
- Non-magnetic properties
- Pure copper is soft, malleable and ductile metal with a reddish-brown appearance.
- High electrical conductivity
- It can be soldered, brazed, or welded.
- Very good machinability

Applications of copper

- Copper is mainly used in making electric cables and wires for electric machinery, motor winding, electric conducting appliances, and electroplating etc.
- It can be easily forged, casted, rolled and drawn into wires.
- Copper in the form of tubes is used widely in heat transfer work mechanical engineering field.

The following copper alloys are important

- 1) Copper-zinc alloys (Brasses)
- 2) Copper-tin alloys (Bronzes)

c) Brasses

Brasses are widely used alloy of copper and zinc.

They also contain small amounts of lead or tin or aluminum. The most commonly used copper-zinc alloy is brass.

There are various types of brasses, depending upon the proportion of copper and zinc.

The fundamental a binary alloy comprises 50% copper and 50% zinc. By adding small quantities of other elements, properties of brass may be greatly changed. For example addition of lead (1 to 2%) improves the machining quality of brass. It has a greater-strength than that of copper, but has a lower thermal and electrical conductivity.

Brasses alloys are very resistant to atmospheric corrosion and can be easily soldered.

They can be easily fabricated by processes like spinning and can also be electroplated with metals like nickel and chromium.

d) Bronzes

Bronze is a common alloy of copper and tin. The alloys of copper and tin are generally termed as bronzes.

The wide range of composition of these alloys comprise of 75 to 95% copper and 5 to 25% tin.

Bronze has higher strength, better corrosion resistance than brasses.

It is comparatively hard and resists surface wear and can be shaped or rolled into wire, rods and sheets very easily. It has antifriction or bearing properties. Bronze is costlier than brass. The tensile strength of bronze increases gradually with the amount of tin, reaching a maximum when tin is about 20%. However the percentage of tin content if increases beyond this amount, the tensile strength decreases very rapidly. Bronze is most ductile when it contains about 5% of tin.

As the amount of tin increases about 5%, the ductility gradually decreases and practically disappears with about 20% of tin. Whereas presence of zinc in the bronze increases fluidity of molten metal, strength and ductility.

e) Nickel

Nickel is a silvery shining white metal having extremely good response to polish. The most important nickel's ore is iron sulphides which contain about 3% of nickel. About 90% of the total production of nickel is obtained by this source. This ore is mainly found in Canada and Norway.

Properties

- Nickel is as hard as steel. It possesses good heat resistance. It is tough and having good corrosion resistance. Its melting point is 1452°C and specific gravity is 0.85. At normal temperature, nickel is paramagnetic.
- Nickel alloys are sometimes used for their high potential field strengths, some for their permeability and some for their high coercive force.
- When it contains small amount of carbon, it is quite malleable. It is somewhat less ductile than soft steel, but small amount of magnesium improves ductility considerably.

Applications

- Nickel is used in kitchen utensils and appliances, and in laundry and dairy machinery.
- It is extensively useful for electroplating plating work for protecting surfaces of iron and brass from corrosion.
- It is also utilized as an important alloying element in some type of cast iron and steel. It is helpful for making stainless steel.

f) Lead

It is a very durable and versatile material. The heavy metal obtained from the bottom of the furnace is further oxidized.

Properties

- Lead has properties of high density and easy workability.
- It has very good resistance to corrosion and many acids have no chemical action on it.
- Its melting point is 327°C and specific gravity is 11.35.
- It is the softest and heaviest of all the common metals.
- It is very malleable and it can readily be scratched with fingernail when pure.

Applications

- ✓ Lead is used in safety plug in boilers, fire door releases and fuses.

- ✓ It is also used in various alloys such as brass and bronze. It finds extensive applications as sheath for electric cables, both overhead and underground.
- ✓ Its sheets are used for making roofs, gutters etc.
- ✓ It is employed for chemical laboratory and plant drains.
- ✓ In the soldering process, an alloy of lead and tin is most widely utilized as a solder material for joining metals in joining processes.

g) Zinc

The oxide is heated in an electric furnace where the zinc is liberated as vapor. The vapors are then cooled in condensers to get metallic zinc.

Properties

- Zinc possesses specific gravity is 6.2 and low melting point of 480°C.
- Its tensile strength is 19 to 25 MPa. It becomes brittle at 200°C and can be powdered at this temperature.
- It possesses high resistance to corrosion. It can be readily worked and rolled into thin sheets or drawn into wires by heating it to 100-150°C.

Applications

- With regards to industrial applications, zinc is the fourth most utilized metal after iron, aluminum, and copper.
- Zinc is commonly used as a protective coating on iron and steel in the form of a galvanized or sprayed surface.
- It is used for generating electric cells and making brass and other alloys.
- The oxide of zinc is used as pigment in paints.
- Parts manufactured by zinc alloys include carburetors, fuel pumps, automobile parts, and so on.

h) TIN

Tin is recognized as brightly shining white metal. It does not corrode in wet and dry conditions.

Therefore, it is commonly used as a protective coating material for iron and steel.

The main source of tin is tinstone.

Properties

- Tin is considered as a soft and ductile material. It possesses very good malleability.
- Its melting point is 232°C and specific gravity is 7.3. It is malleable and hence can be hammered into thin foils

Applications

- Tin-base white metals are commonly used to make bearings that are subjected to high pressure and load.
- Tin is used as coating on other metals and alloys owing to its resistance to corrosion. It is employed in low melting point alloys.
- It is generally preferred as moisture proof packing material. Because of its high malleability, it finds application in tin cans for storing food and food items.

1.1.4. Alloys

An alloy is a mixture of a metal with another element, either metal or nonmetal.

- homogeneous combination of 2 or more elements
- at least one of which is a metal
- has metallic properties

Need to improve some properties of the base metal Density, reactivity, electrical and thermal conductivity is often the same as a constituent metal Mechanical properties (strength, Young's modulus, etc.) can be very different • Comparative cost of the element components

Steel: \$0.27 /lb Cu: \$0.76 / lb Al: \$0.67 /lb Zn: 0.45 /lb (2001)

\$0.36 /lb \$3.62 / lb \$1.14 /lb 1.34 /lb (2007)

A. Ferrous Alloys

I. Cast Iron

•The cast irons are the ferrous alloys with greater than 2.14 wt. % carbon, but typically contain 3-4.5 wt. % of C as well as other alloying elements, such as **silicon** (~3 wt... %) which controls kinetics of carbide formation

These alloys have relatively low melting points (1150-1300°C), do not form undesirable surface films when poured, and undergo moderate shrinkage during solidification. Thus can be easily melted and amenable to **casting**

•There are **four general types** of cast irons:

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White iron has a characteristics white, crystalline fracture surface. Large amount of Fe_3C are formed during casting, giving hard brittle material

Gray iron has a gray fracture surface with finely faced structure. A large Si content (2-3 wt. %) promotes C *flakes* precipitation rather than carbide

Ductile iron: small addition (0.05 wt... %) of Mg to gray iron changes the flake C microstructure to spheroidal that increases (by factor ~20) steel ductility

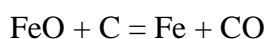
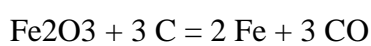
Malleable iron: traditional form of cast iron with reasonable ductility. First cast to white iron and then heat-treated to produce nodular graphite precipitates.

II. Iron and Steel

First step: Fe extraction in blast furnaces (reduction reaction at $\sim 400^\circ C$):

- Main iron ore: Fe_2O_3
- Resulting raw iron is molten: Fe ($\sim 4\%$ C) \Rightarrow steel-making furnace Steel: alloy of Fe and C (up to 1.2%)

\Rightarrow oxidize impurity (S, P, etc) and C in the raw iron until the carbon content is below the required level



III. Basic ferrous alloys

There are many varieties of alloy steel used in the manufacture of different types of equipment. They have greater strength and durability than carbon steel, and a given strength is secured with less material weight.

Manganese steel is a special alloy steel that is always used in the cast condition (see cast steel above).

Nickel, chromium, vanadium, tungsten, molybdenum, and silicon are the most common elements used in alloy steel.

1. **Chromium** is used as an alloying element in carbon steels to increase hardenability, corrosion resistance, and shock resistance. It imparts high strength with little loss in ductility.
2. **Nickel** increases the toughness, strength, and ductility of steels, and lowers the hardening temperatures so than an oil quench, rather than a water quench, is used for hardening.
3. **Manganese** is used in steel to produce greater toughness, wear resistance, easier hot rolling, and forging. An increase in manganese content decreases the weldability of steel.

4. **Molybdenum** increases hardenability, which is the depth of hardening possible through heat treatment. The impact fatigue property of the steel is improved with up to 0.60 percent molybdenum. Above 0.60 percent molybdenum, the impact fatigue property is impaired. Wear resistance is improved with molybdenum content above 0.75 percent. Molybdenum is sometimes combined with chromium, tungsten, or vanadium to obtain desired properties.
5. **Titanium and columbium (niobium)** are used as additional alloying agents in low-carbon content, corrosion-resistant steels. They support resistance to intergranular corrosion after the metal is subjected to high temperatures for a prolonged time period.
6. **Tungsten**, as an alloying element in tool steel, produces a fine, dense grain when used in small quantities. When used in larger quantities, from 17 to 20 percent, and in combination with other alloys, it produces steel that retains its hardness at high temperatures.
7. **Vanadium** is used to help control grain size. It tends to increase hardenability and causes marked secondary hardness, yet resists tempering. It is also added to steel during manufacture to remove oxygen.
8. **Silicon** is added to steel to obtain greater hardenability and corrosion resistance and is often used with manganese to obtain strong, tough steel. High-speed tool steels are usually special alloy compositions designed for cutting tools. The carbon content ranges from 0.70 to 0.80 percent. They are difficult to weld except by the furnace induction method.
9. **High yield strength, low alloy structural steels** (often referred to as constructional alloy steels) are special low carbon steels containing specific small amounts of alloying elements. These steels are quenched and tempered to obtain a yield strength of 90,000 to 100,000 psi (620,550 to 689,500 kPa) and tensile strength of 100,000 to 140,000 psi (689,500 to 965,300 kPa), depending upon size and shape. Structural members fabricated of these high strength steels may have smaller cross-sectional areas than common structural steels and still have equal strength. In addition, these steels are more corrosion and abrasion-resistant. In a spark test, this alloy appears very similar to the low carbon steels.

B. Nonferrous Alloys

I. Al Alloys –

Lower density: 2.7g/cm³

Cu, Mg, Si, Mn, Zn additions

Solid solutions or precipitation strengthened (structural aircraft parts & packaging)

Cu Alloys

Brass: Zn is prime impurity (costume jewelry, coins, corrosion resistant)

Bronze: Sn, Al, Si, Ni are prime impurities (bushings, landing gear)

Cu-Be precipitation-hardened for strength

II. Ti Alloys

- Lower density: 4.5g/cm³ vs. 7.9 for steel
- Reactive at high T
- Space applications

III. Mg Alloys

- very low density : 1.7g/cm³
- ignites easily
- aircraft, missiles

IV. Refractory metals

- high melting T
- Nb, Mo, W, Ta

V. Noble metals

- Ag, Au, Pt
- oxidation/corrosion resistant

1. Cooper and its Alloys

•Cooper: soft and ductile; unlimited cold-work capacity, but difficult to machine.

•Cold-working and solid solution alloying

•Main types of Copper Alloys:

–**Brasses:** zinc (Zn) is main substitution impurity; applications: cartridges, auto-radiator.

Musical instruments, coins

–**Bronzes:** tin (Sn), aluminum (Al), Silicon (Si) and nickel (Ni); stronger than brasses with high degree of corrosion resistance

–**Heat-treated** (precipitation hardening) **Cu-alloys**: beryllium coopers; relatively high strength, excellent electrical and corrosion properties BUT expensive; applications: jet aircraft landing gear bearing, surgical and dental instruments.



Fig.1.1.Copper and copper alloys

Copper's advantages as primary metal and recycled metal, for brazed, long-life radiators and radiator parts for cars and trucks:

2. Aluminum and its Alloys

- Low density ($\sim 2.7 \text{ g/cm}^3$), high ductility (even at room temperature), high electrical and thermal conductivity and resistance to corrosion but low melting point ($\sim 660^\circ\text{C}$)
- Main types of Aluminum Alloys:
 - **Wrought** Alloys
 - **Cast** Alloys
 - Others: e.g. **Aluminum-Lithium** Alloys
- Applications: from food/chemical handling to aircraft structural parts

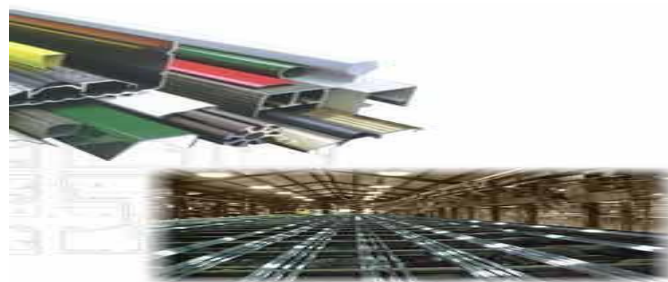


Fig.1.2.Aluminum and its Alloys

3. Magnesium and its Alloys

Key Properties:

- Light weight
- Low density (1.74 g/cm^3 two thirds that of aluminum)
- Good high temperature mechanical properties
- Good to excellent corrosion resistance
- Very high strength-to-density ratios (*specific strength*)

- In contrast with Al alloys that have fcc structure with (12) slip systems and thus high ductility, hcp structure of Mg with only three slip systems leads to its brittleness.

- Applications: from tennis rockets to aircraft and missiles

Example: Aerospace

RZ5 (Zn 3.5 - 5,0 SE 0.8 - 1,7 Zr 0.4 - 1,0 Mg remainder), MSR (AG 2.0 - 3,0 SE 1.8 - 2,5Zr 0.4 - 1,0 Mg remainder) alloys are widely used for aircraft engine and gearbox casings. Very large magnesium castings can be made, such as intermediate compressor casings for turbine engines. These include the Rolls Royce Tay casing in MSR, which weighs 130kg and the BMW Rolls Royce BR710 casing in RZ5. Other aerospace applications include auxiliary gearboxes (F16, Euro-fighter 2000, Tornado) in MSR or RZ5, generator housings (A320 Airbus, Tornado and Concorde in MSR) and canopies, generally in RZ5.



Fig.1.3.Magnesium and its Alloys Gearbox Casting

4. Titanium and its Alloys (1)

- Titanium and its alloys** have proven to be technically superior and cost-effective materials of construction for a wide variety of aerospace, industrial, marine and commercial applications.

- The **properties and characteristics** of titanium which are important to design engineers in a broad spectrum of industries are:

- **Excellent Corrosion Resistance:** Titanium is immune to corrosive attack by salt water or marine atmospheres. It also exhibits exceptional resistance to a broad range of acids, alkalis, natural waters and industrial chemicals.

- **Superior Erosion Resistance:** Titanium offers superior resistance to erosion, cavitation or impingement attack. Titanium is at least twenty times more erosion resistant than the copper-nickel alloys.

- **High Heat Transfer Efficiency:** Under "in service" conditions, the heat transfer properties of titanium approximate those of admiralty brass and copper-nickel.

5. Other Alloys

Alloys of the Co-Cr-Mo system are widely known in the world for their high physical and mechanical properties, corrosion resistance and resistance to aggressive media and critical temperature conditions. Alloys are well studied in domestic and foreign literature. The cobalt structure exists in two crystalline modifications: a low-temperature ϵ -phase with a hexagonal close-packed lattice and a high-temperature γ -phase with a facecentered cubic lattice.

•Miscellaneous Nonferrous Alloys:

- **Nickel and its alloy:** high corrosion resistant (Example: Monel – 65Ni/28Cu/7wt%Fe – pumps valves in aggressive environment)

- **Lead, tin and their alloys:** soft, low recrystallization temperature, corrosion resistant (Applications: solders, x-ray shields, protecting coatings)

•**The Refractory Metals:** **Nb** (m.p. =2468°C); **Mo** (°C); **W** (°C); **Ta**(3410°C) - Also: large elastic modulus, strength, hardness in wide range of temperatures - Applications:

• **The Super alloys** – possess the superlative combination of properties - Examples: - Applications: aircraft turbines; nuclear reactors, petrochemical equipment

• **The Noble Metal Alloys:** **Ru**(44), **Rh** (45), **Pd** (46), **Ag** (47), **Os** (75), **Ir** (77), **Pt** (78), **Au** (79) - expensive are notable in properties: soft, ductile, **oxidation resistant** - **Applications:** jewelry (Ag, Au, Pt), catalyst (Pt, Pd, Ru), thermocouples (Pt, Ru), dental materials etc.

1.2. Properties of metal and metal alloys

Metals in general have high electrical conductivity, thermal conductivity, luster and density, and the ability to be deformed under stress without cleaving. Chemical elements lacking these properties are classed as nonmetals.

A few elements, known as metalloids, sometimes behave like a metal and at other times like a nonmetal. Some examples of metalloids are as follows: boron, arsenic, and silicon.

As you have already studied, metals are divided into two classes, ferrous and nonferrous. Ferrous metals are those in the iron class and are magnetic in nature. These metals consist of iron, steel, and alloys related to them. Nonferrous metals are those that contain either no, or very small amounts of, ferrous metals.

Iron alloyed with various proportions of carbon gives low-, mid- and high-carbon steels, and as the carbon levels increase, ductility and toughness decrease. The addition of silicon will

produce cast irons, while the addition of chromium, nickel, and molybdenum to carbon steels (more than 10%) results in stainless steels.

Since you will work mostly with alloys, you need to understand their characteristics. The characteristics of elements and alloys are explained in terms of physical, chemical, electrical, and mechanical properties.

The basic properties of metals

- ❖ Physical properties
- ❖ Chemical properties
- ❖ Mechanical properties
- ❖ Thermal properties
- ❖ Electrical properties
- ❖ Magnetic properties

Physical properties relate to color, density, weight, and heat conductivity.

Chemical properties involve the behavior of the metal when placed in contact with the atmosphere, salt water, or other substances.

Electrical properties encompass the electrical conductivity, resistance, and magnetic qualities of the metal.

Mechanical properties relate to load-carrying ability, wear resistance, hardness, and elasticity when selecting stock for a job, your main concern is the mechanical properties of the metal.

VI. Physical Properties

The important physical properties of the metals are density, color, size and shape (dimensions), specific gravity, porosity, luster etc. Some of them are defined as under.

a. Density

Mass per unit volume is called as density. In metric system its unit is kg/mm³.

b. Color

It deals the quality of light reflected from the surface of metal.

c. Size and shape

Dimensions of any metal reflect the size and shape of the material. Length, width, height, depth, curvature diameter etc. determines the size. Shape specifies the rectangular, square, circular or any other section.

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d. Specific Gravity

Specific gravity of any metal is the ratio of the mass of a given volume of the metal to the mass of the same volume of water at a specified temperature.

e. Porosity

A material is called as porous or permeable if it has pores within it.

VII. Chemical Properties

The study of chemical properties of materials is necessary because most of the engineering materials, when they come in contact with other substances with which they can react, suffer from chemical deterioration of the surface of the metal. Some of the chemical properties of the metals are corrosion resistance, chemical composition and acidity or alkalinity.

Corrosion is the gradual deterioration of material by chemical reaction with its environment.

Corrosion in metals

- Corrosion may be defined as the deterioration of a material resulting from chemical attack by its environment. Since corrosion is caused by chemical reaction, the rate at which the corrosion takes place will depend to some extent on the temperature & concentration of reactants & products. Other factors such as mechanical stress & erosion may also contribute to corrosion.
- Most corrosion of materials refers to the chemical attack of metals that occur most commonly by electrochemical attack, since metals have free electrons, which are able to set up electrochemical cells within the metals themselves
- Most metals are corroded by water & the atmosphere. Metals can also be corroded by direct chemical attack for chemical solution.
- Most metals exist in nature in the combined state, for example, as oxides, sulfides, carbonates, or silicates, in these combined states the energies of the metals are lower. In the metallic state the energies of metals are higher, & thus there is a spontaneous tendency for metals to react chemically to form compound.

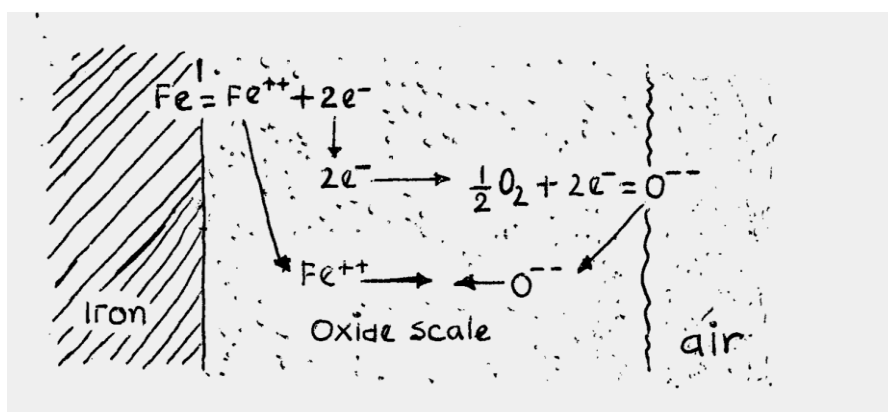


Fig.1.4. Mechanism of corrosion

Rust is the hydrated oxide form of iron; $\text{Fe}(\text{OH})_3$. Both oxygen and water are required for the formation of rust.

VIII. Thermal Properties

The study of thermal properties is essential in order to know the response of metal to thermal changes i.e. lowering or raising of temperature.

Different thermal properties are thermal conductivity, thermal expansion, specific heat, melting point, thermal diffusivity.

Melting Point

Melting point is the temperature at which a pure metal or compound changes its shape from solid to liquid. It is called as the temperature at which the liquid and solid are in equilibrium.

It can also be said as the transition point between solid and liquid phases.

Melting temperature depends on the nature of inter-atomic and intermolecular bonds. Therefore higher melting point is exhibited by those materials possessing stronger bonds. Covalent, ionic, metallic and molecular types of solids have decreasing order of bonding strength and melting point. Melting point of mild steel is 1500°C , of copper is 1080°C and of Aluminum is 650°C .

- Hence melting point of metals is said to be the temperature at which metal starts to change from solid to liquid.

Table: 1.1 the melting points of some common metal are given below

Elements	Melting points, °C
Al	660
Ti	1660
Ni	1455
Fe	1539
CU	1083
Zn	419
Ag	232
Au	1063
Pb	327
W	3416

IX. Electrical Properties

The various electrical properties of materials are conductivity, temperature coefficient of resistance, dielectric strength, resistivity, and thermoelectricity. These properties are defined as under.

a. Conductivity

Conductivity is defined as the ability of the material to pass electric current through it easily i.e. the material which is conductive will provide an easy path for the flow of electricity through it.

b. Temperature Coefficient of Resistance

It is generally termed as to specify the variation of resistivity with temperature.

c. Dielectric Strength

It means insulating capacity of material at high voltage. A material having high dielectric strength can withstand for longer time for high voltage across it before it conducts the current through it.

d. Resistivity

It is the property of a material by which it resists the flow of electricity through it.

e. Thermoelectricity

If two dissimilar metals are joined and then this junction is heated, a small voltage (in the mill-volt range) is produced, and this is known as thermoelectric effect.

X. Mechanical Properties

Under the action of various kinds of external forces, the behavior of the material is studied that measures the strength and lasting characteristic of a material in service. The mechanical properties of materials are of great industrial importance in the design of tools, machines and structures.

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. The main mechanical properties of the metal are strength, stiffness, elasticity, plasticity, ductility, malleability, toughness, brittleness, hardness, formability, cast ability and weld ability.

a. Elasticity or Proof stress

It is defined as the property of a material to regain its original shape after deformation when the external forces are removed. It can also be referred as the power of material to come back to its original position after deformation when the stress or load is removed. It is also called as the tensile property of the material.

b. Plasticity

Plasticity is defined the mechanical property of a material which keep the deformation produced under load permanently. This property of the material is required in forging, in stamping images on coins and in ornamental work. It is the ability or tendency of material to undergo some degree of permanent deformation without its rupture or its failure. Plastic deformation takes place only after the elastic range of material has been exceeded. Such property of material is important in forming, shaping, extruding and many other hot or cold working processes. Materials such as clay, lead, etc. are plastic at room temperature and steel is plastic at forging temperature. This property generally increases with increase in temperature of materials.

c. Strength

Strength is defined as the ability of a material to sustain loads without undue distortion or failure. The internal resistance offered by a material to an externally applied force is called stress.

The capacity of bearing load by metal and to withstand destruction under the action of external loads is known as strength. The stronger the material the greater the load it can withstand.

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This property of material therefore determines the ability to withstand stress without failure. Strength varies according to the type of loading. It is always possible to assess tensile, compressive, shearing and tensional strengths. The maximum stress that any material can withstand before destruction is called its ultimate strength..

d. Toughness

The ability of material to with stand bending or the application of shear stresses without fracture. By this definition, copper is extremely tough but cast iron is not.

Strong materials are generally tough although ductility has a more pronounced effect in determining toughness. Toughness the ability to absorb energy up to fracture.

e. Stiffness

It is defined as the ability of a material to resist deformation under stress. The resistance of a material to elastic deformation or deflection is called stiffness or rigidity. A material that suffers slight or very less deformation under load has a high degree of stiffness or rigidity.

That means, the steel beam is stiffer or more rigid than aluminum beam.

A material which deforms less under a given load is stiffer than one which deforms more.

f. Ductility

Ductility is the capacity of a material to undergo deformation under tension without rupture as in a wire drawing operation.

A ductile material must be strong and plastic. The ductility is usually measured by the terms, percentage elongation and percent reduction in area which is often used as empirical measures of ductility. The materials those possess more than 5% elongation are called as ductile materials.

The ductile material commonly used in engineering practice are mild steel, copper, aluminum, nickel, zinc, tin and lead.

g. Malleability

Malleability is the ability of the material to be flattened into thin sheets under applications of heavy compressive forces without cracking by hot or cold working means.

It is capacity of a material to withstand deformation under compression without rupture.

A malleable material should be plastic but it is not essential to be so strong.

h. Hardness

Hardness is defined as the ability of a metal to cut another metal. A harder metal can always cut or put impression to the softer metals by good quality of its hardness. It holds many

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different properties such as resistance to wear, scratching, deformation and mach inability etc.

i. Brittleness

Brittleness is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. The materials having less than 5% elongation under loading behavior are said to be brittle materials.

Brittle materials when subjected to tensile loads snap off without giving any sensible elongation. Glass, cast iron, brass and ceramics are considered as brittle material.

j. Wear: -

Is a complex surface phenomenon that results in mechanical attrition of moving surfaces in contact, by welding and removal of particles through friction?

k. Yield Stress:

The strength of a material is the property of resistance to external loads or stresses while not causing structural damage. The strongest substance known is tungsten molybdenum; titanium and nickel follow in order of strength of commercially pure metals. Pure iron is much weaker, but, when alloyed with the chemical element known as “carbon” to make steel, it may then become stronger than any of the pure metals except tungsten.

l. Creep

When a metal part is subjected to a high constant stress at high temperature for a longer period of time, it will undergo a slow and permanent deformation (in form of a crack which may further circulate further towards creep failure) called creep.

Properties and applications of metals are:

- Extremely good conductors of electricity and heat,
- Not transparent to visible light,
- A polished metal surface has a lustrous appearance,
- Atoms arranged in a regular repeating structure (crystalline),
- Relatively good strength
- Dense
- Malleable or ductile: high plasticity
- Resistant to fracture: tough

- Some of the metals (Fe, Co, and Ni) have desirable magnetic properties.
- Opaque to visible light
- Shiny appearance

1.3. Metal Identification Methods

Metals play a prominent part in our everyday lives. Some metals do not have all of these features. For example, mercury (Hg) is a liquid at room temperature, but has a high luster, and conducts heat and electricity easily. Part of the metalworker's skill lies in the ability to identify various metal products brought to the shop.

Identifying steels

All steels look very much alike. Thus, it is difficult to identify by looking at it.

There are three methods of identification.

- Number system
- Color code
- Spark test

A. Number system,

A number system to identify steel has been developed by the American Iron and Steel Institute (AISI) and the Society of Automotive Engineering's (SAE).

The systems are based on the use of numbers composed of four digits.]

I. The first number tells the kind of steel:

- shows carbon steel
- shows nickel steel
- shows nickel-chromium steel
- shows molybdenum steel
- Show chromium steel and so on.

II. The second number in alloy steel shows the approximate percent of alloy elements.

For example, SAE 2320 shows a nickel steel with about 3% nickel.

III. The last two numbers shows the carbon content in points. For example, SAE 2320 is a nickel steel with 20 point of carbon.

B. Color code,

Most manufacturers paint each different kind of steels a different color. Some paint only the ends. Others paint all along the bar. If certain steel is painted red, it may mean that it is high carbon steel.

There are several Metal Identification Methods used to identify a piece of metal.

i. The primary method is Visual

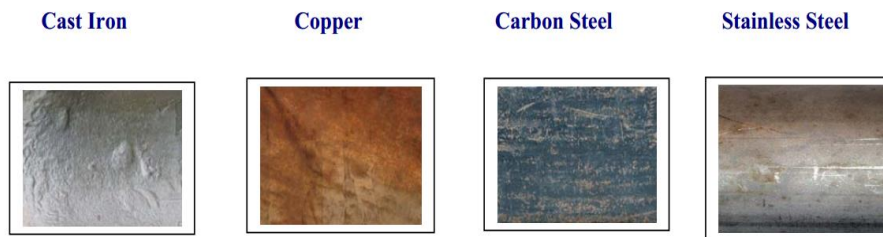


Fig.1.5.Visual Identification Metal

ii. Magnetic Test

The Magnetic Test is another method used to aid in the general identification of metals. Some metals are nonmagnetic. Generally ferrous metals are magnetic, and nonferrous metals are non-magnetic. This test is not 100 % accurate because some stainless steels are non-magnetic. In this instance, there is no substitute for experience.

iii. File Test. One simple way to check for hardness in a piece of metal is to file a small portion of it. If it is soft enough to be machined with regular tooling, the file will cut it. If it is too hard to machine, the file will not cut it.

Observe relative ease of filing

- Soft metal files easily, the file bites into the metal.
- File slides over the surface of hard metal easily.

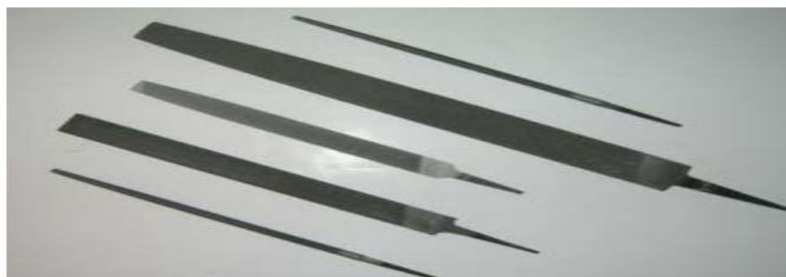


Fig.1.6. File Test

iv. Spark Test

A. **Observe** sparks at grinding wheel under subdued light

- Grinding wheel should be clean
- Pressure on metal should be medium and uniform
- Compare known samples to unknown samples

B. Observe

- Spark Color
- Length of spark lines
- Number of explosions
- Explosion shape

C. It is an accurate method of identification

- Sparks occur relative to oxidation of the heated metal particles
- Iron does not oxidize rapidly therefore the spark lines are long and fade out with cooling
- High carbon steels have a spark with short lines and many explosion

Bench Grinders or portable Grinders



Fig.1.7: Grinding Spark Test.

v. Chip Test

- The chip test is done by removing a small amount of material from the test piece with a sharp, cold chisel.
- The Chip Test shows chips from small, broken fragments to a continuous strip.
- The chip may have smooth, sharp edges or it may be coarse or fine-grained.
- The chip may have saw tooth edges.
- The chip size is important in identifying the metal.
- The ease of the chipping process is a factor in identifying the metal.

vi. Appearance Test

This test includes such things as the color and appearance of machined as well as un-machined surfaces.

SELF CHECK UNIT

PART: I

Write “TRUE” if the statement is correct and “FALSE” if it is wrong statement.

1. High carbon steel provides high hardness and strength.
2. A ferrous and non-ferrous metal contains iron in their chemical compounds.
3. The copper is one of the most common non-ferrous metals.
4. Nickel is an example of non-ferrous metal.

PART: II

Choose the correct answer for the following questions.

1. One of the following is not the classification of metals
 - A. Ferrous metals
 - B. Non-ferrous metals
 - C. Ferrous alloys
 - D. Non-ferrous alloys
 - E. None
2. The basic principle raw material for all ferrous metal is
 - A. Pig iron
 - B. Cast iron
 - C. Malleable iron
 - D. All
3. Grey pig iron contains about _____% carbon in free form
 - A. 4 %
 - B. 3%
 - C. 1%
 - D. 2%
4. Which one of the following is correct about grey cast iron and white iron?
 - A. Low in cost
 - B. Very brittle
 - C. cannot hammered
 - D. All
5. Which one of the following is not correct about low carbon steel is
 - A. Have a lower tensile strength and hardness
 - B. It is easy welded machined, and formed
 - C. It is used for most bench metal
 - D. None
6. Which one the following is not true about the properties of aluminum
 - A. Good electrical conductivity
 - B. Malleable and ductile
 - C. Low thermal conductivity
 - D. Resistance to corrosion
7. Copper is mainly used in
 - A. Making electric cables and wires for electric machinery
 - B. Motor winding
 - C. Electroplating
 - D. All
8. Bronze is commonly an alloy of
 - A. Copper and Aluminum
 - B. copper and Tin
 - C. Copper and Zinc
 - D. Tin and Zinc
9. Which one of the following is not correct about mechanical properties of materials?
 - A. Elasticity
 - B. plasticity
 - C. Density
 - D. Strength

10. Which one of the following is true about metal identification?
A. Magnetic test B. Visual test C. Spark test D. all
11. The ability of a metal to resist being pulled apart by opposing forces acting in a straight line is
A. Shear strength C. shear stress
B. Tensile strength D. Compressive strength
12. The ability of a material to resist penetration and wear by another material is named
A. Hardness C. Fatigue
B. Brittleness D. Toughness

PART: III

Match the following items from column “B” to “A” with their meanings and write your answer on the space provided. (10 %)

Column A Column B

- | | |
|----------------------|--|
| 1. Non-ferrous metal | A. steel |
| 2. Bronze | B. an alloy of CU and Zn |
| 3. Solder | C. an alloy of lead and tin |
| 4. Brass | D. an alloy of CU and Sn |
| 5. Ferrous metal | E. Aluminum |
| 6. Elasticity | F. The property of breaking without warning |
| 7. Ductility | G. A combination of high strength and medium ductility |
| 8. Malleability | H. The capacity to be rolled or hammered into thin sheets |
| 9. Toughness | I. The capacity to be drawn from a larger to a smaller Diameter of wire |
| 10. Brittleness | J. The ability of material to return to its original size, shape And dimension |

Unit Two: Test Basic Applications and Methods for Manufacturing

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Select Correct cutting tools
- Test metal to manufacturing methods
- Process engineering materials
- methods of manufacturing processes

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Identify Selecting Correct cutting tools for machinability.
- Identifying and Testing basic cast-ability, weld-ability, forge-ability and corrosion resistance of a metal
- Carry out processing engineering materials for rolling, forging, extrusion, drawing and spinning
- Identifying Experiencing methods of manufacturing processes

2.1. Introduction

2.1.1. Selecting Cutting Tools for the Machinability

The development of tool materials for cutting applications has been accomplished very largely by practical craftspeople. The tool materials which have survived and are commercially available today, are those which have proved fittest to satisfy the demands put upon them in terms of the life of the tool, the rate of metal removal, the surface finish produced, the ability to give satisfactory performance in a variety of applications, and the cost of tools made from them. In present-day machine shop practice, the vast majority of tools come from two of these 'genera' - high speed steels and cemented carbides. The other main groups of cutting tool materials are carbon (and lower alloy) steels, cast cobalt-based alloys, ceramics and diamond.

Cutting tool materials should have the following properties in order to do justice to the stresses placed on them:

- ❖ Hardness and pressure resistance,
- ❖ Bending strength and toughness,
- ❖ Edge strength,
- ❖ Inner bonding strength,
- ❖ High temperature strength,
- ❖ Oxidation resistance,
- ❖ Small propensity to diffusion and adhesion,
- ❖ Abrasion resistance,
- ❖ Reproducible wear behavior.

2.1.2. Metallurgy of Machining

Machinability

- Machinability is defined as the property of a metal, which indicates the ease with which it can be cut or removed by cutting tools.
- Machining is a cold working process in which a cutting tool forms chips, owing to a series of fractures at the surface of the metal being cut. The ease with which a material may be machined, and the type of surface finish obtained, depends on many factors. These factors include the nature and microstructure of the material, the type of cutting tool material, the design of the cutting tool, the depth and speed of cut, and the method of lubrication.
- In a metal - cutting operation, the metal just in front of the cutting tool is highly stressed and is subjected to plastic deformation.

- A soft and ductile metal will deform plastically largely and a continuous chip will be formed.
- With a less ductile, severe work hardening of the cut material, will lead to a series of fractures and give rise to the formation of small discontinuous chips.
- Some very soft and highly ductile metal spreads under tool-cutting pressures. The cutting tool tends to become buried in the work piece and a tearing, rather than a clean cutting action, occurs.
- The machine ability of a metal can be improved by any means that will decrease ductility and increase the susceptibility to fracture.

Ex. Magnesium and its alloys.

Mach inability depends on the following factors:

1. Work material
2. Tool material
3. Cutting conditions
4. Machine parameters like speed, feed

The following are the criteria to determine mach inability:

1. Tool life
2. Surface finish

The heat produced from friction affects the microstructure and property of microstructure property of metals during machining.

2.1.3. Structure of Materials

Fundamental Concepts

- ✓ Solid materials may be classified into two (**crystalline & non-crystalline**) according to the regularity with which atoms or ions are arranged with respect to one another.
- ✓ A **crystalline** material is one in which the atoms are situated in a repeating or periodic array over large atomic distances. That is, long-range order exists, such that upon solidification, the atoms will position themselves in a repetitive three-dimensional pattern, in which each atom is bonded to its nearest-neighbor atoms.
- ✓ All metals, many ceramic materials, and certain polymers form crystalline structures under normal solidification conditions.
- ✓ A **non-crystalline (amorphous)** material is that does not crystallize, this long-range atomic order is absent.
- ✓ Some of the properties of crystalline solids

Depend on the **crystal structure** of the material, the manner in which atoms, ions, or molecules are spatially arranged. There is an extremely large number of different crystal structures all having long range atomic order; these vary from relatively simple structures for metals, to exceedingly complex ones.

- ✓ To discuss crystalline structures it is useful to consider atoms as being hard spheres with well-defined radii. In this hard-sphere model, the shortest distance between two like atoms is one diameter.
- ✓ We can also consider crystalline structure as a lattice of points at atom/sphere centers. in this sense “lattice” means a three-dimensional array of points coinciding with atom positions (or sphere centers).
- ✓ **The unit cell** is the smallest structural unit or building block that can describe the crystal structure. Repetition of the unit cell generates the entire crystal.

Metallic Crystal Structures

- Metallic crystal structures are crystalline structures with relatively large numbers of nearest neighbors and dense atomic packing because they are :-
 1. Typically, made of heavy element.
 2. Metallic bonding is not directional; i.e., no restrictions as to the number and position of nearest-neighbor atoms.
 3. Nearest neighbor distances tend to be small in order to lower bond energy.
- ✓ There are three simple crystal structures are found for most of the common metals: face-centered

Cubic crystal structure (FCC), body-centered cubic crystal structure (BCC), and hexagonal close-packed crystal structure (HCP).

Table 2.1 atomic radii and crystal structures for 16 metals

<i>Metal</i>	<i>Crystal Structure^a</i>	<i>Atomic Radius^b (nm)</i>	<i>Metal</i>	<i>Crystal Structure</i>	<i>Atomic Radius (nm)</i>
Aluminum	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445
Copper	FCC	0.1278	Tantalum	BCC	0.1430
Gold	FCC	0.1442	Titanium (α)	HCP	0.1445
Iron (α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332

^a FCC = face-centered cubic; HCP = hexagonal close-packed; BCC = body-centered cubic.

^b A nanometer (nm) equals 10^{-9} m; to convert from nanometers to angstrom units (Å), multiply the nanometer value by 10.

1. Face Centered Cubic Crystal Structure (FCC):

- ✓ In FCC the atoms are located at each corners and the centers of each cube faces.

- ✓ Each face atom touches its nearest corner atom. Since corner atom is shared by only one adjacent cube (see fig. c shown below), the unit cell contains four atoms

$$((i.e\ 8\ atoms\ at\ the\ corners \times \frac{1}{8} = 1\ atom) + (6\ face\ centered\ atoms \times \frac{1}{2} = 3\ atoms) = 4\ atoms)$$

- ✓ The coordination number for the FCC crystal structure is 12; each center atom has as nearest neighbors its twelve corner atoms. The atomic packing factor for FCC 0.74, this indicates that FCC is more densely packed than BCC structure.
- ✓ Examples of metals that crystallize in the FCC structure are aluminum (Al), nickel (Ni), copper (Cu), gold (Au), silver (Ag), lead (Pb), platinum (Pt), and () iron.

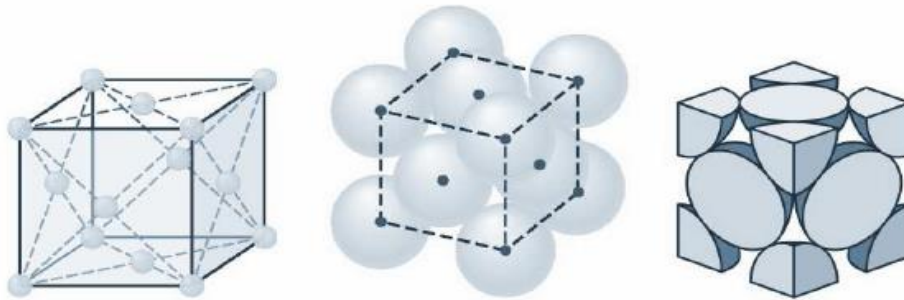


Figure: 2.1.FaceCenteredCubicCrystalStructure

2. *Body Centered Cubic Crystal Structure (BCC):*

- ✓ In BCC structure the atoms are located at each corner and at the center of the cube.
- ✓ The centre atom touches each corner atom but do not touch each other. Since each corner atom is shared by eight adjoining cubes and the atom in the center cannot be shared by any other cube, see the fig. c shown below), the unit cell of B.C.C structure contains two atoms.

$$\left(i.e\ 8\ atoms\ at\ the\ corners \times \frac{1}{8} = 1\ atm \right) + (1\ centre\ atom) = 2\ atoms$$

Examples of metals that crystallize in the B.C.C structure are chromium (Cr), tungsten (W), alpha () iron, delta() iron, molybdenum (Mo), vanadium (V), and sodium (Na).

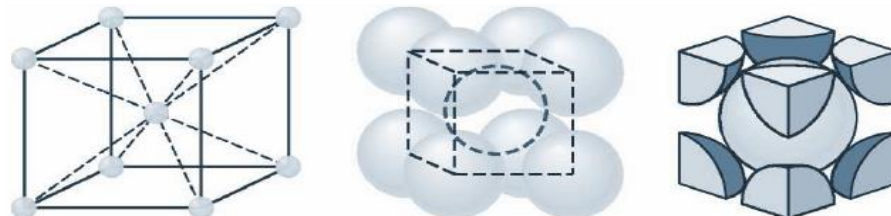


Figure: 2.2.BodyCenteredCubicCrystalStructure

- ✓ The coordination number for the BCC crystal structure is 8; each center atom has as nearest neighbors its eight corner atoms. The atomic packing factor for BCC 0.68.

3. *Hexagonal Close Packed Crystal Structure (HCP):*

- ✓ In HCP structure the top and bottom faces of the unit cell consist of six atoms that form regular hexagons and surround a single atom in the center. Another plane that provides three additional atoms to the unit cell is situated between the top and bottom planes.
- ✓ The atoms in this mid plane have as nearest neighbors atoms in both of the adjacent two planes. The equivalent of six atoms is contained in each unit cell; one-sixth of each of the 12 top and bottom face corner atoms, one-half of each of the 2 center face atoms, and all the 3 mid plane interior atoms. .
- ✓ The HCP metals include cadmium (Cd), magnesium (Mg), titanium (Ti), and zinc (Zn); some of these are listed in Table 3.1.

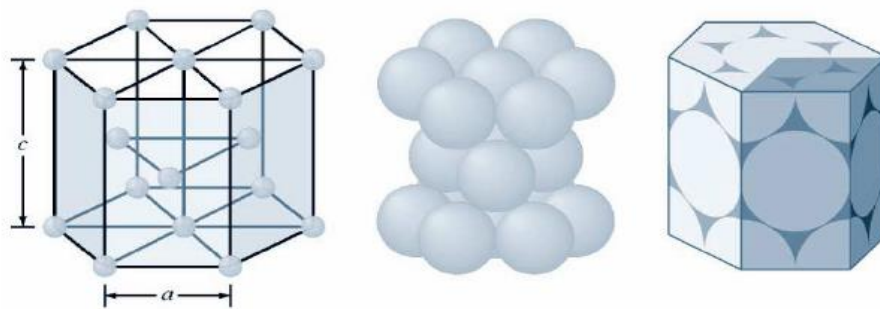


Figure: 2.3.Hexagonal Close Packed Crystal Structure (HCP):

2.1.4. Grains and Strains Boundaries

- Metallic engineering materials, however are not normally in the form of single crystals, but are composed of many small crystals are called grains. Crystallization is a process of transformation from the liquid state to the solid state by cooling. At the liquid state atoms are free to move and there is not definite order of arrangement. But during solidification, atoms will be arranged in good order.
- In the process of crystallization, solidification will start by forming very small microscopic crystals (embryo). At a time, thousands of nuclei may emerge and some of them might be dissolved. The new created nucleus might grow till the full (grain size). The growth of the nucleus can be shown using dendrite (tree like) structure
- Once the nucleus is formed it will develop. The growths of the crystals continue in the liquid metals and finally all the arms of the grains will push one another showing there will not be any more growth of grains i.e. growth of crystal will cease in case the liquid is solidified.

- Finally, the emerged nucleus will grow to the final size (grain size) and the structure of the metals will be thousands of grains.
- The boundary, which isolated one grains from the other, is called grain boundary

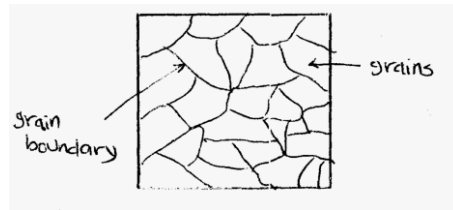


Fig.2 .4 representations of grains and grain boundary

- Whenever any metal is analyzed using microscope after being polished and etched then grain structure will be seen.

2.2. Testing For Manufacturing

Proper manufacturing process selection is related to characteristics of materials, tolerances, surface finishes obtained and cost. Many traditional manufacturing processes have been now automated and are being computer controlled to optimize the processes. Some materials can be processed at room temperature, but others require elevated temperatures, which mean additional furnaces and appropriate tooling. Some materials are soft and ductile, whereas others are hard, brittle and abrasive, thus requiring special processing techniques and tool and die materials.

Different materials have different manufacturing characteristics, such as cast ability, forgeability, workability, machinability and weld ability. Few materials have the same favorable characteristics in all categories. For example, a material that is castable or forgeable may later present problems in machining, grinding or finishing operations that may be required in order to produce a product with acceptable surface finish and dimensional accuracy.

Castability

Is defined as the property of metal, which indicates the ease with it can be casted into different shapes and sizes. Cast iron, aluminum and brass are possessing good castability.

Casting is an operation of shaping metal by pouring it in the liquid state into a mold followed by solidification. **Casting** is also a metal detail, produced as a result of pouring a metal into a mold. In some cases casting is the only method of shaping metal or alloy: when the alloy is not malleable and therefore its plastic deformation is not possible or when a large detail of complex shape is to be produced.

Weld ability

Is the capability of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service? Weld ability depends on various factors such as, nature of metals, weld designs, welding techniques, skills, etc. It has been stated that all metals are weldable but some are more difficult than another.

Steel is readily weldable (in many ways) than aluminum and copper. Copper is not easily welded due to its high thermal conductivity which makes it difficult to raise the parent metal to its melting point. It requires preheating ~300- 400°C

Forgeability

The ease with which forging is done is called forgeability. The forgeability of a material can also be defined as the capacity of a material to undergo deformation under compression without rupture. Forgeability increases with temperature. The pure metals have good malleability and thus good forging properties. The metals having high ductility at cold working temperature possesses good forgeability.

Corrosion is defined as the deterioration of a material, usually a metal, because of a reaction with its environment.

Corrosion

- ✓ A natural phenomenon that occurs over time.
- ✓ An electrochemical reaction (on metals)
- ✓ Happens at different rates with different metals and in different environments

With other metals such as copper, brass, zinc, aluminum, and stainless steel we can expect corrosion to take place, but it might take longer to develop. Unfortunately ordinary iron or steel does not form this protective layer, so must be separated from the environment by some other means. Generally protective coatings are utilized to protect metals from corrosion.

2.3. Manufacturing methods of processing engineering materials

Forming processes are those in which the shape of a metal piece is changed by plastic deformation.

Forming processes are commonly classified into hot-working and cold-working operations.

Typical forming processes of metals are:

1. Rolling
2. Extrusion
3. Forging
4. Drawing

5. Spinning

2.3.1. Rolling

Is a process of reduction of the cross-sectional area or shaping a metal piece through the deformation caused by a pair of rotating in opposite directions metal rolls? The gap between the rotating rolls is less than the thickness of the entering bar therefore a friction force is necessary in order to bite the bar and to pull it through the rolls. A metal bar passing through the rotating rolls is squeezed, and it elongates while its cross section area decreases.

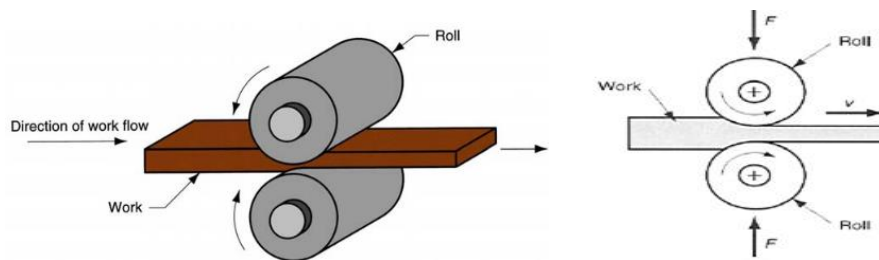


Fig.2.5Rolling process

2.3.2. Extrusion

Is a metal forming process involving shaping a metal billet (hot or cold) by forcing it through a die with\ an opening. The two possible schemes of extrusion are presented in the picture:

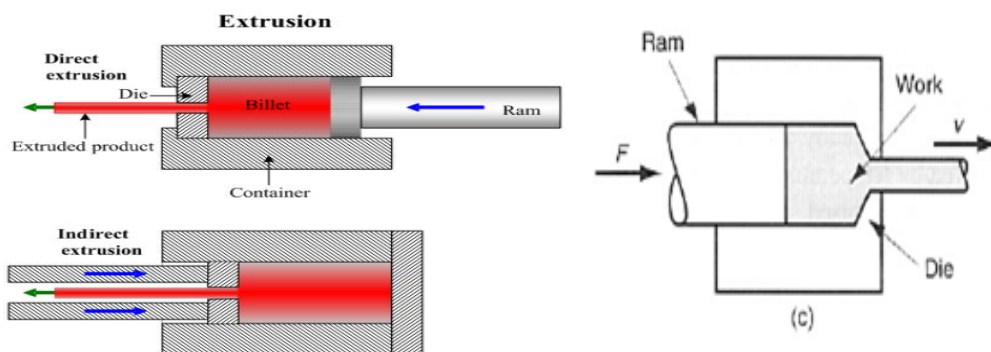


Fig.2.6Extrusion process

2.3.3. Forging

Is a compressive metal forming process, involving shaping a metal piece by hammer or press. The work piece is compressed between two opposing dies so that the die shapes are imparted to the work.

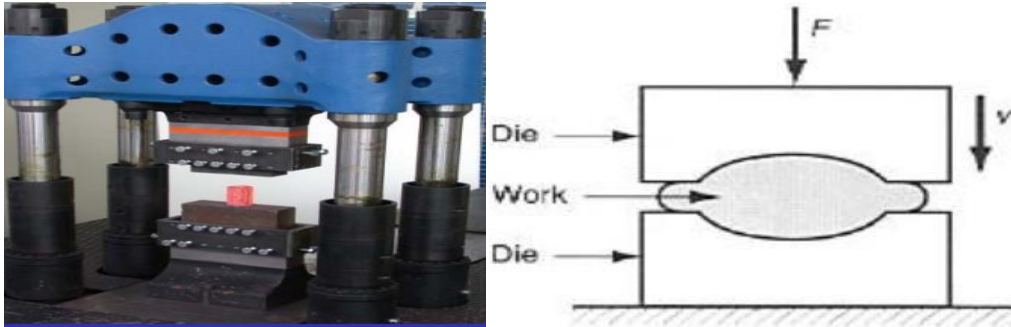


Fig.2.7forging process

2.3.4. Drawing

The diameter of a wire or bar is reduced by pulling it through a die opening (bar drawing) or a series of die openings (wire drawing).

Is a metal forming process involving pulling a work piece (cold or hot) through a die providing reduction of the cross section of the work piece.

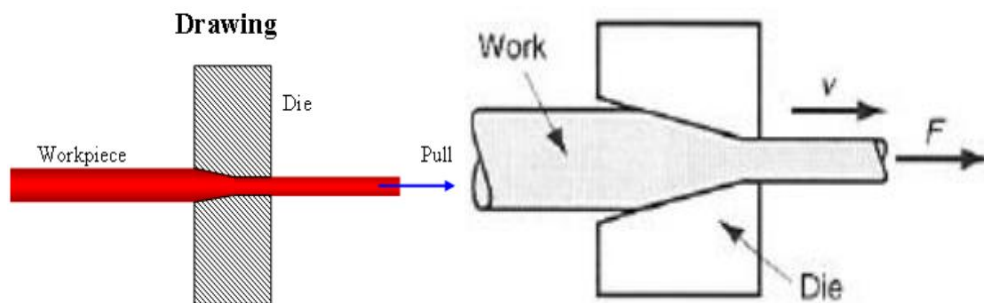


Fig.2.8drawing process

Drawing is the process most commonly used to make wires from round bars; this process is very similar to extrusion, except that instead of pressure from the back end, in drawing, the wire is pulled from the side where it emerges from the circular die. Dies are made of especially hardened tool steels, or tungsten carbide. Diamond dies are used for drawing very fine wires.

2.3.5. Spinning

Is used to make tubular (axis-symmetric) parts by fixing a piece of sheet stock to a rotating form (mandrel). Rollers or rigid tools press the stock against the form, stretching it until the stock takes the shape of the form. Spinning is used to make rocket motor casings, missile nose cones, satellite dishes and metal kitchen funnels.



Fig.2.9spinning process

Typical shapes produced by the conventional spinning process. Circular marks on the external surfaces of components usually indicate that the parts have been made by spinning, such as aluminum kitchen utensils and light reflectors.

2.4. Experiencing Methods of Manufacturing

2.4.1. Hot working: -

Homogenizes and refines the crystallographic structure of the material and thus ultimately improves its strength and toughness

2.4.2. Cold working: -

Increases its strength and hardness, dimensional tolerances and improves surface finish. Hot operations are carried out at elevated temperatures and, consequently yield a hot-finished product showing a relatively low level of stress. While cold forming operations are confined to ambient temperature and are characterized by a high energy requirement.

2.4.3. Thermal processes

Thermal processing of materials refers to manufacturing and material fabrication techniques that are strongly dependent on the thermal transport mechanisms. Materials processing is one of the most important and active areas of research in heat transfer today. Heat transfer is extremely important in a wide range of materials processing techniques such as crystal growing, casting, glass fiber drawing, chemical vapor deposition, spray coating, soldering, welding, polymer extrusion, injection molding, and composite materials fabrication.

Self-Check –UNIT- II

Part: I

Choose the correct answer for the following questions.

- The last step of manufacturing process is
A. Machining B. Casting C. Deformation D. Polishing
- Which of the following is deformation process?
A. Rolling B. Extrusion C. Forging D. All
- _____ is a process of reduction of the cross-sectional area or shaping a metal piece through the deformation caused by a pair of rotating in opposite directions metal rolls.
A. Rolling B. Extrusion C. Forging D. Casting
- _____ is a metal forming process involving shaping a metal billet (hot or cold) by forcing it through a die with an opening.
A. Rolling B. Extrusion C. Forging D. Casting
- _____ is a compressive metal forming process, involving shaping a metal piece by hammer or press.
A. Rolling B. Extrusion C. Forging D. Casting
- _____ is a metal forming process involving pulling a work piece (cold or hot) through a die providing reduction of the cross section of the work piece.
A. Rolling B. Extrusion C. Drawing D. Casting
- _____ is manufacturing processes by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify.
A. Rolling B. Extrusion C. Forging D. Casting

Part: II

Directions: Answer all the questions listed below.

- State at least five properties cutting tool materials.
- Write the process in which have proved fittest to satisfy the demands put upon them in terms of the life of the tool
- Briefly define the following property of metals in manufacturing process:
 - Castability
 - Weldability
 - Forgeability
- Briefly define the following basic methods of engineering materials processing:
 - Rolling

- b. Forging
- c. Extrusion
- d. Drawing
- e. Spinning

5. Briefly define the following methods of manufacturing:

- a. Hot working
- b. Cold working
- c. Thermal processes

Unit Three: Perform Basic Common Metal Tests

This unit to provide you the necessary information regarding the following content coverage and topics:

- metal tests
- Compare and record test results.

This guide will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Performing metal Test property
 - ✓ Tensile strength
 - ✓ Hardness
 - ✓ Shear stress
 - ✓ Impact resistance
 - ✓ Spark and bend tests
- Comparing and recording material test results

3.1. Introduction

We select materials for many components and applications by matching the properties of the material to the service conditions required of the component.

The first step in the selection process requires that we analyze the application to determine the most important characteristics that the material must possess. Should the material be strong, or stiff, or ductile? Once we have determined the required properties, we can select the appropriate material.

Some of the purposes for the testing of material are:

- *To determine the quality of a material.*
- *To determine such properties as strength, hardness, ductility, etc*
- *To check for defects within a material or in a finished component.*

Testing is conducted using a material sample. The results of testing are assumed to apply to all material from which the sample is taken.

Testing can be destructive or non-destructive:

- **In destructive testing**, the test piece is destroyed and is no longer usable.
- **In non- destructive testing** the test piece is not destroyed and can, therefore, be used in a finished product.

Testing Of Metals

Metal testing is accomplished for the purpose of for estimating the behavior of metal under loading (tensile, compressive, shear and impact etc.) of metal and for providing necessary data for the product designers, equipment designers, tool and die designers and system designers.

3.1.1. Tensile test

A tensile test is carried out on standard tensile test specimen in universal testing machine.

Fig. 3.1 shows a schematic set up of universal testing machine reflecting the test specimen gripped between two cross heads. Fig. 3.2 shows the stress strain curve for ductile material. Fig. 3.3 shows the properties of a ductile material.

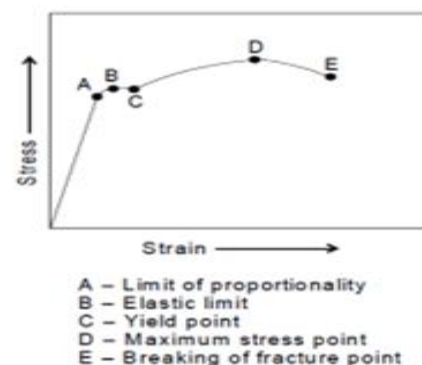
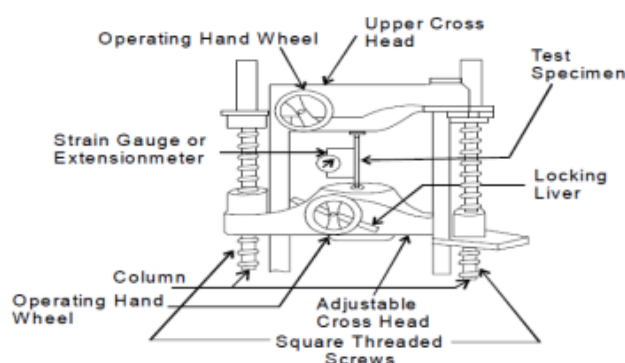


Fig.3.1. universal testing machine**Fig.3.2.stress strain curve**

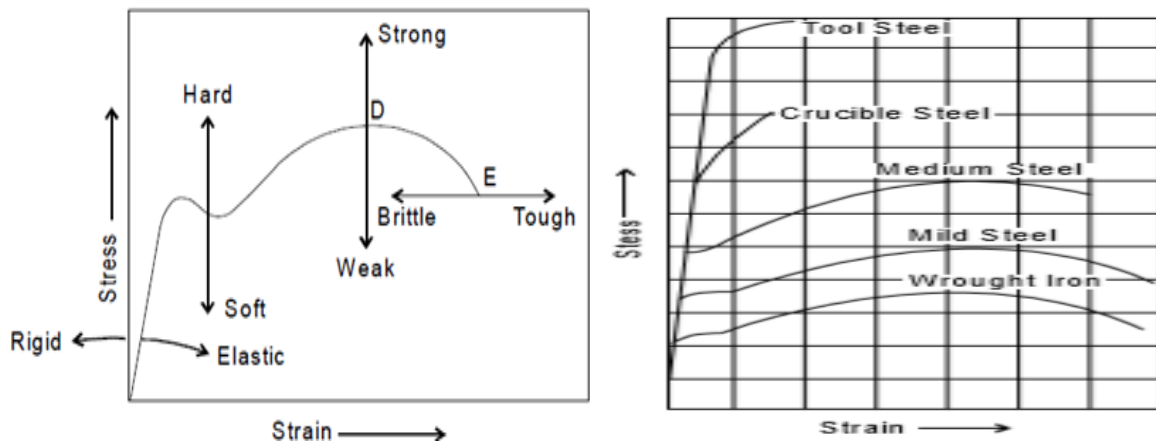


Fig.3.3.Properties of ductile metals

Engineering stress and engineering strain are defined by the following equations.

$$\text{Engineering Stress} = F/A_0$$

$$\text{Engineering Strain} = (l - l_0)/l_0$$

Where A_0 = Original cross - sectional area of the specimen before the test begins

l_0 = the original distance between the gage marks.

l = the distance between 1; he; age marks after the force is applied.

F =force

The stress - strain curve is used to record the results of a tensile test.

The following information is determined from the tensile test.

1. **Tensile strength (ultimate tensile strength):** t maximum load sustained by the test - piece.

$$\text{Tensile strength} = \text{Maximum load applied} / \text{Original cross - sectional area.}$$

2. **Yield point:** there is a sharp discontinuity in he stress-strain diagram and the material will suddenly yield with little or no increase in the applied load.

$$\text{Yield strength} = \text{applied load at the yield point} /$$

$$\text{Original cross - sectional area}$$

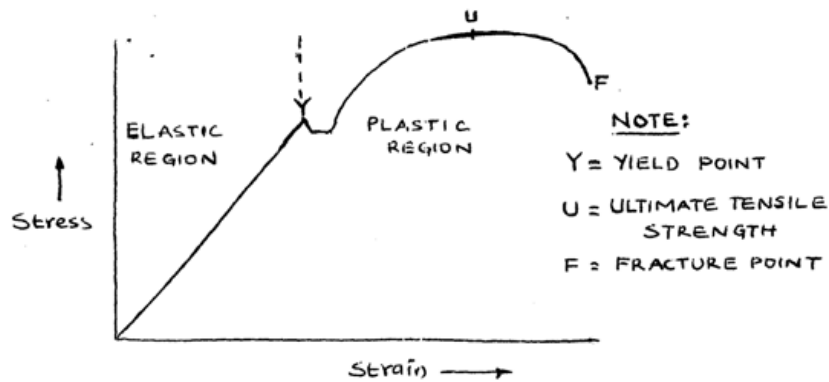


Fig.3.4 typical stress-strain curve

- The standard diameter is approximately **12.8 mm (0.5 in.)**, whereas the reduced section length should be at least four times this diameter; **60mm (2 in.)** is common. the standard value is **50 mm (2.0 in.)**.

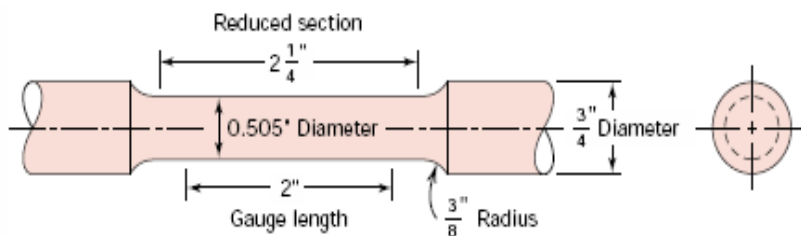


Fig.3.5 Astandard tensile specimen with circular cross section

- The specimen is mounted by its ends into the holding grips of the testing apparatus (Figure 3.5). The tensile testing machine is designed to elongate the specimen at a constant rate, and to continuously and simultaneously measure the instantaneous **applied load (with a load cell)** and the resulting **elongations (using an extensometer)**.
- A stress–strain test typically takes several minutes to perform and is destructive; that is, the test specimen is permanently deformed and usually **fractured**.

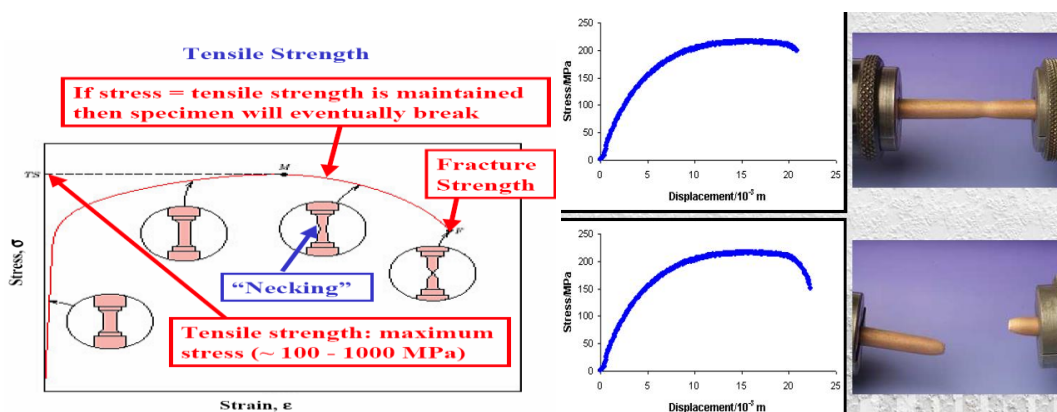


Fig.3.6 Aresponse of metal during tensile test

3.1.2. Compression Test

Compression test is reverse of tensile test. This test can also be performed on a universal testing machine. In case of compression test, the specimen is placed bottom crossheads.

After that, compressive load is applied on to the test specimen.

This test is generally performed for testing brittle material such as cast iron and ceramics etc.

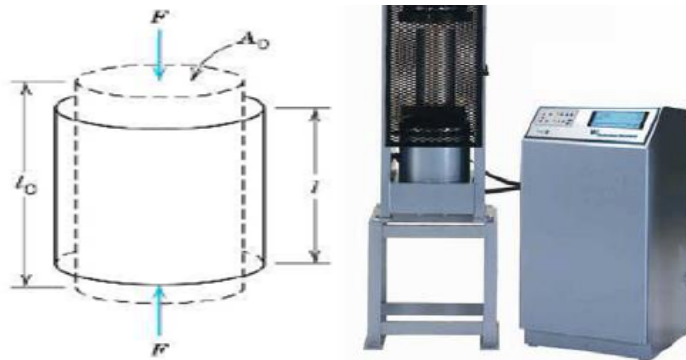


Fig.3.7Compressive Tests of Standard Test Specimen and machine

3.1.3. Hardness test

- The hardness test measures the resistance to penetration of the surface of a material by a hard object. Indentation is produced in the component by applying a constant load on a specific indenter in contact with the surface of the component for a fixed time.

A variety of hardness tests have been devised, but the most commonly used are: **Rockwell test and the Brinelltest.**

Brinell test: In this test a hardened steel ball of 10mm diameter is pressed in to the surface of a specimen for a period of 15 seconds under the action of a static load. The size of the indentation made is measured, using a microscope and the hardness of the material is given by:

$$\text{Brinell hardness number (HB)} = (\text{Applied load} / \text{Surface area of indentation})$$

Indentation Hardness Measurement

- A load is applied by pressing the indenter at right angles to the surface being tested.
- The three commonly used indentation hardness tests is:
 - Brinell Hardness Test
 - Rockwell Hardness Test
 - Vickers Pyramid Hardness Test

a) Brinell Hardness Test

- In the Brinell hardness test a hardened steel or tungsten carbide ball of diameter 10mm Dis load of 500 to 3000 kg forced in to the surface of the material for 10 to 30 seconds.

The hardness is then calculated from the diameter of the indentation left in the surface, d , following removal of the indenter.

- For Brinell numbers less than 450 the steel ball can be used.
- For Brinell number values over 450 the tungsten carbide ball should be used.
- The Brinell number is defined as: Brinell hardness test: sphere indenter of D , load F , measure the size of indentation d

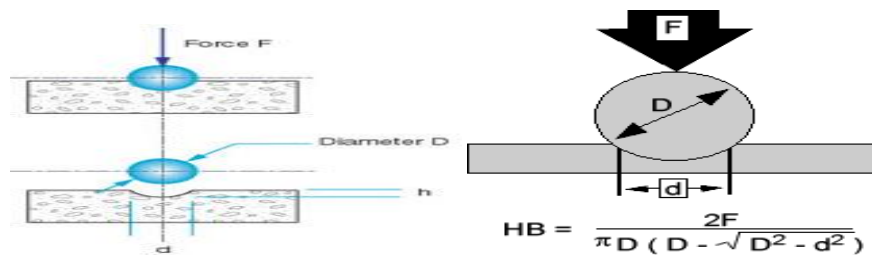


Fig.3.8 Brinell hardness Test sphere indenter

Brinell Test Method

1. The indenter is pressed into the sample by an accurately controlled test force.
2. The force is maintained for a specific dwell time, normally 10 - 15 seconds.
3. After the dwell time is complete, the indenter is removed leaving a round indent in the sample.
4. The size of the indent is determined.
5. The Brinell hardness number is a function of the test force divided by the curved surface area of the indent.

Table: 3.1: Brinell hardness Measurements

<i>Material</i>	<i>Aluminum</i>	<i>Brass</i>	<i>Mild Steel</i>
P kg	15625 kg	15625 kg	15625 kg
D mm	2.5 mm	2.5 mm	2.5 mm
d mm	451.83 um	432.44 um	329.00 um
BHN kg/mm ²	96.7	105.6	189.8
	$HB = \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})}$		

a. Rockwell Hardness Test

Rockwell Hardness Test

- In the Rockwell hardness test either a 120° conical diamond (C scale) or a steel ball (B scale) indenter is pushed into the surface of the test piece with a load of.

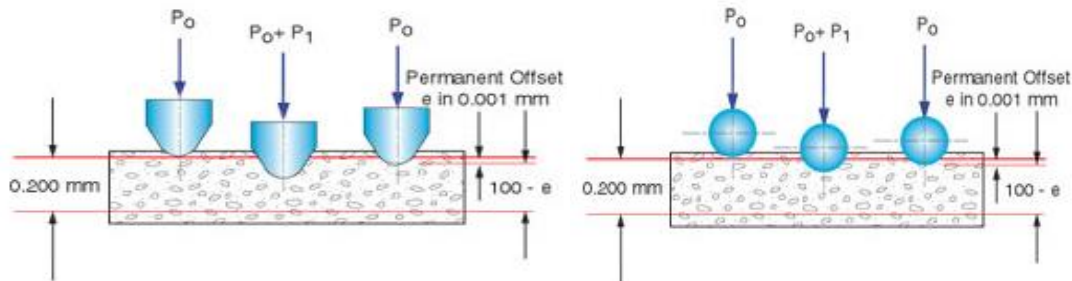


Fig.3.9 Rockwell C Diamond Indenter Test and Rockwell B Indenter test

Principle of the Rockwell Test

- 1) Select image to enlarge The indenter moves down into position on the part surface
- 2) A minor load is applied and a zero reference position is established
- 3) The major load is applied for a specified time period (dwell time) beyond zero
- 4) The major load is released leaving the minor load applied

The resulting Rockwell number represents the difference in depth from the zero reference position as a result of the application of the major load.

Rockwell hardness test:

Measures the depth of indentation

Table: 3.2: Brinell hardness Measurements

Material	Aluminum	Brass	Mild Steel
Specimen	Scale *	Scale *	Scale *
1	56.8	70.2	82.9
2	54.3	66.6	88.0
3	56.4	69.7	86.3
HR	55.83	68.7	85.73

b. Vickers Hardness Test

- Vickers hardness test: square based pyramid diamond indenter, load F , measure the size of indentation d .

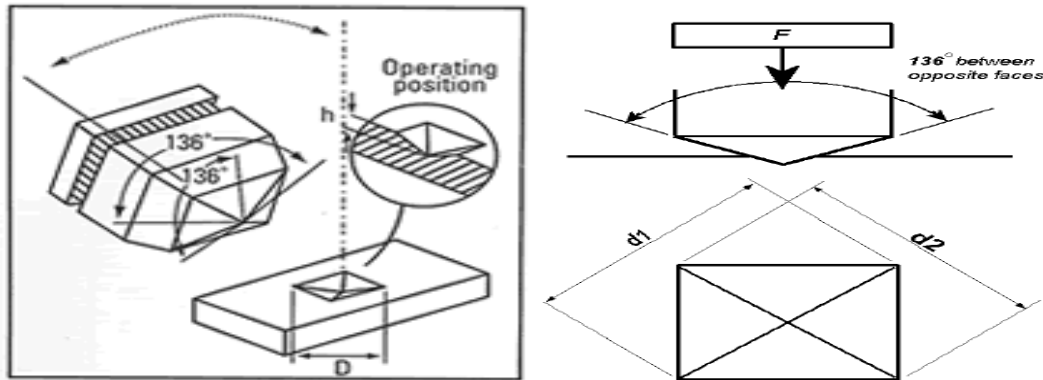


Fig.3.10VickersHardnessTest

VickersTestMethod

All Vickers ranges use a 136° pyramidal diamond indenter that forms a square indent.

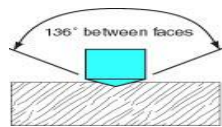


Fig.3.11Vickers ranges

- 1) The indenter is pressed into the sample by an accurately controlled test force.
- 2) The force is maintained for a specific dwell time, normally 10 – 15 seconds.
- 3) After the dwell time is complete, the indenter is removed leaving an indent in the sample that appears square shaped on the surface.
- 4) The size of the indent is determined optically by measuring the two diagonals of the square indent.



Fig.3.12size of the indent

- 5) The Vickers hardness number is a function of the test force divided by the surface area of the indent
- 6) The average of the two diagonals is used in the following Formula to calculate the Vickers hardness

$$HV = 1.854 \frac{F}{d^2} \text{ approximately}$$

3.1.4. Impact test

- In order to select a material to withstand a sudden intense load, we must measure a material's resistance to failure in an impact test.
- The test involves measuring the energy consumed in breaking a notched specimen when hammered by a swinging pendulum.
- The energy absorbed can be calculated by measuring the change in the potential energy of the pendulum before and after breaking the specimen ($M \cdot g \cdot \text{difference in height}$).
- ASTM has standardized the impact test with two testing approaches: the Charpy and the Izod. The two tests differ mainly in how the specimen is support during the impact loading. In the Charpy test the specimen is supported as a **simple-beam** while in the Izod test the specimen is supported as a **cantilever-beam**
- Both tests use square bar specimens with machined notches taking the shape of the letter V hence giving other common names for these tests as Charpy V-notch (CVN) or Izod V-notch.
- The hammer is released from fixed height h and Strikes the specimen; the energy expended in fracture is reflected in the difference between h and the swing height h' .

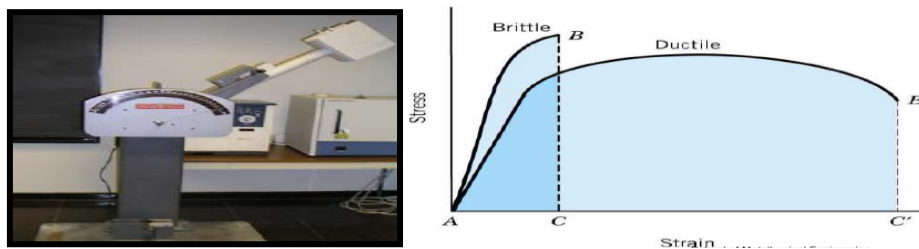


Fig.3.13:Impact test machines and phase diagram curve

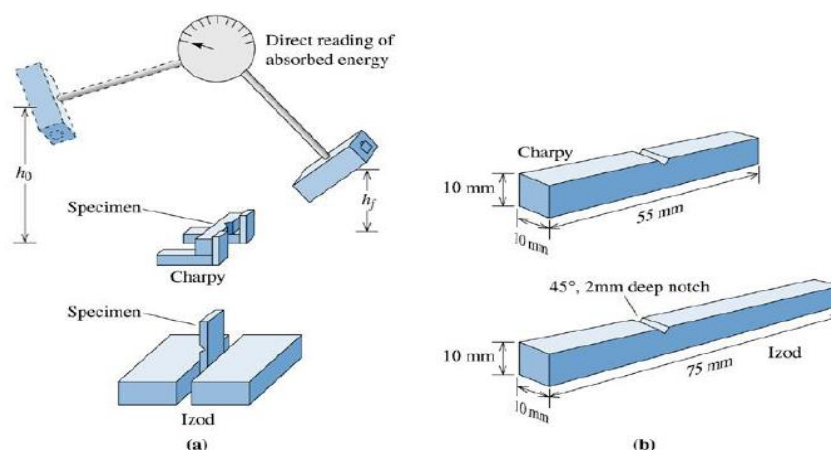


Fig.3.14: Specimen used for Charpy and Izod impact tests, & A schematic drawing of an impact testing apparatus.

3.1.5. Creep Test

- ✓ If we apply a stress to a material at a high temperature, the material may stretch and eventually fail, even though the applied stress is less than the yield strength at that temperature.
- ✓ Creep is time-dependent permanent deformation of a material under constant loading at high temperatures.
- ✓ The temperature at which a material starts to creep depends on its melting point. It is found that creep in metals starts when the temperature is > 0.3 to $0.4 T_m$ (the melting temperature in Kelvin).
- ✓ For example, creep of carbon steels is important at temperatures above $500\text{ }^{\circ}\text{C}$, aluminum starts to creep above $100\text{ }^{\circ}\text{C}$, and since lead is a low melting metal ($T_m = 600\text{ K}$) it creeps even at room temperature.

The main objective in a creep test is to measure how a given metal or an alloy will perform under constant load, at elevated temperatures

Creep Test

- 1) Usually a tensile bar
- 2) Dead load applied
- 3) Strain is plotted with time
- 4) Test usually ends with rupture (failure)

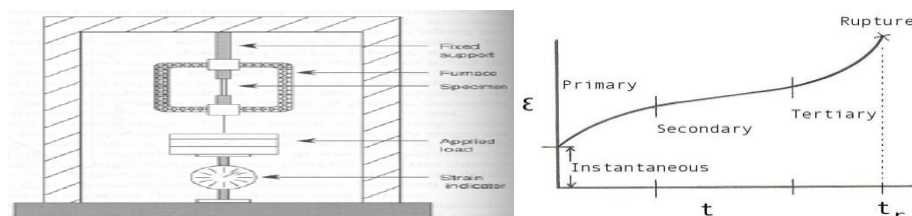


Fig.3.15: Creep test and Classical Creep Curve

- ✓ Figure 3.14 is a schematic representation of the typical constant load creep behavior of metals. Upon application of the load there is an instantaneous deformation, which is mostly elastic. The resulting creep curve consists of three regions, each of which has its own distinctive strain–time feature.
- ✓ *Primary* or *transient creep* occurs first, typified by a continuously decreasing creep rate; that is, the slope of the curve diminishes with time. This suggests that the material is experiencing an increase in creep resistance or strain hardening thus deformation becomes more difficult as the material is strained.

3.1.6. Torsion Test

- ✓ A torsion test is an experiment in which a torque is applied to a sample.
- ✓ The amount of plastic deformation that can be introduced in the samples in this type of tests is much larger than in tensile tests (necking) or in compression tests (barreling, increase in section).
- ✓ It directly gives information about the material behavior under shearing and information about behavior under tension can be easily extracted.

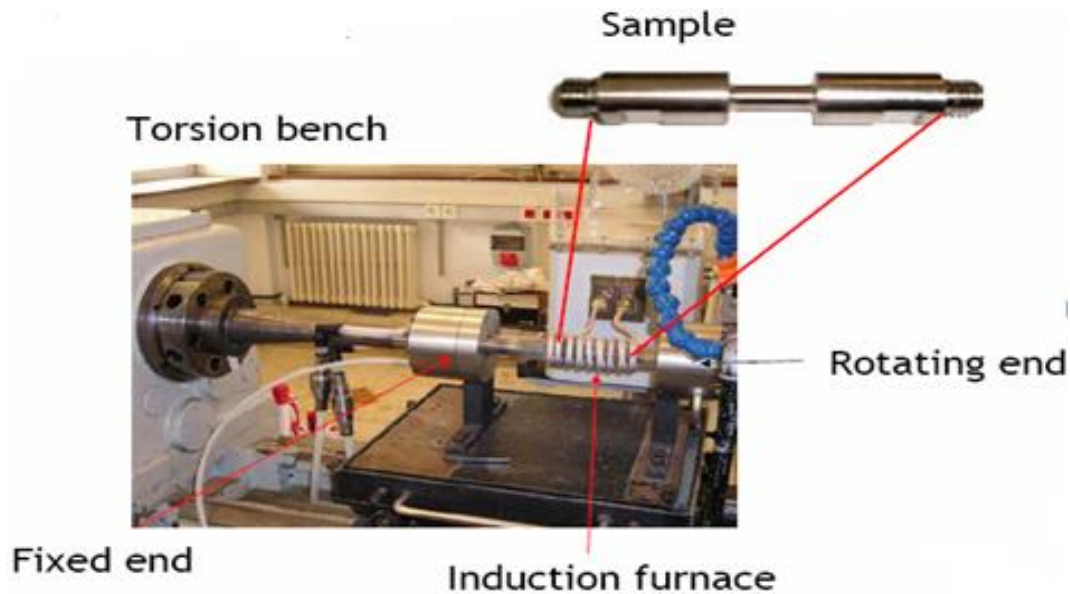


Fig.3.16: experimental set up of torsion

3.1.7. Bending Test:-

Keep the bending table on the lower table in such a way that the central position of the bending table is fixed in the central location value of the lower table. The bending supports are adjusted to required distance.

Stuffers at the back of the bending table at different positions. Then place the specimen on bending table & apply the load by bending attachment at the upper stationary head. Then perform the test in the same manner as described in tension test.

3.1.8. Shear Test:-

Place the shear test attachment on the lower table, this attachment consists of cutter. The specimen is inserted in roles of shear test attachment & lift the lower table so that the zero is adjusted, then apply the load such that the specimen breaks in two or three pieces. If the specimen breaks in two pieces then it will be in angle shear, & if it breaks in three pieces then it will be in double shear.

A)

B)

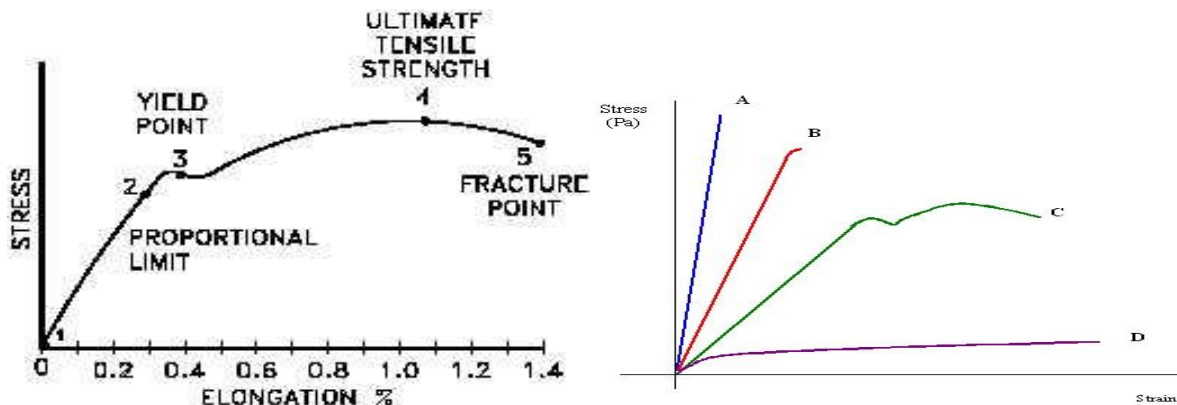


Fig.3.17: A) Stress-strain graph of Mild Steel and B) Stress-strain graphs of different materials.

- Curve **A** shows a **brittle** material. This material is also strong because there is little strain for a high stress. The fracture of a brittle material is sudden and catastrophic, with little or no plastic deformation. Brittle materials crack under tension and the stress increases around the cracks. Cracks propagate less under compression.
- Curve **B** is a **strong** material which is not ductile. Steel wires stretch very little, and break suddenly. There can be a lot of elastic strain energy in a steel wire under tension and it will “whiplash” if it breaks. The ends are razor sharp and such a failure is very dangerous indeed.
- Curve **C** is a **ductile** material
- Curve **D** is a **plastic** material. Notice a very large strain for a small stress.

The material will not go back to its original length.

3.1.9. Spark Test

You perform the spark test by holding a sample of the unidentified material against an abrasive wheel and visually inspecting the spark stream. This test is fast, economical, convenient, easily accomplished, and requires no special equipment.

The sparks (or lack of sparks) given off can help you identify the metal. Features you should look for include:

- ✓ Length of the spark stream
- ✓ Form of the sparks
- ✓ Colour of the sparks

Table: 3.3 metal identification by spark test either a portable or stationary grinder

Metal Identification by Spark Test with either a portable or stationary grinder.

METAL	COLOR of Stream		Stream		Spurts	
	NEAR WHEEL	NEAR END	Volume	Length in/mm	Quantity of	Nature of
Wrought Iron	Straw	White	Large	65/1651	Very Few	Forked
1020 steel	White	White	Large	70/1778	Few	Forked
Carbon Tool Steel	White	White	(M)Large	55/1397	Very Many	Fine repeating
Gray Cast Iron	Red	Straw	Small	25/635	Many	Fine repeating
White Cast Iron	Red	Straw	Very small	20/508	Few	Fine repeating
Annealed Malleable cast	Red	Straw	Moderate (M)	30/762	Many	Fine repeating
High Speed steel	Red	Straw	Small	60/1524	Very Few	Forked
Manganese steel	White	White	(M)Large	45/1143	Many	Fine repeating
Stainless	Straw	White	Moderate (M)	50/1270	Many	Fine repeating
Tungsten Cr Die steel	Red	Straw	Small	35/889	Many	Fine repeating
Nitrided nitralloy	White	White	Large curved	55/1397	Moderate	Forked
Stellite	Orange	Orange	Very small	10/254	none	
Cemented tungsten carbide	Light Orange	Light Orange	Extra small	2/50.8	none	
Nickel	Orange	Orange	Very small	10/254	none	
Copper, brass, Aluminum			none		none	

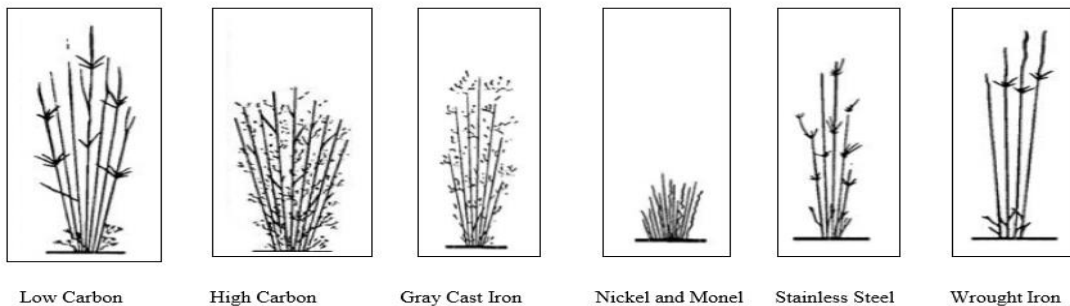


Fig.3.17: Metal Identification by Spark Test Either A Portable or Stationary Grinder

3.2. Nondestructive Testing Methods

It is examination of an object in any manner which will not impends its future use. The objects of Non - destructive testing:

- 1. Improved productivity:** Defective material may be isolated at an early stage in production so that further manpower is not frustrated in future processing.
- 2. Increased serviceability:** Here NDT is used to detect faults are likely to reduce the service life of the finished component.

Some Types of Nondestructive Testing Method

- ❖ Magnetic Particle
- ❖ Liquid Penetrant
- ❖ Eddy Current
- ❖ Radiography
- ❖ Ultrasonic
- ❖ Acoustic Emission

3.2.1. Magnetic Particle Testing

Magnetic testing is a highly sensitive method for the detection of surface defect and some sub-surface effect in ferromagnetic metals and alloys.

- ✓ *The component under test is magnetized.*
- ✓ *Use magnetic iron oxide powder in air suspension or suspension of fine powder in a liquid, such as kerosene.*

Near a defect some of the magnetic lines of force will pass through the air, and any small magnetic particles on the surface of the metal will tend to collect in this region and indicate the presence of the defect. Distortion in a magnetic field which may be induced (induct) a defect.

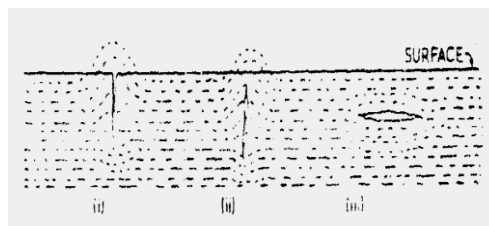


Fig.3.18 Magnetic particle testing

3.2.2. Liquid penetrates

Inspection based on the use of liquid penetrates can be employed to detect cracks and other defects occurring at the surface of a material.

The penetrant is a low-viscosity fluid with the ability to be drawn in to any small crack or other defect.

- ❖ The component under test is soaked in penetrant and, after allowing sufficient time for penetration of defects, excess penetrant is removed from the surface.

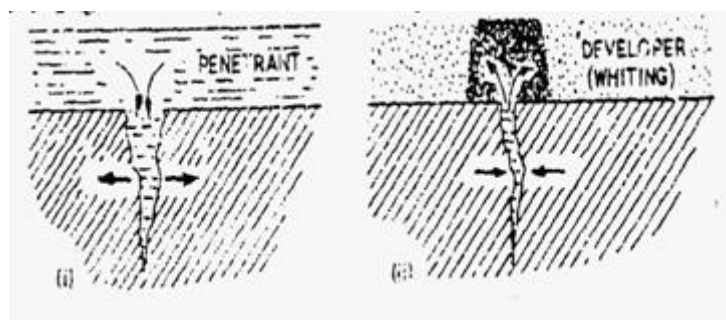


Fig.3.19 Liquid penetrates testing

- ❖ The surface is then 'developed' by coating it with a fine layer of an absorbent powder. This acts as a blotter and draws the penetrant out from the defect.
- ❖ Penetrants may either be of the dye type or the fluorescent type. In the case of red-dye penetrants, red marks on the developed surface will indicate the presence of defects.

- ❖ If a fluorescent penetrant is used the developed surface must be viewed under ultra-violet light to reveal the presence of defect

3.2.3. Eddy - Current Testing

In this method a primary magnetic field is generated by an alternating current passing through a solenoid. This field induces eddy currents in the surface the metal under test. These flow in concentric paths normal to the direction of the primary field. The eddy currents in turn generate their own magnetic field which is in opposition to the primary field which is consequently modified so that an impedance change occurs in the solenoid circuit .Cracks or other faults in or near the test surface or other faults in or near the test suit will deflect the eddy currents.



Fig.3.20 Eddy - Current Testing machine

3.2.4. Ultrasonic Testing

- ✓ Ultrasonic techniques highly suitable for the detection of sub - surface defects in materials. The upper limit of sound frequency audible to the human ear is about 15KHZ. Above this frequency were in the ultrasonic range. For metals inspection, frequencies in the range from 0.5 to 15 MHZ are generally used.
- ✓ When an ultrasonic wave passes from one medium to another, some reflection takes place. (This reflection can approach 100 per cent at a metal to - air interface.) any defect will therefore act as a reflecting surface for ultrasonic waves.
- ✓ Ultrasonic waves are produced by stimulating a piezoelectric crystal in to a high frequency vibration by an electrical impulse. Because ultra - sound is quickly dissipated in air, there must be close coupling through a high density medium between the crystal face and the surface of the metal under test.
- ✓ This is achieved by having a film of oil on the metal surface.
- ✓ The time of pulse transmission, and the reflected echo signals are displayed on the cathode ray tube.



Fig.3.21: Ultrasonic Testing

3.2.5. X-ray methods of Radiography

- ✓ X - Rays are produced when high - velocity electrons strike a metal target.
- ✓ Hence the basic requirements for producing a beam of x-rays are.
 - i. *a suitable source of electors*
 - ii. *Some means of accelerating, these electrons to a high velocity.*
 - iii. *a suitable metal target*
- ✓ Like light, x -rays travel in straight lines and can therefore be used to produce a reasonably sharp image on a photographic film.



Fig.3.22: X-ray machines

3.3. Record and report test results of materials

Reporting, recording and filing test reports and documentation included in this section.

Recording: is the act or process of storing sounds or images on tape or a disk.

Reporting: give a spoken or written account of something that one has observed, heard, done, or investigated present oneself formally as having arrived at a particular place or as ready to do something.

3.3.1. Benefits of Reporting

Reporting is the necessary prerequisite of analysis; as such, it should be viewed in light of the goal of making data understandable and ready for easy, efficient and accurate analysis.

- ✓ Collecting and presenting data ready to be analyzed, including historical data that can be tracked over time
- ✓ Empowering end-users with the knowledge to become experts in their area of business
- ✓ Having the underlying figures to back up actions and explain decisions.

Self-Check –UNIT- III

Part: I

Write “TRUE” if the statement is correct and “FALSE” if it is wrong statement. (%)

1. Materials are tested to determine what properties they possess and to what degree.
2. In non- destructive testing the test piece is not destroyed and can, therefore, be used in a finished product.
3. Compression test is reverse of tensile test.
4. Hook’s law states that when a material is loaded within elastic limit (up to proportional limit), stress is proportional to strain.

Part: II

Fill in the blank space

1. _____: is the act or process of storing sounds or images on tape or a disk.
2. _____: give a spoken or written account of something that one has observed, heard, done, or investigated present oneself formally as having arrived at a particular place or as ready to do something.

Part: III

Short Answer Questions

1. Write the purpose of metal testing?
2. What is the difference between destructive testing and non-destructive testing?
3. Mention at least three metal hardness testing machine?
4. List at least three destructive and non-destructive testing machines?

Learning Activity Performance

Operation Sheet 1

Material: ASTM E10

Procedure:

- 1) Using a large block of 1018 Cold Rolled Steel, perform five Brinell hardness (5) tests and five (5) Rockwell Hardness tests.
- 2) When applying the load in the Brinell hardness test, ensure that the load is applied and released uniformly without bouncing the load and that the load is applied for fifteen (15) seconds.

To be included in the laboratory report:

- 1) Compute the Brinell hardness number (BHN):
- 2) Compare this value with the expected Brinell hardness number using the table on the next page and the Rockwell Hardness number.

Metals Test Data

Brinell hardness Test

(1). 1018 Cold Rolled Steel (large block)

Diameter of indented surface:

- (1) _____
- (2) _____
- (3) _____
- (4) _____
- (5) _____

Average: _____

Operation Sheet 2

Date: _____

Name: _____

I.D NO: _____

Objective: At the end of the activity, the Learner should be able to:

conduct a tensile test on a mild steel specimen and determine the following:

- **Limit of proportionality**
- **Elastic limit**
- **Yield strength**
- **Ultimate strength**

- **Young's modulus of elasticity**
- **Percentage elongation**
- **Percentage reduction in area.**

Apparatus: -

- a. Universal Testing Machine (UTM)
- b. Mild steel specimens
- c. Graph paper
- d. Scale
- e. Vernier Caliper

Procedure:-

1. Measure the original length and diameter of the specimen. The length may either be length of gauge section which is marked on the specimen with a preset punch or the total length of the specimen.
2. Insert the specimen into grips of the test machine and attach strain-measuring device to it.
3. Begin the load application and record load versus elongation data.
4. Take readings more frequently as yield point is approached.
5. Measure elongation values with the help of dividers and a ruler.
6. Continue the test till Fracture occurs.
7. By joining the two broken halves of the specimen together, measure the final length and diameter of specimen.

Observation:-

A) Material:

B) Original dimensions

Length = -----

Diameter = -----

Area = -----

-

C) Final Dimensions:

Length = -----

Diameter = -----

Area = -----

Observation Table:-

S/No	Load (N)	Original Gauge length	Extension (mm)	Stress=Load/Area (N/mm ²)	Increase in length Strain= Original length
1					
2					
3					
4					
5					

Lab Test 1

Aim: - Hardness Test of Mild Steel.

Object: - To conduct hardness test on mild steel, carbon steel, brass and aluminum specimens.

Apparatus: - Hardness tester, soft and hard mild steel specimens, brass, aluminum etc.

Procedure:-

1. Place the specimen securely upon the anvil.
2. Elevate the specimen so that it come into contact with the penetrate and put the specimen under a preliminary or minor load of 100 ± 2 N without shock
3. Apply the major load 900N by loading lever.
4. Watch the pointer until it comes to rest.
5. Remove the major load.
6. Read the Rockwell hardness number or hardness scale.

Observation Table:-

S/NO	Specimens	Reading(HRC/HRB)			Mean
		1	2	3	
1	Mild Steel				HRB =
2	High Carbon steel				HRC =
3	Brass				HRB =
4	Aluminum				HRB =

Result: - The hardness of the metal is found to be

- i) **Hard steel**
- ii) **Unhardened Steel**

Precaution:-

1. Brielle test should be performed on smooth, flat specimens from which dirt and scale have been cleaned.
2. The test should not be made on specimens so thin that the impression shows through the metal, nor should impression be made too close to the edge of a specimen.

Lab test-2

To plot the stress strain curve and determine the following.

- I. Limit of proportion = $\frac{\text{Load at limit of proportionality}}{\text{Original area of cross-section}} = \dots \text{ N/mm}^2$
 - II. Elastic limit = $\frac{\text{load at elastic limit}}{\text{Original area of c/s}} \dots \text{ N/mm}^2$
 - III. Yield strength = $\frac{\text{Yield load}}{\text{Original length of cross section}} = \dots \text{ N/mm}^2$
 - IV. Ultimate strength = $\frac{\text{Maximum tensile load}}{\text{Original length of cross section}} = \dots \text{ N/mm}^2$
 - V. Young's modulus, E = $\frac{\text{stress below proportionality limit}}{\text{Corresponding strain}} = \dots \text{ N/mm}^2$
 - VI. Percentage elongation = $\frac{\text{Final length (at fracture) - original length}}{\text{Original length}} = \dots \%$
 - VII. Percentage reduction in area = $\frac{\text{Original area - area at fracture}}{\text{Original area}} = \dots \%$
- Result: -**
- i) Average Breaking Stress =
 - ii) Ultimate Stress =
 - iii) Average % Elongation =

Precaution:-

1. If the strain measuring device is an extensometer it should be removed before necking begins.
2. Measure deflection on scale accurately & carefully

Unit Four: Define common heat treatment outcomes and applications

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- heat treatment
- heat changes in metal property
- reasons for heat treatment

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Identifying and performing heat treatment processes
- Explaining heat changes in metal property
- Explaining the reasons for heat treatment

4.1. Introduction

Metals and alloys may not possess all the desired properties in the finished product. Alloying and heat treatment are two methods which are extensively used for controlling material properties.

It is defined as an operation of heating and cooling of metals in the solid state to induce certain desired properties in to them.

Heat treatment is an important operation in the manufacturing of machine parts and tools.

Heat treatment can alter the mechanical properties of steel by *changing the size and shape of the grains* of which it is composed.

In heat treatment, the microstructures of materials are modified. The resulting phase transformation influences mechanical properties like strength, ductility, toughness, hardness and wear resistance.

Purpose of heat treatment is to increase service life of a product by increasing its strength or hardness, or prepare the material for improved manufacturability.

It is generally employed for the following purposes.

- a. To improve machinability
- b. To change or refine grain size
- c. To relieve the stresses of the metal induced during cold or hot working.
- d. To improve mechanical properties example tensile strength, hardness, ductility...

The basis of change in properties is phase or equilibrium diagrams.

Heat Treatment Terms

Upper critical Temperature point A_3 and A_{cm}

- ❖ Is the highest temperature at which steel may be quenched in order to attain maximum hardness and the finest grain structure?
- ❖ above which all material is austenite
- ❖ Lower critical Temperature point A_1
- ❖ Is the lowest temperature at which steel may be quenched in order to harden it?
- ❖ below which austenite does not exist
- ❖ Critical range

The temperature range bounded by the upper and the lower critical temperature.

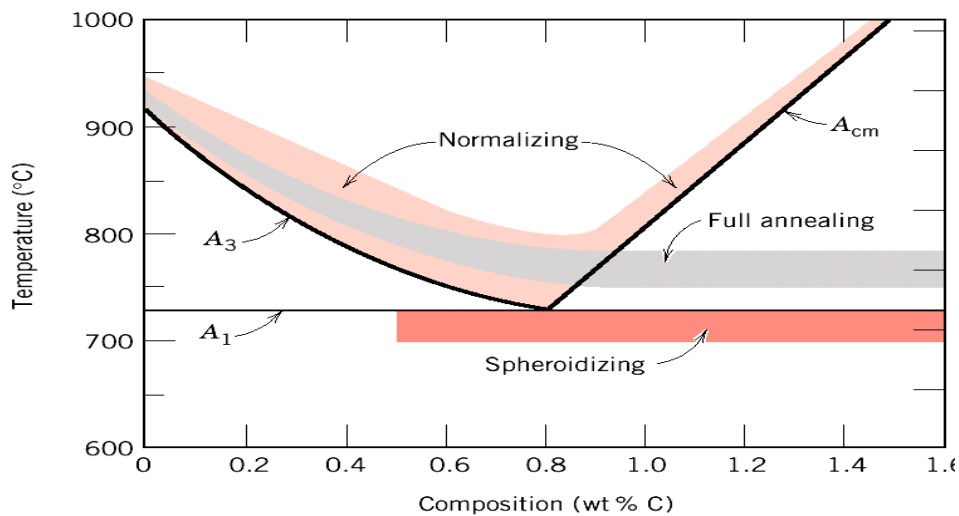


Fig: 4.1.The iron–iron carbide phase diagram in the vicinity of the eutectoid, indicating heat treating temperature ranges for plain carbon steels.

Pearlite

- Is laminated structure of ferrite (iron and cementite(iron carbon)), usually the condition of steel before heat treatment.

Cementite

- Is carbide of iron (Fe_3C) which is the hardener in steel.

Austenite

- Is a solid solution of carbon in iron. which exists between the lower and upper critical temperature
- It is the start for all quench hardened material
- This is the structure of irons and steels at high temperatures (over 800 deg C).
- For quench hardening all the material must start as Austenite.
- Quenching causes the Austenite to be partially or totally transformed to Martensite.

Martensite

- Is the structure of fully hardened steel obtained when austenite is quenched?
- has strongest microstructure
- Only formed by very rapid cooling from the austenitic structure
- Can be made more ductile by tempering
- Needs to be above the Critical Cooling Rate.

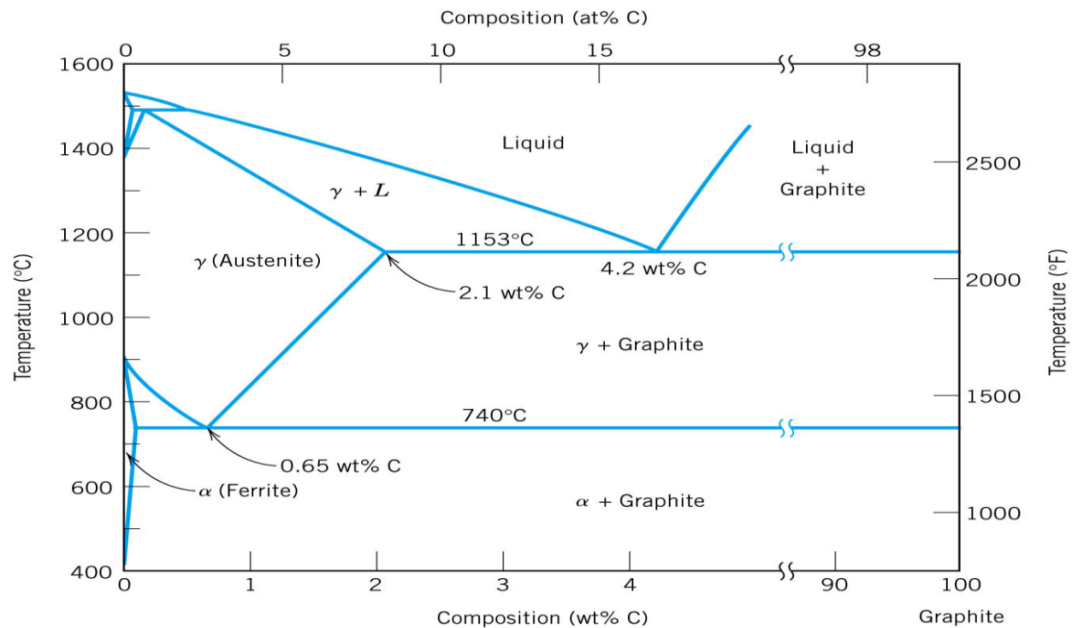


Figure 4.2. The Iron–Iron Carbide Phase Diagram.

4.2. Steps of Heat Treatment

Heat treatment can be defined as heating and cooling of a solid metal or alloy in such a way as to obtain desired conditions of properties.

Heat treatment can be defined as the controlled heating and cooling of metals for the primary purpose of altering their properties (strength, ductility, hardness, toughness, machinability, etc.)

- Can be done for Strengthening Purposes (converting structure to martensite)
- Can be done for Softening and Conditioning Purposes (annealing, tempering, etc.)
- Heating for the sole purpose of hot working is excluding the meaning of heat treatment.

The Basic Steps Of Heat Treatment Are:

1. **Heating:** -Heating the material properly up to the required temperature but below its melting point.
2. **Soaking:** - keeping the material in the heating equipment for some time.
3. **Cooling:** - Cooling the material in appropriate media.

Heat - > Soaking - > Cooling

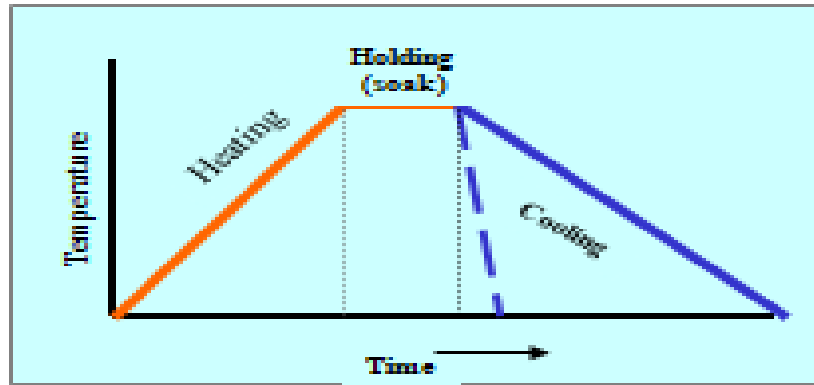


Figure 4.3. Basic Steps of Heat Treatment

4.3. Classification of Heat Treatment Processes

✓ Based on their purpose and operational methods the different types of the heat treatment process include:

1. Annealing
2. Normalizing
3. Hardening
4. Tempering
5. Case or surface hardening

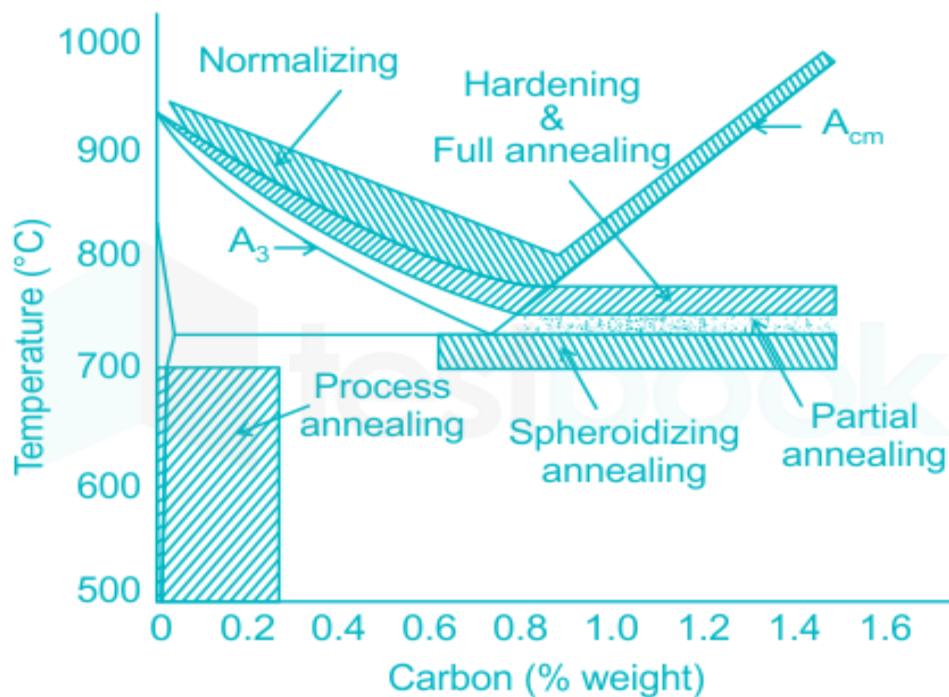


Fig: 4.4. Shows the Heating Temperature Ranges and carbon content for Various Heat Treatment Processes

4.3.1. Annealing

Annealing refers to a heat treatment in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled around 10°C per hour. Process is carried out in a controlled atmosphere of inert gas to avoid oxidation.

Annealing is carried out to

- relieve residual stresses;
- increase softness, ductility, and toughness; and
- Produce a specific microstructure.
- To reduce hardness and improve machinability.
- To soften the metal so that it can be cold worked

A variety of annealing heat treatments are possible; they are characterized by the changes that are induced, which many times are micro structural and are responsible for the alteration of the mechanical properties.

✓ Any annealing process consists of three stages:

- (1) Heating to the desired temperature,
- (2) Holding or “soaking” at that temperature, and
- (3) Cooling, usually to room temperature.

✓ **Time is an important parameter in these procedures.** During heating and cooling, there exist temperature gradients between the outside and interior portions of the piece; their magnitudes depend on the size and geometry of the piece.

✓ If the rate of temperature change is too great, temperature gradients and internal stresses may be induced that may lead to warping or even cracking. Also, the actual annealing time must be long enough to allow for any necessary transformation reactions.

The Heating And Cooling Of Steel Is Carried Out As Follows:

- ✓ Heating is carried out (20°C) above the upper critical temperature of steel in case hypo - eutectoid steel and the same degree above the lower critical point in case of hyper - eutectoid steel.
- ✓ The time for which an article is held in the furnace is recommended as 1 to 2 hours

Slow cooling=furnace cooling

Important Points:

1. The structure of annealed, parts depends on the temperature and the degree of homogeneity at that temperature.
2. When steel is heated above its critical temperature, austenite is formed and when it is cooled below the critical temperature austenite transforms back to ferrite and carbide

4.3.2. Normalizing

It is defined as the process in which iron - base alloys are heated 40 to 50°C above the upper transformation range and held there for a specified period and followed by cooling in air at room temperature. For both steels - done above the upper critical temperature.

Normalized steel consists of ferrite and pearlite for hypo - eutectoid, and pearlite and cementite for hyper - eutectoid steel.

Air cooling = medium cooling

The objects of normalizing are:-

1. To eliminate coarse grain structure obtained during forging
 2. To increase the strength of material.
 3. To improve the machinability of material.
 4. To improve structure of welds
 5. To reduce internal stresses.
 6. To achieve desired results in mechanical and electrical properties.
- ✓ Steels that have been plastically deformed by, for example, a rolling operation, consist of grains of pearlite (and most likely a proeutectoid phase), which are irregularly shaped and relatively large, but vary substantially in size.
 - ✓ An annealing heat treatment called normalizing is used to refine the grains (i.e., to decrease the average grain size) and produce a more uniform and desirable size distribution; fine-grained pearlitic steels are tougher than coarse-grained ones.

4.3.3. Hardening

It is defined as the heat - treating process in which steel is heated at 20°C above the transformation range, soaking at this temperature for a considerable period to ensure thorough penetration of the temperature inside the component, followed by fast cooling.

Fast cooling = water quenching

Heating and cooling of steel is carried out as follows:

- Heating is carried out (20°C) above the upper critical temperature of steel in case hypo - eutectoid steel and same degree above the lower critical point of steel in case of hyper - eutectoid steel.
- Upon cooling (2000°C/minute) the austenite is changed into fine needle like microstructure known as martensite.
- Martensite is a super - saturated solution of carbon in -iron. Hardness in steel is due to this very microstructure.
- Steel containing less than 0.15% carbon does not respond to hardening treatment.

The hardness obtained from the hardening process depends on the following factors:

- a. Carbon content
- b. Quenching rate
- c. Work size
- Quenching (cooling suddenly) in a suitable cooling medium like water and oil or other solution.

Purpose of Hardening:

- a. To harden the steel to resist wear
- b. To enable steel to cut other metals.
- c. To increase strength.

4.3.4. Tempering

- ✓ Martensite is very hard and brittle.
- ✓ Tempering is applied to hardened steel to reduce brittleness, increase ductility, and toughness and relieve stresses in martensite structure.
- ✓ In this process, the steel is heated to lower critical temperature keeping it there for about one hour and then cooled slowly at prescribed rate.
- ✓ This process increases ductility and toughness but also reduces hardness, strength and wears resistance marginally. Increase in tempering temperature lowers the hardness
- ✓ It is defined as the reheat process, reheating being carried out under sub - critical temperatures.
- ✓ Toughness and ductility are improved at the expense of hardness and strength.
- ✓ Tempering temperature range is usually from 200°C to 350°C.
- ✓ We use tempering process because the hardened steel is brittle and unsuitable for most uses.

Tempering is carried out:

- a. To decrease the brittle.
- b. To increase strength.

4.3.5. Case (Surface) Hardening

- ✓ Case hardening is hardening a ferrous alloy so that the outer portion or case is made substantially harder than the inner portion, or core.
- ✓ Typical processes used for case hardening are carburizing, nitriding, cyaniding, carbonitriding, induction hardening, and flame hardening.

I. Carburizing

- ✓ Carburizing is introducing carbon into a solid ferrous alloy by holding at elevated temperature in contact with a suitable carbonaceous material, which can be a solid, liquid, or gas. The carbonized alloy is usually quench-hardened.
- ✓ The common carburizing methods are pack carburizing, gas carburizing, and liquid carburizing.

i. Pack Carburizing

- In pack carburizing, the work piece is surrounded by carbonaceous materials in a closed container. The container is heated to the proper temperature for the required amount of time and then slowly cooled.
- The gas carburizing materials can be hard wood charcoal, coke and barium carbonate.

ii. Gas Carburizing

- ✓ In gas carburizing the steel is heated in contact with carbon monoxide and/or a hydrocarbon which is readily decomposed at the carburizing temperature.
- ✓ The hydrocarbon can be methane, propane, natural gas, or vaporized fluid hydrocarbon.

iii. Liquid Carburizing

- ✓ In liquid carburizing the steel is placed in a bath of molten cyanide so that the carbon will diffuse from the bath into the metal and produce a case comparable to one resulting from pack or gas carburizing.
- ✓ Liquid carburizing may be distinguished from cyaniding by the character and composition of the case produced. The cyanide case is higher in nitrogen and lower in carbon; the reverse is true of liquid carburized cases.

II. Cyaniding

- ✓ Cyaniding is introducing carbon and nitrogen into the solid ferrous alloy by holding at proper temperature, in contact with molten cyanide of suitable composition.
- ✓ In cyaniding the proportion of nitrogen and carbon in the case produced by a cyanide bath depends on both composition and temperature of bath.

III. Carbonitriding

- ✓ Carbonitriding is introducing carbon and nitrogen into a solid ferrous alloy by holding at proper temperature in an atmosphere that contains suitable gases such as hydrocarbons, carbon monoxide, and ammonia.
- ✓ During carbonitriding the carbon and nitrogen are absorbed by the surface of steel simultaneously.

IV. Nitriding

- ✓ Nitriding is introducing nitrogen into a solid ferrous alloy (alloy steels) by holding at suitable temperature in contact with nitrogenous material, usually ammonia or molten cyanide of appropriate composition. Quenching is not required to produce a hard case.
- ✓ The effectiveness of the process depends on the formation of nitrides in the steel by reaction of nitrogen with certain alloying elements.

V. Flame & Induction Hardening

- ✓ In flame and induction hardening selected areas of the steel is heated into austenite range and quenched to form martensite.
- ✓ Flame and induction hardening do not change the chemical composition of steel. They are essentially shallow hardening methods.
- ✓ Flame hardening is a method quench hardening in which the heat applied directly by flame.
- ✓ Induction hardening is also quench hardening method in which the heat generated by electrical induction.

i. Induction hardening

1. Surface of component heated by high frequency induction, the frequency and power requirements depending on size and geometry of component and depth of hardening required.
2. Three main types of induction machines: vacuum tube oscillator > 500 kHz
spark gap oscillator 10–30 kHz motor generator 5–10 kHz
3. Heat-up times can be controlled to within ± 0.1 s and should be less than 20 s to prevent distortion and avoid post-treatment machining or grinding.
4. Process can also be used for through hardening of small components.
5. Tempering and/or stress relieving can also be done by induction heating, often with the same induction coil.
6. Process is easily automated and can give uniform quality and repeatability, although high capital and running costs make it most suitable for long production runs.
7. Typical applications include gears, crankshafts and camshafts.

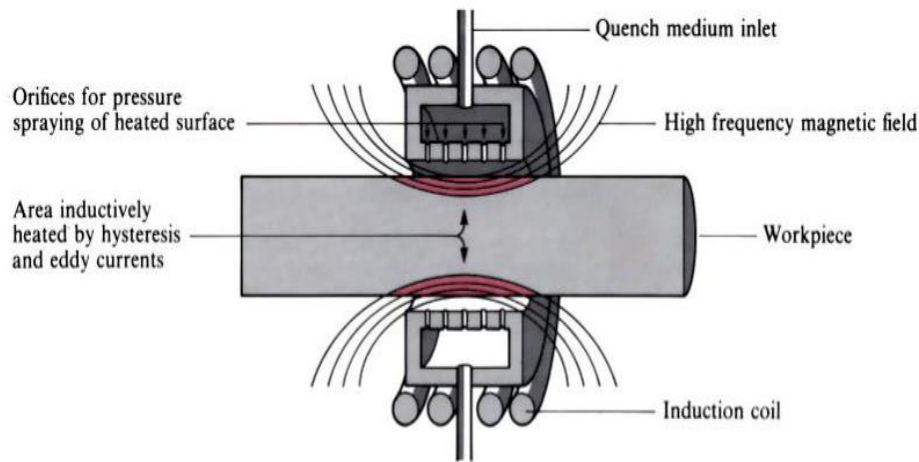


Fig: 4.5.Induction hardening

ii. Flame hardening

1. Heating by means of oxy-fuel burners.
2. Quenching jets follow burners, the quench rate being controlled by the distance from the jets to the burners and the volume of quenchant.
3. Tempering and/or stress relieving flame often follow the quenching jets.
4. Can be used on flat, circular or irregular-shaped components, but is best suited to circular components which can be rotated between centers.
5. The steep thermal gradients required necessitate high flame temperatures, with the risk of overheating, burning and distortion, so the process is usually automated using specially shaped burners.
6. Typical applications include gear teeth, brake drums, axles, cams and crankshafts.

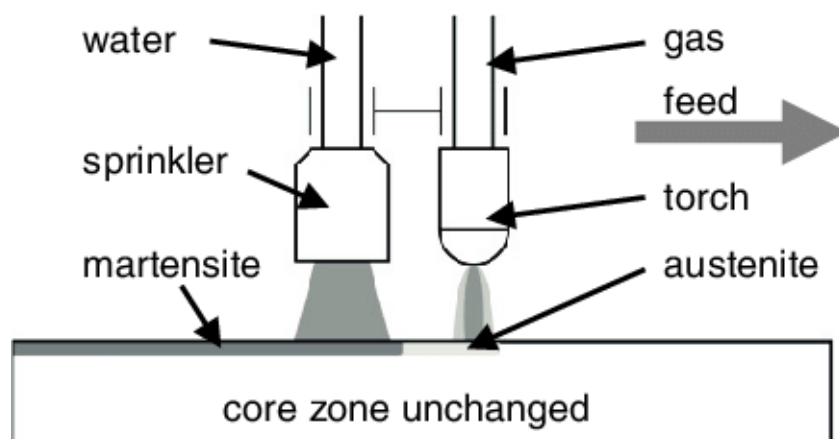


Fig: 4.6.Flame hardening

4.4. Quenching Media

- ✓ Brine (water and salt solution)
- ✓ Water
- ✓ Oil
- ✓ Air
- ✓ Turn off furnace

The rate at which you can cool an object will depend on several factors:

✓ **Size of the part**

The mass of the part will affect quenching; the greater the mass, the greater the time required for complete cooling.

✓ **Configuration of the part**

Parts may be of the same size, but those containing holes or recesses cool more rapidly than solid objects.

✓ **Composition of the part**

The composition of a metal will determine the maximum cooling rate possible without the danger of cracking or warping.

✓ **Initial temperature of the part**

Different steels and steel alloys require a wide range of temperatures for heat treatment.

✓ **Final properties desired**

The medium must cool the metal at the rate you need (rapidly or slowly) to produce the results you want.

4.5. Heat Treatment of Non-Ferrous Metals?

Heat treatment, combining heating and cooling, of non-ferrous metals is a process to alter the metal properties, such as hardness, softness and ductility, without changing their shapes.

Examples of heat treatment of non-ferrous metals are as follows:

Examples of heat treatment of non-ferrous metals

- ✓ **Metal** copper alloys, aluminum alloys, magnesium, titanium alloys, gold, silver, etc...
- ✓ **Heat treatment solution:** annealing, age hardening, etc...
- ✓ **Product:** contacting materials, such as connector parts, automobile wheels, eyeglass frames, fashion accessories, automobile parts, aircraft parts and other parts.

Heat Treatment for Each Type of Metal

✓ **Copper alloys and gold**

These metals have high ductility and repeating heat treatment processes extends them to form thin sheets. Heat treatment is performed in a nitrogen atmosphere to restrict oxidation. When quick cooling is required, a nitrogen and hydrogen atmosphere is used for cooling.

✓ **Titanium alloys**

An argon gas atmosphere is generally used because the nitrogen atmosphere causes nitriding and the hydrogen atmosphere causes embrittlement.

✓ **Aluminum alloys**

Since the surface is covered with a tough oxide film, aluminum alloys are generally heat treated in an air atmosphere.

Heat treatments in aluminum alloys

Principles of age-hardening

Age hardening requires a decrease in solid solubility of the alloying elements with decreasing temperature.

Heat treatment usually involves the three following stages:

1. Solution treatment at relatively high temperature to dissolve the alloying elements.
2. Rapid cooling or quenching usually to room temperature to obtain supersaturated solid solution (SSSS) of these elements in aluminum.
3. Controlled decomposition of the SSSS to form a finely dispersed precipitates, normally accompanied with ageing at appropriate

Self-Check –Unit- IV

Part I:

Write “TRUE” if the statement is correct and “FALSE” if it is wrong statement. (%)

1. The objective soaking is to hold the metal to the proper temperature until the desired internal structural changes take place.
2. The objective of annealing is the opposite of hardening.
3. The purpose of hardening is only to harden metal(steel)
4. Tempering consists of heating the steel to a specific temperature above its hardening temperature.

Part: II

Choose the correct answer for the following questions.

1. As percentage of carbon increase in steel its _____decrease?
 - i. Corrosion resistant
 - ii. Ultimate strength
 - iii. Hardness
 - iv. Ductility
2. What is the purpose of annealing process
 - A. To increase hardness
 - B. To decrease machinability
 - C. To remove internal stress
 - D. For surface hardening
3. The process of reheating the martenstic steel to reduce its brittleness with out any significant loss in its hardness is
 - A. Normalizing
 - B. Annealing
 - C. Quenching
 - D. Tempering
4. The machine tool guide ways are usually hardened by
 - A. Induction hardening
 - B. Flame hardening
 - C. Vacuum hardening
 - D. Tempering

5. Which one of the following mediums is used for the fastest cooling rates of steel quenching
A. Air B. Oil C. Water D. Brine
6. During quenching martensite is produced
A. With an appropriate cooling rate such the carbon has time to migrate
B. With low cooling rate
C. Rapid cooling rate
D. Medium cooling rate
7. _____ is a surface hardening process given maximum hardness to the surface
A. Pack hardening
B. Nitriding
C. Cyaniding
D. Induction hardening
8. Heat treatment process used for steel casting is _____
A. Normalizing
B. Annealing
C. Tempering
D. Hardening
9. The essential ingredient of any hardened steel is
A. Austenite B. Pearlite C. Martensite D. Cementite
10. Which one of the following is not a case hardening process?
A. Normalizing B. Annealing C. Cyaniding D. Both A and B

Part III: matching

- | A | B |
|---------------------------------|------------------|
| 1. Tempering | A. Age hardening |
| 2. Quenching | B. Strengthening |
| 3. Annealing | C. Toughening |
| 4. Normalizing | D. Hardening |
| 5. Principle of aluminum alloys | E. Softening |

Part IV:

Give short answer for the following questions

1. Explain the stages of heat treatment
2. List four basic types of heat treatment
3. Why normalizing is needed for metals

Operation sheet:-1 (heat treatment process)

Purpose: correctly performs heat treatment process, to identify their temp, cooling media, soaking time

Instruction

The following procedures are suggested for a safe heat treating operation.

1. Wear heat-resistant protective clothing, gloves, safety glasses, and a face shield to prevent exposure to hot oils, which can burn skin.
2. Before lighting the furnace, make sure that air switches, exhaust fans, automatic shut-off valves, and other safety precautions are in place.
3. Make sure that there is enough coolant for the job. Coolant will absorb heat given off by the metal as it is cooling, but if there is insufficient coolant, the metal will not cool at the optimal speed.
4. Make sure that there is sufficient ventilation in the quenching areas in order to maintain desired oil mist levels.
5. When lighting the furnace, obey the instructions that have been provided by the manufacturer.
6. During the process of lighting an oil or gas-fired furnace, do NOT stand directly in front of it.
7. Make sure that the quenching oil is not contaminated by water. Explosions can be results of moisture coming into contact with the quenching oil.
8. Before taking materials out of the liquid carburizing pot, make sure that the tongs are not wet and that they are the correct tongs for the job.
9. Make sure that an appropriate fungicide or bacterial inhibitor has been mixed into the quenching liquid.
10. When quench tanks are not being used, always cover them.
11. Use a nonflammable absorbent to clean leaks and oil spills. This should be done immediately.
12. If possible, keep tools, baskets, jigs, and work areas free from oil contamination.

13. Before breaks and before moving on to the next task, wash your hands thoroughly.
14. If any skin trouble is shown or suspected, report to your instructor and get medical help.
15. Fumes from the molten carburizing salt bath should not be inhaled, because carbon monoxide is a product of the carburizing process.
16. Make sure there is good ventilation in the work area.
17. Be on the lookout for contamination from pieces of carburized metal.
18. Do not take oil-soaked clothes or equipment to areas where there are food or beverages.
19. Do not take food or beverages where oils are either being used or stored.

Tools and requirement

- ✓ Induction furnace
- ✓ Ferrous metals
- ✓ Measuring tool
- ✓ Tong
- ✓ Quenching media

Procedure to hardening

The first important thing to know when heat treating a steel is its hardening temperature. Many steels, especially the common tool steels, have a well established temperature range for hardening. O-1 happens to have a hardening temperature of 1450 – 1500 degrees Fahrenheit. To begin the process:

1. Safety first. Heat treating temperatures are very hot. Dress properly for the job and keep the area around the furnace clean so that there is no risk of slipping or stumbling. Also, preheat the tongs before grasping the heated sample part.
2. Preheat the furnace to 1200 degrees Fahrenheit.
3. When the furnace has reached 1200 degrees Fahrenheit, place the sample part into the furnace. Place the sample part into the center of the oven to help ensure even heating. Close and wait.
4. Once the sample part is placed in the furnace, heat it to 1500 degrees Fahrenheit. Upon reaching this temperature, immediately begin timing the soak for 15 minutes to an hour (soak times will very depending on steel thickness).

Table 1: Approximate Soaking Time for Hardening, Annealing and Normalizing Steel

Thickness Of Metal (inches)	Time of heating to required Temperature (hr)	Soaking time (hr)
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up to 1/8	.06 to .12	.12 to .25
1/8 to 1/4	.12 to .25	.12 to .25
1/4 to 1/2	.25 to .50	.25 to .50
1/2 to 3/4	.50 to .75	.25 to .50
3/4 to 1	.75 to 1.25	.50 to .75
1 to 2	1.25 to 1.75	.50 to .75
2 to 3	1.75 to 2.25	.75to 1.0
3 to 4	2.25to 2.75	1 to 1.25
4 to 5	2.75 to 3.50	1 to 1.25
5 to 8	3.50 to 3.75	1 to 1.50

Soak time is the amount of time the steel is held at the desired temperature, which is in this case 1500 degrees Fahrenheit.

- When the soak time is complete, very quickly but carefully take the sample out with tongs. Place the sample part into a tank of oil for quenching. Move the sample part around as much as possible while it is quenching.
- Once the sample part has been quenched down to around 125 degrees Fahrenheit, begin the tempering process. To temper the sample part it must be placed into the furnace at 375 degrees Fahrenheit. Allow it to soak for 2 hours, then remove the sample part and allow it to cool to room temperature. The sample part should now be approximately at a hardness of 60 RC.

Procedure to Annealing

This process is also referred to as annealing. During annealing, the steel goes through the following temperature histories:

- Place the steel in the furnace at 1562°F in the austenite range, and keep it there for an hour until the metal has reached its equilibrium temperature and corresponding solid solution structure.
- Furnace-Cool: cool the steel slowly in the furnace. Allow the temperature to drop from 1562°F to 1292°F over a ten hour period.

- Air-cool: Take the steel out of the furnace and let it air-cool to room temperature.

Procedure Normalizing

- Place the steel in the furnace at 1562°F in the austenite range, and keep it there for an hour until the metal has reached its equilibrium temperature and corresponding solid solution structure.
- Air-cool: Take the steel out of the furnace and let it air-cool to room temperature.

Procedure Tempering:

- Temper: Bring the steel to the tempering temperature and hold it there for about 2 hours.
- There is a range of different tempering temperatures. For 1045 steel the range is from 392 to 932°F.
- The different temperatures lead to differences in mechanical properties.
- Lower temperatures give higher yield strength but lower toughness and ductility.
- Higher temperatures give lower strength but increase toughness and ductility.
- Air-cool: Take the steel out of the furnace and let it air-cool to room temperature.

(Lap) Test-1

1 - Project Making

Learning Activity Performance

Date: _____

Name: _____

I.D NO: _____

Performing heat treatment process (----- %)

Objective: to identify the heat reason to change microstructure of the steel, their properties of metal, and other effects like quenching media.

Heat treatment process

Take

- Ferrous metal
- Non-ferrous metal

Apply all heat treatment process and discuss results within group.

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5						
6						
7						

Reference Books

- ✓ Metals Handbook – Vol IV, 10th Edition, ASM International Publication (19913.
Metallurgy & Heat Treatment of Tool Steels by Robert Wilson
- ✓ T. V.Sharma Rajan, C. P. Sharma, Ashok Kumar Sharma “Heat Treatment: Principles and
Techniques”
- ✓ Manufacturing Technology: Foundry, Forming & Welding by P N Rao
- ✓ TTLM
- ✓ Web Site
- ✓ Material books