METALLURGY FOR NON-METALLURGISTS

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SYLLABUS

- Introduction to Corrosion science and engineering
- Treatment of steels such as Plating, Galvanizing, Aluminizing
- Destructive and Non-Destructive Testing

CORROSION

INTRODUCTION

- Corrosion is a process of formation of the compound of pure metal by the chemical reaction between metallic surface and its environment.
- It is an oxidation process. It causes loss of metal.
- Hence, disintegration of a metal by its surrounding chemicals through a chemical reaction on the surface of the metal is called corrosion.

- Example: Formation of rust on the surface of iron, formation of green film on the surface of copper.
- The responsible factors for the corrosion of a metal are the metal itself, the environmental chemicals, temperature and the design.

DIFFERENT THEORIES OF CORROSION

There are three theories of corrosion:

- (1) acid theory,
- (2) dry or chemical corrosion and
- (3) galvanic or electrochemical

(1) ACID THEORY

- This theory suggests that corrosion of a metal (iron) is due to the presence of acids surrounding it.

- According to this theory, iron is corroded by atmospheric carbon di-oxide, moisture and oxygen. The corrosion products are the mixture of $Fe(HCO3)2$, $Fe(OH)CO3$ and $Fe(OH)3$.

THE CHEMICAL REACTIONS SUGGESTED ARE GIVEN BELOW

$$\mathrm{Fe} + 2\mathrm{CO_2} + \mathrm{H_2O} + \frac{1}{2}\mathrm{O_2} \longrightarrow \mathrm{Fe(HCO_3)_2}$$

$$2\mathrm{Fe(HCO_3)_2} + \mathrm{H_2O} + \frac{1}{2}\mathrm{O_2} \longrightarrow 2\mathrm{Fe(OH)CO_3} + 2\mathrm{CO_2} + 2\mathrm{H_2O}$$

$$2\mathrm{Fe(OH)CO_3} + 2\mathrm{H_2O} \longrightarrow 2\mathrm{Fe(OH)_3} + 2\mathrm{CO_2}$$

(2) CHEMICAL THEORY OF CORROSION

- According to this theory, corrosion on the surface of a metal is due to direct reaction of atmospheric gases like oxygen, halogens, oxides of sulphur, oxides of nitrogen, hydrogen sulphide and fumes of chemicals with metal.
- The extent of corrosion of a particular metal depends on the chemical affinity of the metal towards reactive gas.
- Oxygen is mainly responsible for the corrosion of most metallic substances when compared to other gases and chemicals.

THERE ARE MAIN three types of CHEMICAL CORROSION.

- (i) Oxidation corrosion (*Reaction with oxygen*)
- (ii) Corrosion by other gases
- (iii) Liquid metal corrosion

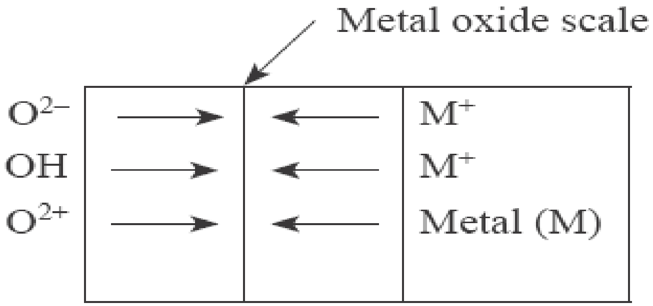
(I) OXIDATION CORROSION (REACTION WITH OXYGEN)

- Some of the metals directly react with oxygen in the absence of moisture.
- Alkali and alkaline earth metals react with oxygen at room temperature and form corresponding oxides, while some metals react with oxygen at higher temperature.
- Metals like Ag, Au and Pt are not oxidized as they are noble metals.

$$\mathrm{M} \longrightarrow \mathrm{M}^{n+} + ne^{-} \qquad (\text{if } n = 1)$$

$$\frac{1}{2}\mathrm{O}_2 + 2e^{-} \longrightarrow \mathrm{O}^{-} \qquad \text{for alkali metals.}$$

$$\overline{2\mathrm{M} + \frac{1}{2}\mathrm{O}_2 \longrightarrow \mathrm{M}_2\mathrm{O}}$$



- During oxidation of a metal, metal oxide is formed as a thin film on the metallic surface which protects the metal from further corrosion.

- If diffusion of either oxygen or metal is across this layer, further corrosion is possible. Thus, the layer of metal oxide plays an important role in the process of corrosion..

- Oxides of Pb, Al and Sn are stable and hence inhibit further corrosion. They form a stable, tightly adhering oxide film.
- In case of porous oxide film, atmospheric gases pass through the pores and react with the metal and the process of corrosion continues to occur till the entire metal is converted into oxide.
- Porous oxide layer is formed by al- kali and alkaline earth metals. Molybdenum forms a volatile oxide film of MoO3 which accelerates corrosion.
- Au, Ag, Pt form unstable oxide layer which decomposes soon after the formation, thereby preventing further corrosion.

(ii) Corrosion by other gases (Cl2, SO2, H2S, Nox)

- In dry atmosphere, these gases react with metal and form corrosion products which may be protective or non-protective.

- Dry Cl2 reacts with Ag and forms AgCl which is a protective layer, while SnCl4 is volatile.

- In petroleum industries at high temperatures, H2S attacks steel forming FeS scale which is porous and interferes with normal operations.

(iii) Liquid - metal corrosion

- In several industries, molten metal passes through metallic pipes and causes corrosion due to dissolution or due to internal penetration.
- For example, liquid metal mercury dissolves most metals by forming amalgams, thereby corroding them.

(3) Wet or electrochemical theory of corrosion

- It is a common type of corrosion of metal in aqueous corrosive environment. This type of corrosion occurs when the metal comes in contact with a conducting liquid or when two dissimilar metals are immersed or dipped partly in a solution.
- According to this theory, there is the formation of a galvanic cell on the surface of metals. Some parts of the metal surface act as anode and rest act as cathode.

- The chemical in the environment and humidity acts as an electrolyte.
- Oxidation of anodic part takes place and it results in corrosion at anode, while reduction takes place at cathode.
- The corrosion product is formed on the surface of the metal between anode and cathode.

DIFFERENCES BETWEEN DRY AND WET CORROSION

Dry corrosion	**Wet corrosion**
Corrosion occurs in the absence of moisture.	Corrosion occurs in presence of conducting medium.
It involves direct attack of chemicals on the metal surface.	It involves formation of electrochemical cells.
The process is slow.	It is a rapid process.
Corrosion products are produced at the site of corrosion.	Corrosion occurs at anode but rust is deposited at cathode.
The process of corrosion is uniform.	It depends on the size of the anodic part of metal.

Factors Influencing Corrosion

- The nature and extent of corrosion depend on the metal and the environment. The important factors which may influence the corrosion process are
- (i) Nature of the metal
- (ii) Environment
- (iii)Concentration of electrolyte
- (iv) Temperature
- (v) Electrode potential and
- (vi) Hydrogen over voltage

TYEPS OF CORROSION

- There are basically eight types of corrosion

I. Uniform corrosion
II. Pitting corrosion
III. Transgranular and Intergranular (Intercrystalline) corrosion
IV. Exfoliation corrosion
V. Stress corrosion
VI. Crevice corrosion
VII. Galvanic corrosion
VIII. Erosion

I. Uniform corrosion

- This type of corrosion develops as pits of very small diameter, in the order of a micrometer, and results in a uniform and continuous decrease in thickness over the entire surface area of the metal.
- The rate of uniform corrosion can be easily determined by measuring the mass loss, or the quantity of released hydrogen

II. Pitting corrosion

- This localized form of corrosion is characterized by the formation of irregularly shaped cavities on the surface of the metal. Their diameter and depth depend on several parameters related to the metal, the medium and service conditions.

- Unlike uniform corrosion, the intensity and rate of pitting corrosion can be assessed neither by determining the mass loss nor by measuring released hydrogen.

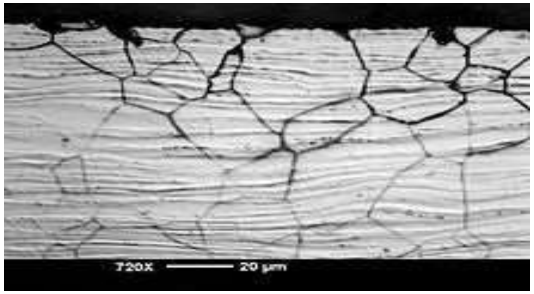
- Pitting corrosion can be assessed using three criteria : the density, i.e. the number of pits per unit area, the rate of deepening and the probability of pitting.

- In fact, these measurements do not make sense because a very deep and isolated pit results only in a small mass loss, where as a very large number of superficial pits can lead to a larger mass loss.

III. Transgranular and Intergranular (Intercrystalline) corrosion

- Within the metal, at the level of the grain, corrosion may propagate in two different ways :

(i) It spreads in all directions, corrosion indifferently affects all the metallurgical constituents; there is no selective corrosion.



This is called transgranular or transcrystalline corrosion because it propagates within the grains.

(II) IT FOLLOWS PREFERENTIAL PATHS: CORROSION propagates at grain boundaries. Unlike transgranular corrosion, these forms of intercrystalline corrosion consumes only a very small amount of metal, which is why mass loss is not a significant parameter for assessment of this type of corrosion.

- It is not detectable which naked eye but requires microscopic observation, typically at a magnification of 50. When penetrating into the bulk of the metal, intercrystalline corrosion may lead to a reduction of mechanical properties and even lead to the rupture of components.

IV. Exfoliation Corrosion

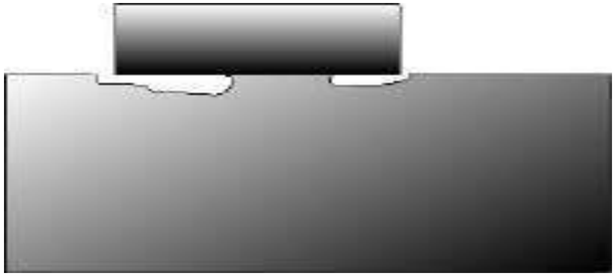
- Exfoliation corrosion is a type of selective corrosion that propagates along a large number of planes running parallel to the direction of rolling or extrusion.
- Between these planes are very thin sheets of sound metal that are not attacked, but gradually pushed away by the swelling of corrosion products, peeling off like pages in a book; hence the term exfoliation corrosion.
- The metal will swell, which results in the spectacular aspect of this form of corrosion.

V. Stress corrosion

- This type of corrosion results from the combine action of a mechanical stress (bending, tension) and a corrosive environment.

- Each of these parameters alone would not have such a significant effect on the resistance of the metal or would have no effect at all.

VI. Crevice corrosion



- Crevice corrosion is a localized corrosion in recesses :
- overlapping zones for riveting, bolting or welding, zones under joints and under various deposits. These zones also called crevices, are very tiny and difficult to access for the aqueous liquid that is covering the rest of the readily accessible surfaces.
- This type of corrosion is also known as deposit attack.

VII. Galvanic corrosion

- When two dissimilar metals are in direct contact in a conducting liquid, experience shows that one of the two may corrode. This is called galvanic corrosion. The other metal will not corrode; it may even be protected in this way.
- This corrosion is different in its kind and intensity from the one that would occur if they were placed separately in the same liquid.

- Unlike other types of structural corrosion, galvanic corrosion does not depend on the metal's texture, temper,etc.
- Galvanic corrosion may occur with any metal, as soon as two are in contact in a conductive liquid. It works like a battery.
- The appearance of galvanic corrosion is very characteristic. It is not dispersed like pitting corrosion, but highly localized in contact zone with the other metal.
- The zone affected by galvanic corrosion often has a shinier aspect than the rest of the surface.

VIII. Erosion

- Corrosion by erosion occurs in moving media. This type of corrosion is related to the flow speed of the fluid.

- It leads to local thinning of the metal, which results in scratches, gullies, and undulations, which are always oriented in the same direction, namely the flow direction.

Electroplating is a process that uses electrical current to reduce dissolved metal cations so that they form a coherent metal coating on an electrode

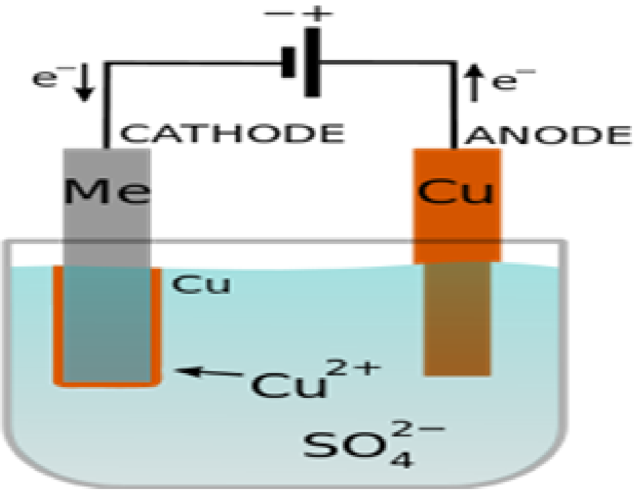
The process used in electroplating is called electrodeposition. It is analogous to a galvanic cell acting in reverse. The part to be plated is the cathode of the circuit. In one technique, the anode is made of the metal to be plated on the part. Both components are immersed in a solution called an electrolyte containing one or more dissolved metal salts as well as other ions that permit the flow of electricity.

Effects

Electroplating changes the chemical, physical, and mechanical properties of the workpiece. An example of a chemical change is when nickel plating improves corrosion resistance. An example of a physical change is a change in the outward appearance. An example of a mechanical change is a change in tensile strength or surface hardness which is a required attribute in tooling industry.

Process

Electroplating of a metal (Me) with copper in a copper sulfate bathThe cations associate with the anions in the solution. These cations are reduced at the cathode to deposit in the metallic, zero valence state. For example, in an acid solution, copper is oxidized at the anode to Cu^{2+} by losing two electrons. The Cu^{2+} associates with the anion SO_4^{2-} in the solution to form copper sulfate. At the cathode, the Cu^{2+} is reduced to metallic copper by gaining two electrons. The result is the effective transfer of copper from the anode source to a plate covering the cathode.



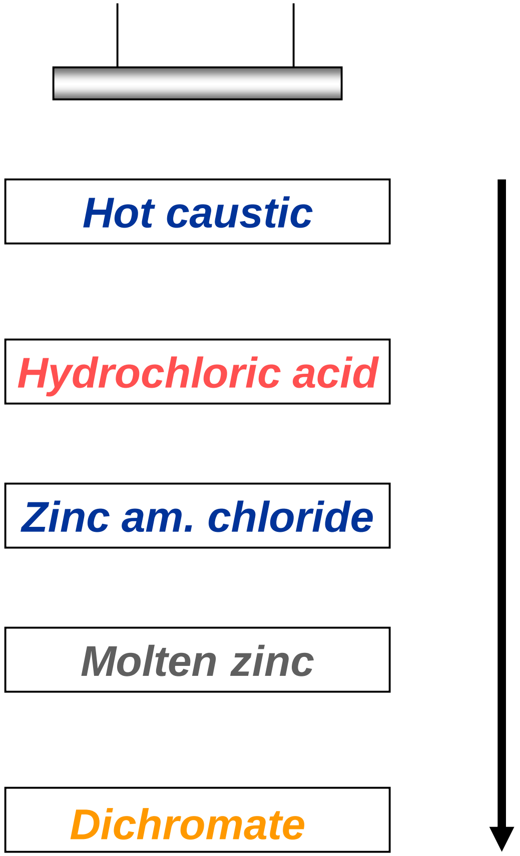
Uses

Electroplating is widely used in various industries for coating metal objects with a thin layer of a different metal. The layer of metal deposited has some desired property, which the metal of the object lacks. For example chromium plating is done on many objects such as car parts, bath taps, kitchen gas burners, wheel rims and many others for the fact that chromium is very corrosion resistant, and thus prolongs the life of the parts. Electroplating has wide usage in industries. It is also used in making inexpensive jewelry. Electroplating increases life of metal and prevents corrosion.

The hot dip galvanizing process

The hot dip galvanizing process

- ***Loading - jigging***
- ***Degreasing***
- ***Pickling***
- ***Pre-fluxing***
- ***Hot dip galvanizing***
- ***Quenching***



Hot caustic

Hydrochloric acid

Zinc am. chloride

Molten zinc

Dichromate

The hot dip galvanizing process

Loading - jigging

The steel items need to be supported during the hot dip galvanizing process.

Can the item be easily jigged?
Will touch marks be a problem?

Solutions and molten zinc must be able to flow into all sections and drain off all sections.

Steel items must be designed to prevent air, solutions and molten zinc becoming trapped

Check design for possible problems

The hot dip galvanizing process

Degreasing

A hot (90°C) caustic bath is used to remove -
Oil, grease, paint another organic compounds

If these contaminating materials are not removed, the next stage of the process (pickling) is affected

Check if any paint is on item - some paints are not easily removed and may require abrasive blasting before galvanizing

Some pipes and pipe fittings have a black varnish coating that cannot be removed in the caustic bath.

The hot dip galvanizing process

Acid pickling

The steel items are immersed in hydrochloric acid to remove - rust, mill scale and other metal oxides

The steel surface must be perfectly clean of these oxides for the molten zinc to react with the steel

Very heavy rust may not be easily removed by pickling - badly rusted items should be abrasive blasted or mechanically cleaned first.

The hot dip galvanizing process

Pre-fluxing

Steel items are water rinsed after pickling and immersed in hot (70-80^{o}C) zinc ammonium chloride (ZAC) solution.

The ZAC solution conditions the clean steel surface ready for hot dip galvanizing.

Good pre-treatment = good quality galvanizing

The hot dip galvanizing process

Quenching

After hot dip galvanized steel item is removed from the galvanizing bath, it is immediately quenched in a sodium dichromate solution

The dichromate quenching cools the item so that it can be quickly handled and passivates the surface of the galvanized coating to maintain its bright appearance.

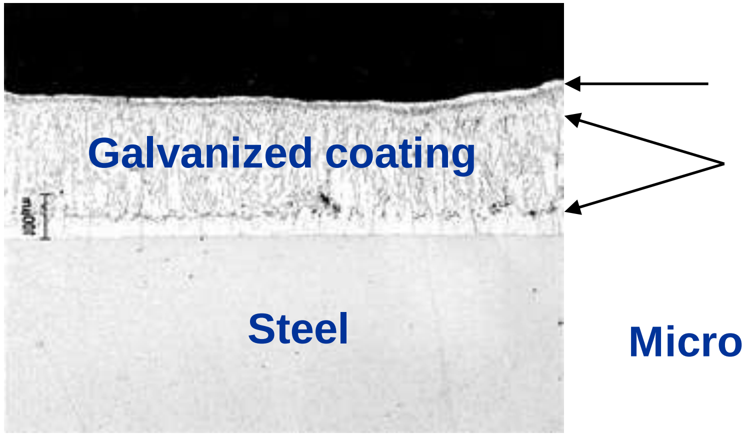
The hot dip galvanizing process

Hot dip galvanizing

The steel is immersed in molten zinc (temp 450^0C)

The clean steel surface reacts with the molten zinc to form a zinc-iron alloy which is very strongly bonded to the surface.

The hot dip galvanized coating forms in 3-5 minutes, depending on the steel thickness.



Free zinc layer

Alloy layers

Micrograph - 100 X

The hot dip galvanizing process

Quenching

After hot dip galvanized steel item is removed from the galvanizing bath, it is immediately quenched in a sodium dichromate solution

The dichromate quenching cools the item so that it can be quickly handled and conditions the surface of the galvanized coating to maintain its bright appearance.

Dichromate quenching will reduce white rusting problems. White rust forms when rainwater reacts with newly galvanized steel to form zinc hydroxide.

Poor storage or HDG steel will also promote white rust.

The hot dip galvanizing process

Characteristics

- ***Typically 65 - 150 microns thick (1 mm = 1000 microns)***
- ***Zinc iron alloy layers make up 80% - 100% of the***

coating.

- ***The zinc-iron alloy layers are harder than 250 grade steel***

Micrograph of hot dip galvanized coating

The hot dip galvanizing process

Coating comparisons

Compared to zinc electroplating (ZEP)and continuous galvanizing (CG), hot dip galvanizing (HDG) is better because…..

- HDG is thicker and will last over 50 years or more without rusting

- HDG is harder and is 5 times more abrasion resistant than ZEP and CG

- HDG coats all external and internal surfaces and edges. All CG coatings have cut, exposed edges after processing.

Presentation

On

Testing Of Materials – DT & NDT

OVERVIEW

:-

- Introduction.
- Types- DT and NDT.
- Hardness Test.
- Tension test.
- Impact Test.
- Non-destructive testing.
- Advantages & Application.

INTRODUCTION:-

Prolonged endurance testing under the most severe operating conditions, continued until the component, equipment, or product specimen fails (is broken or destroyed). The purpose of destructive & Non destructive testing is to determine service life and to detect design weaknesses that may not show up under normal working conditions.

DESTRUCTIVE TESTING
- DT

Destructive testing is changes the dimensions or physical and structural integrity of the specimen. (It is essentially destroyed during the test).

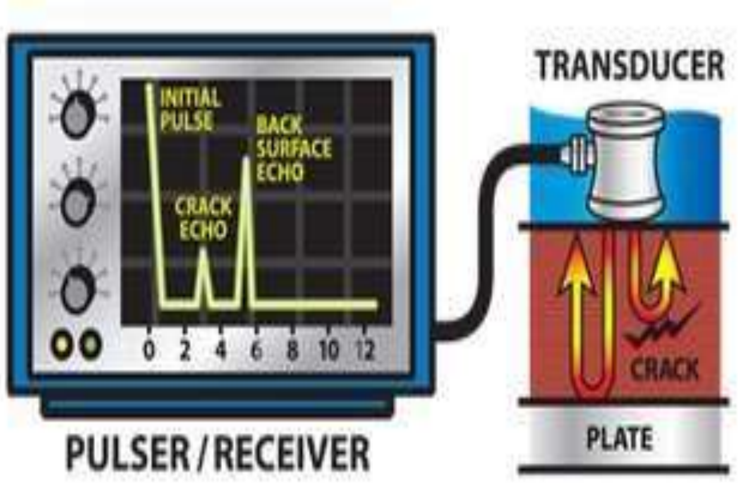
Ex:- Tensile, Compression, Shear and Rockwell

Hardne
s

NON DESTRUCTIVE TESTING - NDT

Non-Destructive testing does not affect the structural integrity of the sample. (A measurement that does not effect the specimen in any way).

Ex:- Radiography , Ultrasonic, Dye penetration test etc.



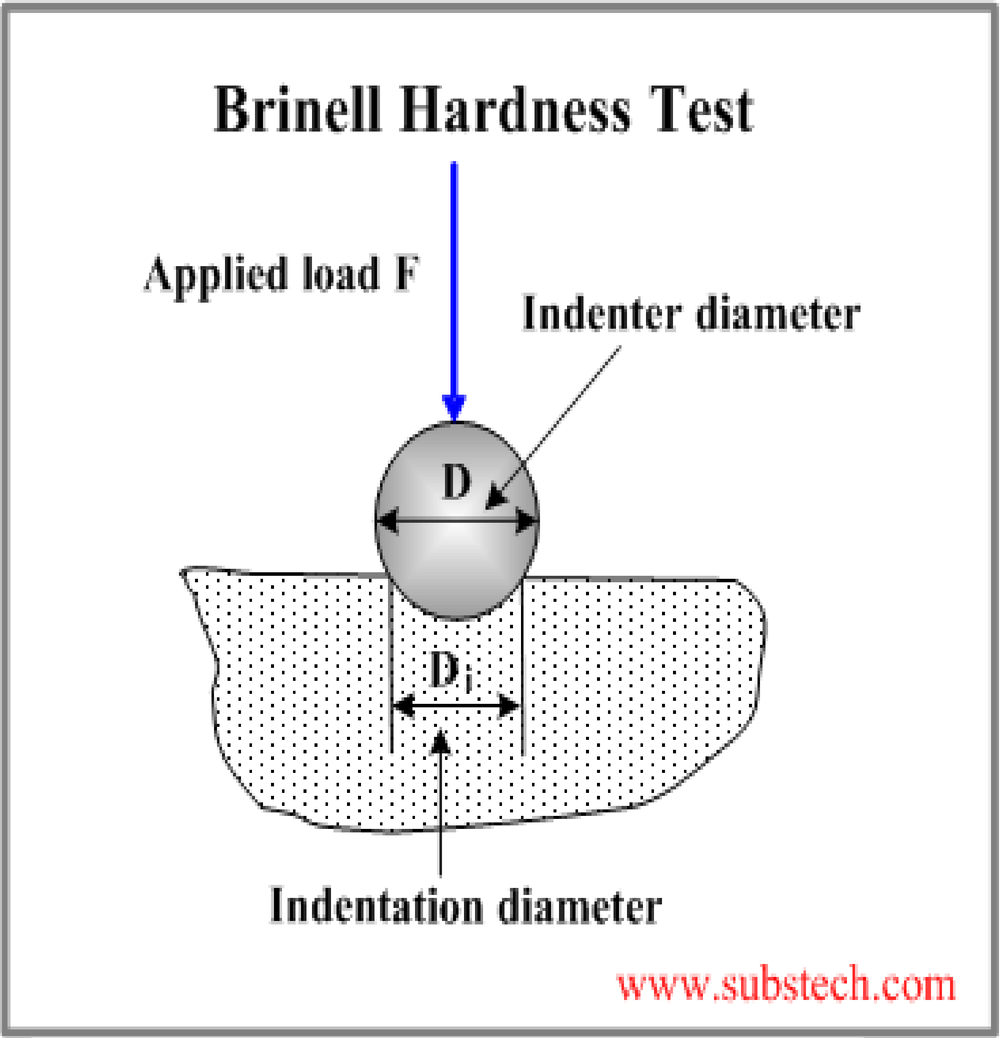
HARDNESS TESTING:-

Hardness, as a mechanical property, is the resistance of a material to surface penetration .The indenter used varies with the test selected, but is generally hardened steel or diamond.

Common hardness tests include the Rockwell and Brinell. Other test procedures used include the scleroscope, Rebound Test, Vickers, and Tukon-Knoop testing.

BRINELL HARDNESS TEST

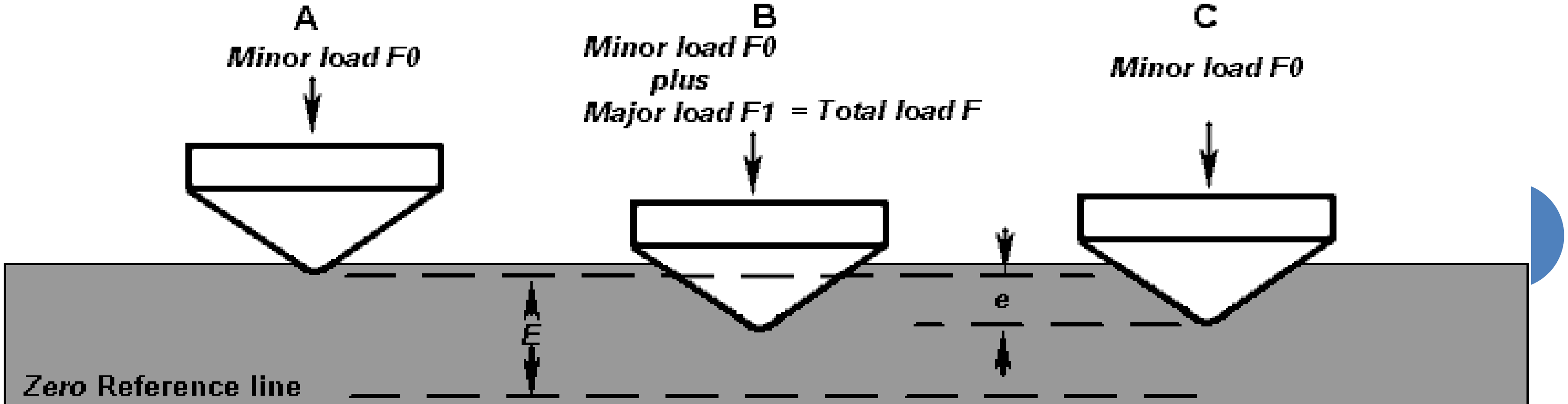
The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel subjected to a load of 3000 kg .The full load is normally applied for 10 to 15 seconds . The diameter of the indentation left in the test material is measured with a low powered microscope.



$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

ROCKWELL HARDNESS TEST

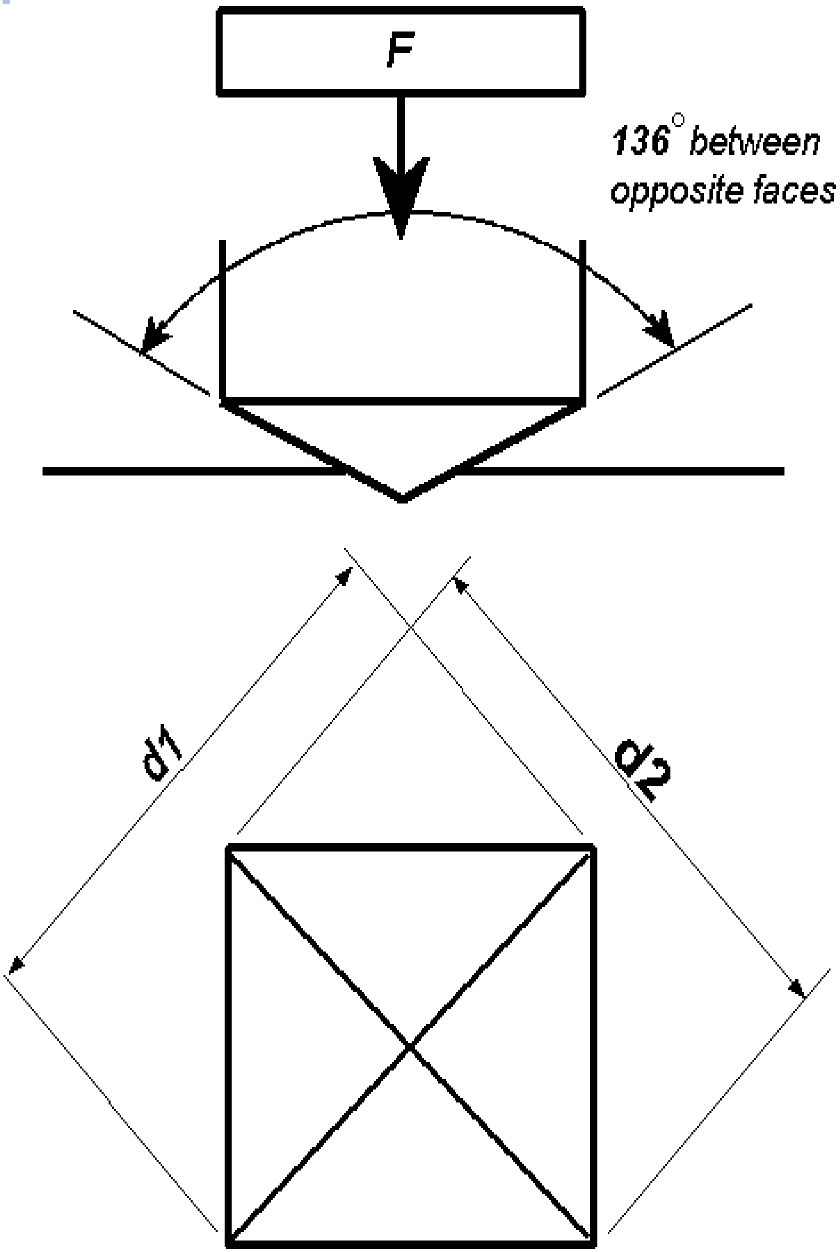
- The Rockwell hardness test provides more direct results. A specially-designed testing machine is typically used and provides a dial reading for the Rockwell Hardness Number, so no special calculations or measurements are necessary.



Scale	Indenter	Applied Load (kg)
A	Diamond cone	60
B	1/16-inch ball	100
C	Diamond cone	150
D	Diamond cone	100
E	1/8-inch ball	100
F	1/16-inch ball	60

VICKER HARDNESS TEST:-

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average

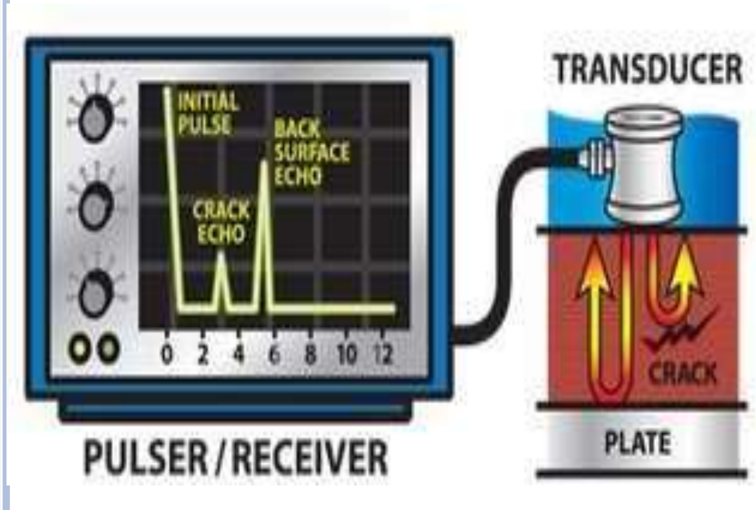


$$HV = \frac{2F\sin\frac{136^o}{2}}{d^2} \qquad HV = 1.854\,\frac{F}{d^2}\ \text{approximately}$$

NON DESTRUCTIVE TESTING - NDT

Non-Destructive testing does not affect the structural integrity of the sample. (A measurement that does not effect the specimen in any way).

Ex:- Radiography , Ultrasonic, Dye penetration test

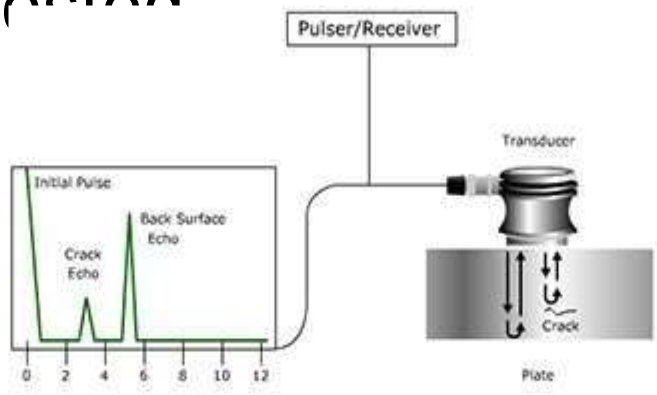


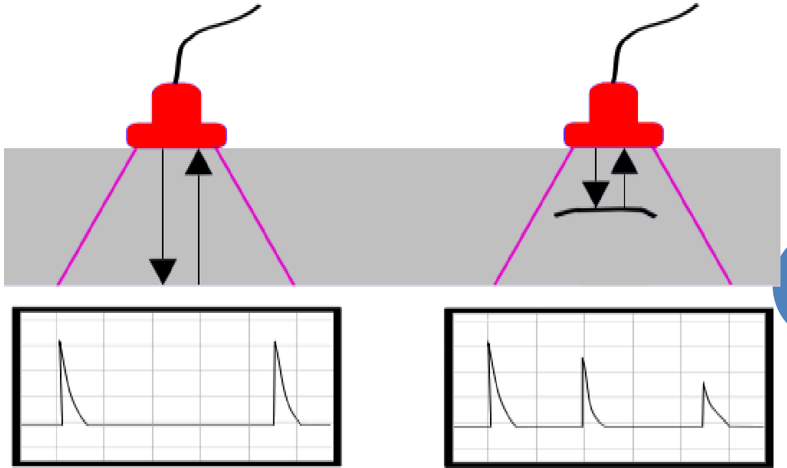
Major types of NDT

- Detection of surface flaws
  - Visual
  - Magnetic Particle Inspection
  - Fluorescent Dye Penetrant Inspection
- Detection of internal flaws
  - X-Radiography
  - Ultrasonic Testing
  - Eddy current Testing

ULTRASONIC TEST

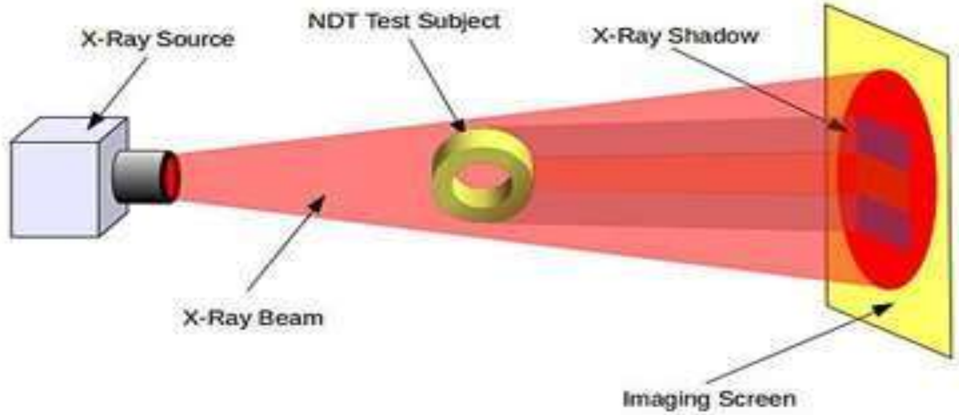
Ultrasonic Testing is a non-destructive testing technique that utilizes high-frequency sound waves to detect imperfections in metal materials, as well as changes in properties within the materials that could cause problems or failure of the component being tested





RADIOGRAPHY TEST

- the part to be inspected is placed between the radiation source and a piece of radiation sensitive film
- .The radiation source can either bean X-ray machine or a radioactive source .The part will stop some of the radiation where thicker and more dense areas will stop mor



DYE PENETRATION TEST

- This method is frequently used for the detection of surface breaking flaws in non-ferromagnetic materials
- .The subject to be examined is first of all cleaned to remove all traces of foreign material etc. Than penetrant and developer is applied.

A. Penetrant applied to the surface and enters defect

B. Excess penetrant removed from surface

ADVANTAGES OF DESTRUCTIVE TESTING

- ❑ Allows a roughly identify the mechanical properties of the adhesive joint (fracture strength, elongation, modulus of elasticity ....)
- ❑ Ability to compare type of testing Verification of surface preparation, curing conditions, working conditions and adhesives system products (primers, activators, adhesives ...)
- ❑ Predict and identify the approximate nature of the failure or breakdown that may occur during the lifetime of the bonded joint in use.

ADVANTAGES OF NDT

- The equipments are easy to handle
- Defects can be detected without damaging the components
- Methods are quick and accurate
- Components can be sorted out on the basis of electrical, magnetic or chemical properties
- Test results and other information can be conveniently recorded on paper films, cassettes and floppies