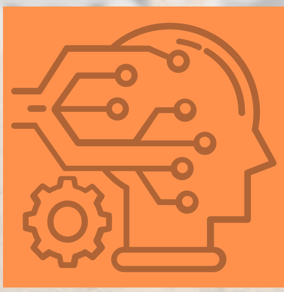
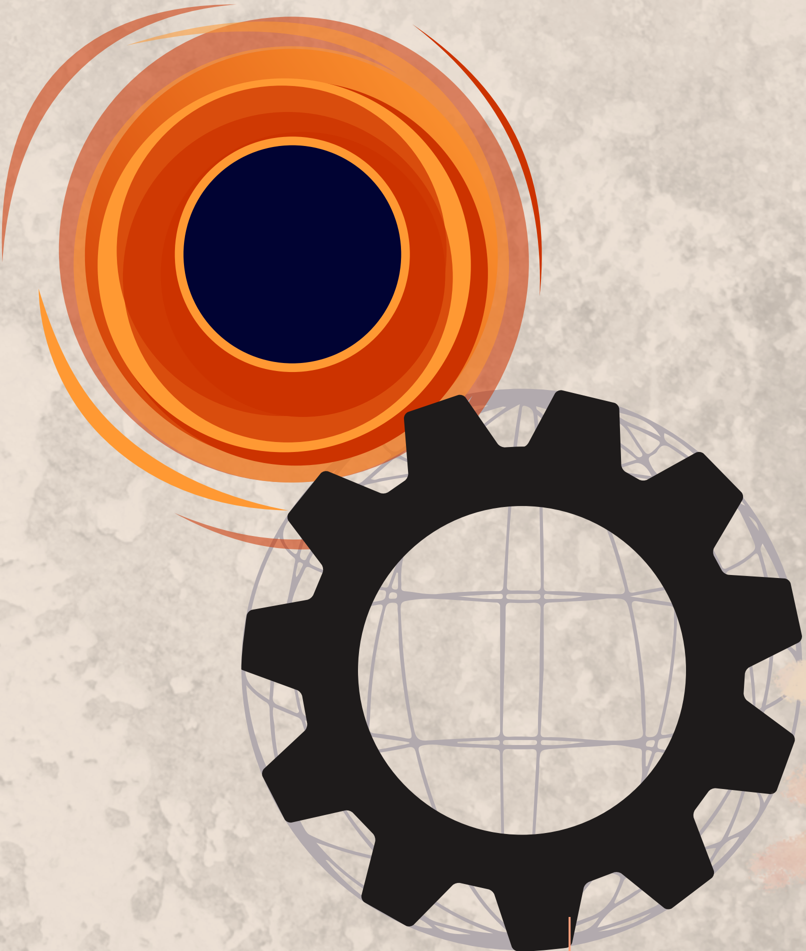
MATERIAL TESTING

MATERIAL SCIENCE & ENGINEERING



1ST EDITION



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Preface

This eBook as a title **MATERIAL TESTING** is developed in support of the Material Science and Engineering subject for Diploma Mechanical Engineering students. This eBook also reviews about fundamental principles, methodologies, and applications of material testing. Either you are a lecturer, a student, a researcher or an engineer in material science and engineering field, we hope this book will deliver the knowledge as a valuable resource throughout your journey. Material is the backbone in modern era, and their properties determine a crucial role in shaping the technology and infrastructure around us. All the material products will be testing to get accurate characterization of the material properties and ensure more safety, reliability, and optimal performance in diverse application.

This eBook aims to provide a comprehensive knowledge of material testing including a wide range of techniques, concepts, and applications. Secondly, this eBook introduces to the common concepts of material testing, destructive testing (hardness test and impact test) and non-destructive test (liquid penetration test, powder magnetic test, ultrasonic test, and x-ray test). Lastly, this eBook also to guide various experimental employed to analyse the mechanical, thermal, electrical, and chemical properties of material and detect of defect on materials.

This eBook is free limitation, and we hope this eBook will be enlightening and inspiring the reader with the knowledge and tools to make decisions, solve practical challenges, and contribute to the continuous advancement of materials science and engineering. We would like to special thank Polytechnic Ungku Omar (PUO) giving opportunity for their staff to write and publish this eBook.

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1 : Introduction to Material Testing

1.1 Introduction of Material Testing in Mechanical Engineering

Material Testing is a key role for selection, designing and manufacturing of a material for end use and final product with a minimum of desired reliability. In the manufacturing processes, manufacturers must test their products to investigate its mechanical, physical, and chemical properties under certain load before deliver to the customer. Mechanical behaviour can be described to give engineers design data or as a guideline for the raw material standard. This is to ensure the products is safe to use, stronger, more long-lasting materials and accordance in certain standards as required by the local authorities.

1.2 Purpose of Material Testing

The purposes of materials need to be testing are:

- To determine the basic mechanical properties of ductility, hardness, toughness, malleability, strength etc.
- To evaluate composition of chemical.
- To determine quality or performance of material / product.
- To verify a material suitability for a certain application.
- To determine data. For example, force deformation (or stress) values to draw up sets of specifications upon which the engineer can base his design.
- To detect the defects in raw materials or products.

1.3 Different Between Destructive Test and Non-Destructive Test

Testing of materials are generally classified in two categories.

- **Destructive Test (DT)**

  The component or test piece after doing the testing either fractures or ceases to be useful for additional usage.

- **Non-destructive Test (NDT)**

  A component does not fracture even after being tested, so it can be used for the next application.

Table 1 Comparison between Destructive Test (DT) and Non-Destructive Test (NDT)

Destructive Test (DT)	Non-Destructive Test (NDT)
Used for determining the properties and behaviour of the materials.	Used for finding out defects of materials.
Load applies on the material.	Load is not applied on the material.
Material get damage after load is applied on it.	Material does not damage because no load is applied on it.
Most equipment test are not portable	Equipment's are portable
Equipment's are less costly	Most equipment's are expensive
No need high skill to interpret the data.	Need skill or competence personnel to interpret the data
E.g: Hardness test, tensile test, impact test, bending test, etc.	E.g: Liquid penetration test, magnetic powder test, ultrasonic test, x-ray test, etc.

1.4 Exercises

1. After the heat treatment, a product will undergo material testing for a particular purpose. List down **FOUR (4)** purpose of material testing is being performed.
2. Compare **TWO (2)** difference between Destructive Test and Non-Destructive Test in material testing.

2 : Destructive Testing (DT)

2.1 Introduction of Destructive Testing

Destructive test is one of material testing type that involve a material, component, or structure to carried out its properties when applied extreme load, ultimately leading to its failure or destruction. The purpose of this test is to understand the behaviour, performance, and limits of the tested materials.

Destructive test usually used in various industries, including manufacturing, engineering, construction, and material science. Their structures, equipment, and products are usually gaining access become loaded and deformed. Thus, the material properties under the load and deformation become an important engineering consideration and broadly classed as mechanical properties. Inappropriately, these properties cannot be related on the structural or bonding consideration but more depending on crystal imperfection and other factors such as composition, grain size, heat treatment etc.

The table 2 shows about the types of mechanical tests which give worthy information about materials especially metals and alloys as given below:

Table 2 Type of Mechanical Tests and Its Information [1]

No.	Name of Test	Information of the Test
1	Hardness test	Wear resistance, indentation resistance, scratch resistance or cutting ability of a material.
2	Impact test	A material toughness under shock loading conditions.
3	Tensile test	Tensile strength, yield point, elastic limit, Young's modulus, ductility, toughness etc. toughness of a material under
4	Creep test	Behaviour of a material under a steady load over a long period of time and creep limit of a material.
5	Fatigue test	Behaviour of a material under repeatedly applied stress and its endurance limit.

2.2 Tensile Test

The **Tensile Test** is used to evaluate the strength of metals, alloy, composite, polymer etc. In this test a test piece is pulled by Universal Testing Machine (UTM) to failure in a quite short time at a constant rate. Figure 1 show a Universal Testing Machine (UTM) for tensile test.

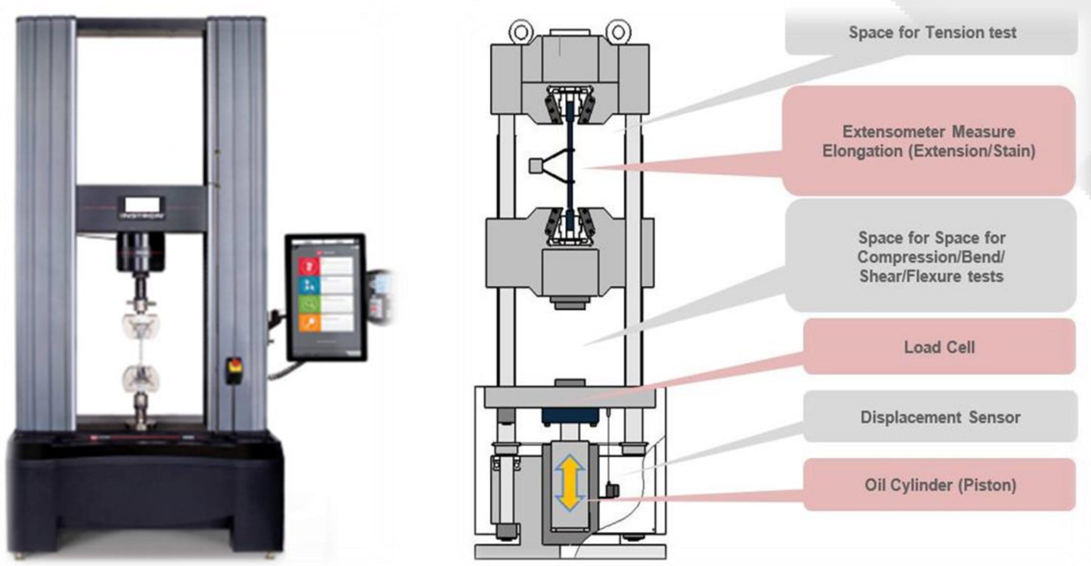
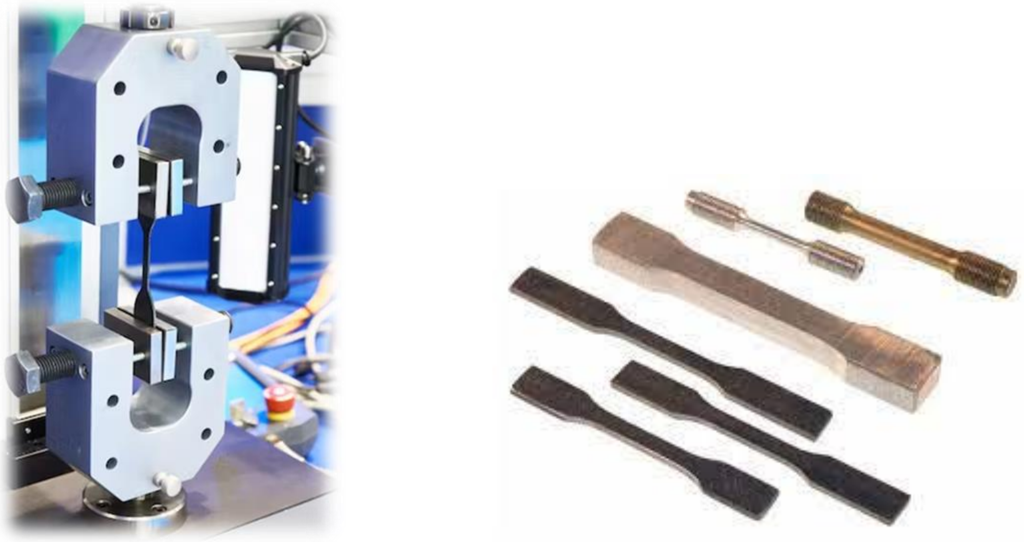


Figure 1 Universal Testing Machine



(a) (b)

Figure 2 (a) Close-up of the tensile machine jaws with specimen (b) Examples of the geometrical shape for specimen test

Basically, the tensile test is carried out on uniform cross-section of a bar or sheet throughout the gauge length. The specimen is fixed between the jaws of the testing machine and then, load is applied gradually. The elongation of the specimen is recorded continuously and finally carried out a load versus elongation or stress versus strain graph that shown in Figure 3.

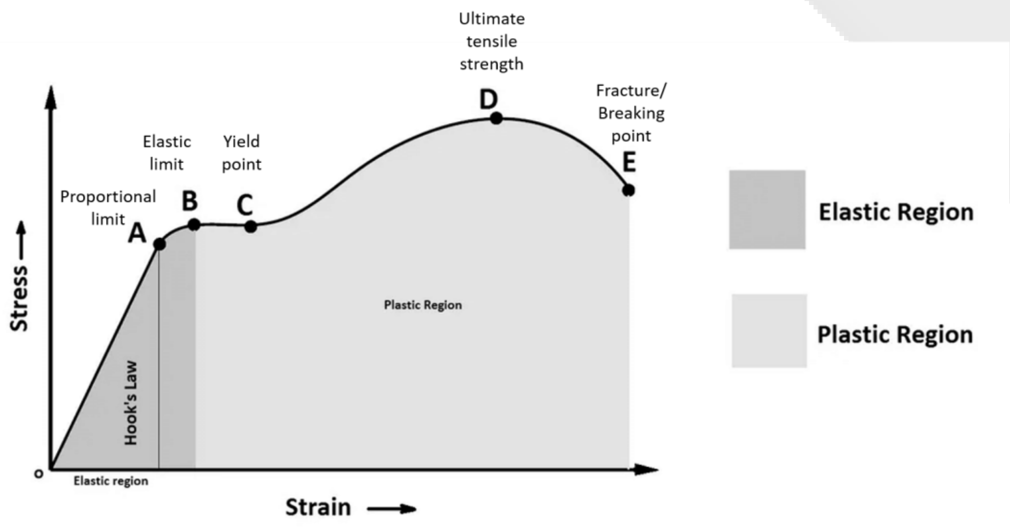


Figure 3 Stress versus strain graph

The list below shows about the numerous properties related with the tensile test:

- **Proportional limit** – the maximum load or stress that proportional with the elongation or strain.
- **Elastic limit** – the maximum load or stress which the material can withstand without permanent deformation after release the load or stress and back to the original shape.
- **Yield strength** – the stress at which a material exhibits a specified limiting permanent set.
- **Yield point** – the stress at which the first point occurs when the strain increases without increasing stress.
- **Tensile strength (ultimate or maximum strength)** – the result when the maximum load during a tensile test over original cross-sectional area of specimen.
- **Elongation** – Elongation of the specimen after fracture may be determined by difference between final length and original length of the specimen. Elongation

considerable engineering requirement because it indicates ductility or ability of the material extend before fracture.

$$\% \, Elongation = \frac{final\ length - original\ length}{Original\ length} \times 100\%$$

- **Reduction of area** – Difference between original area and final area after specimen has fractured.

$$\% \, Reduction\ of\ Area = \frac{original\ area - area\ at\ fracture}{Original\ area} \times 100\%$$

- **Modulus of Elasticity (E)** – is a measure of stiffness of a material which the slope of the linear part or elastic line of the stress-strain curve for the material under tension or compression.

$$E = \frac{stress}{strain}$$

Did You Know?

The higher tensile strength for a material, the higher load is required to pull apart the material.

2.3 Hardness Testing

Hardness is defined as the ability of a material to withstand plastic or permanent deformation because of being indented by a rigid body. Commonly, the material hardness is measured by pressing in a specific load using a sharp indenter of known geometry and mechanical properties against the test material. There have three types of hardness test depending upon the way the test conducted. The types of hardness test are following below:

a) Brinell Test
b) Rockwell Test
c) Vickers Test

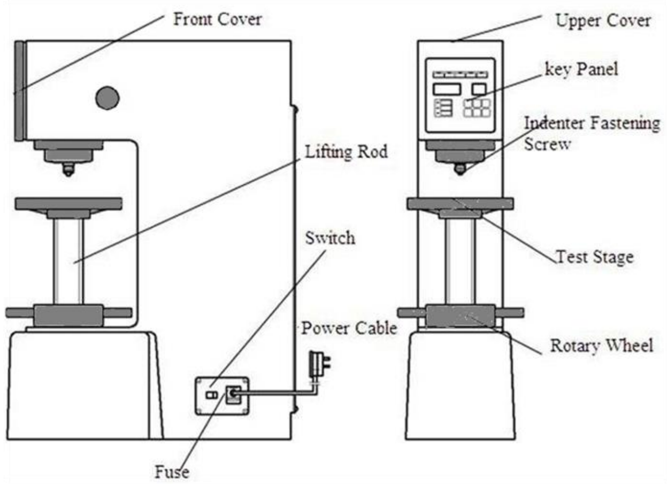
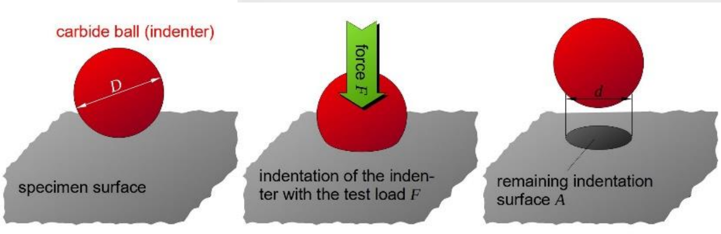


Figure 4 Hardness Test Machine

2.3.1 Brinell Test

- In 1900, J. A. Brinell proposed to widely used and standardized indentation-hardened test.
- The testing indents the metal surface by a 10mm diameter carbide ball at a load until 3,000 kg. For soft metal, the load is reduced to 500kg to avoid too deep indent.



(a) (b)

Figure 5 (a) Brinell Test Machine (b) Brinell Hardness Test Procedure

- The hardness will be carried out by a microscope and the Brinell hardness number (B.H.N).

$$B.H.N = \frac{load}{area\ of\ impression\ or\ indentation} = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2}}$$

Where P = load (kgf)

D = diameter of ball (mm)

d = diameter of indentation (mm)

2.3.2 Rockwell Test

- The Rockwell test is the most popular indentation hardness test, and it is used in a large variety of application. This test is defined in the ASTM E 18 standard. [2] [3] [4] [5]
- Its general acceptance is owing to its speed, freedom from personal error, ability to distinguish small hardness differences in hardened steel, and the small size of indentation.
- This test measuring by the depth of indentation and under constant load.

- Firstly, a minor load of 10 kg is applied to indent the specimen.
- In the Rockwell hardness test, the indenter is indented into the specimen may be either using a cone-shape or a small diameter ball with diameter 1.6mm or 3.2mm (1/16 in or 1/8 in) indenter.
- Then, a major load between 60kg, 100kg or 150kg is applied to indent the specimen in a certain distance beyond its initial position. Normally, the full load is applied between 10 to 15 seconds.

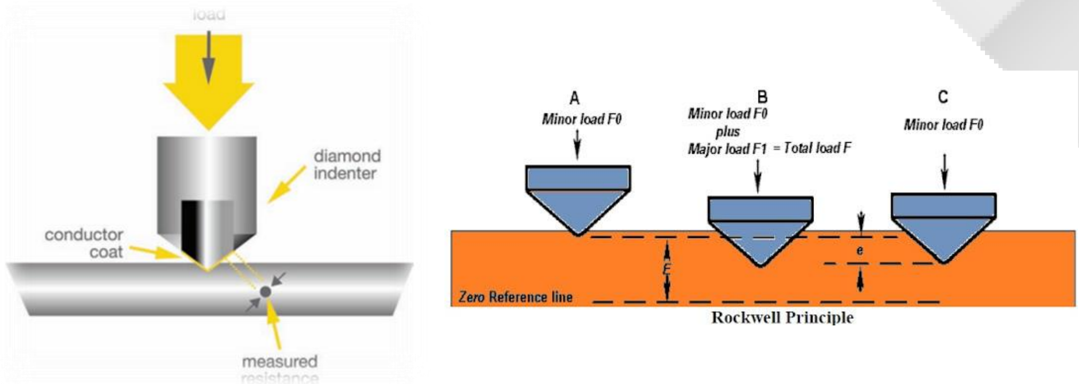


Figure 5 The principle of Rockwell hardness testing using cone-shape. This principle is same principle applies for steel ball indenters [6].

- The Rockwell hardness number (HR) is calculated by equation below:

$$HR = E - e$$

Where E = a number that depends on the form of indenter (100 units for cone diamond and 130 units for ball)

e = the permanent increase in depth of penetration

Table 3 Rockwell Standard Hardness [6]

Scale symbol	Indenter	Major load, kg_f	Typical applications
A	Diamond (two scales—carbide and steel)	60	Cemented carbides, thin steel, and shallow case-hardened steel.
B	1/16 in. (1.588 mm) ball	100	Copper alloys, soft steels, aluminum alloys, malleable iron.
C	Diamond	150	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardened steel, and other materials harder than 100 HRB.
D	Diamond	100	Thin steel and medium case-hardened steel and pearlitic malleable iron.
E	1/8 in. (3.175 mm) ball	100	Cast iron, aluminum and magnesium alloys, bearing metals.
F	1/16 in. (1.588 mm) ball	60	Annealed copper alloys, thin soft sheet metals.
G	1/16 in. (1.588 mm) ball	150	Phosphor bronze, beryllium copper, malleable irons. Upper limit 92 HRG to avoid possible flattening of ball.
H	1/8 in. (3.175 mm) ball	60	Aluminum, zinc, lead.
K	1/8 in. (3.175 mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
L	1/4 in. (6.350 mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
M	1/4 in. (6.350 mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
P	1/4 in. (6.350 mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
R	1/2 in. (12.70 mm) ball	60	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
S	1/2 in. (12.70 mm) ball	100	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.
V	1/2 in. (12.70 mm) ball	150	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that do not produce anvil effect.

* To ensure an accurate test, the range from centre to centre of indentations should be apart by a minimum of three indentation diameters

2.3.3 Vickers Test

- In the Vickers hardness test, the pyramid-shaped diamond indenter is indented into the material.
- The included angle between opposite faces of the pyramid is 136°. Because of the shape of indenter, the test also called as the diamond-pyramid hardness test.
- The load used ranges between 1kg and 100kg. Each load applied take 10 to 15 seconds.
- After remove the load, a microscope is using to measure the two diagonals of the indentation left in the material test surface and then calculate the area of the indentation sloping surface.
- The Vickers hardness number (*HV*) is measured by dividing the load and the area of the indentation.

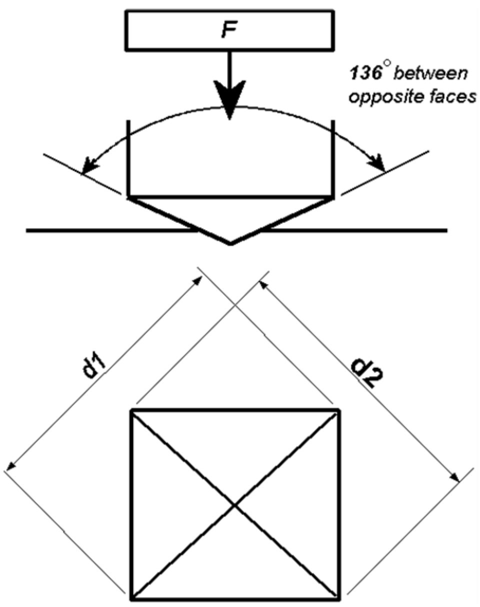


Figure 6 The principal indentation of Vickers hardness test

- The Vickers hardness number (HV) formulation given by:

$$HV = \frac{2F sin\frac{136°}{2}}{d^2}$$

Where F = the load is applied
d = the average of d_1 and d_2

2.3.4 Advantages & Disadvantages Brinell, Rockwell and Vickers Test

Table 4 The advantages testing of Brinell, Rockwell and Vickers test.

Brinell	Rockwell	Vickers
Despite this test more complicated than the other test but is still simple.	It is more flexible than the Brinell test; many combinations of indenter and loads makes it more beneficial to test a wide range of materials.	Greater accuracy in the measurement of the square diagonal as compared to the circular Brinell impression diameter.
Consideration in surface preparation is not required.	Machine tester fitted with several fixtures for testing different sizes and shapes of metal parts.	The test can also be used for testing harder materials because it uses a diamond material.
Its results correlate well with tensile properties.	Measurement taken almost quickly than shore sceleroscope because they are read directly from the instrument scale.	
Although the effects of modulus of elasticity into the hardness material, it is a fewer significance factor than another test.		
Brinell machine is large enough to give a representative hardness, not often affected by small soft spots and small hard spots.		

Table 5 The disadvantages testing of Brinell, Rockwell and Vickers test.

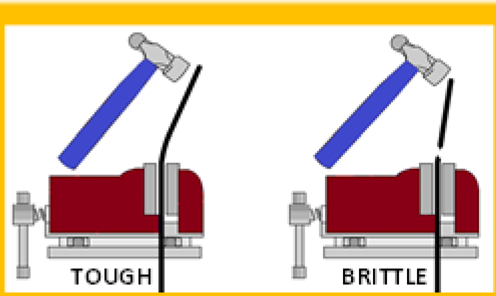
Brinell	Rockwell	Vickers
Limitation of the size indentation.	This tester needs concentrate of specimen preparation to make more sensitive of its offset.	This tester very complex and expensive than either Rockwell or Brinell test.
Test equipment is portable but heavy.		The tester turns into semi-micro hardness because of the small indent.
The specimen size is limited to the space between the anvil and indenter.		
The test is slow to determine the hardness.		
Brinell cannot be available for very hard material and readings become inaccurate data.		

2.4 Toughness / Impact Testing

Toughness is the ability of a material to prevent high impact load without fracture. Properties of toughness decreases when the material is heated [7]. It is also measured by the amount of energy where the material has absorbed after being impact it. For example, when a load is suddenly applied to a piece of medium carbon steel and continue to a piece of glass, it shown the medium carbon steel will absorb much more energy before failure occurs. While a brittle material such as glass may be strong but easily break is occurred when once a crack is started because just little energy is absorbed. There have two types of toughness test which are **Charpy test** and **Izod test**.

Did You Know?

This test is to hit a sample of material with a hammer. If it survives the hit, without bending too far, it can call to be tough. If it breaks, it can call to be brittle.



2.4.1 Izod Test

- The Izod test involves a hammer to strike a suitable specimen that it is mounted at the end of a pendulum.
- In this test, the size of specimen is fixed (10 x 10 x 75mm) with rectangle or square shape and has a V-notch facing to the hammer.
- The specimen is clamped vertically between the anvil.
- The hammer swing downwards impact to the test piece at the bottom of its swing as shown in Figure 6.
- The hammer is raised to a certain height and released. When released, a weighted of hammer is used to break the specimen and the machine take the reading how much the material (specimen) absorbed the energy before break.

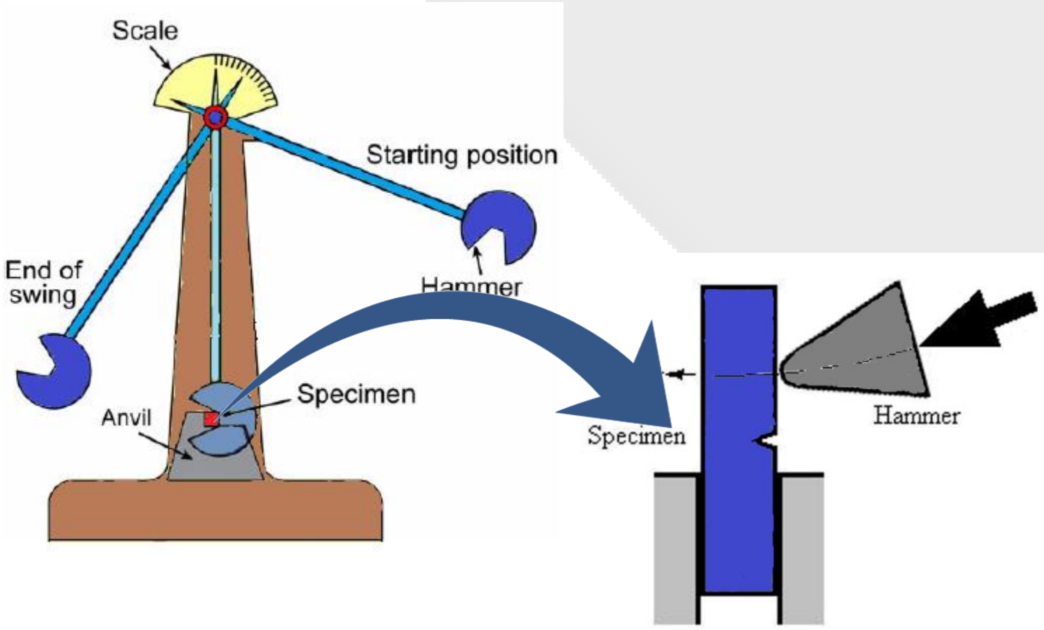


Figure 6 The principal of Izod test strike on the specimen

2.4.2 Charpy Test

- The Charpy test also involves a hammer to strike a suitable specimen that it is mounted at the end of a pendulum.
- In this test, the size of specimen is fixed (10 x 10 x 55mm) with rectangle or square shape.
- The specimen is clamped horizontally between the anvil and placed behind the notch by the impact of a heavy swinging pendulum.
- The hammer swing downwards impacting the test piece at the bottom of its swing as shown in Figure 7.
- The hammer is raised to a certain height and released. When released, a weighted of hammer is used to break the specimen and the machine take the reading how much the material (specimen) absorbed the energy before break. The specimen is bend and fracture by apply a force at a high strain ratio the order of 103/s.
- Most commonly used on metals, ceramics, polymers, and composites.

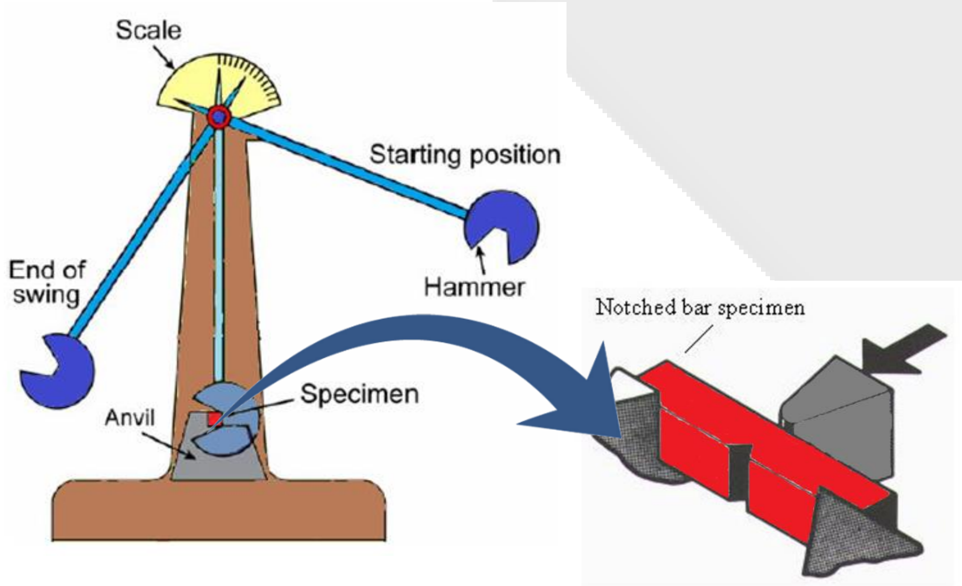


Figure 7 The principal of Charpy test on the specimen

2.5 Exercises

1. In destructive testing, several tests are carried out to determine the mechanical properties. Give **TWO (2)** types of hardness test and explain the procedure for each test.
2. A steel manufacturer decides to test the resistance to failure of a new product when an impact force is imposed on it.
   i. Choose the best method to measure its resistance to failure.
   ii. Sketch the method and explain how the method will carry out.
3. Destructive testing (DT) is one of the Material Testing that carried out to determine the mechanical properties of a material. The most common destructive test is Hardness Test and Impact Test.
   i. State the mechanical property that could be measured using Brinell, Vickers, and Rockwell testing.
   ii. Based on your answer in question 3(i), give the definition of the given property.
   iii. Briefly explain about the Rockwell test.
   iv. State the purpose of conducting Impact test and **TWO (2)** differences between Izod and Charpy Impact test.
4. Draw with appropriate explanation about Brinell and Vickers hardness test.

3 : Non-Destructive Testing (NDT)

3.1 Introduction to Non-Destructive Testing

Non-destructive test (NDT) is a wide group analysis techniques used in science and technology industry to evaluate the properties of material, component, or system without causing damage. NDT involves the assessment, evaluation, and inspection process of materials for characterization or finding defects or flaws without altering the original attributes or damage the materials being tested. NDT commonly used in mechanical engineering, forensic engineering, civil engineering, system engineering, aeronautical engineering, medicine, and others. The types of NDT are listed below:

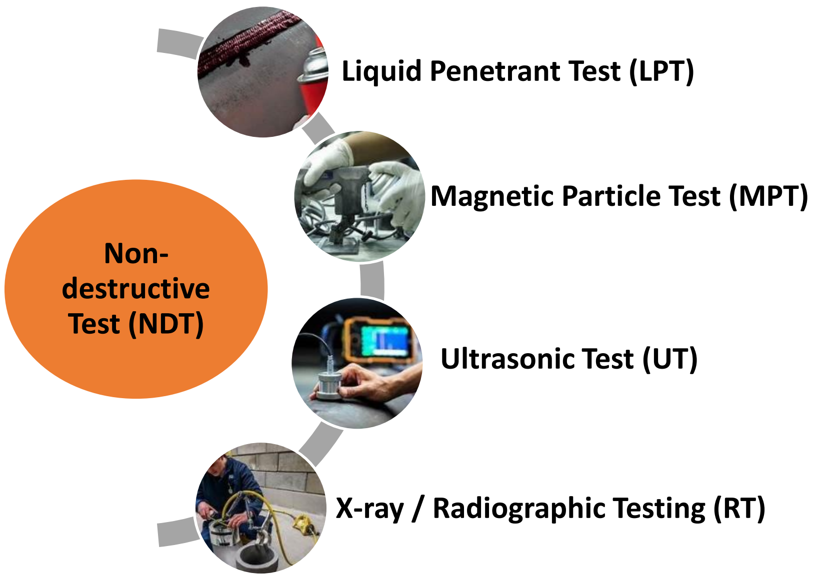


Figure 8 Types of Non-destructive Testing

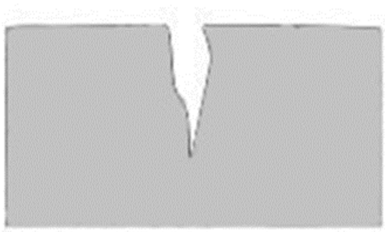
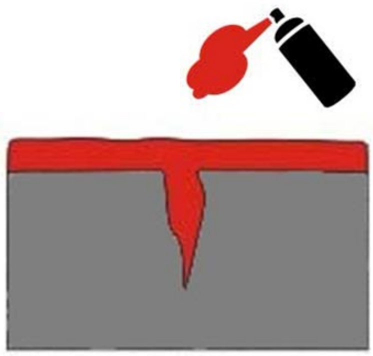
3.2 Liquid Penetrant Testing (LPT)

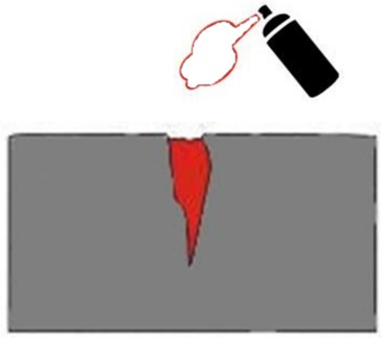
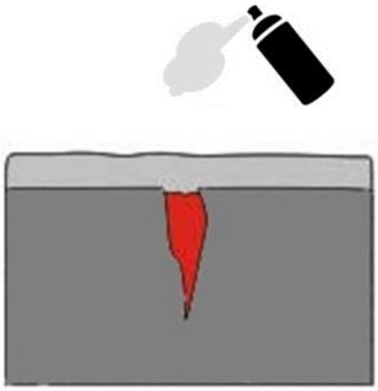
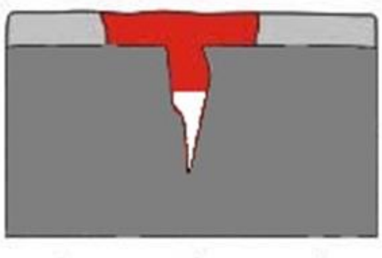
Liquid penetration test (LPT) is a widely applied and low-cost inspection method used to identify the surface defects in all non-porous materials such as metals, ceramics, polymers, and composites. The identification results data are easy to interpret but only surface defects can be detected. In fact, LPT is used to detect casting and forging defects, cracks and leaks in new products, and fatigue cracks on in-service component.

3.2.1 Method of Liquid Penetration Test (LPT)

The following Table 6 below shows a basic step of LPT using three liquid sprays such as cleaner, developer and penetrant liquid spray.

Table 6 Method of Liquid Penetration Test

1		**Contaminated test piece** Dirty test piece with a crack surface is not visible using naked eye.
2		**Pre-cleaning** Brush and cleaner spray is using to remove any particle dirt, paint, oil, grease, or any loose scale.
3		**Test piece ideal pre-cleaned** The test piece ready to be tested using liquid penetrant.
4		**Apply penetrant liquid** Applied penetrant liquid on the test surface. The penetrant liquid is allowed penetrant to soak into any surface flaws and let it dry (generally between 10 to 30 minutes).

5		**Excess penetrant removal** Remove penetrant excess from test surface. Removal method is controlled by the type of penetrant used. The common choice of cleaner is water washable, solvent-removable, lipophilic post-emulsifiable, or hydrophilic post-emulsifiable.
6		**Apply developer** Applied a thin layer of developer on the test surface to draw penetrant trapped in flaws back to the surface. Developers come in a variety of type such as dusting (dry powdered), dipping, or spraying (wet developers).
7		**Inspecting the crack** Performed inspection under appropriate visible light to detect indications from any flaws crack or defect which may be present.

3.2.2 Advantages of LPT method

- Low cost from others NDT testing.
- The flaws are more visible because the defect indication has a high visual contrast, and the developer draws the flaws wider area than the real flaw.
- Limited training is required for the operator.

3.3 Magnetic Particle Testing (MPT)

Magnetic particle testing (MPT) is an NDT method that checks for surface discontinuities but can also reveal discontinuities slightly below the surface. MPT is very popular because of low-cost test to perform NDT of ferromagnetic material.

3.3.1 How Magnetic Particle Testing (MPT) Works

When particle magnet is applied on the material surface (typically iron or steel), the particle will form lines of magnetic flux (field) through the material without any interruption.

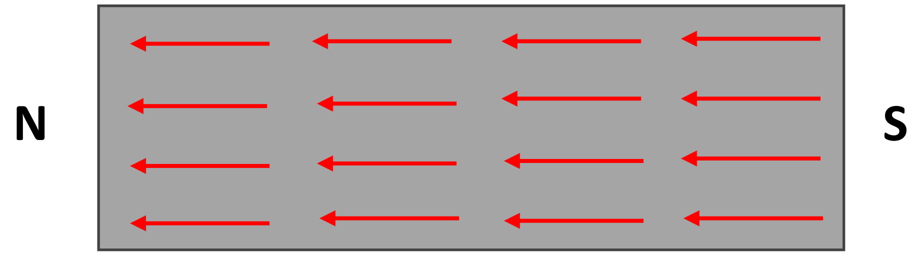


Figure 8 Magnetic Field Line

But when a crack or other discontinuity is present, the magnetic flux leaks out of the material. Apart from that, magnetic flux (magnetic field) will collect magnet particles, making the size and shape of the discontinuity easily visible.

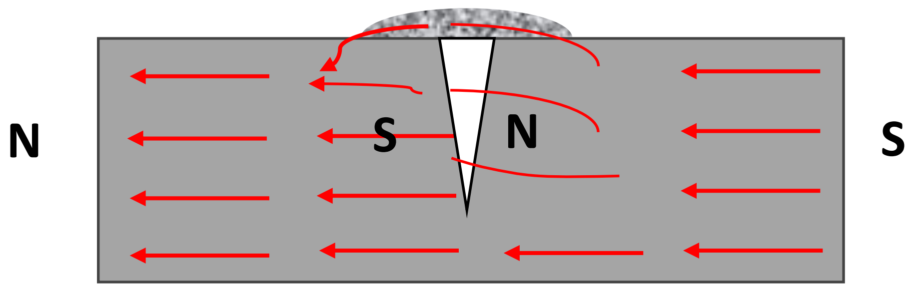


Figure 9 Magnetic flux when crack

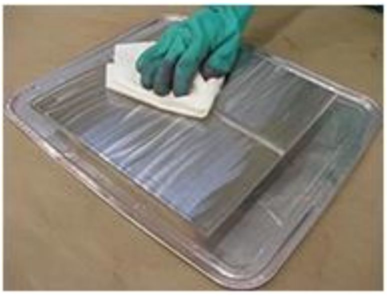
Nevertheless, the magnetic flux will only leak out of the material if the discontinuity is perpendicular to its flow. If the discontinuity, such as a crack or flaws, is parallel to the lines of magnetic flux, there will be found that no leakage shown on the surface. While, when the magnetic flux is perpendicular with discontinuities, the leakage is detected.

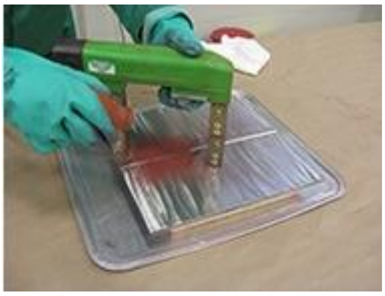
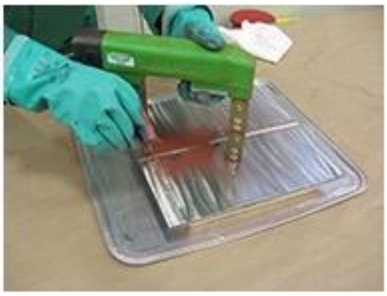
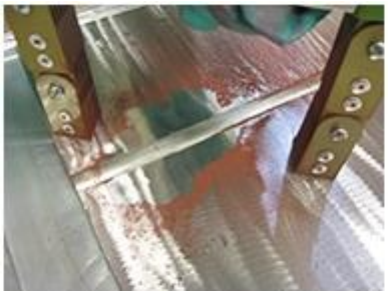
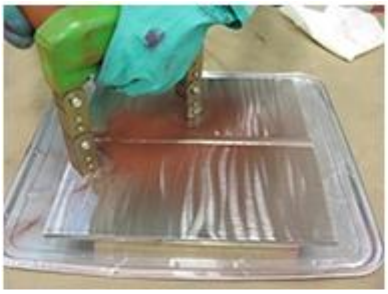
Figure 10 External longitudinal seam being checked with MPT using an AC yoke with dry powder [8]

3.3.2 Method of Magnetic Particle Testing (MPT)

The following Table 7 below illustrates about basic steps to use with the dry powder, non-fluorescent, and yoke technique in MPT.

Table 7 Method of Magnetic particle testing [8]

1		Clean the material surface to be inspected. It can be applied using detergents, paint removers, organic solvent, ultrasonic cleaning, grit or sand blasting, or descaling solutions methods.
2		Apply a magnetic field using AC yoke into the test piece.

3		Apply the magnetic powder while the material is still magnetised.
4		Remove excess magnetic powder with a light air stream from a bulb, syringe, or other source of low-pressure dry air.
5		Interpret and identified of any discontinuity such as crack or flaws.
6		Turn the AC yoke to 90^{o} from the original position and continue step from 2 to 5. Clean and demagnetised if necessary.

3.3.3 Advantages of MPT method

- Can detect both side surface test piece.
- Surface preparation is not complicated rather than other NDT methods.
- A fasting method testing, and lower cost comparing to others NDT methods.
- A portable method, especially when used with battery-powered yoke equipment.
- Easily to utilize and needs minimal amount of training.

3.4 Ultrasonic Testing (UT)

Ultrasonic testing (UT) is most popular method in NDT using high frequency sound waves to characterize the internal structure or thickness of a test piece. UT presents immediately results with a high degree of accuracy for cracks and internal flaws such as gas porosity. The test is appropriate for metals, plastic, glass and ceramics. The test piece that are thin, small, complex shapes or rough surface are difficult to test and interpret.

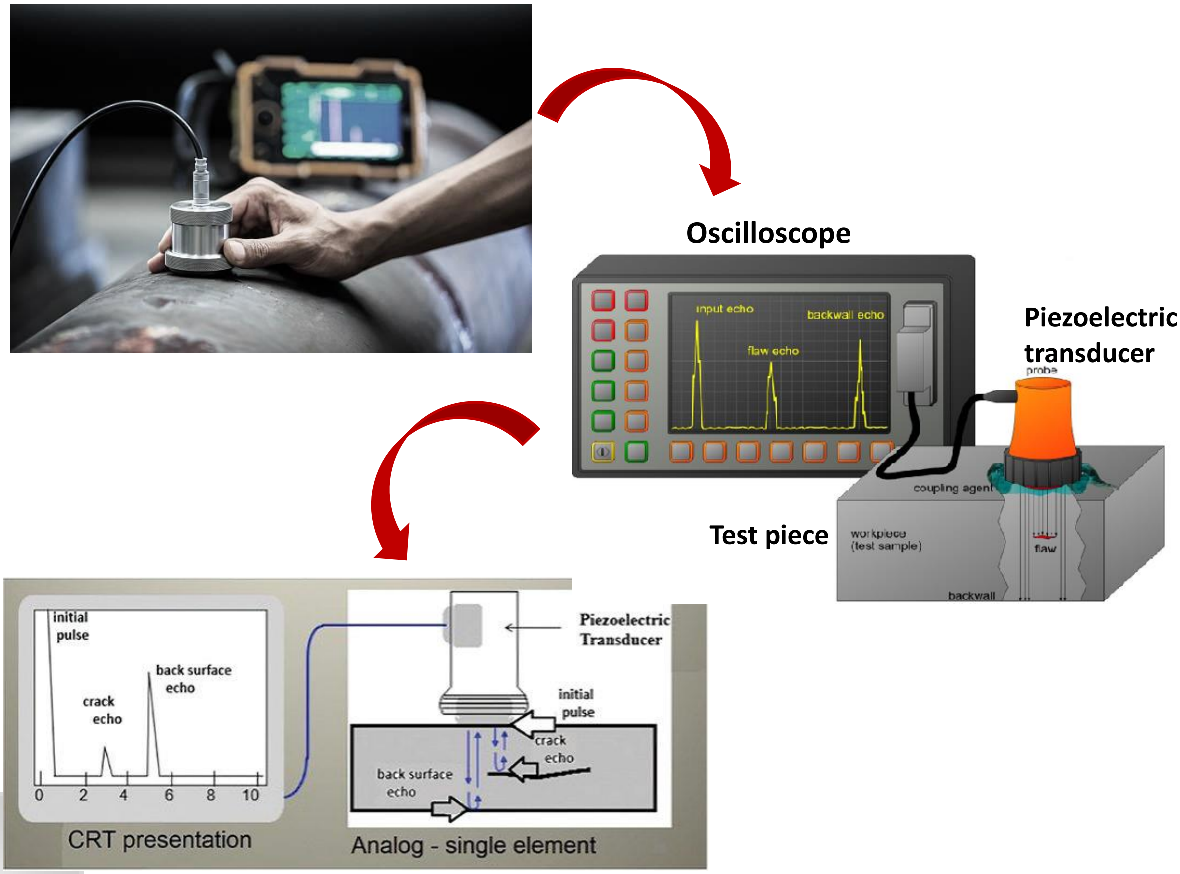
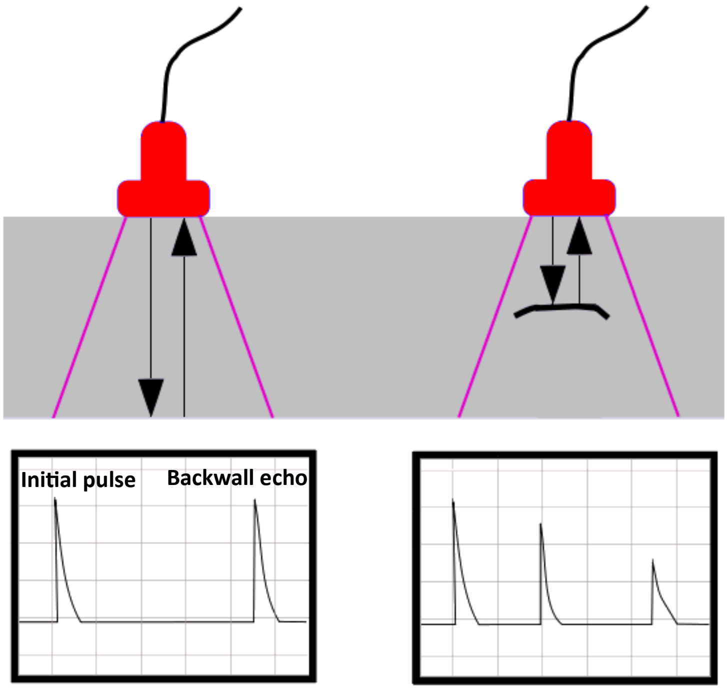


Figure 11 Principle of ultrasonic testing

3.4.1 Method of Ultrasonic Testing (UT)

- High frequency ultrasonic waves (between 0.5MHz to 20Mhz) are used for surface and internal flaws detection in the test piece.
- The ultrasonic waves are usually generated by the piezoelectric effect which convert electrical energy to mechanical energy. The piezoelectric transducer is placed on the surface test piece when it will be tested.
- Vibrations penetrate the test piece and are refracted and reflected signal which is display on an oscilloscope. Another transducer picks up the reflected and display on oscilloscope.



(a) (b)

Figure 11 Display result on oscilloscope

- Ultrasonic testing principle is shown in Figure 11:
  (a) A piezoelectric transducer transfers a sound wave into a material or test piece. There are two types of indications where one from the transducer initial pulse, and the second due to the backwall echo.
  (b) A third indication and simultaneously reduces the amplitude of the back wall indication is created by a defect.

3.4.2 Advantages of Ultrasonic Testing (UT)

- High penetration power which allows the detection of deep flaws in the test piece.
- High sensitivity which able to detect of small flaws.
- Greater accuracy than other NDT methods in determining the thickness of the test piece and depth of internal flaws.
- The testing machine is portable or highly automated operation.

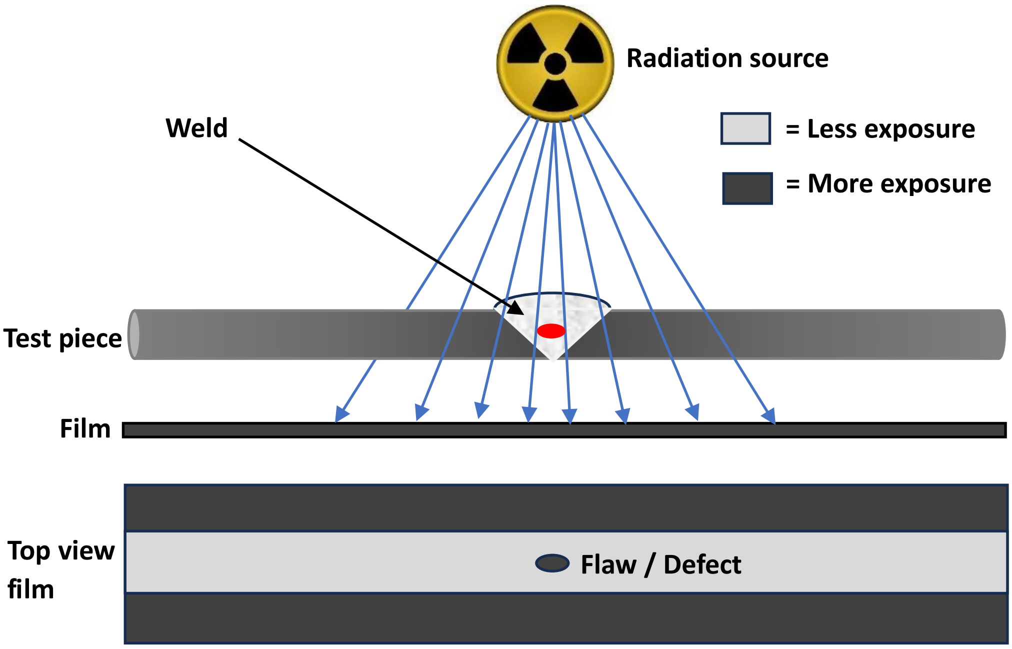
3.5 X-Ray / Radiography Testing (RT)

Radiography testing (RT) is an imaging method that uses x-rays to view the internal structure of a test piece. An x-ray generator or radioactive source produces a beam of x-ray and a form of electromagnetic radiation and then projected directly onto the test piece to create the image in film. The radiation is used a higher energy (shorter wavelength) version of the electromagnetic waves in radiography testing. It also can be performed using either x-ray or gamma rays. Both rays are formed as electromagnetic radiation.

3.5.1 Principles of Radiography Testing (RT)

- The test piece is positioned between a film and the radiation source.
- The test piece will stop with some of radiation. Deeper and more intense area will stop more of the radiation.
- The film darkness (density) will vary with the amount of radiation reaching the film through the test piece that shown in Figure 12.
- Penetration power will affect by the energy of the radiation. The higher energy radiation can penetrate thicker and need more radiation.
- The radiation energy and/or exposure time must be controlled to make a proper and interesting image.

(a)



(b)

Figure 12 Principle of Radiography Testing (RT)

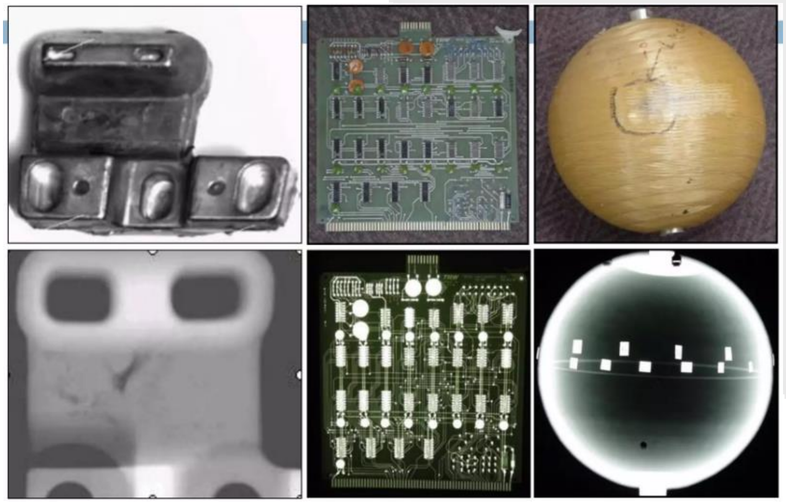


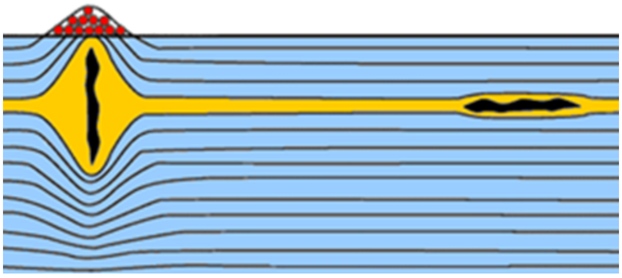
Figure 12 Radiographic test piece image

3.5.2 Advantages of Radiography Testing

- Can testing assembled component.
- Minimum surface preparation required.
- Can detect surface, subsurface, and internal flaws or defects test piece.
- Verify internal flaws on complex structures.
- Sensitive to changes in material density, corrosion, defects, and thickness changes.

3.6 Exercises

1. Non-destructive testing is widely applied in industrial field such as oil and gas, construction, piping and many more. Define the meaning of non-destructive testing.
2. Identify TWO (2) advantages in Ultrasonic Inspection Method.
3. Explain briefly the method used in the test with the aid of diagram as shown in diagram below.



4. Ali wants to test a concrete beam which is suspected to have a surface defect.
   Write **ONE (1)** suitable testing to inspect the beam.
5. In the oil and gas industry, radiography testing is often used to check equipment, such as pressure vessels and boiler to detect for flaws.
   i. Draw the diagram of radiographic testing.
   ii. Show how radiographic testing is carried out

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