MODULE - 1

Mechanical Behavior of Engineering Materials

COURSE CODE: 21AE32

Introduction to Aircraft Materials

- General properties of materials
- Definition of terms
- Requirements of aircraft materials
- Testing of aircraft materials
- Inspection methods
- Application and trends in usage in aircraft structures and engines
- Selection of materials for use in aircraft.

General Properties of Materials

1. **Strength**
2. **Hardness**
3. **Toughness**
4. **Elasticity**
5. **Plasticity**
6. **Ductility**
7. **Malleability**
8. **Brittleness**
9. **Stiffness**
10. **Resilience**
11. **Creep**

1. **Strength** : The ability of the material to resist the external forces causing various types of stresses without breaking or rupture.
2. **Hardness** : The resistance of the material to penetration or permanent deformation.
3. **Toughness** : The ability of the material to absorb energy before fracture takes place.
4. **Elasticity** : The ability of the material to regain its original shape and size after the deformation, when the external forces are removed.
5. **Plasticity** : The ability of the material to retain the deformation produced under the load on a permanent basis.

6. Ductility : The ability of the material to deform to a greater extent before the sign of crack , when it is subjected to tensile force.

7. Malleability : The ability of the material to deform to a grater extent before the sign of crack, when subjected to compressive force.

8. Brittleness : It is the property of the material which shows negligible plastic deformation before fracture takes place.

9. Stiffness: It is the ability of the material to resist deformation under the action of an external load.

10 Resilience : It is the ability of the material to absorb energy when deformed elastically and to release this energy when unloaded.

11. Creep : Whenever a member or part of a machine subjected to a constant stress at high temperature for a longer period of time, it will undergo a slow and permanent deformation called creep.

12. Density : Density is the weight of a unit volume of the material.

13. Fusibility : Fusibility is the property of being liquefied by heat.

14. Conductivity : Conductivity is the property of transmitting heat or electricity.

15. Contraction and Expansion : Contraction and expansion are caused by the cooling or heating of metals.

Definition of terms

1. **Annealing :** Annealing is the process of heating steel above the critical range, holding it at that temperature until it is uniformly heated and the grain is refined, and then cooling it very slowly.
2. **Normalizing :** Normalizing is similar to annealing, but the steel is allowed to cool in still air - a method that is somewhat faster than annealing cooling. Normalizing applies only to steel.
3. **Heat Treatment :** Heat treatment consists of a series of operations which have as their aim the improvement of the physical properties of a material.
4. **Hardening :** Hardening of steel is done by heating the metal to a temperature above the critical range and then quenching it.

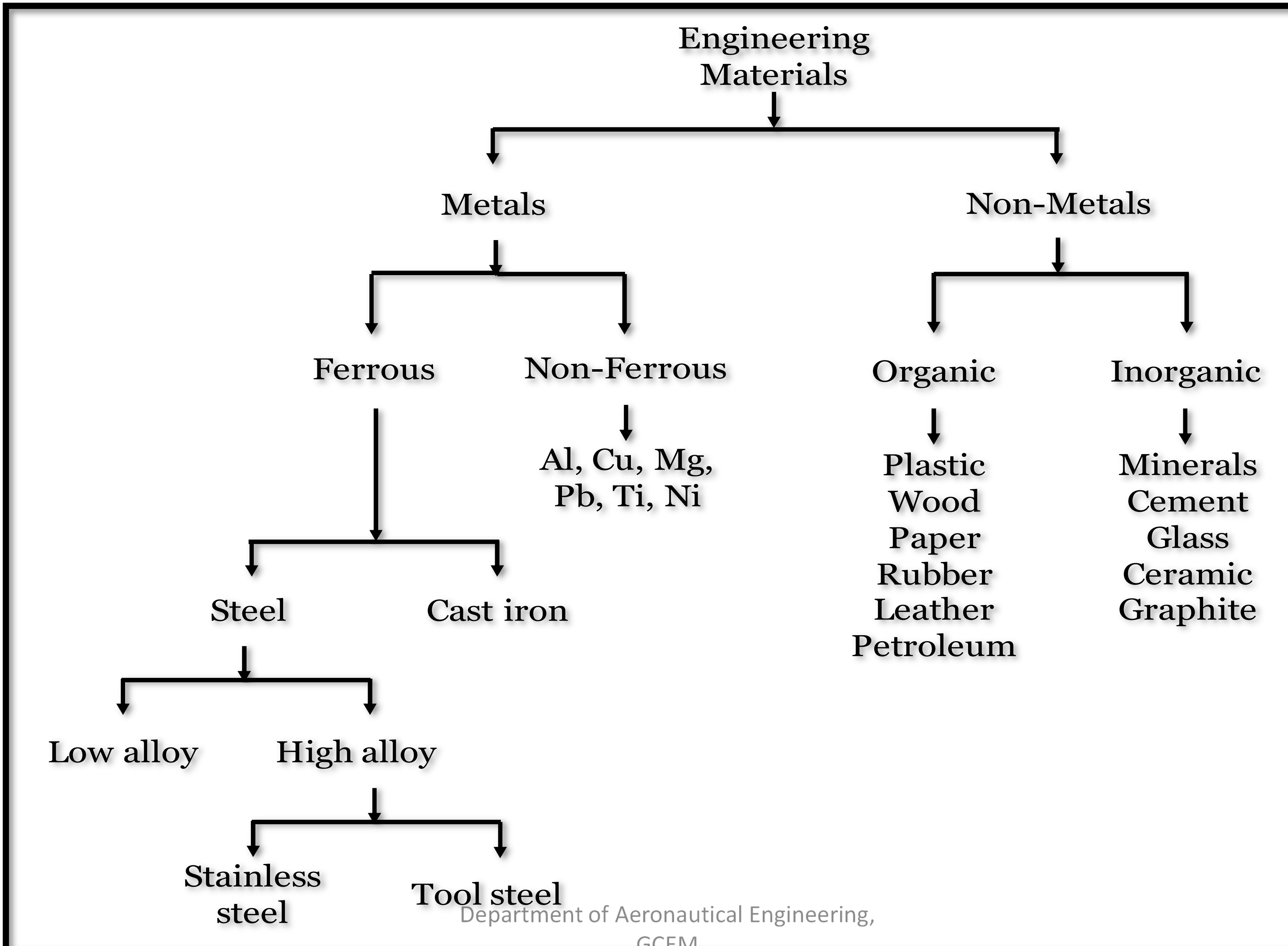
5. Quenching: Quenching is the immersion of the heated metal in a liquid, usually either oil or water, to accelerate its cooling.

6. Tempering: Tempering is the reheating of hardened steel to a temperature below the critical range, followed by cooling as desired. Tempering is sometimes referred to as “drawing”.

7. Carburizing: Carburizing is the addition of carbon to steel by heating it at a high temperature while in contact with a carbonaceous material in either solid, liquid, or gaseous form.

8. Case-hardening: Casehardening consists of carburizing, followed by suitable heal treatment to harden the metal.

Classification of materials



Metals and Non-metals

Metals	Non-metals
Metals are good conductors of heat and electricity.	Non-metals are bad conductors of heat and electricity.
Metals are malleable that is they can be beaten into sheets.	Non-metals are not malleable.
Metals are ductile that is they can be drawn into wires.	Non-metals are non-ductile.
Metals are sonorous.	Non-metals are not sonorous.
Metals have high tensile strength due to high attraction between molecules.	Non-metals have low tensile strength due to low attraction between molecules.
Metals have high density.	Non-metals have low density.
Metals have high melting and boiling points.	Metals have low melting and boiling points.
Metals combine with oxygen and forms basic oxides.	Non-metals combine with oxygen and form acidic oxides.

Difference between Ferrous & Non-Ferrous Metals

	Ferrous Metals	Non-Ferrous Metals
1.	Contains any amount of iron in its basic form.	Does not contains any amount of iron in its basic form.
2.	That's why they possesses magnetic property and makes them prone to corrosion.	They do not possess magnetic property, but resist corrosion much better than ferrous metals.
3.	They have a high tensile strength since they can carry a high amount of strain.	They have very low tensile strength.
4.	They have the ability for oxidation, known as corrosion. Oxidation of ferrous metals forms as a reddish-brown deposit on the surface & is oxide of iron.	They have typically lighter weights, higher melting points & are basically resistant to corrosion.
5.	Typically used when the magnetic attraction of iron may be a disadvantage. (used where strength is the primary focal point)	Ideal for electronic & electrical applications.
6.	Eg., pig iron, steel, cast iron, etc.	Eg., cobalt, aluminium, zinc, etc.

Requirements of aircraft materials

1. Low density
2. High strength and rigidity
3. High specific properties
4. High fatigue strength
5. High toughness
6. Low rate of crack propagation
7. Resistance to stress corrosion cracking

Requirements of aircraft materials

8. High corrossion resistance
9. High temperature resistance
10. High damage tolerance
11. High erosion resistance
12. Resistance to thermal shock and creep
13. Good technology properties (formability, machinability, weldability)

TESTING OF AIRCRAFT MATERIALS
(Different types of testing)

1. Tension testing
2. Hardness testing
3. Bending tests
4. Impact tests
5. Crushing tests
6. Hydrostatic test
7. Torsion test
8. Fatigue testing

Different type of testing

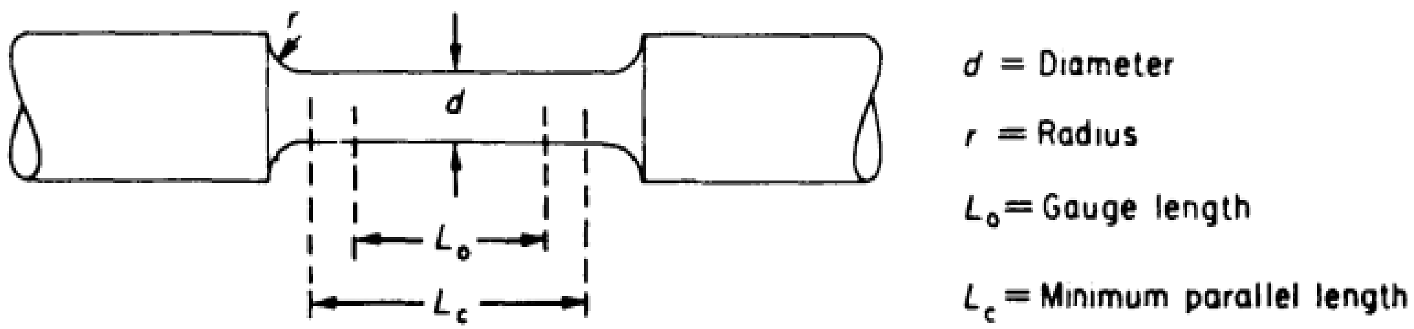
Tension test

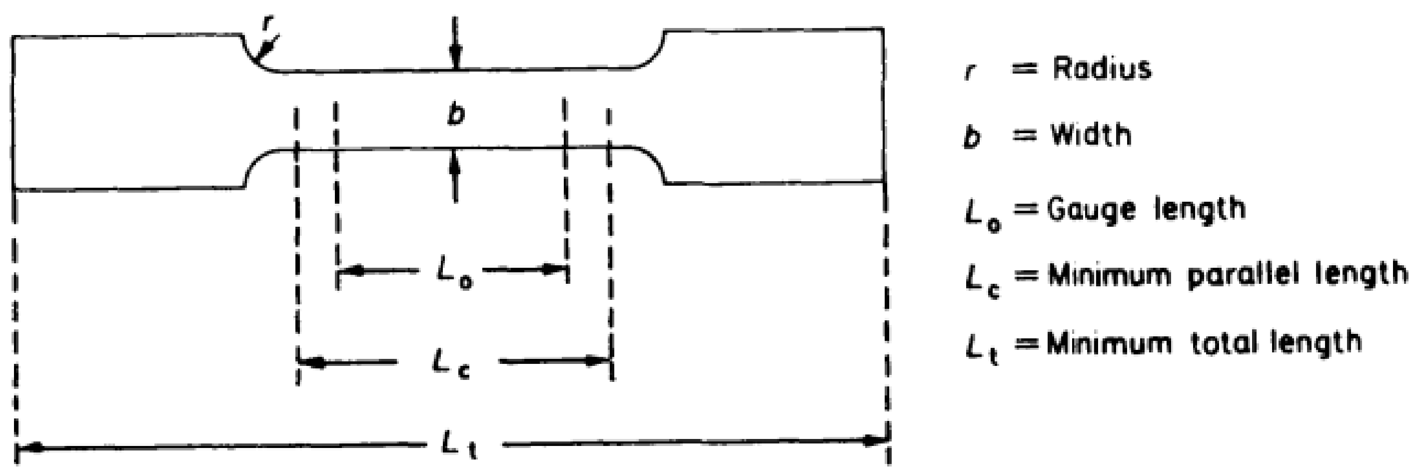
- It is the most commonly used method to identify the basic properties of the material.
- Universal testing machine with extensometer dial gauge.
- Wire, strip or machined samples with either circular or rectangular cross section.
- Test specimens can be screwed or gripped in the jaws.

Different type of testing

Tension test

Types of test specimens:

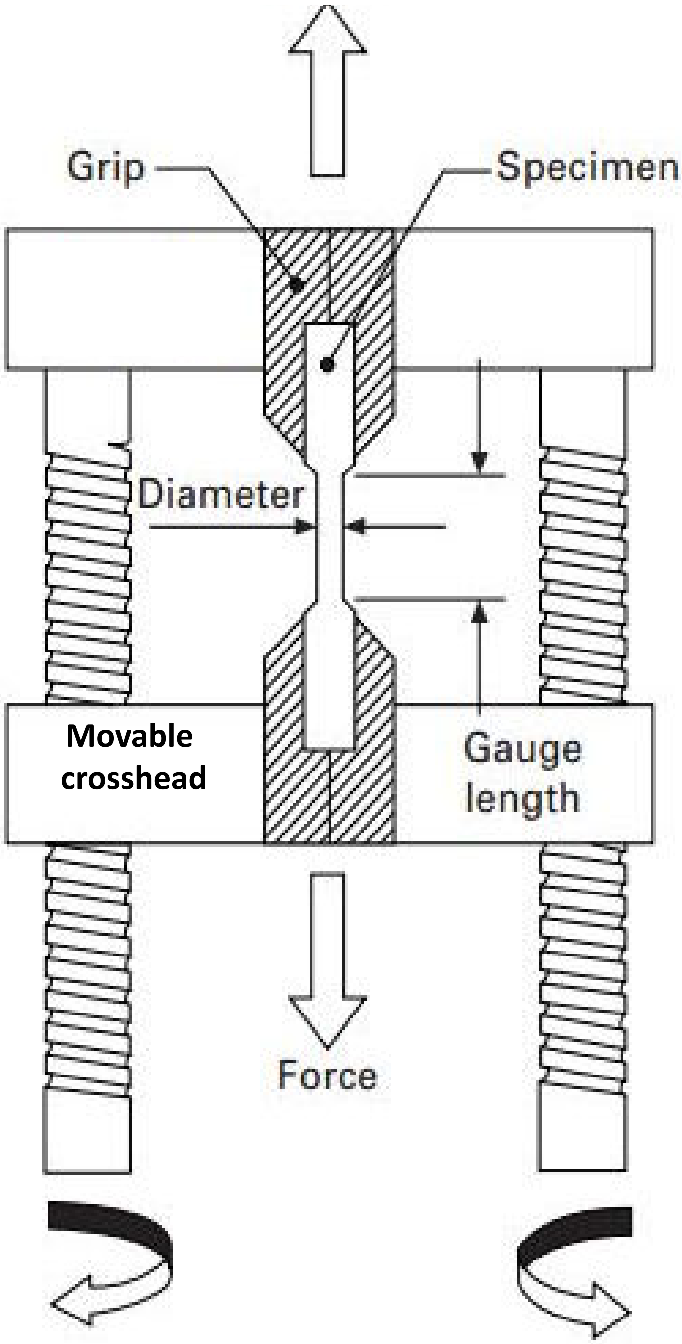




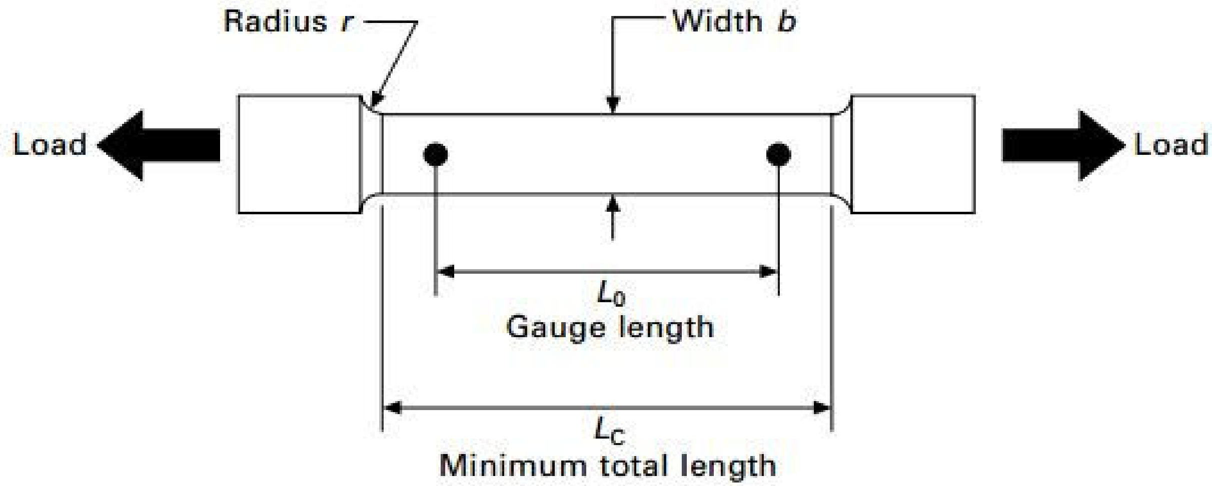
Different type of testing

Properties obtained using tension test

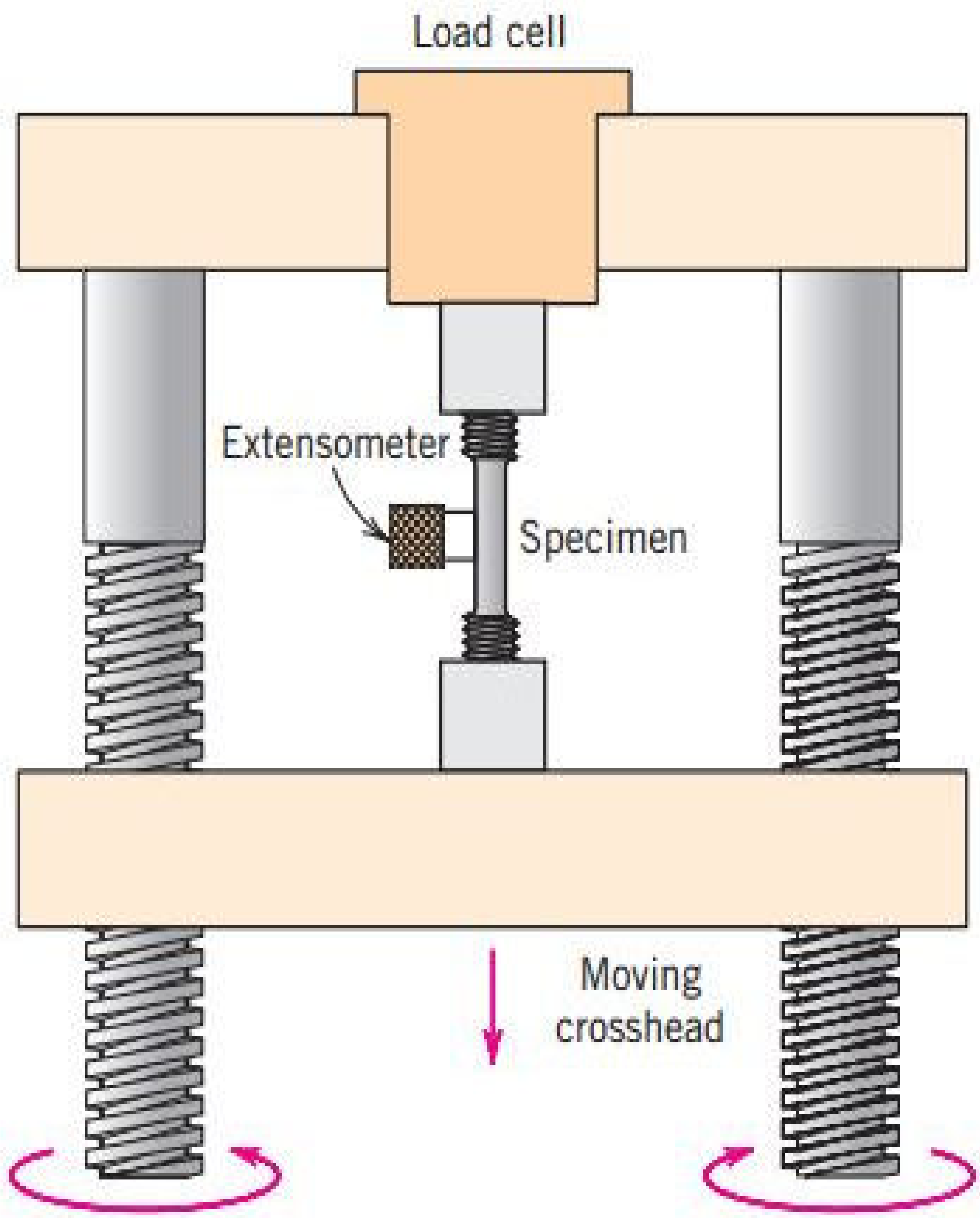
1. Tensile strength (Ultimate tensile strength)
2. Yield stress
3. Percentage increase in length
4. Percentage reduction in area
5. Breaking stress
6. **Yield point determination**
    a. Divider method
    b. Drop of beam method



Grip
Specimen
Diameter
Movable crosshead
Gauge length
Force



Radius r
Width b
Load
Load
L0
Gauge length
LC
Minimum total length


Load cell
Extensometer
Specimen
Moving
crosshead

Tension testing

Procedure for conducting tension test

1. Initial diameter and gauge length
2. Fix the specimen in the jaws
3. Load the specimen in steps – extensometer meter reading
4. Load at yield point – rapid movement of the indicator in extensometer dial gauge
5. Maximum load and elongation – rupture
6. Final diameter of specimen
7. Graph is plotted by taking load on **y axis** and elongation on **x axis**

Tension testing

Tensile strength:

$$\text{T.S.} = \frac{\text{Maximum load applied}}{\text{Original cross-sectional area}}$$

Yield stress:

$$\text{Yield stress} = \frac{\text{Applied load at the yield point}}{\text{Original cross-sectional area}}$$

Tension testing

Percentage increase in length:

$$\left(\frac{L - L_0}{L_0}\right) \times 100$$

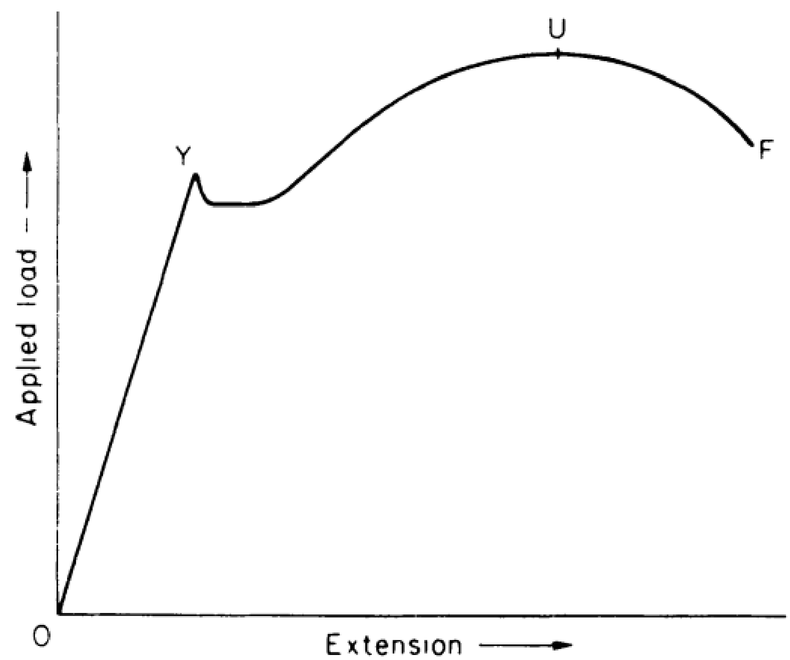
Percentage reduction in area:

$$\left(\frac{A_0 - A}{A_0}\right) \times 100$$

Tension testing

Breaking stress:

$$B\,S = \frac{\text{Load at failure}}{\text{Original cross sectional area}}$$



Tension testing

Yield point determination:

a. Divider method

- Divider is set to the exact distance between two gage marks.
- Loaded - one arm of the dividers centred in one gage mark and the other arm held free above the other gage mark.
- At the instant visible stretch - the load should be noted.
- The yield-point stress is computed from this load.

Tension testing

Yield point determination:

b. Drop of beam method

- The load is applied uniformly and the recording beam kept balanced by the operator.
- At the yield-point load the beam will drop suddenly as the elongation increases rapidly at this point without increase in load.
- Testing machine – self indicating load measuring device, the pointer will halt momentarily at the yield-point load.
- The yield-point stress is computed from this load.

Different type of testing

Compression test

- Universal testing machine.

Shape of the specimen:

a. Metals and certain plastics: Cylinder
b. Building materials (concrete or stone): Cube

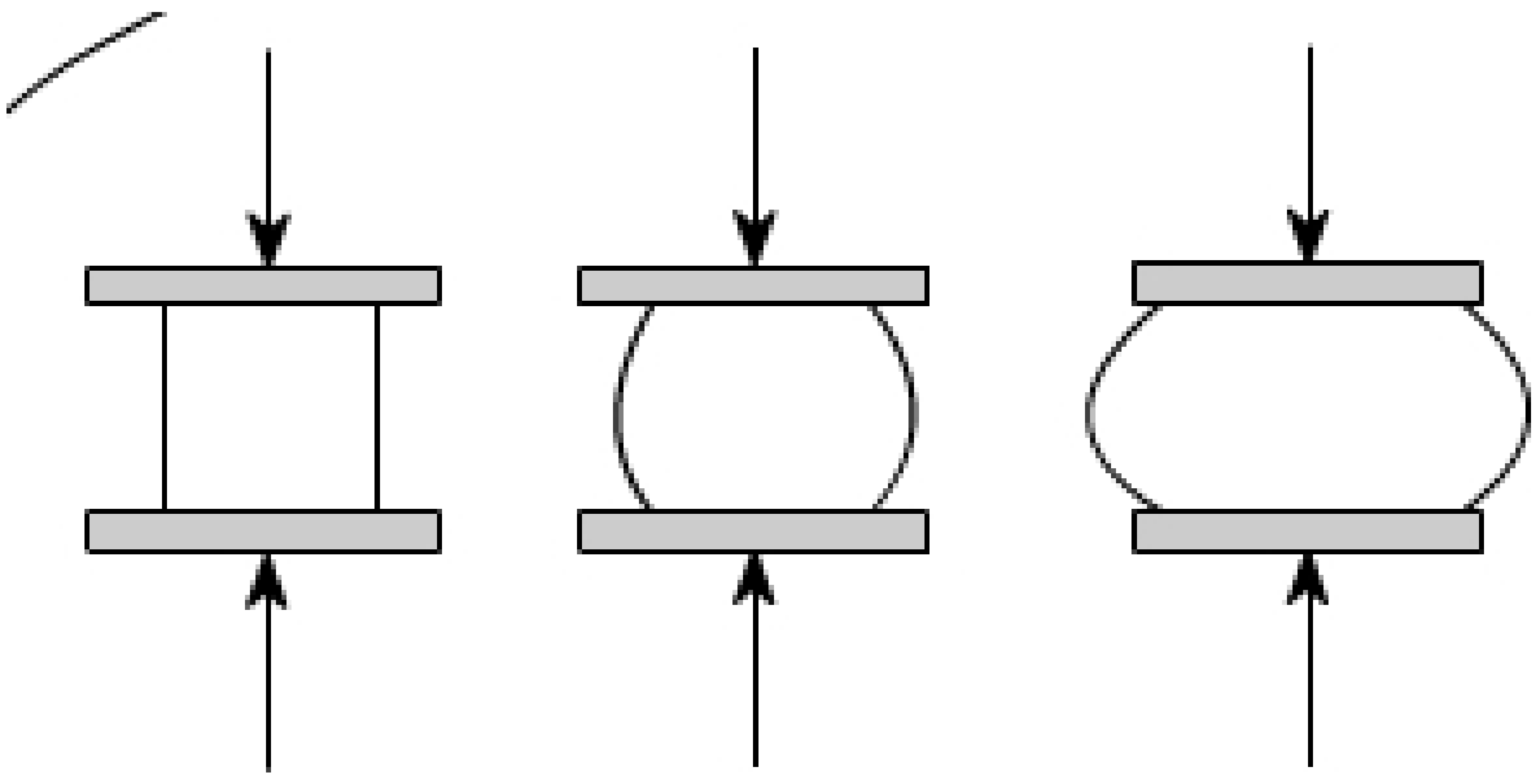
Ductile Materials:

- Steel, Aluminum and copper: Similar stress – strain curves as in tensile test.
- Proportional limits in compression test are very much close to those in tension.

Compression test

Ductile Materials:

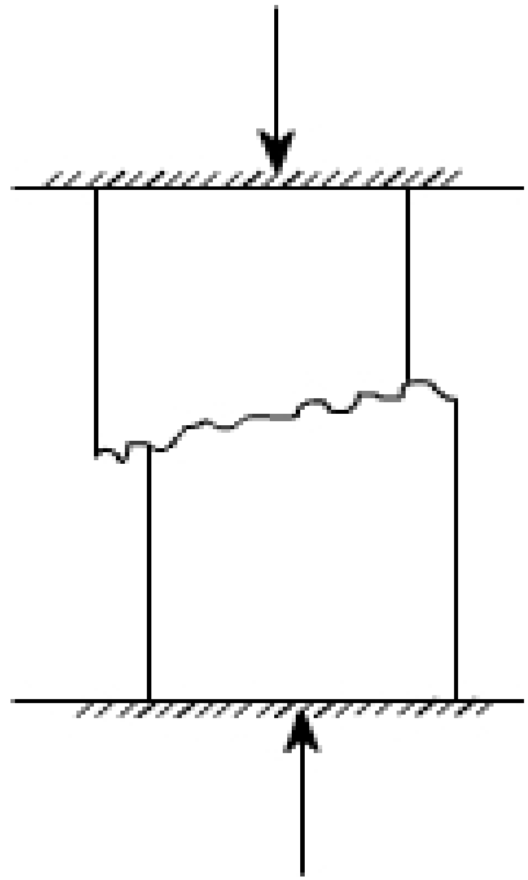
- Specimen bulges on sides and becomes barrel shaped.
- With increasing load, the specimen is flattened out, thus offering increased resistance to further shortening



Compression test

Brittle Materials:

- Brittle materials fails suddenly by splitting or by cracking.
- In brittle fracture there is no appreciable plastic deformation.



Hardness test

- Test specimen exhibits different properties than the manufactured component.
- Hardness test is a comparative test to determine the overall strength of a materials without destroying or hammering the manufactured components.

Types of hardness test:

1. Brinell hardness test.
2. Rockwell hardness test.
3. Vickers hardness test.
4. Shore Scleroscope hardness test.

Hardness test

Sample preparation:

- Tested surface should be smooth and free from scratches, ridges, scales, or other unevenness.
- Specimen must also be sufficiently thick so, that the impression made by the testing apparatus does not bulge the opposite side.

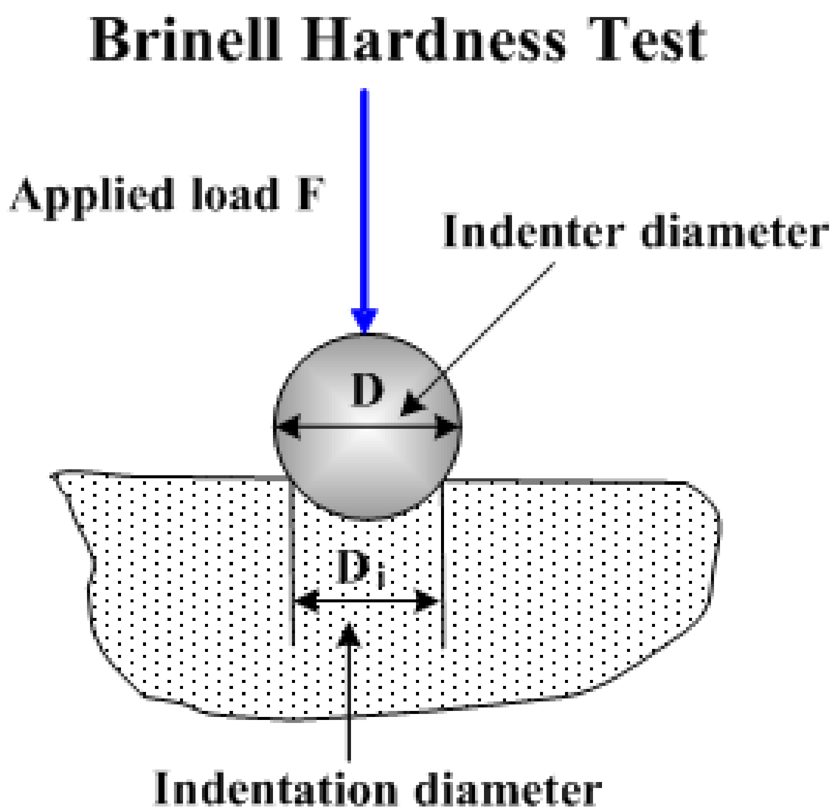
- **Micro hardness test:**

  For very thin materials, the surface of the material must be highly polished.

Brinell hardness test:

- In this method, a **hardened steel ball** is pressed into the flat surface of a test piece for 10 -15 seconds using a specified force.
- The ball is then removed and the diameter of the resulting indentation is measured using a microscope.
- Hardened steel ball : 2.5, 5 or **10** mm.
- Indenter hardness : 1.7 times than the test specimen.
- Force:

  Steel – 3000 kg
  Aluminium – 500 kg



Brinell hardness test

$$H_B = \frac{\text{Applied load (kg)}}{\text{Surface area of the impression (mm}^2\text{)}}$$

$$H_B = \frac{F}{A}$$

$$H_B = \frac{2F}{\Pi D[D - \sqrt{D^2 - {D_i}^2}]}$$

F = Load applied to the ball.

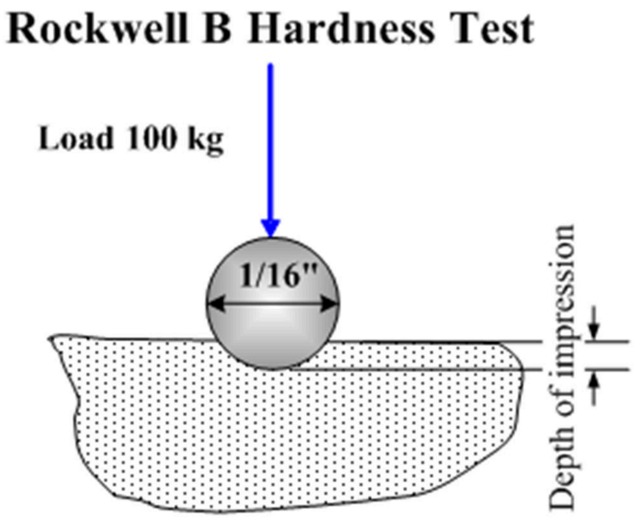
A = curved area of the indentation

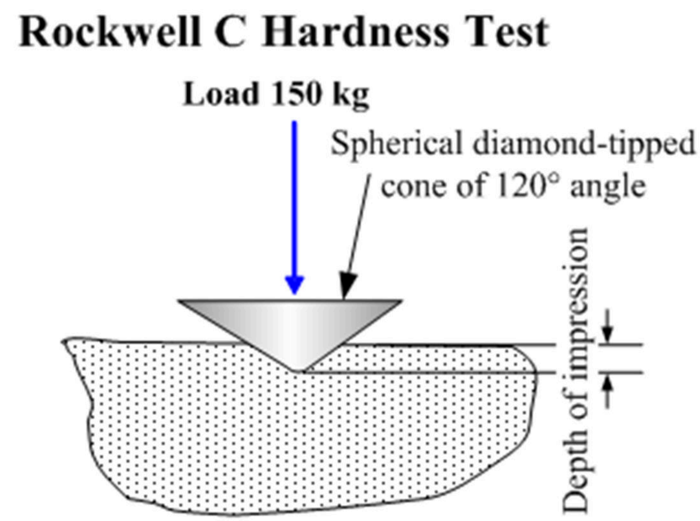
D = diameter of the ball,

D_i = the diameter of the indentation.


BRINELL HARDNESS TESTER

Rockwell hardness test





Indenter:

1. Steel ball: 1/16", 1/8"
2. Spherical diamond tipped cone: 120°

Procedure:

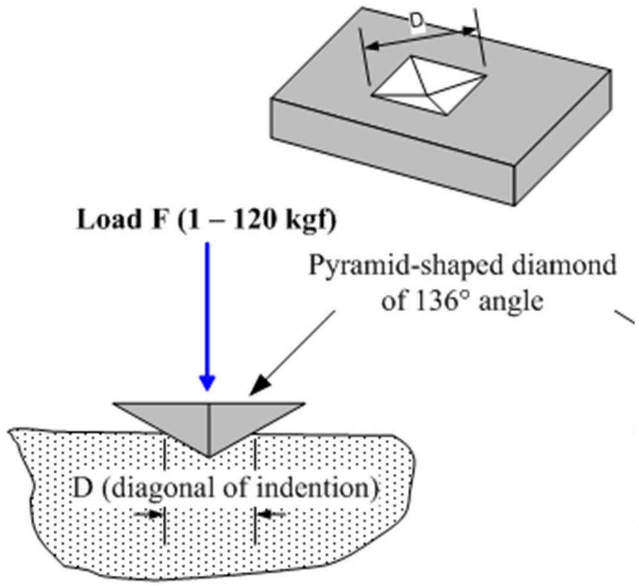
1. Minor load of 10 kgf - indicator is set to zero.
2. After that the major load (60, 100 or 150 kgf) is applied.

B scale: 0-100 kg, red dial ; **C scale:** 20-150 kg, black dial

53 HRC


DIGITAL HARDNESS TESTER
HRC
00.0
FN
ENT
SCL
RST
START
HARDNESS TESTER
MODEL
SR. NO.

Vickers hardness test



- Vickers Hardness method is similar to the Brinell method.
- Indenter is a 136° square-based diamond pyramid.
- Impression is clearer than Brinell indenter, hence more accurate.
- Load: 1 - 120 kg, is usually applied for 30 seconds

$$HV = \frac{1.854 \times F}{D^2}$$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Bending test

- Aircraft metals must pass a bending test.
- It involves **cold bending** through an angle of **180°**, over a pin equal to the diameter or thickness of the test specimen, without cracking.
- Metal is ductile and not inclined to brittleness.
- **Universal Testing Machine** : Compression mode
- Bend radius is a function of the thickness of the material hence results are expressed as 1T, 2T,3T,etc.

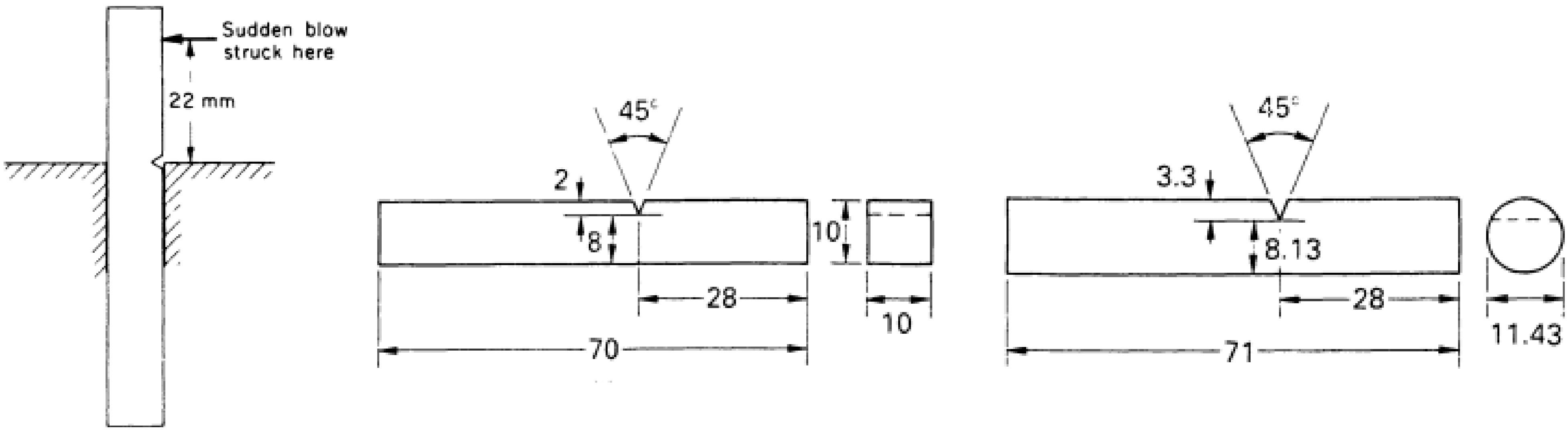
Sample preparation

- 1 inch wide by 6 inches long and the full thickness of the material.
- Edges should be rounded to remove rough spots.
- For heavy shapes : specimen with rectangular cross-section is used.

Impact Test

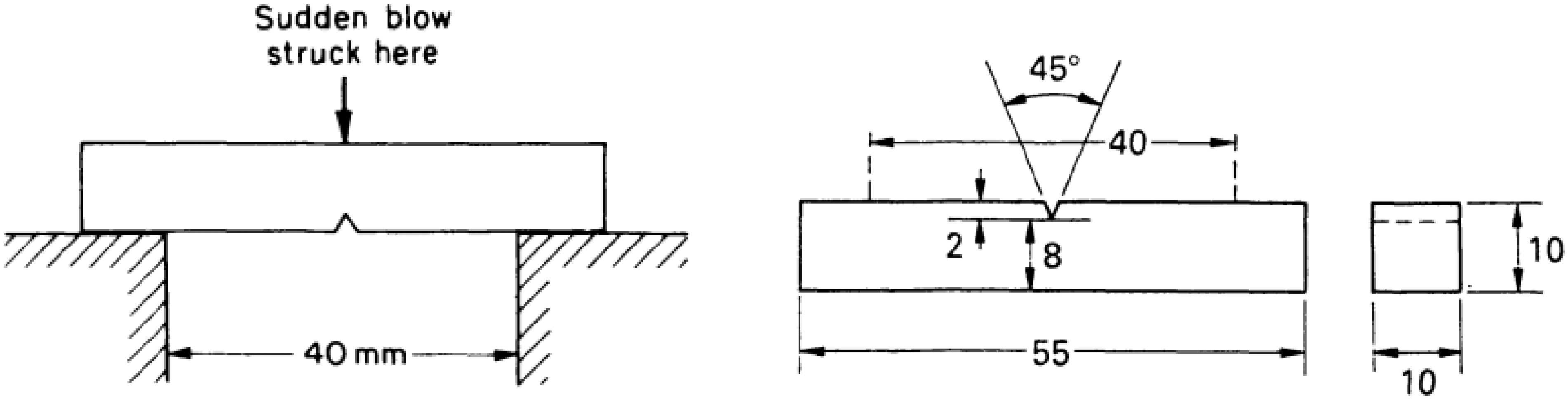
- Notch impact tests are widely used in industry as acceptance checks.
- Simple and are easy and rapid to conduct.
- The general principle is that a test specimen, containing a milled notch is struck by a fast moving hammer and the energy that is absorbed in fracturing the test-piece is measured
- Another major use of notch impact testing is to determine whether heat treatments have been carried out successfully.
- **Izod and Charpy test**

Izod Test

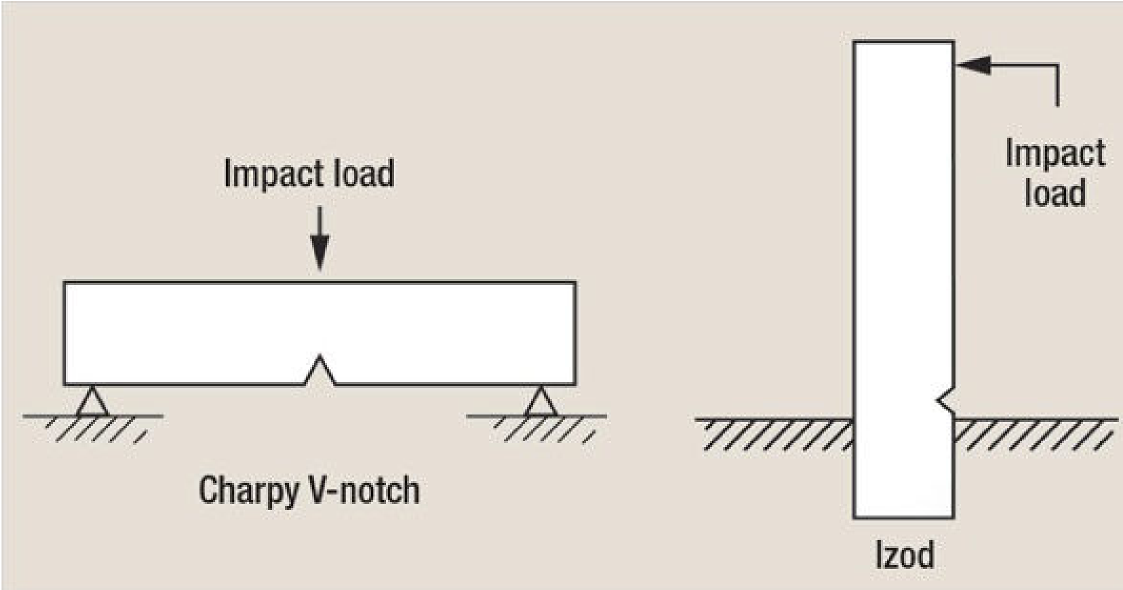


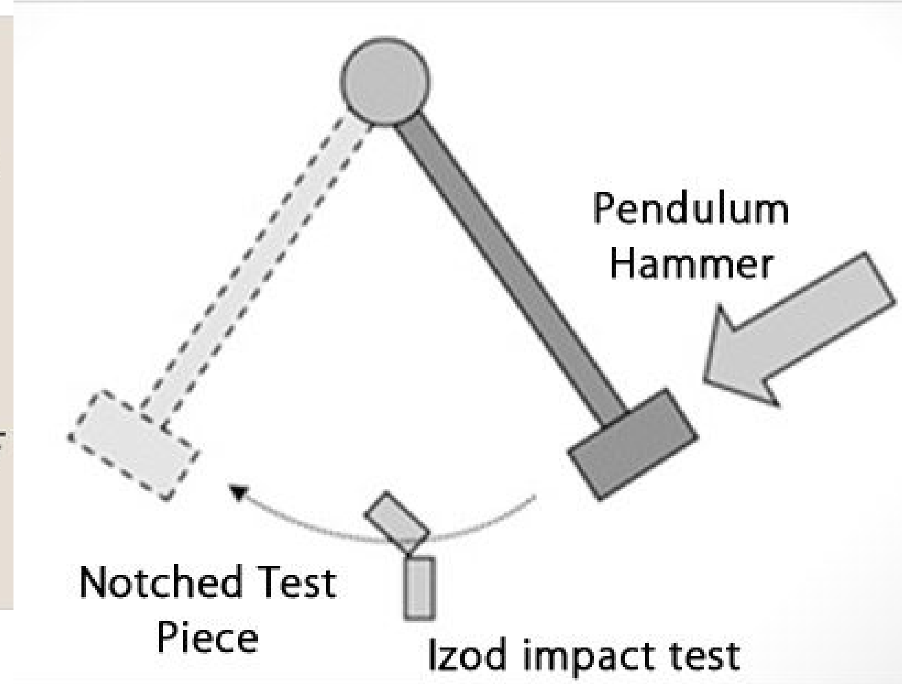
- Notched specimen is clamped in heavy jaws, with the notch at the top of the jaws and facing a heavy pendulum.
- When the pendulum is released from a fixed height; it swings down and hits the specimen at the lowest point of its path. Breaking the specimen retards the pendulum and reduces its upswing.
- The height of the reduced upswing is measured using a calibrated scale.

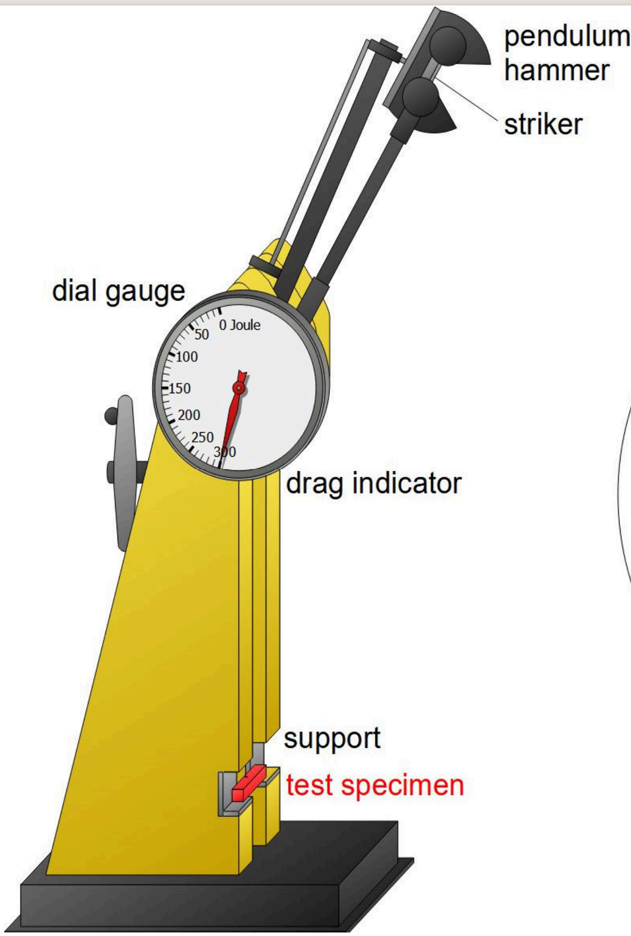
Charpy Test

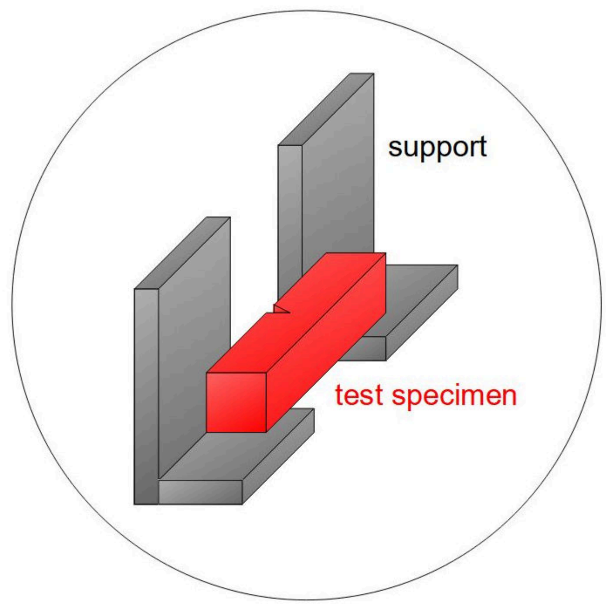


- In Charpy test: specimen is mounted as a simply supported beam and the impact blow occurs at mid-span directly behind the notch.
- V-notch or U-notch
- Notch impact properties at temperatures other than ambient.


Impact load
Charpy V-notch
Impact load
Izod


Pendulum Hammer
Notched Test Piece
Izod impact test


pendulum hammer
striker
dial gauge
0 Joule
50
100
150
200
250
300
drag indicator
support
test specimen


support
test specimen

TORSION TEST

- Wire is always subjected to a torsion test.
- For wire over 0.033 inch in diameter the test specimen must be at least 10 inches long.
- It is held by two clamps 8 inches apart.
- One of these clamps is fixed and the other is rotatable.
- The movable clamp is rotated until the wire splits, at a uniform speed not exceeding 60 revolutions per minute or slower, if necessary, to prevent undue heating of the wire.
- The wire is under sufficient tension to prevent it from kinking during the test.
- For wire over 0.033 inch in diameter the test specimen must be at least 10 inches long must be used.
- The centre of this length of wire is passed round a hook held in the movable clamp.
- The movable head is then rotated as for the heavier wire and the number of revolutions are counted before the wire splits.

FATIGUE TESTING

- The fatigue stress is defined as that stress which the material will endure without failure no matter how many times the stress be repeated.
- For hard steels a 20,00,000 cycle test is necessary to definitely establish fatigue stress; for soft steels 1,00,00,000 cycles are necessary; for aluminium and magnesium alloys 50,00,00,000 cycles of completely reversed stress are required.
- The most common fatigue testing apparatus are rotating-beam or rotating-cantilever tests.
- These rotating tests give a completely reversed stress in which the maximum unit tensile and compressive stresses in the surface of the specimen are equal.
- The speed of rotation varies in different machines but is usually of the order of 2000 rpm or in high-speed work 12,000 rpm.
- Fatigue test specimens are usually rolled- or forged-bar stock 1 inch in diameter.
- It must be remembered that these smooth, cylindrical test rods are free from holes, notches, or abrupt changes of cross-section and give maximum test results.
- The fatigue limit of a material is half its fatigue range.
- Heat-treated materials have higher tensile strengths and fatigue limits than annealed materials.

Inspection Methods/Non-destructive testing

- Defects, such as cracks, porosity and inclusions may be introduced into components during manufacture, and other defects, such as fatigue cracks, may be generated during service.
- It is necessary to detect and identify such defects and to know their position and size.
- Different type of inspection methods used are

  1. Visual Inspection
  2. Liquid penetrant test
  3. Magnetic particle test
  4. Eddy current inspection
  5. Ultrasonic testing
  6. Radiography

Inspection Methods/Non-destructive testing

System	*Features*	*Applicability*
Visual inspection probes	Detection of defects which break the surface, surface corrosion, etc	Interior of ducts, pipes and assemblies
Liquid penetrant	Detection of defects which break the surface	Can be used for any metal, many plastics, glass and glazed ceramics
Magnetic particle	Detection of defects which break the surface and sub-surface defects close to the surface	Can only be used for ferro-magnetic materials (most steels and irons)
Electrical methods (Eddy currents)	Detection of surface defects and some sub-surface defects. Can also be used to measure the thickness of non-conductive coatings, e.g. paint on a metal	Can be used for any metal
Ultrasonic testing	Detection of internal defects but can also detect surface flaws	Can be used for most materials
Radiography	Detection of internal defects, surface defects and to check correctness of assemblies	Can be used for most materials but there are limitations on the maximum material thickness

Visual Inspection

- **First stage**: Examination by naked eye will only reveal relatively large defects.
- Effectiveness of the process can be improved
  a. External surfaces: Hand lens or stereoscopic microscope.
  b. Internal surfaces: Optical inspection probes.
- Practically all the components are subjected to some visual inspection

Liquid penetrant test

- Liquid penetrant inspection is one of the simple NDT which can applied to detect surface defects.
- It is an important industrial method and it can be used to indicate the presence of defects such as cracks, porosity, inclusions, etc., in a wide variety of components.
- The method is applicable to almost any component, whether it be large or small, of simple or complex configuration.
- Different steps in the penetrant inspection method are
  1. Surface preparation
  2. Application of penetrant
  3. Removal of excess penetrant
  4. Development
  5. Observation and inspection.

Liquid penetrant test

Surface preparation

- Important step: Surface must be free from oil, water, grease or other contaminants.
- Uncleaned surfaces may inhibit the penetrant from entering the crack.
- Solvents: Acetone, isopropyl alcohol, methylene chloride, etc
- Vaporized

Application of penetrant

- Penetrant: Fluorescent dye – Dipping, pouring, spraying, brushing
- Penetrant: High fluidity, low viscosity, high wettability
- Sufficient time

Liquid penetrant test

Removal of excess penetrant:

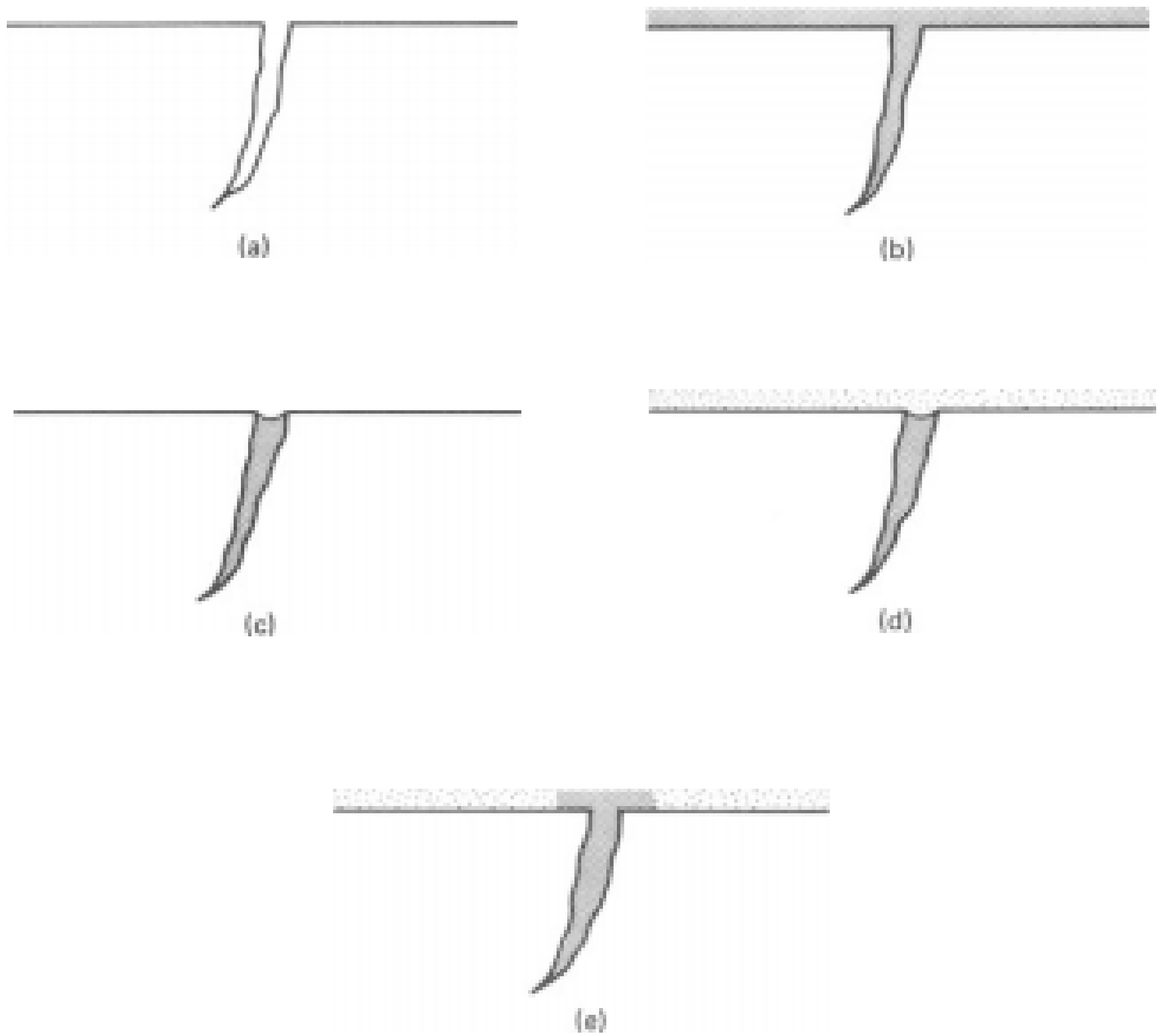
Development:

- Developer absorbs the penetrant from defects and makes discontinuities readily visible.
- Developer is usually a very fine chalk powder.
- Calcium Carbonate

Inspection:

- The part is inspected in dark enclosure under UV or black light.
- Fluorescent particle will illuminate under UV light revealing the size and shape of the defect.

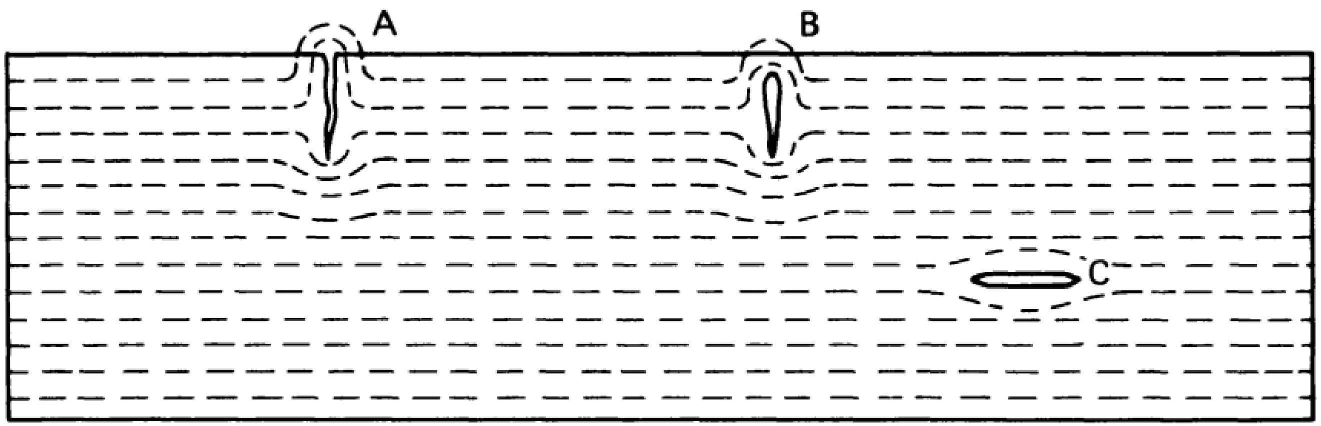
Liquid penetrant test



Magnetic particle test

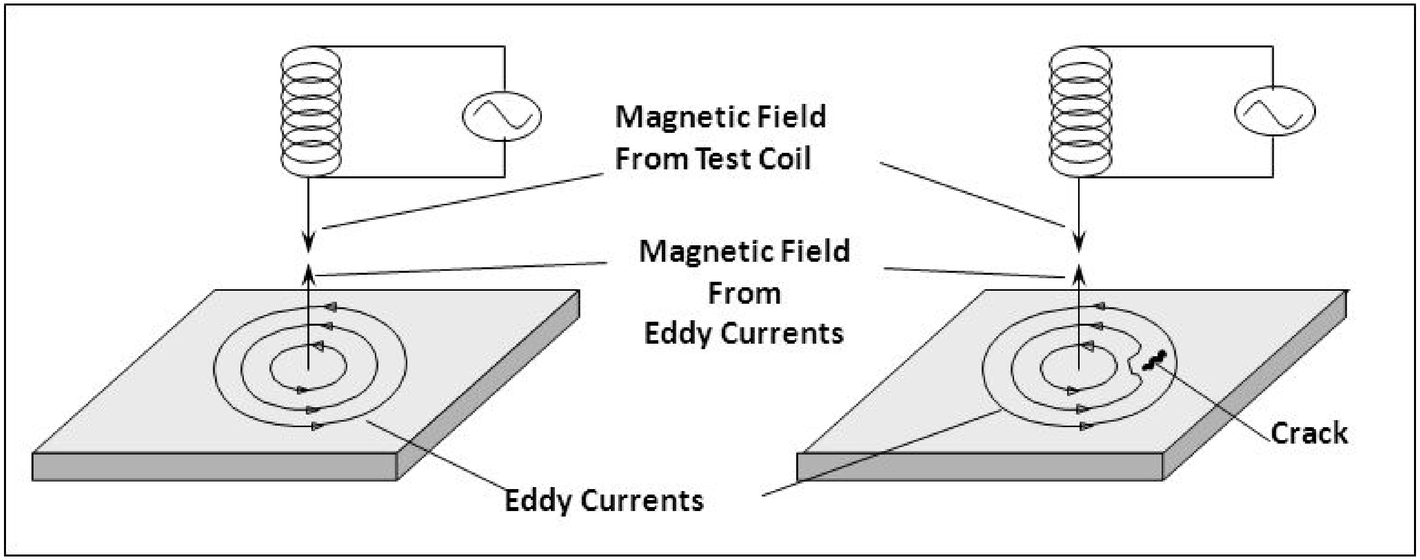
- Sensitive method of locating surface and some sub-surface defects in ferromagnetic components.

Principle:



- Metal is magnetized, magnetic flux are generated at right angles to the flow of current.
- Magnetic flux intersects with defects, magnetic poles are induced on either side of defect.
- Leakage of flux and can be detected by magnetic powder which gets attracted and piles up around the defect.

Eddy current inspection



- Electromagnetism principle
- AC coil : Circular currents (Eddy current)
- Impedance (resistance) of AC coil
- Impedance : CRT type displays
- Defects : Changes coil impedance/magnetic field

Ultrasonic testing

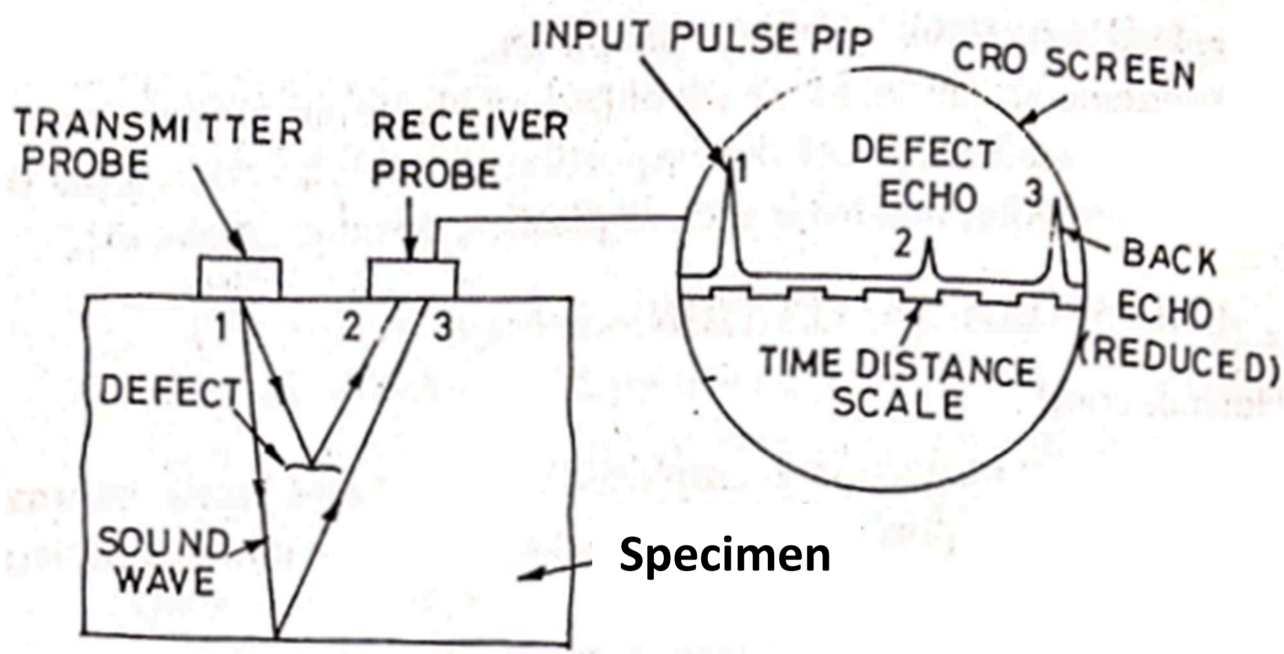
- Frequencies : 20,000 Hz
- NDT: 1 to 15 MHz

Principle:

- Piezoelectric Effect: Electric energy to mechanical energy which leads to generation of ultrasonic waves.
- High frequency AC is impressed on faces of Piezoelectric material.
- Crystal expands in first half & contracts when current is reversed resulting mechanical vibrations.
- These waves can pass through a solid object with little absorption.

Ultrasonic testing

Testing Procedure:

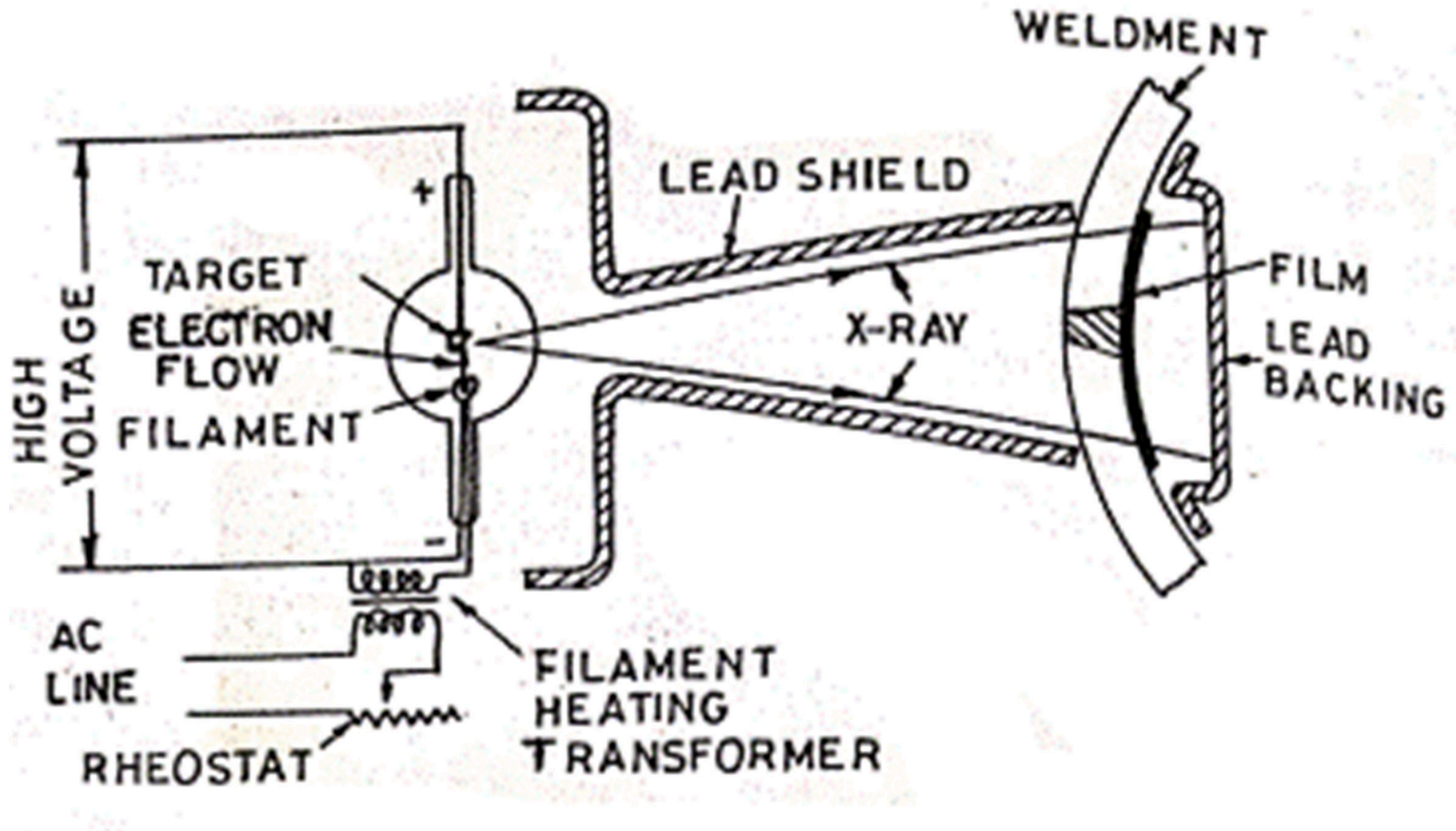


- Specimen must be cleaned and made smooth.
- Transducer is placed on the surface.
- Couplant is used between workpiece and transducer – medium to transfer sound vibrations.

Radiography

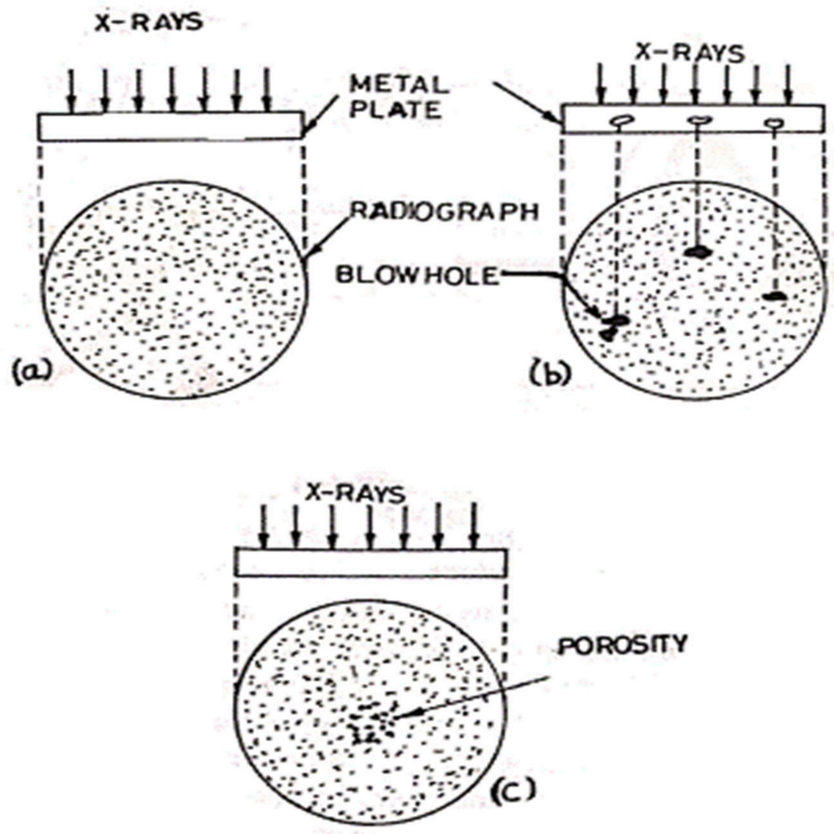
- This method uses X-rays or gamma rays for locating cracks.
- X-rays are light rays having wavelengths of the order of 10^{-6} to 10^{-9} centimetres.
- X-rays: up to 3 inch
- Gamma-rays are light rays having wavelengths of about 10^{-11} centimetres.
- Gamma-rays: up to 8 inch.

X-ray Radiography



- X-rays: High energy electrons collide with nucleus of atom.
- Intensity of X-ray depends on No. of electrons freed from filament.
- Absorption of X-ray depends on density and thickness of material.

X-ray Radiography



- Cracks, slags inclusions, porosity, etc.
- All metals can be tested.
- Slow and expensive process; radiation hazards.

Aircraft Metal Alloys

- Aluminium alloys
- Magnesium alloys
- Titanium alloys
- Plain carbon and Low carbon Steels
- Corrosion and Heat resistant steels
- Maraging steels
- Copper alloy
- Producibility and Surface treatments aspects for each of the above

Aluminium alloys

- Aluminium became an important structural material, especially after A. Wilm had discovered the age hardening capability of AI-Cu alloys in 1906.
- Nowadays high strength aluminium alloys are still the most important structural materials for aircraft.
- Pure aluminium is a very soft metal which cannot be used for structural applications.
- When alloyed with certain other elements, it gains strength by solid solution hardening, but the most effective strengthening mechanism is age or precipitation hardening.
- Commercial high strength aluminium alloys mostly contain two or more primary alloying elements (copper, zinc, magnesium, lithium), at least one minor alloying element (manganese, chromium, zirconium), plus various impurities (iron, silicon).
- Aluminium alloys rapidly form a protective oxide layer of alumina on their surface, making them quite corrosion resistant.

- The Aluminium Association (AA) of the United States has introduced a four-digit numerical system for designating wrought aluminium and aluminium alloys.
- This system has been accepted by most countries and is now called the International Alloy Designation System (lADS).
- The first of the four digits indicates the alloy group.
- The last two digits are arbitrary numbers identifying the specific alloy in the alloy group, except group for I XXX where they indicate the aluminium purity.
- The second digit indicates modifications of the original alloy, e.g. 2124 and 7475 are higher purity versions of 2024 and 7075, respectively.
- Alloys which are still experimental have the letter X preceding their designation number.
- The high strength age-hardenable aluminium alloys are found in the following alloy groups:
  a. The AI-Cu and AI-Cu-Mg alloys in the 2XXX group
  b. A few AI-Mg-Si alloys in the 6XXX group
  c. The AI-Zn-Mg-Cu alloys in the 7XXX group
  d. Lithium containing alloys with lithium as the major alloying element in the 8XXX group

Designation	Al content or major alloying elements
1XXX	99.00% aluminimum[2])
2XXX	copper
3XXX	manganese
4XXX	silicon
5XXX	magnesium
6XXX	magnesium and silicon
7XXX	zinc
8XXX	lithium or others
9XXX	unused

- In order to specify the mechanical properties of an alloy, an Aluminium Association temper designation system is used.
- The temper designation system for heat-treatable aluminium products employs the letter T followed by a number from 1 to 10 for the basic alloy conditions.
- Often additional digits are added to the basic designation in order to give a more detailed description of the respective condition.

Design ation.	**Description**
T3	• Indicates that a product is solution heat treated, cold worked and naturally aged. • It applies to alloys which achieve a stable condition during natural aging and whose strength is improved by cold deformation.
T4	• Designates a product that is solution heat treated and naturally aged. • It applies to products which achieve a stable condition during natural aging and which are not (or cannot) be cold worked after solution heat treatment.
T6	Designates a product that is solution heat treated and artificially aged.
T7	• Means that a product is solution heat treated and stabilized. • It applies to products that are over-aged during artificially aging to provide specific characteristics such as improved resistance to stress corrosion.
T8	Indicates that a product is solution heat treated, cold worked and artificially aged.

Alloy	Al	Cu	Mg	Zn	Mn	Cr	Zr	Fe	Si	others
2014	Bal	3.9-5.0	0.2-0.8	0.25	0.4-1.2	0.1	-	0.7	0.5-1.2	
2024	Bal	3.8-4.0	1.2-1.8	0.25	0.3-0.9	0.1	-	0.5	0.5	
2324	Bal	3.8-4.4	1.2-1.8	0.25	0.3-0.9	0.1	-	0.12	0.1	
2219	Bal	5.8-6.8	0.02	0.1	0.2-0.4	-	0.1-0.25	0.3	0.2	
2618	Bal	1.9-2.7	1.3-1.8	0.1	-	-	-	0.9-1.3	0.1-0.25	0.9-1.2 Ni
X2095	Bal	3.9-4.6	0.25-0.6	0.25	0.1	-	0.04-0.18	0.15	0.12	0.25-0.6 Ag 1-1.6 Li
6013	Bal	0.6-1.1	0.8-1.2	0.25	0.2-0.8	0.1	-	0.3	0.6-1.0	
7075	Bal	1.2-2.0	2.1-2.9	5.1-6.1	0.3	0.18-0.28	-	0.5	0.4	
7475	Bal	1.2-1.9	1.9-2.6	5.2-6.2	0.06	0.18-0.25	-	0.12	0.1	
7050	Bal	2.0-2.6	1.9-2.6	5.7-6.7	0.1	0.04	0.08-0.15	0.15	0.12	

Alloy Temper	Product	YS MPa	UTS MPa
2014-T6	sheet	400	455
2024-T361[1]	sheet	330	440
2324-T39	plate	386	455
2219-T81	sheet	345	455
		421[2]	572[2]
2618-T61		372	441
X2095-T8	extrusion	696	715
6013-T6	sheet	324	359
7075-T6	sheet	469	538
7075-T6[1]	sheet	427	496
7475-T61	sheet	496	552
7475-T7351	plate	393	475
7050-T73651	plate	455	510

Aircraft	Upper Wing Skin	Lower Wing Skin	Fuselage Skin
BAe 146	7075-T6	2024-T351	2024-T3[1]
A300/310	7075-T651	2024-T351	2024-T3[1]
A320/330/340	7150-T651	2024-T351	2024-T3[1]
			-T351[1]
			-T42[1]
B747	7075-T651	2024-T351	2024-T3[1]
B757/767	7150-T651	2324-T39	2024-T3[1]
B777	7055-T7751	2324-T39	2XXX[2]-T3[1]
C-5B	7175-T73	7175-T73	7475-T6[1]

- 2024-T3 - It has high ductility, excellent fatigue crack propagation resistance, and high fracture toughness

Magnesium alloys

- Magnesium is the lightest of the structural metals available for aircraft construction.
- Pure magnesium weighs only 65% as much as aluminium.
- It is a silvery white metal that is relatively soft, and does not have the strength or other properties required for structural use.
- Pure magnesium has the following properties:

Specific gravity	1.74	Mean coefficient of thermal expansion, per inch per °F.(32°–750°F.)	0.0000166 inches
Density	0.064 lb./cu. in.	Modulus of elasticity	6,500,000 p.s.i.
Melting point	1204°F.		
Flame temperature	8760°F.		
Electrical conductivity:			
Volume basis	38% of copper		
Mass basis	197% of copper		

- Magnesium is commonly alloyed with aluminium, zinc, and manganese, to create usable structural materials.
- The light weight and relatively high strength of magnesium alloys results in a strength/weight ratio that is very attractive in aircraft design.

- There are many places in aircraft construction, such as fairings, ducts, doors, brackets, bulkheads and partitions, and similar locations, where strength is secondary and a minimum thickness of material is all that is necessary.
- Magnesium alloys are non-sparking and nonmagnetic.
- These alloys are very poor as regards toughness and notch sensitivity in fatigue, and some alloys are susceptible to stress-corrosion cracking.
- Suitable heat treatment, good design, and the proper choice of alloy for a given application will minimize these disadvantages.
- The common impurities found in magnesium alloys are iron, nickel, and copper.
- These impurities affect the corrosion resistance of the alloy and must be held to a minimum.

Titanium alloys

- Titanium the so-called wonder metal.
- Titanium is extremely active at elevated temperatures and will combine with practically anything it comes into contact with.
- Alpha titanium: hexagonal close-packed crystal structure
- Beta titanium: body-centered cubic crystal structure.
- The physical properties of pure titanium is as given in the table:

Physical Properties	*Titanium*
Atomic Number	22
Atomic Weight	47.9
Crystal Structure	Alpha—H.C.P. (below 1625°F.) Beta–B.C.C. (above 1625°F.)
Transformation	1625°F.
Density	4.5 gm. per c.c.
Melting Point	3272°F.
Linear Coefficient of Thermal Expansion	4.3×10^{-6}/°F.
Specific Heat	0.129 Cal./gm./°C.
Electrical Conductivity	3.5% I.A.C.S.*
Magnetic	Para
Electrode Potential	1.75

All-Alpha

Advantages

- Useful strength to almost 1200°F.
- Resistant to air contamination to 2000°F, permitting higher forging temperature.
- No embrittling heat treatment response.
- Weld ductility and strength comparable to that of base metal.
- Tough at low temperatures.

Disadvantages

- Sheet bend ductility not as good as alpha-beta alloys, considerably poorer than beta alloys.
- Requires more power than alpha-beta alloys for hot working.

Combined Alpha-Beta

Advantages

- Double the strength of unalloyed titanium and about as strong below 600°F, as all-alpha and all-beta.
- Good ductility, including bend.
- Forging, rolling and forming easier than alpha and beta alloys (beta has better bend ductility).
- Relatively simple to produce in quality.
- Heat-treatable to high strengths.

Disadvantages

- Poorer weld ductility than alpha.
- Temperature ceiling for useful strength about 800°F.

Advantages	Disadvantages
Heat Treatable Beta	
• Quenchable to give medium strength with high ductility. • Can be heat-treated to higher strength (with some loss in ductility) after little fabrication. • Elevated-temperature properties similar to alpha-beta alloys.	• Embrittled by 24 to 96 hr. at 350 to 800°F. • Control of composition critical. • Restricted to parts that can be heat treated after fabrication or require little forming after heat-treating. • Requires relatively high content of strategic alloying materials.
Non-Heat Treatable Beta	
• Excellent ductility, particularly bend. • High strength useful to approx. 1000°F. • Does not require heat treatment for high strength. • Good weldability with some composition.	• Greater spring back in forming. • Uses higher content of strategic alloying materials than unstable beta. • Relatively high density.

Steel and its alloys

- The basis of all steel is iron which, when combined with carbon and other elements in varying amounts, gives a wide range of physical properties.
- Exact control of the alloying elements is essential to obtain a high-grade steel for aircraft use.
- Due to the large number of elements that will combine with iron, an infinite number of steels is obtainable.
- In order to classify the better-grade steels used in automotive and aircraft work, the Society of Automotive Engineers has formulated a numerical index system which is generally used.

Type of Steel	Numerals (and Digits)
Carbon steels	1xxx
Plain carbon	10xx
Free cutting (screw stock)	11xx
Manganese steels	13xx
Nickel steels	2xxx
3.50% nickel	23xx
5.00% nickel	25xx
Nickel-chromium steels	3xxx
1.25% nickel; 0.60% chromium	31xx
1.75% nickel; 1.00% chromium	32xx
3.50% nickel; 1.50% chromium	33xx
Corrosion- and heat-resisting steels	30xxx
Molybdenum steels	4xxx
Carbon molybdenum	40xx
Chromium molybdenum	41xx
Chromium-nickel molybdenum	43xx
Nickel molybdenum; 1.75% nickel	46xx
Nickel molybdenum; 3.50% nickel	48xx
Chromium steels	5xxx
Low chromium	51xx
Medium chromium	52xxx
Corrosion- and heat-resisting	51xxx
Chromium-vanadium steels	6xxx
1% chromium	61xx
Nickel-chromium-molybdenum steels.	8xxx
0.55% nickel; 0.50% chromium: 0.20% molybdenum	86xx
0.55% nickel; 0.50% chromium; 0.25% molybdenum	87xx
Silicon-manganese steels	9xxx
2% silicon	92xx

Effect of individual elements

1. **Carbon:** Carbon is by far the most important constituent of steel. It combines readily with iron to form iron carbide, which is a compound known as cementite. It is largely due to the quantity and behaviour of this compound that steels can be heat-treated to various degrees of strength and toughness.
2. **Manganese:** Its primary purpose is to deoxidize and desulfurize the steel to produce a clean, tough metal.. This excess magnitude exists as manganese carbide which has characteristics in hardening and toughening the steel.
3. **Silicon:** A small amount of silicon improves the ductility of the metal. Its main purpose, however, is to produce a sound metal
4. **Sulfur:** The presence of sulfur renders steel brittle at rolling or forging temperatures.
5. **Phosphorus:** Phosphorus is believed responsible for "cold shortness" or brittleness when the metal is cold.

6. **Nickel:** . The addition of nickel to steels increases the strength, yield point, and hardness without materially affecting the ductility.
7. **Chromium:** Chromium imparts hardness, strength, wear resistance, and corrosion resistance to steel. It also improves the magnetic qualities to such an extent that chromium steel is used for magnets.
8. **Molybdenum:** It improves the homogeneity of the metal and reduces the grain size. It also increases the elastic limit, the impact value, wear resistance, and fatigue strength.
9. **Vanadium:** Improves the grain structure and fatigue strength. Vanadium also increases the ultimate strength, yield point, toughness, and resistance to impact, vibration, and stress reversal.
10. **Tungsten:** "High-speed steel" is a tungsten-chromium steel used for tools which will retain their cutting edge even when heated to dull redness by working.
11. **Titanium:** Titanium is often added in small quantities to corrosion resisting steel to reduce the embrittlement at the operating temperatures of exhaust stacks and collectors.

Plain carbon Steels

- The classification of iron and steel is based on the percentage of carbon present.
- The generally accepted classification is as follows:

Wrought iron	Trace to 0.08%
Low carbon steel	0.10% to 0.30%
Medium carbon steel	0.30% to 0.70%
High carbon steel	0.70% to 2.2%
Cast iron	2.2% to 4.5%

- The addition of a metallic alloying element to plain carbon steels results in the formation of a new alloy steel with wholly different properties.
- The carbon content of alloy steels is of prime importance but varying properties can be obtained by adding an alloy.
- The metals commonly used as alloys in steel are nickel, chromium, molybdenum, vanadium, and tungsten.

Corrosion resisting steels

- Corrosion resisting steels are not fully resistant to all corrosive agents.
- Their corrosion resistance depends upon their own physical state as well as the temperature and concentration of the particular corrosive agent.
- In aircraft design the most severe corrosive agent to be guarded against is salt water.
- Specimens are rated A, B, C, or D-A representing the best resistance and D an unacceptable condition.

Copper alloy

- COPPER, brass, and bronze have a limited use in aircraft construction.
- They do have important specialized applications, however, such as bearings and fuel and oil lines.
- Copper wire is used throughout the electrical system.
- In general these metals are corrosion resistant, nonmagnetic, fairly strong, and good conductors of electricity.

Copper Tubing

- Copper tubing is very generally used for fuel and oil lines.
- The copper used in the manufacture of this tubing must contain at least 99.90% copper.
- The tubing is purchased in the soft annealed condition and it is seamless drawn.
- In the purchased condition or after annealing it has the following physical properties:

Ultimate tensile strength (p.s.i.)	32,000
Yield point (p.s.i.)	6,000
Elongation (%)	52%
Rockwell hardness	63 (B-1/8-100)

Copper-Silicon-Bronze Tubing

- This tubing is considerably stronger than pure copper tubing and has largely superseded it for fuel, oil, water, and air lines.
- This tubing can be annealed at a temperature of 1000-1000°F, if required after severe forming and bending.

Copper Wire

A soft copper wire is used as a locking wire in aircraft construction. It is drawn from pure copper and has a tensile strength approaching 40,000 PSI and an elongation of 25%.

Beryllium copper

This material is a high-strength, heat-treatable non-magnetic alloy available as bar, rod, sheet, strip, and wire.

BRASS

- Brass is a copper alloy consisting of a solid solution of zinc in copper.
- In addition to zinc and copper, brasses sometimes contain a small amount of aluminium, iron, lead, manganese, magnesium, nickel, phosphorus, or tin.
- Brass with a zinc content of 30% to 35% is very ductile, and with 45% zinc content it has a relatively high strength.
- Brasses with a zinc content up to 37% are in so-called "alpha solution," while above that percentage a "beta solution" condition exists.
- It is the difference between these two conditions that accounts for the ductility of the low-zinc brass and the strength of the high-zinc brass.
- Alpha-solution brass can only be annealed, but beta-solution brass can be increased in strength by heat treatment.

Selection of Aerospace Material:

- Selecting the best material is an important task for the aerospace engineer.
- The success or failure of any new aircraft is partly dependent on using the most suitable materials.
- Cost, flight performance, safety, operating life and environmental impact from engine emissions are dependent on the types of materials.
- The selection of materials is performed during the early design phase of aircraft, and has a lasting influence which remains until the aircraft is retired from service.

Selection of Aerospace Material:

- Key requirements and factors in the selection of materials are

1. Costs
2. Availability
3. Manufacturing
4. Density
5. Mechanical properties
6. Fatigue durability
7. Damage tolerance
8. Environmental durability
9. Thermal properties
10. Electrical and magnetic properties

Selection of Aerospace Material:

Cost:

1. Purchase cost
2. Processing costs, including machining, forming, shaping
3. Heat treatment costs
4. In-service maintenance costs, including inspection and repair costs
5. Recycling and disposal costs

The cost of aerospace materials must be acceptable to the aircraft operator, and obviously should be kept as low as possible.

Selection of Aerospace Material:

Availability:

There must be a plentiful, reliable and consistent source of materials to avoid delays in aircraft production and large fluctuations in purchase cost.

Manufacturing:

It must be possible to process, shape, machine and join the materials into aircraft components using cost-effective and time-efficient manufacturing methods.

Density:

Materials must be lightweight for aircraft to have good manoeuvrability, range and speed together with low fuel consumption.

Selection of Aerospace Material:

Mechanical properties:

High stiffness, strength and fracture toughness to ensure that structures can withstand the aircraft loads without deforming excessively (changing shape) or breaking.

Fatigue durability:

Aerospace materials must resist cracking, damage and failure when subjected to fluctuating (fatigue) loads during flight.

Damage tolerance:

Aerospace materials should not break after being damaged (cracks, delaminations, corrosion) from bird strike, lightning strike and the many other damaging events experienced during routine operations.

Selection of Aerospace Material:

Environmental durability:

- Aerospace materials must be durable and resistant to degradation in the aviation environment.
- This includes resistance against corrosion, oxidation, wear, moisture absorption and other types of damage caused by the environment which can degrade the performance, functionality and safety of the material.

Thermal properties:

- Aerospace materials must have thermal, dimensional and mechanical stability for high temperature applications, such as jet engines and heat shields.
- Materials must also have low flammability in the event of aircraft fire.

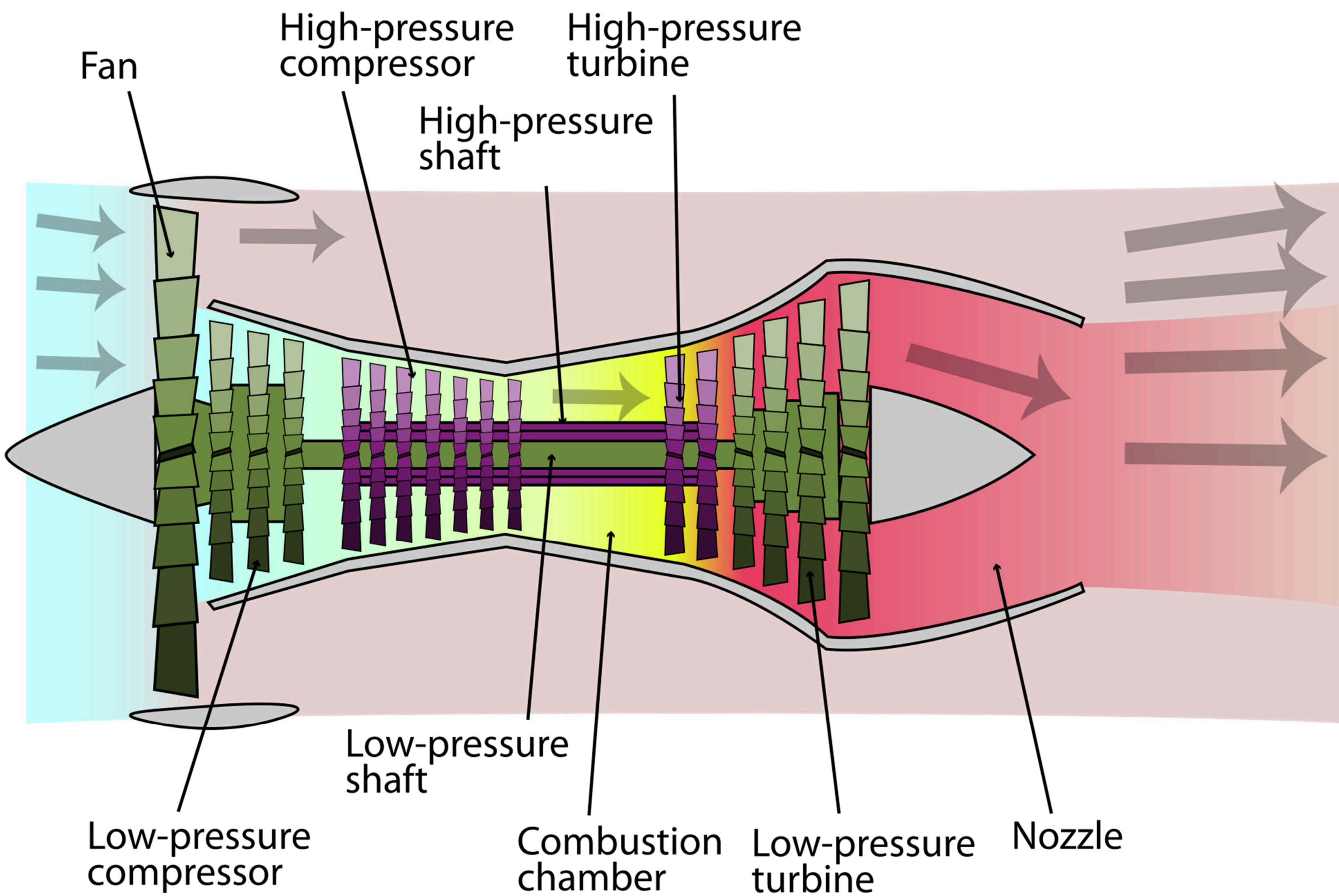
Selection of Aerospace Material:

Electrical and magnetic properties:

- Aerospace materials must be electrically conductive to dissipate the charge in the event of lightning strike.
- Aerospace materials must have low electromagnetic properties to avoid interfering with the electronic devices used to control and navigate the aircraft.
- Materials used in the skin of stealth military aircraft must have the ability to absorb radar waves to avoid detection.

Materials used in aircraft engines:

Engine structure (turbofan):



Materials used in aircraft engines:

Fan:

This typically does not get very hot (<150 °C) so aluminum, titanium, or stainless steel are all suitable for the fan blades. Most engines use titanium because it has a high strength-to-weight ratio, is corrosion and fatigue resistant, and would be able to withstand the impact of a bird strike.

Materials used in aircraft engines:

Compressor section:

- The pressure of the air can be raised up to 30 times and the temperature, depending on the number of stages in the compressor, can rise to 1000 °C.
- Here the materials must have high strength at high temperatures; must resist fatigue, cracking, and oxidation; and also must resist "creep."
- Very high- temperature alloys are called super alloys and are generally nickel, cobalt, or iron-based alloys.
- Aluminium and/or titanium are added for strength, and chromium, as well as rare earth elements like yttrium, are added to improve corrosion resistance.

Materials used in aircraft engines:

Combustion chamber:

- Temperatures can exceed 1800 °C and again super alloys are used, but without the titanium or aluminium.
- Instead, refractory metals such as tungsten, molybdenum, niobium, tantalum, and rhenium are often added to a super alloy - high resistance to heat, corrosion, and wear.
- Ceramics and ceramic-metal mixes are also used here because of their high heat resistance.
- They have very high melting points and don’t require the cooling systems like those needed to keep metals from melting so they make for lighter, less complicated engine parts.
- Disadvantage is that they tend to fracture under stress, so trend is to create new ceramics composites that incorporate other materials to improve properties.

Materials used in aircraft engines:

Turbine:

- The first set of turbine blades are in the highest pressure, hottest part of the gas flow and are generally made of nickel-based super alloy or ceramic blades.
- Unheated outside air is circulated through channels inside of the turbine blades to keep them from melting in this extreme environment.
- The blades lower pressure turbine are made of iron-based super alloy or even stainless steel.

Materials used in aircraft engines:

Exhaust:

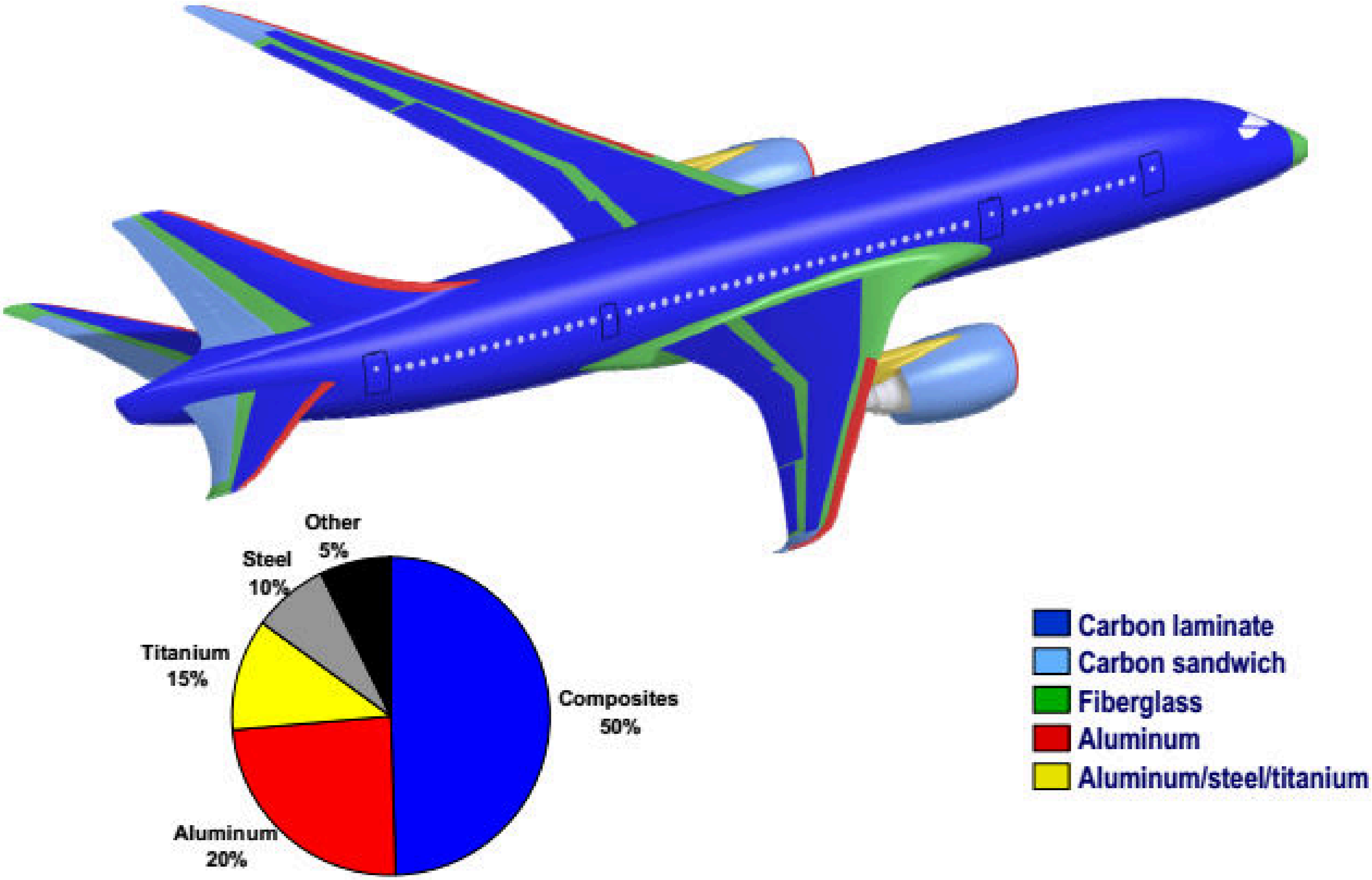
- Inconel and stainless steel alloys. The Inconel [nickel-chromium-iron] alloys are frequently used in turbine engines because of their ability to maintain their strength and corrosion resistance under extremely high temperature conditions.

Casing:

- Although it need not withstand high temperatures like the core of the turbine, the materials here need to be strong enough that if a blade were to break off it would be contained within the casing and not enter the wing or cabin of the aircraft and cause further damage.
- Aluminum or some polymer matrix materials are used as engine casings.

Materials used in aircraft structures:

Boeing 787:



Materials used in aircraft structures:

Boeing 787:

- Jets made of composites require far fewer parts, so there's less to bolt together.
- Since these plastics weigh less than aluminium, the planes should burn less fuel - together with improved engines, 20% drop in fuel costs.
- Improve passenger comfort - superior strength of the composite fuselage will allow the passenger cabin to withstand higher pressurization.
- It's easier to control cabin temperature, humidity, and ventilation.
- Maintenance costs will be 30% lower than for aluminium planes - corrosion and fatigue benefits are going to be astounding.

Bauschinger's effect

The Bauschinger effect refers to a property of materials where the material's stress/strain characteristics change as a result of the microscopic stress distribution of the material. For example, an increase in tensile yield strength occurs at the expense of compressive yield strength. The effect is named after German engineer Johann Bauschinger.