DEPARTMENT OF METALLURGY ENGINEERING

LECTURE NOTE ON

MATERIAL TESTING

Subject Code: MTPC209
Theory (TH): 5
3rd Semester — Metallurgy Engineering

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Session: 2026 – 2027

Vision and Mission of the Department

VISION: To offer quality technical education in the field of Metallurgical Engineering with orientation towards industry, entrepreneurship, higher education and to strive for developing professionally competent technicians meeting the needs of the global economy.

MISSION:
M1: To develop students in the field of Metallurgical Engineering as highly motivated, skilful and qualified manpower for employment and higher learning.
M2: To promote a conducive environment for all round development of students.
M3: To promote linkages with external agencies to meet changing needs of industry and society.
M4: To Improve Laboratories.

Program Education Objectives (PEOs)
PEO 1: Diploma professionals will be able to make a successful career in metallurgical industries or higher studies to meet the needs of future requirements.
PEO 2: Diploma metallurgists will have technical and behavioural competencies through adequate exposure to industry.
PEO 3: To impart technological knowledge and skills for solving real-time engineering problems.
PEO 4: To develop human resources with capabilities of effective communication, moral values and socially responsible.

TH-5: MTPC209 — Material Testing

Course Code	MTPC209
Course Title	Material Testing
Course Type	Theory (Programme Core)

Course Outcomes (CO1-CO5): -

CO	Bloom's Level	Course Outcome
CO1	Remember	List standard testing organizations (ASTM, ISO, IS, DIN) and classify materials based on mechanical behaviour.
CO2	Understand	Explain stress-strain behaviour, elastic/plastic deformation and fatigue/creep phenomena in materials.
CO3	Apply	Apply destructive testing methods (tensile, compression, hardness, impact) to evaluate mechanical properties.
CO4	Analyze	Analyze fatigue, creep and fracture-mechanics data to determine causes of material failure.
CO5	Evaluate	Evaluate non-destructive testing results and advanced testing techniques for quality control.

CONTENTS

UNIT I

Introduction & Fundamentals of Material Testing

1. Introduction to Material Testing

1.1 Simple Definition

Material testing is the systematic process of determining how a material behaves when it is subjected to specified mechanical, physical or environmental conditions. A test converts material behavior into measurable engineering information such as strength, stiffness, ductility, toughness or resistance to repeated loading.

1.2 Why Do We Test Materials?

- To verify whether a material meets a specified requirement.
- To determine engineering properties needed for design.
- To compare different materials before selection.
- To check the effect of manufacturing, heat treatment, forming or joining.
- To support quality control of raw materials and finished components.
- To investigate material failures and identify possible causes.
- To improve safety, reliability and service performance.

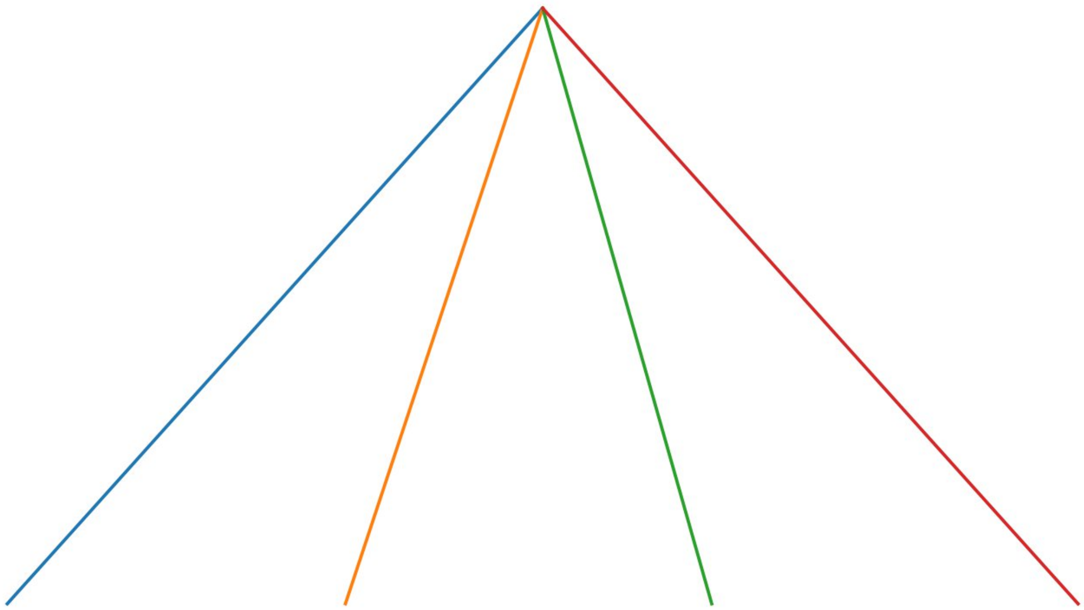
1.3 Basic Testing Philosophy

A useful way to think about testing is: SERVICE CONDITION → REQUIRED PROPERTY → TEST METHOD → MEASURED RESULT → ENGINEERING DECISION.

For example, if a component will carry a repeated load, static strength alone is not enough. Fatigue behavior must also be considered. If a component may experience impact at low temperature, toughness and transition behavior become important.

2. Classification of Engineering Materials

The syllabus identifies four broad material groups: metals, ceramics, polymers and composites.



Material class	Basic description	Typical strengths	Common limitations	Examples
Metals	Metallic bonding; often strong, ductile and conductive.	Strength, toughness, machinability; many can be heat treated.	Corrosion or high density may be concerns.	Steel, aluminium, copper
Ceramics	Inorganic, non-metallic materials.	High hardness, wear resistance and high-temperature capability.	Often brittle; low tensile toughness.	Alumina, silica, zirconia
Polymers	Long-chain molecular materials.	Low density, easy processing, corrosion resistance.	Lower stiffness/temperature capability for many grades.	PVC, polyethylene, nylon
Composites	Combination of two or more distinct constituents/phases.	Properties can be tailored; high specific strength/stiffness possible.	Manufacturing complexity and anisotropy may occur.	GFRP, CFRP, concrete

2.1 Metals

Metals are widely used in engineering because many metallic materials combine strength, toughness and ductility. Their properties depend strongly on composition, crystal structure, defects, grain size and processing history.

2.2 Ceramics

Ceramics are generally hard and resistant to heat and wear. Their major limitation in many engineering situations is brittleness, especially under tensile or impact loading.

2.3 Polymers

Polymers generally have low density and can be processed into many shapes. Their mechanical behavior can be strongly affected by temperature and loading time.

2.4 Composites

Composites combine constituents to obtain a desired combination of properties. Fibers, particles or other reinforcements may be used within a matrix. Their properties can depend on direction and manufacturing quality.

3. Standard Organizations: ASTM, ISO, IS and DIN

Standardized testing is essential because a test result has meaning only when the method is defined and controlled. The uploaded syllabus specifically lists ASTM, ISO, IS and DIN.

Organization / designation	Meaning / role	Importance to testing
ASTM	ASTM International develops technical standards used for materials, products and test methods.	Helps specify specimen preparation, test procedure, measurements and reporting.
ISO	International Organization for Standardization develops international standards.	Promotes common procedures and comparability between countries.
IS	Indian Standards issued through the Indian standardization system.	Important for engineering practice and conformity in India.
DIN	German standards organization and standards designation.	Provides standardized technical requirements and test procedures.

Important: The purpose of standards is not simply to give a name to a test. Standards control details such as specimen dimensions, loading conditions, equipment requirements, measurement and reporting so that results can be compared.

4. Mechanical Properties of Materials

Mechanical properties describe how a material responds when forces or loads are applied. The most important properties in this syllabus are elasticity, plasticity, strength, ductility, brittleness, toughness, resilience, fatigue resistance and creep resistance.

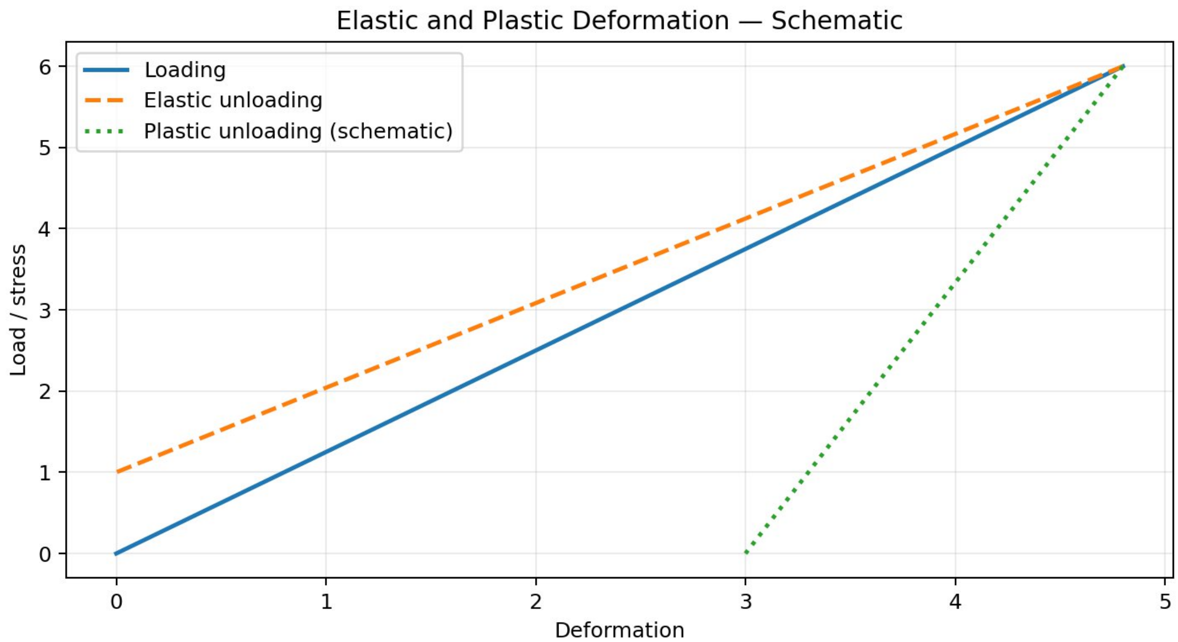
5. Elastic and Plastic Deformation

5.1 Elastic Deformation

Elastic deformation is recoverable deformation. When the applied load is removed, the material returns approximately to its original shape, provided the elastic range has not been exceeded.

5.2 Plastic Deformation

Plastic deformation is permanent deformation. After the load is removed, a permanent change in shape or dimensions remains.



Key distinction: Elastic = temporary/recoverable; Plastic = permanent/non-recoverable.
Engineering importance: Elastic behavior is important for stiffness and dimensional accuracy. Plastic behavior is important in forming operations and also marks the onset of permanent damage from a design perspective.

6. Stress–Strain Behavior

6.1 Stress

Stress is the internal resisting force per unit area developed in a material under an applied load.

Engineering stress: $\sigma = P / A_0$

where P = applied load and A_0 = original cross-sectional area. If P is in newtons and A_0 is in mm^2, stress is obtained in N/mm^2, numerically equal to MPa.

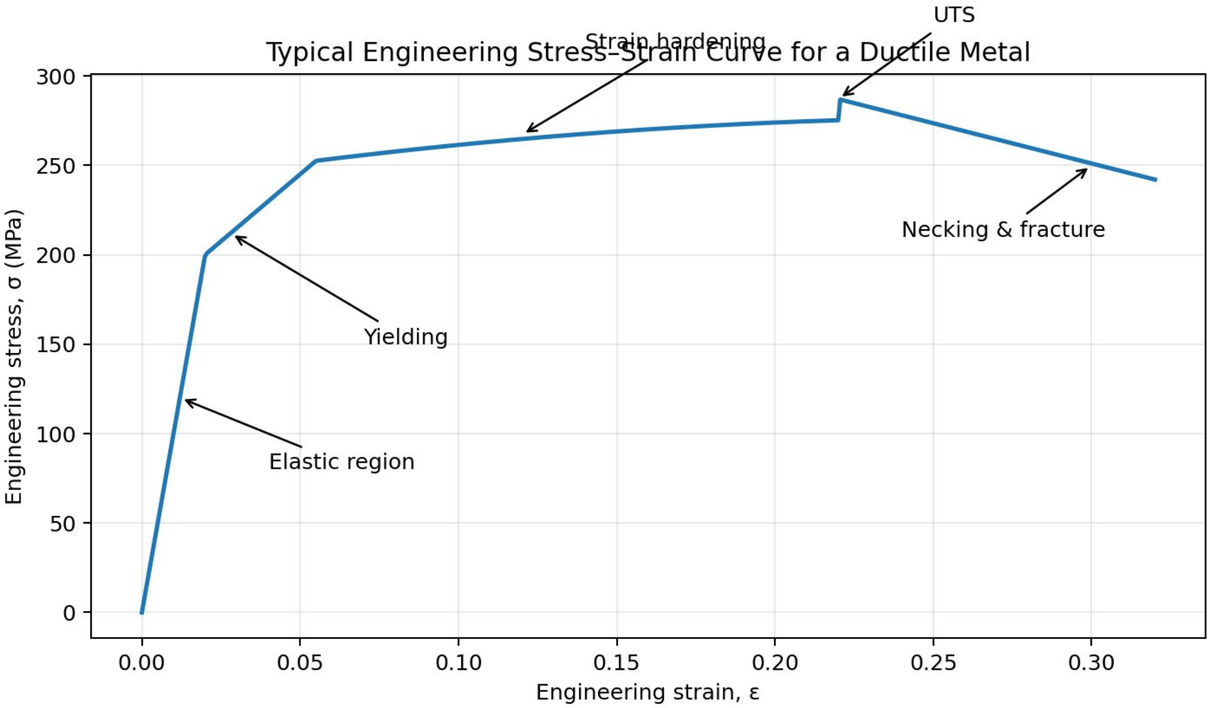
6.2 Strain

Strain is the deformation divided by the original dimension. For a tensile specimen:

Engineering strain: $\varepsilon = \Delta L / L_0 = (L - L_0) / L_0$

Strain is dimensionless because it is a ratio of two lengths.

6.3 Typical Tensile Stress–Strain Curve



The exact shape varies with material. The diagram is a schematic representation of a typical ductile metal and is intended for study and examination.

Elastic region

The initial portion is approximately linear for many engineering metals. Deformation is substantially recoverable.

Yielding

The material begins significant plastic deformation. Some materials show a clear yield point; for others, proof stress is used.

Strain hardening

After yielding, further plastic deformation can require increasing stress because the material becomes stronger as it deforms.

Ultimate tensile strength (UTS)

UTS is the maximum engineering stress reached during the tensile test.

Necking

After UTS in a typical ductile tensile test, deformation becomes localized in a reduced region called a neck.

Fracture

The specimen finally separates. The stress at the final point is associated with fracture strength.

7. Hooke's Law

Within the elastic range, stress is proportional to strain. This relationship is expressed as:

$$\sigma = E\,\varepsilon$$

E is Young's modulus (modulus of elasticity). It represents the stiffness of the material in tension or compression.

Interpretation: A high Young's modulus means that a larger stress is required to produce a given small elastic strain. Stiffness and strength are different concepts.

8. Yield Strength, UTS and Fracture Strength

Yield strength

Stress associated with the beginning of significant plastic deformation. When a clear yield point is not observed, a specified proof stress may be used.

Ultimate tensile strength (UTS)

Maximum engineering tensile stress reached in a tensile test.

Fracture strength

Stress corresponding to the final fracture point on the engineering stress–strain curve.

Common mistake: UTS is not the same as fracture strength. In a typical ductile engineering stress–strain curve, fracture occurs after UTS and necking.

9. Ductility and Brittleness

9.1 Ductility

Ductility is the ability of a material to undergo appreciable plastic deformation before fracture. In a tensile test, percentage elongation and reduction of area are commonly used indicators.

Percentage elongation = $[(L_f - L_0) / L_0] \times 100$

Reduction of area = $[(A_0 - A_f) / A_0] \times 100$

9.2 Brittleness

Brittleness describes a tendency to fracture with little plastic deformation. A brittle material may have high hardness or compressive strength but comparatively poor tensile ductility and impact toughness.

Comparison: Ductile materials can absorb deformation before fracture; brittle materials generally show limited plastic deformation before fracture.

10. Toughness and Resilience

10.1 Toughness

Toughness is the ability of a material to absorb energy before fracture. In a tensile stress–strain diagram, the area under the curve up to fracture represents the energy absorbed per unit volume in a simplified interpretation.

10.2 Resilience

Resilience is the ability of a material to absorb elastic energy and release it when the load is removed. For an ideal linear elastic region, the modulus of resilience is related to the area under the elastic portion of the stress–strain curve.

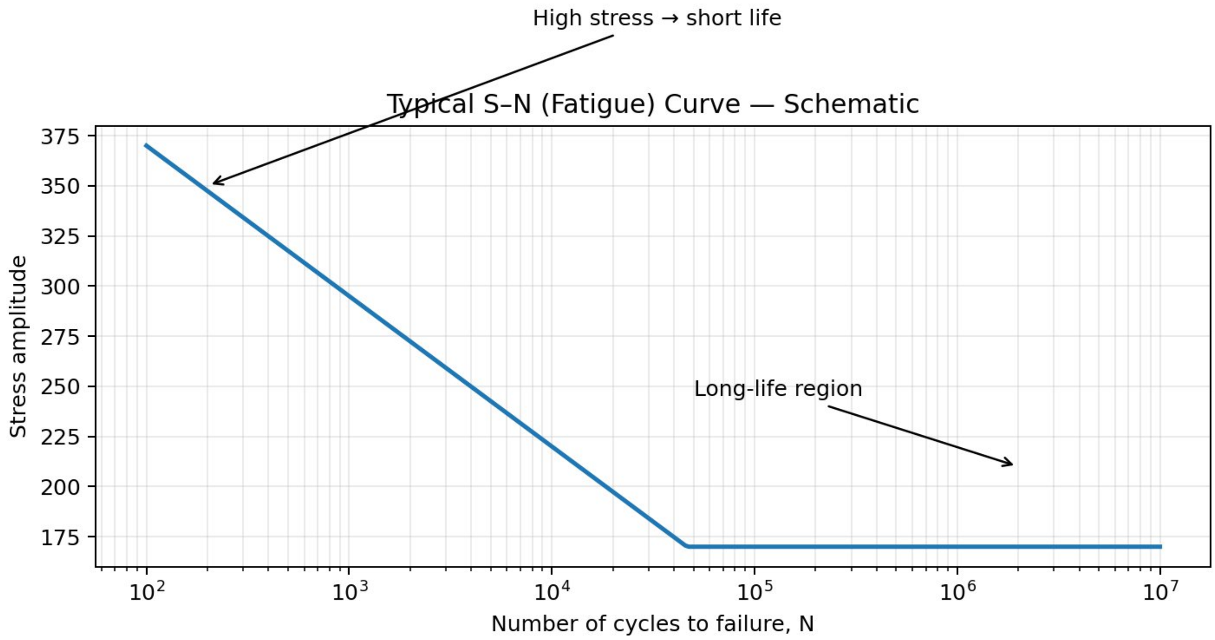
Do not confuse: Toughness includes energy absorbed through elastic and plastic deformation up to fracture; resilience concerns the elastic portion.

11. Fatigue

Fatigue is progressive damage caused by repeated or cyclic loading. A component can fail by fatigue even when the maximum applied stress is below the material's static tensile strength.

11.1 Basic Fatigue Terms

- Cyclic stress: stress that varies repeatedly with time.
- Stress amplitude: half the difference between maximum and minimum stress.
- Mean stress: average of maximum and minimum stress.
- S–N curve: relationship between stress level and number of cycles to failure.
- Endurance limit: a specified long-life stress level for materials/conditions where such a limit is observed.



11.2 Factors Affecting Fatigue

- Surface finish and surface defects.
- Stress concentration such as notches, holes and sharp corners.
- Residual stresses.
- Microstructure and inclusions.
- Mean stress and loading type.
- Temperature and environment.
- Manufacturing and heat-treatment history.

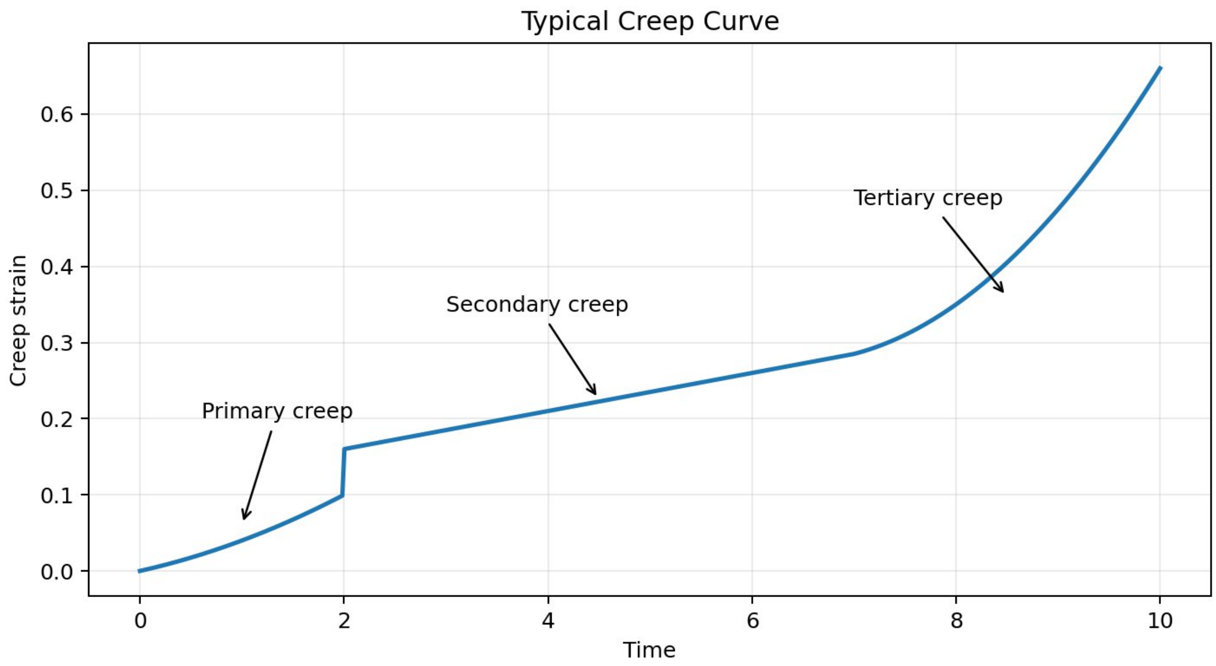
11.3 Real-World Example

A rotating shaft may experience millions of stress cycles during service. A small surface notch can become a crack initiation site, and the crack can gradually grow under cyclic loading. Fatigue testing and good design practice therefore consider cyclic loading, surface condition and stress concentration.

12. Creep

Creep is time-dependent permanent deformation that occurs under sustained load, particularly when the material is exposed to elevated temperature.

12.1 Stages of Creep



Primary creep

Creep rate decreases with time as the material responds to the applied conditions.

Secondary creep

Creep rate becomes approximately steady over a substantial period. This stage is often important for service-life assessment.

Tertiary creep

Creep rate accelerates, often associated with damage, necking, cracking or other changes, and eventually leads toward rupture.

12.2 Factors Affecting Creep

- Temperature — increasing temperature generally increases creep susceptibility.
- Applied stress — increasing stress generally increases creep rate.
- Time — creep is inherently time dependent.
- Microstructure and grain structure.
- Material composition and strengthening mechanisms.
- Environment and component geometry.

12.3 Real-World Example

High-temperature engineering components that remain under load for long periods must be checked for creep behavior. A material that is strong at room temperature may still suffer unacceptable time-dependent deformation at elevated service temperature.

13. Quick Comparison of Major Mechanical Properties

Property	Meaning	Typical testing/indicator
Elasticity	Ability to recover deformation after unloading.	Elastic part of stress–strain curve; Young's modulus
Plasticity	Ability to undergo permanent deformation.	Tensile/compression behavior
Strength	Resistance to applied stress.	Yield strength, UTS, fracture

		strength
Ductility	Plastic deformation before fracture.	% elongation, reduction of area
Brittleness	Fracture with limited plastic deformation.	Fracture behavior / impact response
Toughness	Energy absorbed before fracture.	Area under stress–strain curve; impact test
Resilience	Elastic energy absorption.	Elastic area / modulus of resilience
Fatigue resistance	Resistance to cyclic damage.	S–N testing
Creep resistance	Resistance to time-dependent deformation.	Creep testing / creep curve

14. Simple Worked Example

A tensile specimen has an original cross-sectional area of 100 mm^2 and carries a load of 20,000 N.

Engineering stress = P/A_0 = 20,000 / 100 = 200 N/mm^2 = 200 MPa.

If its original gauge length is 50 mm and the length under load is 51 mm:

Engineering strain = (51 − 50)/50 = 0.02 = 2%.

This example shows how a raw measurement (load and dimensional change) is converted into engineering quantities used to describe material behavior.

15. Module-Wise Short Questions

1. Define material testing.
2. State four objectives of material testing.
3. Classify engineering materials into the four groups listed in the syllabus.
4. Name the four standards organizations listed in the syllabus.
5. Define elastic deformation.
6. Define plastic deformation.
7. Differentiate elastic and plastic deformation.
8. Define stress.
9. Define strain.
10. Write the engineering stress equation.
11. Write the engineering strain equation.
12. State Hooke’s law.
13. What is Young’s modulus?
14. Define yield strength.
15. What is proof stress?
16. Define ultimate tensile strength (UTS).
17. Define fracture strength.
18. Define ductility.
19. Define brittleness.
20. Define toughness.
21. Define resilience.
22. What is fatigue?
23. What is creep?
24. What is an S–N curve?
25. Name the three stages of creep.

16. Module-Wise Long Questions

1. Explain the importance and objectives of material testing with suitable engineering examples.
2. Classify metals, ceramics, polymers and composites and compare their general engineering characteristics.
3. Explain the role of ASTM, ISO, IS and DIN in material testing and standardization.
4. Explain elastic and plastic deformation with a neat labeled diagram.
5. Explain stress and strain and derive/describe the engineering stress–strain relationship.
6. Draw and explain a typical engineering stress–strain curve for a ductile metal, identifying yield strength, UTS, necking and fracture strength.
7. State and explain Hooke's law. Explain the significance of Young's modulus.
8. Explain yield strength, proof stress, UTS and fracture strength with reference to a tensile stress–strain curve.
9. Define and differentiate ductility, brittleness, toughness and resilience.
10. Explain fatigue, S–N curve and factors affecting fatigue behavior.
11. Explain creep and describe primary, secondary and tertiary creep using a neat diagram.
12. Compare fatigue and creep in terms of loading condition, time dependence, typical service condition and test approach.

Explain how material testing supports quality control, material selection, design and failure analysis.

17. Viva Examination Questions

- Why are standards needed in material testing?
- Why is stress called an internal resisting force per unit area?
- What is the difference between stiffness and strength?
- Can a hard material be brittle? Explain.
- Why is UTS different from fracture strength in a typical ductile metal?
- Why is toughness important for impact-loaded components?
- Why can fatigue occur below static tensile strength?
- Why is creep associated strongly with elevated temperature?
- What information does an S–N curve provide?
- What are the three stages of a creep curve?

UNIT II

Destructive Testing (DT) Methods

Destructive Testing (DT) Methods

1. Tensile Test

1.1 Definition and Purpose

A tensile test is a destructive test in which a standard specimen is pulled axially until substantial deformation and fracture. It provides strength, stiffness and ductility information.

1.2 Test Procedure

1. Measure original gauge length L_0 and area A_0.

Grip the specimen axially in the testing machine.
Apply tensile load gradually at the specified rate.
Record load and extension.
Convert readings into engineering stress and strain.
Identify yield/proof stress, UTS, necking and fracture.
Measure final length and minimum area when ductility is required.

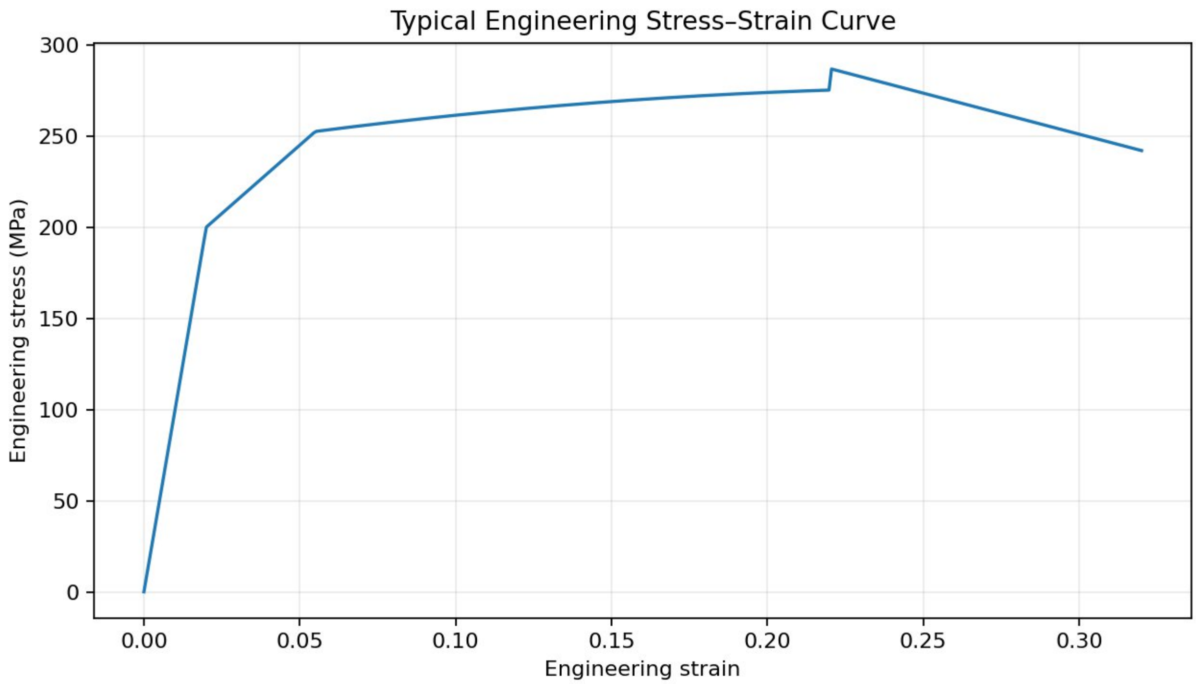
1.3 Engineering Stress and Strain

Engineering stress: $\sigma = P/A_0$

Engineering strain: $\varepsilon = (L - L_0)/L_0 = \Delta L/L_0$

P = load, A_0 = original area, L_0 = original gauge length, L = current gauge length.

1.4 Stress–Strain Curve



Elastic region
Deformation is substantially recoverable; the initial portion is often approximately linear.

Yielding
Permanent plastic deformation begins; proof stress may be used if no sharp yield point exists.

Strain hardening
Many ductile metals require increasing stress for further plastic deformation.

UTS
Maximum engineering stress reached during the test.

Necking
Localized reduction in area after UTS in a typical ductile tensile specimen.

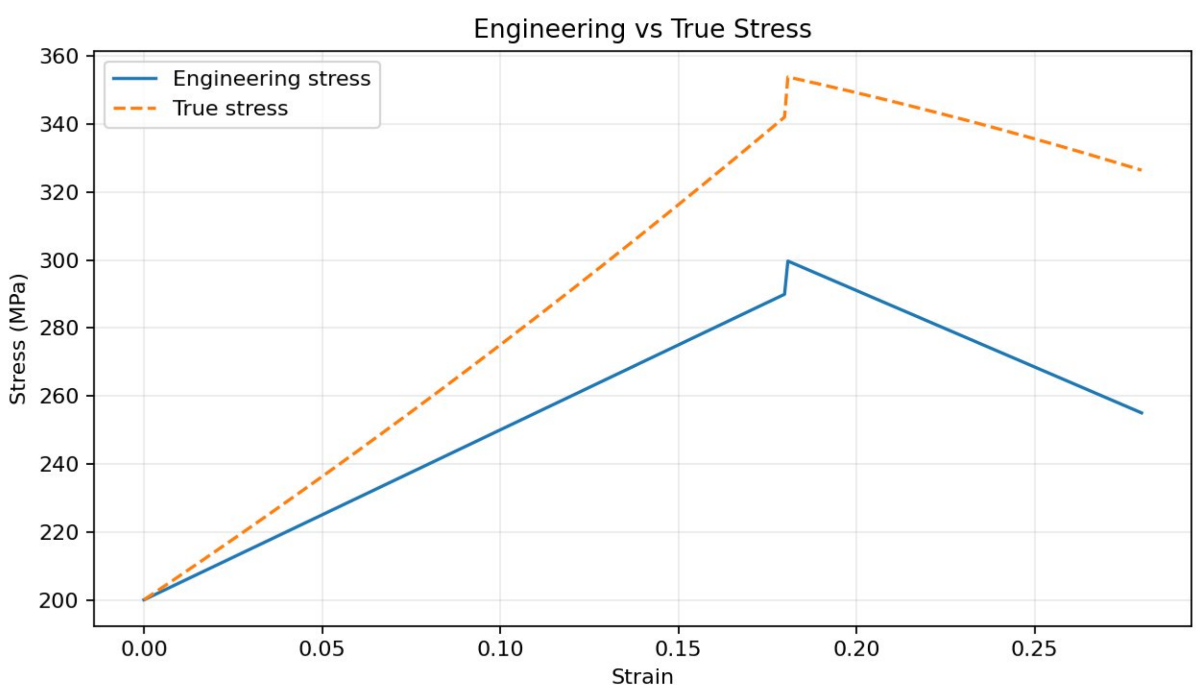
Fracture
Final separation of the specimen.

1.5 Modulus of Elasticity
For the linear elastic region, Hooke's law gives $\sigma = E\varepsilon$, so $E = \sigma/\varepsilon$. Young's modulus is a measure of elastic stiffness.

1.6 Proof Stress
When a material has no clearly defined yield point, a specified permanent strain offset is used to determine proof stress. The offset line is drawn parallel to the elastic portion.

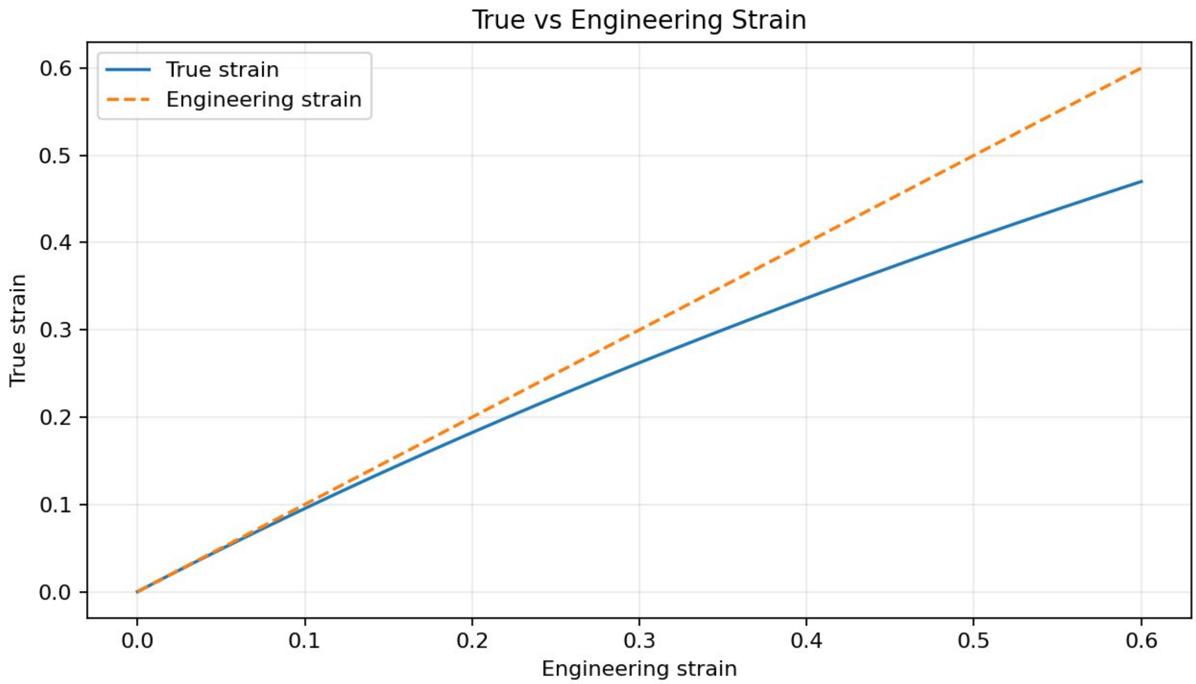
1.7 True Stress and True Strain
True stress: $\sigma_t = P/A$, where A is the instantaneous cross-sectional area. True strain: $\varepsilon_t = \ln(L/L_0)$. For approximately uniform tensile deformation: $\sigma_t = \sigma(1+\varepsilon)$ and $\varepsilon_t = \ln(1+\varepsilon)$.

1.8 True Stress vs Engineering Stress



True stress is generally higher than engineering stress during uniform tensile deformation because the instantaneous area becomes smaller.

1.9 True Strain vs Engineering Strain



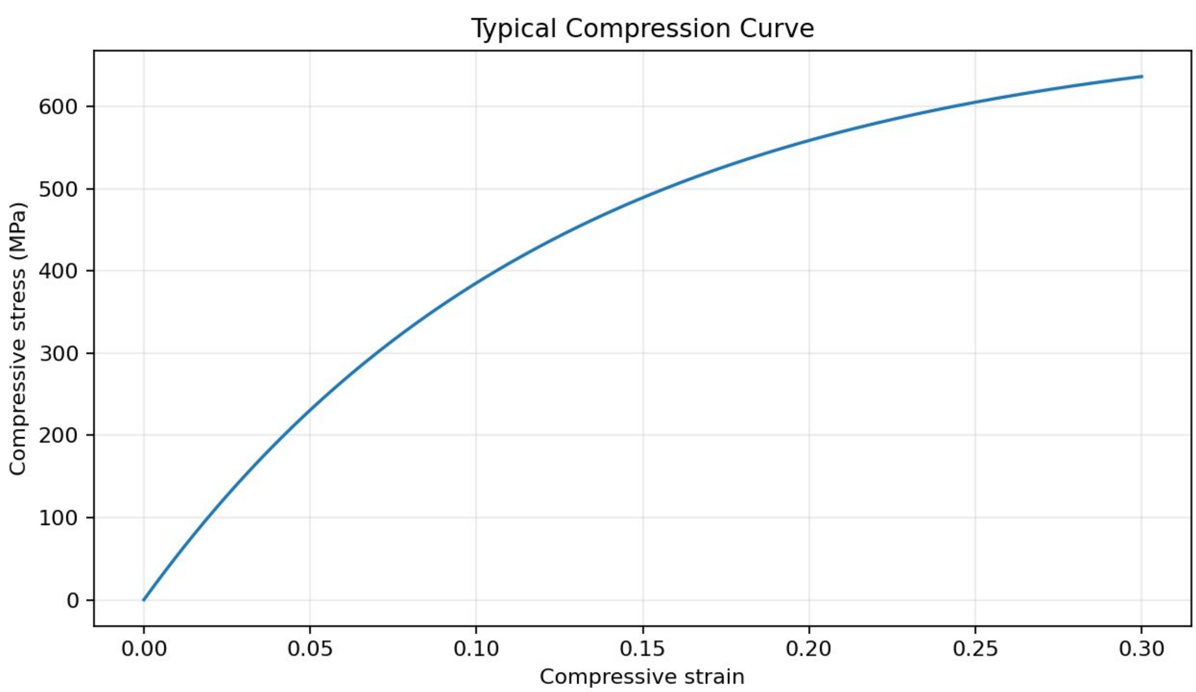
At small strains the two values are close; at large plastic strains the difference becomes significant.

1.10 Ductility and Toughness

% elongation = $[(L\_f-L_0)/L_0]\times100$. Reduction of area = $[(A_0-A\_f)/A_0]\times100$. Ductility describes plastic deformation before fracture; toughness is related to energy absorbed before fracture and the area under the complete stress–strain curve.

2. Compression Test

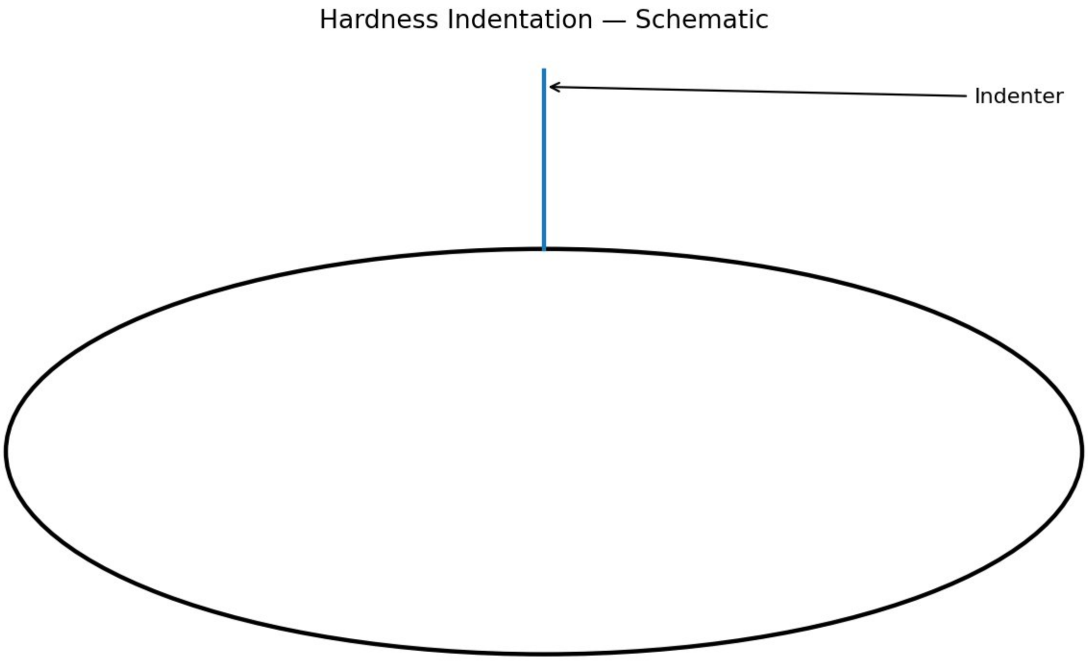
A compression test applies compressive load to determine compressive behavior, compressive strength and plastic deformation.



- Compressive stress = compressive load/original area.
- Ductile materials may undergo large plastic shortening.
- Friction between specimen ends and platens can produce barreling.
- Specimen dimensions and alignment influence results.

3. Hardness Testing

Hardness is resistance to localized permanent deformation such as indentation or scratching.



3.1 Brinell Hardness Test (BHN)

A spherical indenter is pressed into the specimen under a specified load and indentation diameter is measured. $BHN = 2P/[\pi D(D - \sqrt{(D^2 - d^2)})]$.

3.2 Rockwell Hardness Test (RHN)

Rockwell hardness is based on penetration depth after a specified minor and major load sequence. The machine indicates the hardness on the selected scale.

3.3 Vickers Hardness Test (VHN)

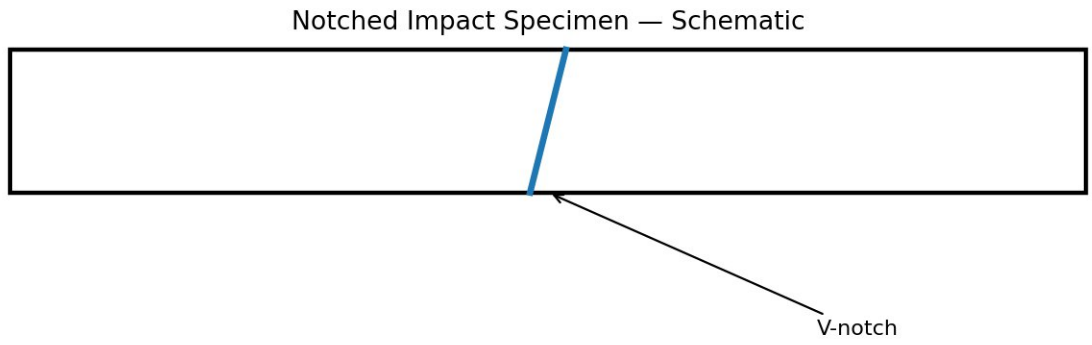
A diamond pyramid indenter produces a square indentation. The two diagonals are measured and used to calculate Vickers hardness.

3.4 Mohs Hardness Test

Mohs hardness is a scratch scale. Reference minerals are ranked from talc 1 to diamond 10. It is ordinal, not linear.

4. Impact Testing — Charpy and Izod

Impact tests measure energy absorbed during rapid fracture and are important for sudden loading and toughness assessment.



4.1 Charpy Test

A notched specimen is supported horizontally and struck by a pendulum. Absorbed energy is determined from the pendulum energy change.

4.2 Izod Test

The specimen is supported vertically and struck by a pendulum. The support arrangement and notch orientation differ from Charpy.

4.3 Transition Temperature

Some materials show a strong change in impact toughness with temperature. Transition-temperature concepts describe the change from predominantly ductile to predominantly brittle fracture behavior.

4.4 Factors Affecting Transition Temperature

- Composition and alloying.
- Grain size and microstructure.
- Heat treatment and processing.
- Notch geometry.
- Loading rate.
- Thickness and constraint.
- Impurities/inclusions.
- Prior deformation and residual stress.

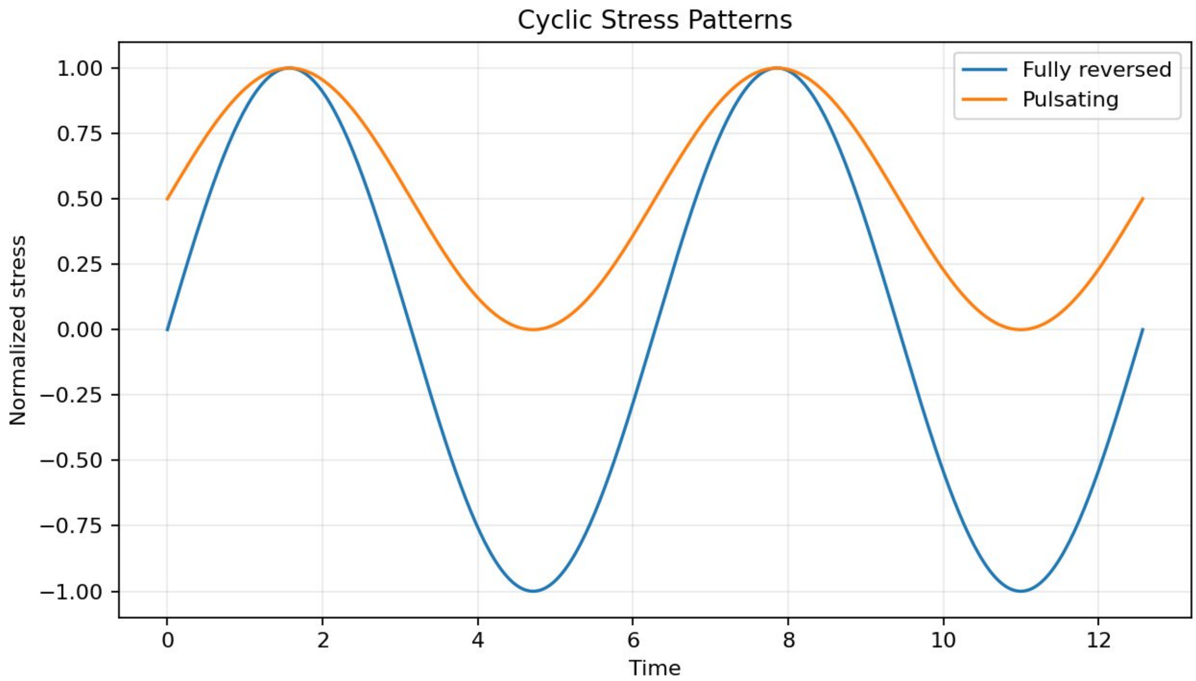
4.5 Ductile and Brittle Fracture

Ductile fracture generally absorbs more energy and involves substantial plastic deformation. Brittle fracture can occur with limited plastic deformation and rapid crack propagation.

5. Fatigue Testing

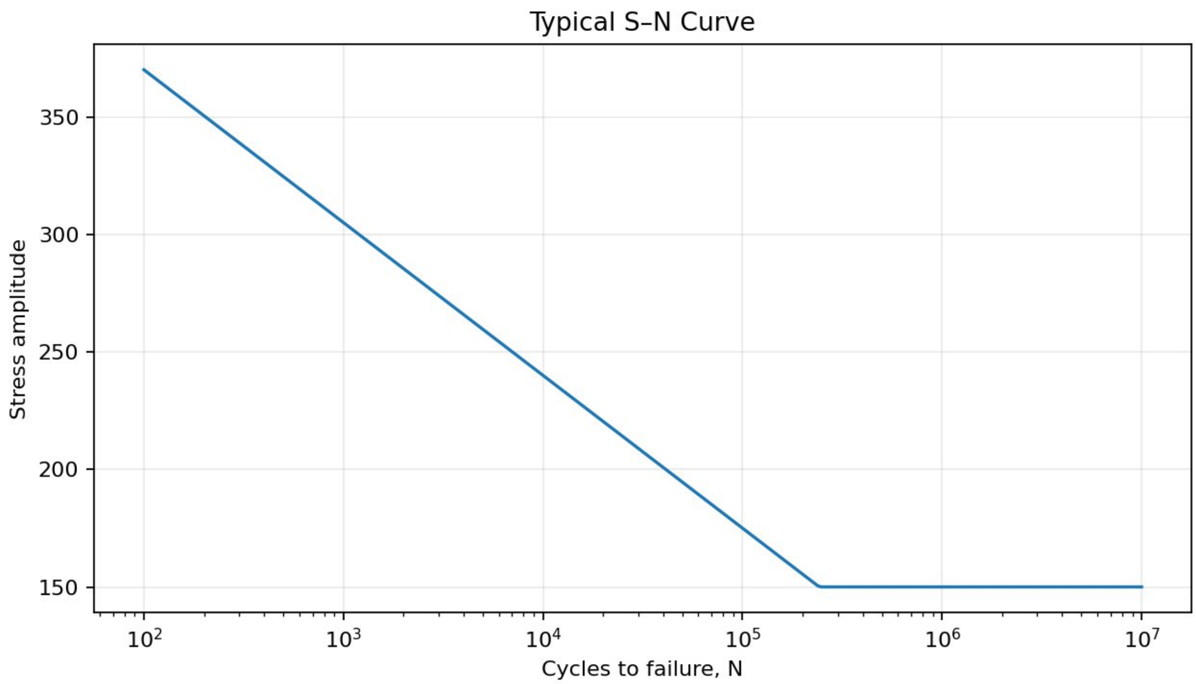
Fatigue is progressive damage under repeated or cyclic loading. Failure can occur even when cyclic stress is below static tensile strength.

5.1 Stress Cycles



Stress amplitude: $\sigma a = (\sigma max - \sigma min)/2$. Mean stress: $\sigma m = (\sigma max + \sigma min)/2$.

5.2 S–N Curve



An S–N curve relates stress amplitude to number of cycles to failure. Higher stress amplitude generally produces shorter fatigue life.

5.3 Endurance Limit

Where a long-life limiting stress is observed, the endurance limit is the stress amplitude associated with the specified long-life regime.

5.4 Fatigue Testing Procedure

2. Prepare the standard specimen.
3. Mount it correctly.
4. Select stress amplitude and loading conditions.
5. Run until failure or specified run-out.
6. Record cycles to failure.
7. Repeat at several stress levels to establish the S–N curve.

5.5 Fatigue Testing Machine

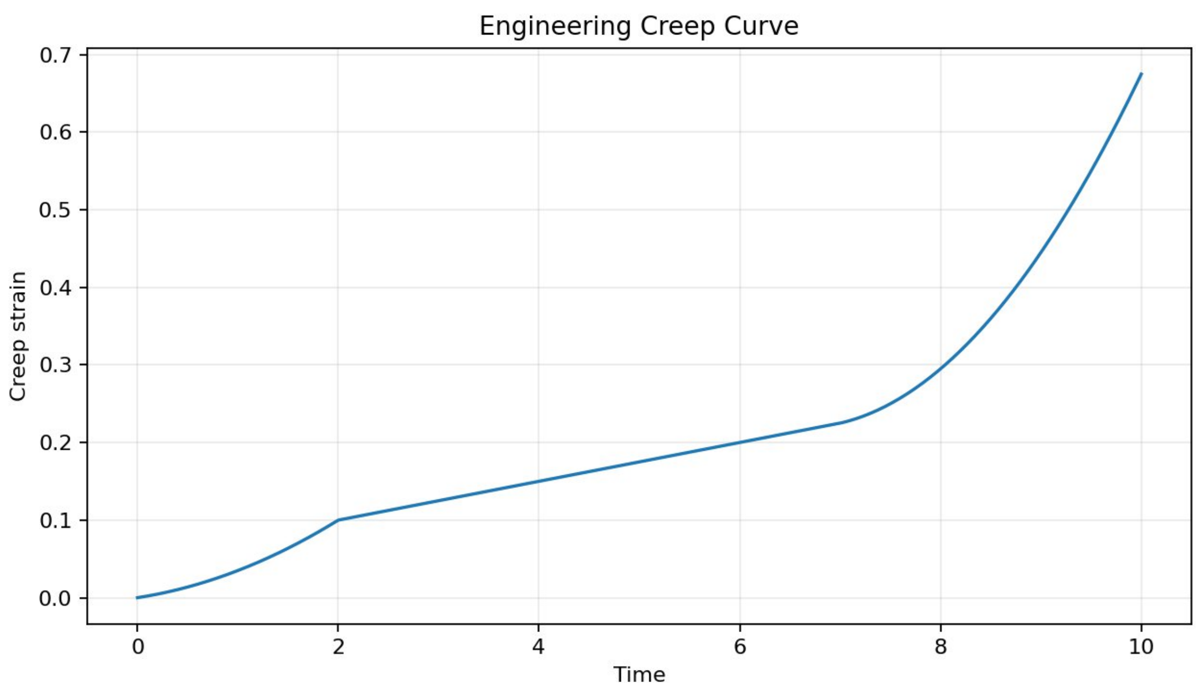
Fatigue machines apply controlled cyclic axial, bending, rotating-bending or torsional loads and record cycles.

5.6 Metallurgical Factors Affecting Fatigue

- Grain size and microstructure.
- Phase constitution.
- Heat treatment.
- Non-metallic inclusions and pores.
- Surface roughness and machining marks.
- Residual stress.
- Precipitates/second phases.
- Surface damage or decarburization.
- Corrosive environment.

6. Creep Testing

Creep is time-dependent permanent deformation under sustained load, especially at elevated temperature.



Primary creep

Creep rate decreases with time.

Secondary creep

Creep rate is approximately steady and is often important for service-life evaluation.

Tertiary creep

Creep rate accelerates because of progressive damage and geometric changes, leading toward rupture.

6.1 Effect of Temperature and Stress

Higher temperature generally increases creep rate. Higher applied stress generally increases creep rate and decreases time to rupture.

6.2 Creep Rate

Creep rate is the rate of change of creep strain with time: $\dot{\varepsilon} = d\varepsilon/dt$.

6.3 Creep Rupture Strength

Creep rupture strength is the stress causing rupture in a specified time at a specified temperature and test condition.

6.4 Constant-Stress Creep Curve

A constant-stress creep test maintains specified stress and temperature while strain is recorded against time. The engineering curve shows primary, secondary and tertiary stages.

6.5 Andrade Concept

Andrade described early-stage creep with an empirical time-dependent relationship. The key idea is that the initial creep response changes with time rather than having a constant rate.

6.6 Equi-Cohesive Temperature

Equi-cohesive temperature is the temperature at which grain-boundary and grain-interior strength become comparably important, helping explain changes in deformation mechanisms.

6.7 Factors Affecting Creep

- Temperature.
- Applied stress.
- Time.
- Grain size and grain-boundary structure.
- Alloy composition.
- Precipitates and strengthening phases.
- Heat treatment and processing.
- Environment and geometry.

6.8 Creep Testing Machine

A creep machine maintains controlled stress/load and temperature while measuring elongation with an extensometer.

6.9 Stress Rupture Test

A specimen is held at specified stress and temperature until rupture, and rupture time is recorded for long-term high-temperature performance assessment.

7. Fracture Mechanics

Fracture mechanics studies crack initiation, crack growth and final failure.

7.1 Types of Fracture

Ductile

Substantial plastic deformation precedes fracture; microvoid growth and coalescence are common.

Brittle

Little macroscopic plastic deformation; rapid crack propagation may occur.

Fatigue

Progressive crack growth under cyclic loading followed by final fracture.

Creep

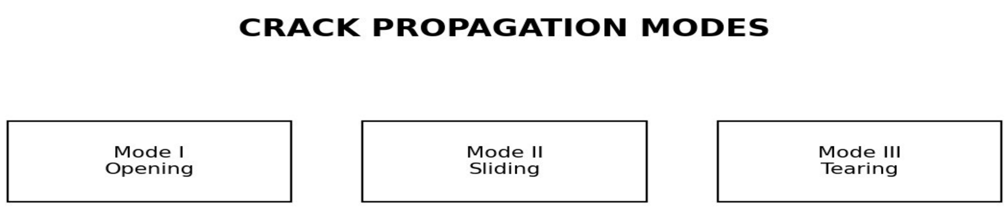
Long-term deformation and damage under sustained stress, often at elevated temperature.

7.2 Crack Initiation

- Surface scratches, notches and geometric stress concentrations.

- Inclusions, pores and internal defects.
- Weld/manufacturing discontinuities.
- Localized cyclic plasticity.
- Corrosion or environmental damage.

7.3 Crack Propagation Modes



Mode I = opening, Mode II = in-plane sliding shear, Mode III = anti-plane tearing shear. Real components may experience mixed-mode loading.

8. Real-World Material Failure Case Studies

8.1 Liberty Ship Brittle Fracture

Historic welded Liberty ships suffered brittle-fracture failures. The events highlighted low temperature, stress concentration, welding details and material toughness as important factors.

8.2 Fatigue Failure of Rotating Shafts

Rotating shafts can experience millions of cycles. Keyways, sharp diameter changes and machining marks can initiate fatigue cracks that grow progressively.

8.3 High-Temperature Creep Damage

Long-term high-temperature service can cause creep deformation and eventual damage. Creep and stress-rupture tests help establish safe operating conditions.

8.4 Engineering Lessons

- Select properties for actual service conditions.
- Control stress concentrations and defects.
- Account for temperature and loading rate.
- Use standardized tests.
- Investigate failures metallurgically.
- Control surface finish, heat treatment and manufacturing quality.

9. Comparison of DT Methods

Test	Main property	Typical result	Key caution
Tensile	Strength/stiffness/ductility	Yield, proof stress, UTS, E	Geometry/rate
Compression	Compressive behavior	Strength/deformation	Friction/barreling
Brinell	Indentation hardness	BHN	Large indentation
Rockwell	Depth hardness	RHN	Correct scale

Vickers	Diamond indentation	VHN	Diagonal measurement
Mohs	Scratch hardness	Mohs number	Ordinal scale
Charpy/Izod	Impact toughness	Absorbed energy	Temperature/notch
Fatigue	Cyclic resistance	S–N curve	Surface/stress concentration
Creep	Time-dependent deformation	Creep rate/rupture life	Temperature/stress
Fracture mechanics	Crack behavior	Crack/fracture data	Geometry/loading mode

10. Important Formula Sheet

- $\sigma = P/A_0$
- $\varepsilon = (L-L_0)/L_0$
- $E = \sigma/\varepsilon$
- $\sigma_t = P/A$
- $\varepsilon_t = \ln(L/L_0)$
- $\sigma_t = \sigma(1+\varepsilon)$ for uniform deformation
- $\varepsilon_t = \ln(1+\varepsilon)$
- % elongation = $[(L_f-L_0)/L_0]\times100$
- Reduction of area = $[(A_0-A_f)/A_0]\times100$
- $\sigma_a = (\sigma_{max}-\sigma_{min})/2$
- $\sigma_m = (\sigma_{max}+\sigma_{min})/2$
- $\dot{\varepsilon} = d\varepsilon/dt$
- $BHN = 2P/[\pi D(D-\sqrt{(D^2-d^2)})]$

11. Short Questions

1. Define destructive testing.
2. State two objectives of the tensile test.
3. Define engineering stress and strain.
4. What is Young's modulus?
5. Define yield strength and proof stress.
6. Define UTS and fracture strength.
7. Define true stress and true strain.
8. State the engineering/true stress relation.
9. State the engineering/true strain relation.
10. Define compressive strength.
11. What is hardness?
12. State the principle of Brinell, Rockwell and Vickers tests.
13. What is Mohs hardness?
14. Differentiate Charpy and Izod tests.
15. What is transition temperature?
16. State four factors affecting transition temperature.
17. Define fatigue and endurance limit.
18. What is an S–N curve?
19. State four metallurgical factors affecting fatigue.
20. Define creep.
21. Name the three creep stages.

22. Define creep rate.
23. What is creep rupture strength?
24. What is stress rupture testing?
25. Define fracture mechanics.
26. Name four fracture types.
27. What is crack initiation?
28. Name three crack propagation modes.

12. Long Questions

1. Explain the tensile test with a neat stress–strain curve and discuss yield strength, UTS, ductility and toughness.
2. Explain modulus of elasticity and proof stress.
3. Explain true stress/true strain and their relationships with engineering values.
4. Explain compression testing, compressive strength and plastic deformation.
5. Explain Brinell, Rockwell, Vickers and Mohs hardness tests and compare them.
6. Explain Charpy and Izod impact tests, transition temperature and influencing factors.
7. Explain fatigue testing, stress cycles, S–N curves, endurance limit, procedure and machine.
8. Discuss metallurgical factors affecting fatigue behavior.
9. Explain creep stages and the effects of stress and temperature.
10. Explain creep rate, creep rupture strength, constant-stress creep curve and stress rupture testing.
11. Write notes on the Andrade concept and equi-cohesive temperature.
12. Explain fracture mechanics, fracture types, crack initiation and crack propagation modes.
13. Discuss real-world material failures and engineering lessons.

13. Viva Questions

- Why is tensile testing destructive?
- Why are true values useful at large plastic strain?
- Why is proof stress used?
- Why does necking occur after UTS?
- Why can friction affect compression testing?
- Why are Rockwell scales different?
- Why is Mohs hardness ordinal?
- Why is a notch used in impact testing?
- Why is low temperature important for brittle fracture?
- Why does surface finish affect fatigue?
- Why is creep temperature dependent?
- Difference between fatigue and creep?
- What is Mode I crack propagation?

UNIT III

Non-Destructive Testing (NDT) Methods

Non-Destructive Testing (NDT) Methods

1. Introduction to NDT

Non-Destructive Testing (NDT) is the examination of a material, component or structure to detect and evaluate discontinuities without destroying the item. NDT supports quality control, maintenance, safety and reliability.

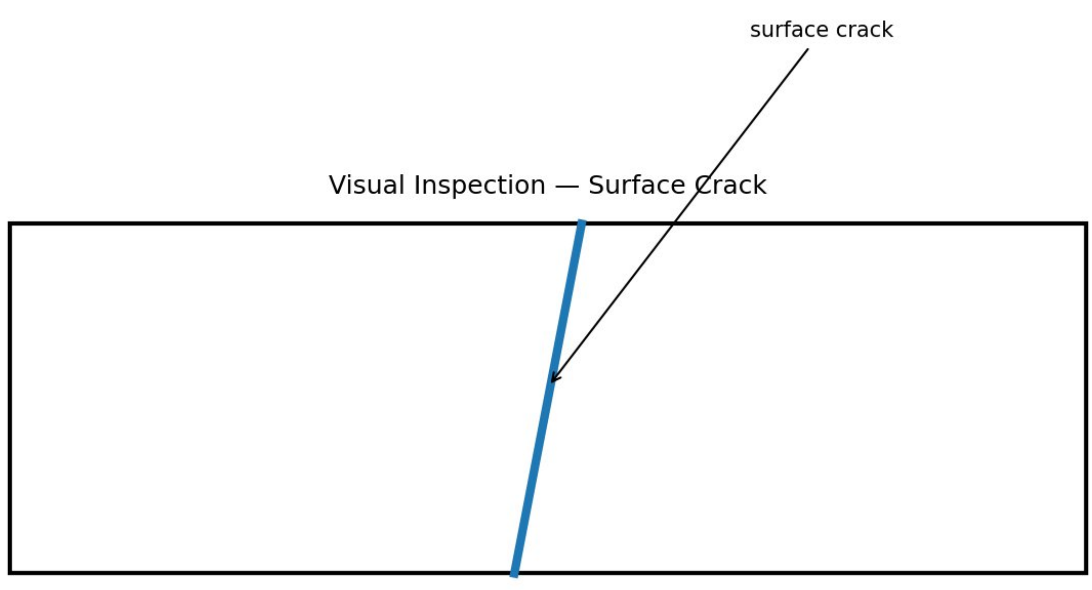
The uploaded syllabus specifies Visual Inspection, Liquid Penetrant Testing, Magnetic Particle Testing, Ultrasonic Testing, Radiographic Testing and Eddy Current Testing under Unit III, with the stated purposes of surface, near-surface, internal and conductivity-related defect detection.

Learning Outcomes

- Explain the principle and purpose of major NDT methods.
- Select a suitable NDT method for a material and defect.
- Describe basic inspection procedures and equipment.
- Interpret basic NDT indications.
- Follow safe inspection practice.

2. Visual Inspection (VI)

VI examines an accessible surface directly or with optical aids for surface defects, cracks and surface roughness.



Principle

VI examines an accessible surface directly or with optical aids for surface defects, cracks and surface roughness.

Basic Procedure

1. Clean the surface.

Provide adequate illumination.
Inspect directly or with magnifiers, mirrors, borescopes or optical instruments.
Check cracks, corrosion, deformation, weld irregularities and roughness.
Record relevant indications.

Advantages

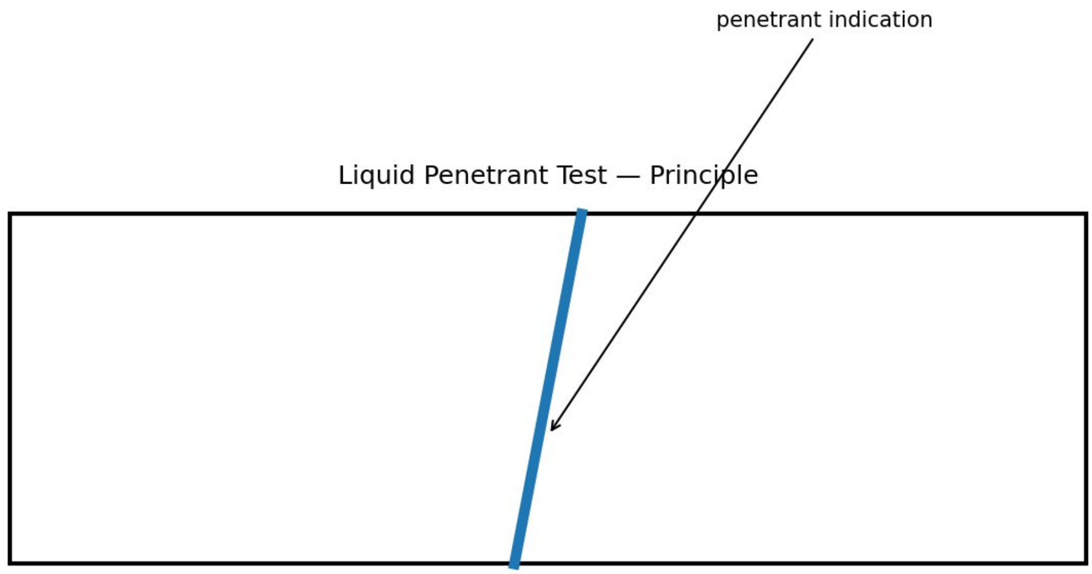
- Simple, rapid and inexpensive.
- No damage to the component.
- Useful as a first-stage inspection.

Limitations

- Small or hidden defects may not be visible.
- Results depend on access, lighting, cleanliness and inspector skill.

3. Liquid Penetrant Test (LPT)

LPT detects discontinuities open to the surface. Liquid penetrant enters the opening by capillary action and is revealed during development.



Principle

LPT detects discontinuities open to the surface. Liquid penetrant enters the opening by capillary action and is revealed during development.

Basic Procedure

2. Pre-clean the surface.

Apply penetrant.
Allow dwell time.

Remove excess penetrant.
Apply developer.
Allow development.
Inspect and record indications.
Post-clean the part.

Advantages

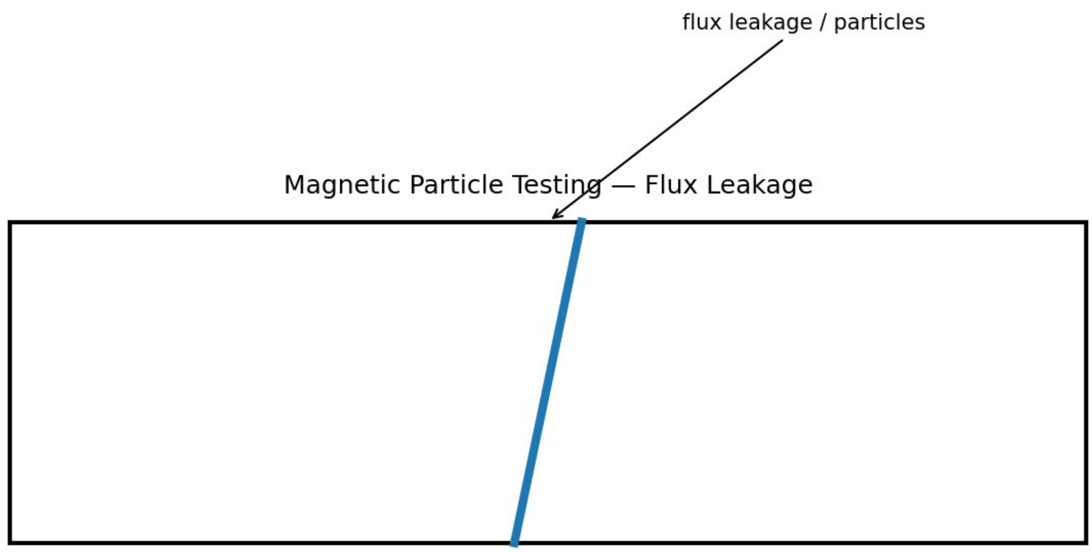
- Sensitive to fine surface-opening cracks.
- Can inspect complex shapes.
- The syllabus specifies surface-defect detection in ferrous and non-ferrous metals.

Limitations

- Normally cannot detect closed internal defects.
- Porous/rough surfaces can interfere.
- Requires careful cleaning and chemical handling.

4. Magnetic Particle Testing (MPT)

MPT detects surface and near-surface discontinuities in ferromagnetic materials. Magnetization causes flux leakage at a discontinuity and magnetic particles accumulate there.



Principle

MPT detects surface and near-surface discontinuities in ferromagnetic materials. Magnetization causes flux leakage at a discontinuity and magnetic particles accumulate there.

Basic Procedure

3. Clean the surface.
4. Magnetize the component.
5. Apply magnetic particles.
6. Observe particle accumulations.
7. Evaluate indications.
8. Demagnetize when required.
9. Clean and document.

Advantages

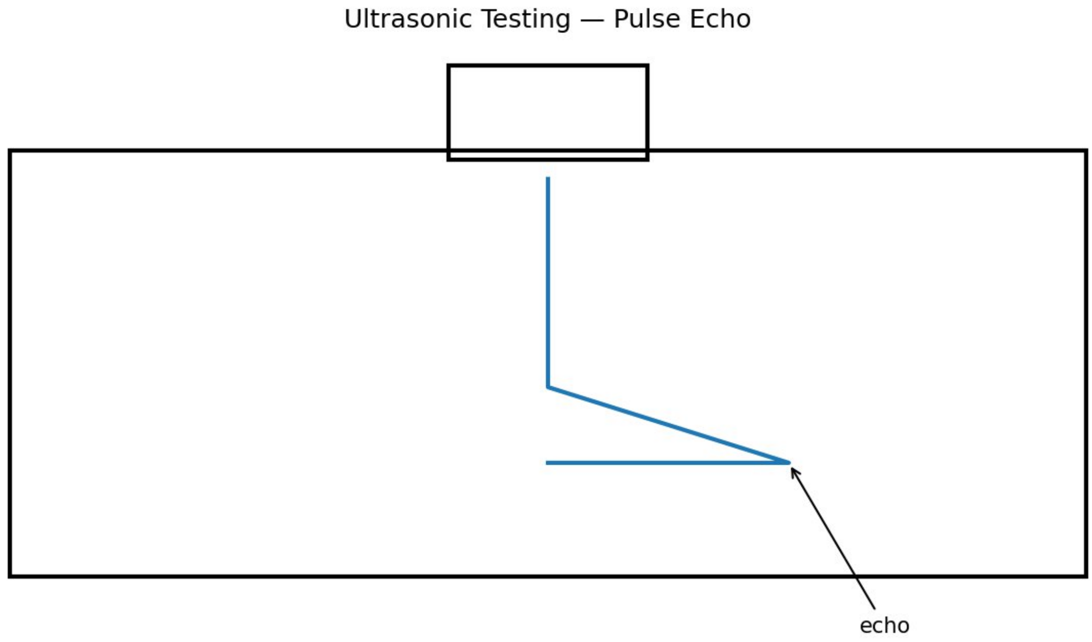
- Very useful for cracks.
- Can reveal some near-surface defects.
- Fast for many inspections.

Limitations

- Material must be suitably ferromagnetic.
- Magnetization direction affects sensitivity.
- Demagnetization may be required.

5. Ultrasonic Testing (UT)

UT uses high-frequency mechanical waves to detect internal discontinuities. The syllabus includes ultrasonic waves and transducers.



Principle

UT uses high-frequency mechanical waves to detect internal discontinuities. The syllabus includes ultrasonic waves and transducers.

Basic Procedure

10. Select probe and technique.

Prepare the surface.
Apply couplant.
Calibrate with the required reference.
Scan systematically.
Observe echoes.
Evaluate indications using the procedure.

Advantages

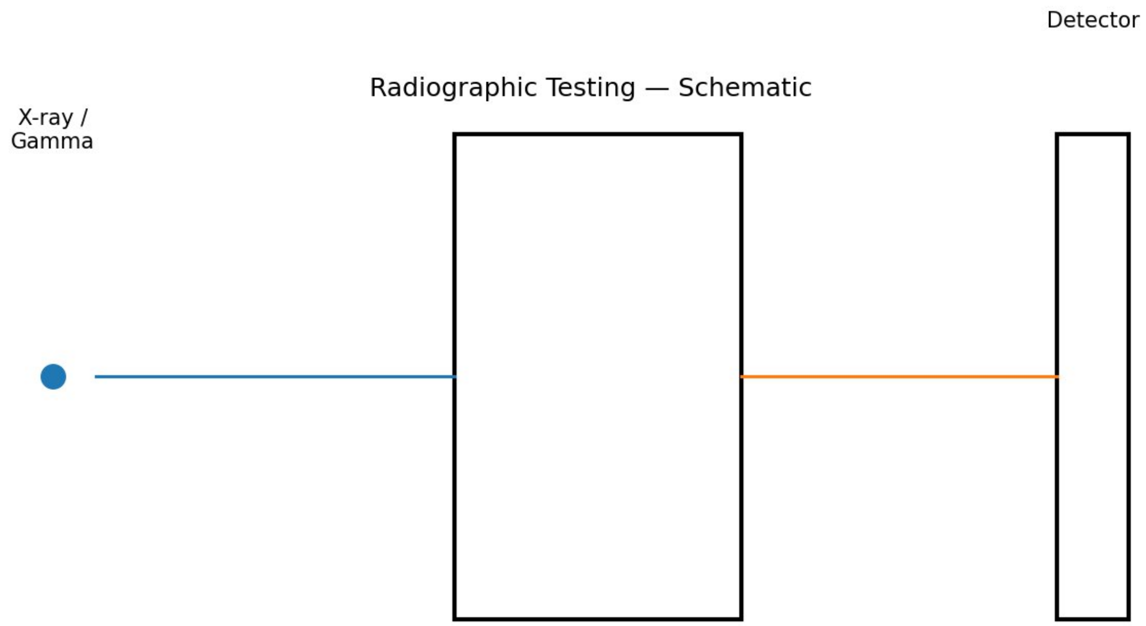
- Detects internal defects.
- Can provide defect-location information.
- Many pulse-echo arrangements require one-side access.
- No ionizing radiation.

Limitations

- Requires calibration and operator skill.
- Surface geometry and coupling affect results.
- Defect orientation can affect detectability.

6. Radiographic Testing (RT)

RT uses penetrating ionizing radiation to form an image related to material attenuation. The syllabus specifies X-ray and gamma-ray testing for welds and castings and notes RT as demonstration-only if available.



Principle

RT uses penetrating ionizing radiation to form an image related to material attenuation. The syllabus specifies X-ray and gamma-ray testing for welds and castings and notes RT as demonstration-only if available.

Basic Procedure

1. Select source and inspection arrangement.
2. Position source, component and detector.
3. Set approved exposure conditions.
4. Establish controlled radiation area.
5. Make the exposure.
6. Process/read the image.
7. Interpret and report results.

Advantages

- Useful for volumetric internal discontinuities.
- Produces a permanent or digital image.
- Widely used for weld/casting inspection.

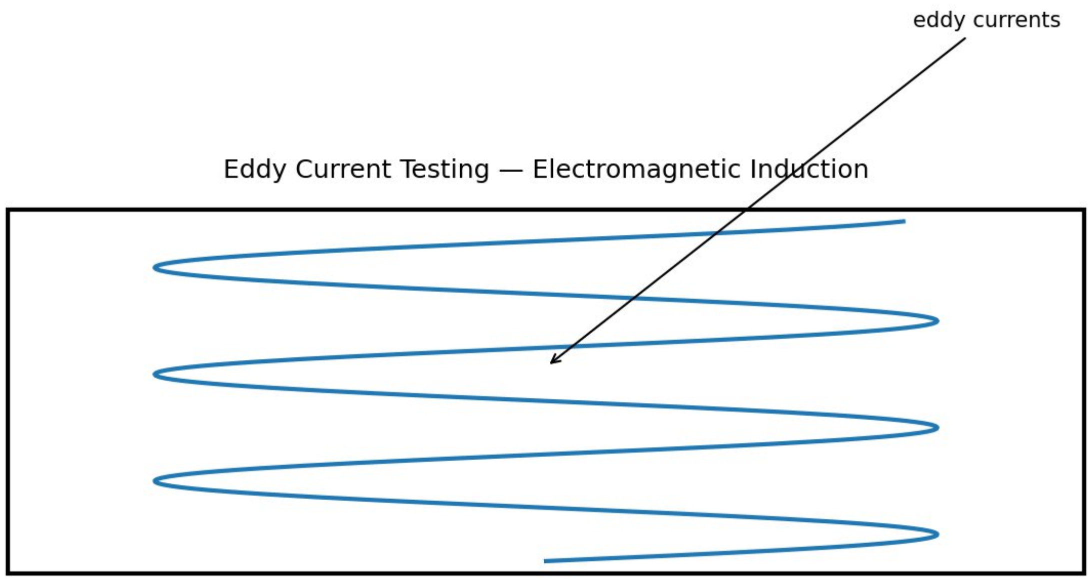
Limitations

- Ionizing radiation requires strict safety controls.
- Geometry can limit inspection.

- Some planar defects are difficult when unfavorably oriented.

7. Eddy Current Testing (ECT)

ECT uses electromagnetic induction to inspect electrically conductive materials. The syllabus identifies conductivity and defect detection in metals.



Principle

ECT uses electromagnetic induction to inspect electrically conductive materials. The syllabus identifies conductivity and defect detection in metals.

Basic Procedure

1. Select probe and frequency.
2. Calibrate with a reference standard.
3. Scan the inspection region.
4. Monitor instrument response.
5. Separate relevant indications from lift-off and geometry effects.
6. Record and evaluate indications.

Advantages

- Fast scanning.
- No penetrant is required.
- Sensitive to many surface/near-surface defects.
- Can provide conductivity information.

Limitations

- Requires electrically conductive material.
- Response is affected by lift-off, geometry, conductivity and permeability.
- Penetration depth depends on frequency and material.

8. Important NDT Equipment and Terms

Visual inspection aids

Magnifiers, mirrors, borescopes and optical instruments improve access or magnification; these are specifically listed in the NDT laboratory syllabus.

LPT penetrant and developer

Penetrant enters surface openings; developer helps reveal trapped penetrant as an indication.

MPT magnetizing equipment

Produces the magnetic field needed to create detectable flux leakage.

UT transducer

Generates and/or receives ultrasonic energy.

RT source and detector

The source produces X-rays or gamma rays; the detector records transmitted radiation.

ECT probe

Generates an alternating magnetic field and senses changes in electromagnetic response.

9. Comparison of NDT Methods

Method	Principle	Main region	Material	Main use
VI	Optical observation	Surface	Accessible surfaces	Surface condition
LPT	Capillary action	Surface-opening	Suitable non-porous surfaces	Fine surface cracks
MPT	Magnetic flux leakage	Surface/near-surface	Ferromagnetic	Cracks/discontinuities
UT	Ultrasonic reflections	Internal	Many engineering materials	Internal defects
RT	Radiation attenuation	Internal/volumetric	Suitable components	Weld/casting imaging
ECT	Electromagnetic induction	Surface/near-surface	Conductive metals	Conductivity/defects

10. Selection of NDT Method

Method selection depends on material, defect type, defect location, geometry, accessibility, required sensitivity, inspection speed, cost and safety.

- Accessible surface crack → VI or LPT; MPT is particularly useful for ferromagnetic materials.
- Near-surface crack in ferromagnetic steel → MPT.
- Internal discontinuity → UT or RT may be selected.
- Conductivity variation or surface/near-surface defect in a conductive metal → ECT.
- Complex accessible surface on a suitable non-porous material → LPT can be useful.

11. NDT Safety and Good Practice

The syllabus emphasizes safety protocols, equipment handling and industry standards including ASNT, ASTM and ISO.

- Follow approved procedures and equipment instructions.
- Use appropriate personal protective equipment.
- Keep inspection surfaces clean.
- Handle LPT chemicals according to applicable safety instructions.
- Follow electrical and equipment safety for MPT/UT/ECT.
- For RT, use controlled areas, radiation monitoring and qualified supervision.
- Maintain calibration and inspection records.

12. Industrial Applications and Case Study Areas

The NDT laboratory syllabus identifies aerospace, automotive and manufacturing as case-study application areas.

Aerospace

NDT supports inspection of critical structures and components without damaging serviceable parts.

Automotive

NDT can support inspection of castings, forgings, welds and safety-critical components.

Manufacturing

NDT supports production quality control and detection of defects before components enter service.

13. Short Questions

1. Define Non-Destructive Testing.
2. State two advantages of NDT.
3. What is visual inspection?
4. Name two optical aids used in VI.
5. What is surface roughness?
6. Define Liquid Penetrant Testing.
7. What is capillary action in LPT?
8. List the basic steps of LPT.
9. What type of defect is detected by LPT?
10. State two limitations of LPT.
11. Define Magnetic Particle Testing.
12. Why must a component be magnetized in MPT?
13. What is magnetic flux leakage?
14. Which materials are suitable for MPT?
15. What defects can MPT detect?
16. Define Ultrasonic Testing.
17. What is an ultrasonic transducer?
18. What is pulse-echo testing?
19. Why is couplant used in UT?
20. State two advantages of UT.
21. Define Radiographic Testing.
22. Name the two radiation sources specified in the syllabus.
23. What is the purpose of a radiographic detector?
24. Why is RT safety important?

25. What is Eddy Current Testing?
26. What is electromagnetic induction?
27. What materials are suitable for ECT?
28. What is lift-off in ECT?
29. State two applications of ECT.
30. Differentiate UT and RT.
31. Differentiate LPT and MPT.
32. Differentiate surface and internal defects.
33. Which NDT method is suitable for ferromagnetic cracks?
34. Which methods can detect internal defects?
35. State four factors for selecting an NDT method.

14. Long Questions

1. Explain Visual Inspection with principle, equipment, procedure, advantages, limitations and a neat diagram.
2. Explain Liquid Penetrant Testing with principle, capillary action, complete procedure, advantages, limitations and applications.
3. Explain Magnetic Particle Testing with magnetic flux leakage, procedure, advantages, limitations and diagram.
4. Explain Ultrasonic Testing, ultrasonic waves, transducers, pulse-echo method, procedure, advantages and limitations.
5. Explain Radiographic Testing using X-rays and gamma rays, basic arrangement, applications and radiation safety.
6. Explain Eddy Current Testing using electromagnetic induction and discuss conductivity and defect detection.
7. Compare VI, LPT, MPT, UT, RT and ECT with respect to principle, defect location, material suitability, advantages and limitations.
8. Explain how an NDT method is selected for a particular material and defect.
9. Discuss NDT applications in aerospace, automotive and manufacturing.
10. Write a detailed note on NDT safety and good inspection practice.

15. Viva Questions

- Why is NDT called non-destructive?
- Why is visual inspection often performed first?
- Why is surface cleaning important in LPT?
- Why does LPT normally detect only surface-opening defects?
- Why is MPT restricted to ferromagnetic materials?
- What causes magnetic flux leakage?
- Why is a couplant used in UT?
- What does an ultrasonic echo represent?
- Why can defect orientation affect UT?
- What is the main safety concern in RT?
- What is the difference between X-ray and gamma-ray sources?
- Why is ECT limited to conductive materials?
- What factors change the eddy-current response?
- Which method would you choose for a surface crack in steel?
- Which methods can detect internal defects?

UNIT IV

Advanced Material Testing Techniques, Industrial Applications & Case Studies

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Advanced Material Testing Techniques & Industrial Applications & Case Studies

1. Introduction

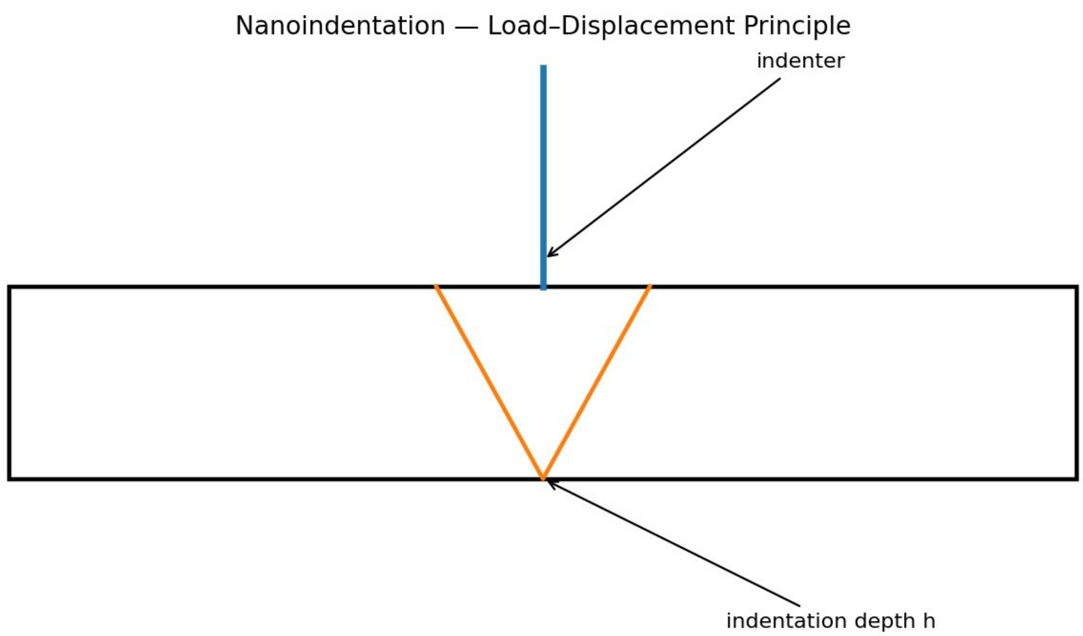
Advanced material testing extends conventional mechanical and non-destructive testing to situations where very small volumes, complex geometries, advanced materials or demanding inspection requirements must be evaluated. In this unit, the syllabus covers Nanoindentation, advanced NDT using the phased-array ultrasound technique, and quality control and material selection.

Why this unit is important

- Nanoindentation can characterize very small regions such as thin films, coatings, microstructural constituents and small volumes.
- Phased-array ultrasonics can electronically steer and focus an ultrasonic beam for improved inspection coverage.
- Quality control connects testing results with manufacturing decisions.
- Material selection links service requirements, properties, processing, cost and reliability.
- The course outcome explicitly connects material testing with material selection, quality control, product design, failure analysis, safety and reliability.

2. Nanoindentation

Nanoindentation is a small-scale mechanical testing technique in which a sharp or rounded indenter is pressed into a material while force and penetration depth are measured continuously. The resulting load–displacement response can be analyzed to estimate properties such as hardness and indentation modulus.



2.1 Basic Principle

A controlled force is applied to an indenter. The instrument records indentation depth as the load changes. During unloading, the elastic response of the material is used in an analysis of the contact stiffness. Because the indentation is extremely small, the method can characterize localized regions rather than requiring a large conventional test specimen.

2.2 Main Components

- Indenter: usually a calibrated diamond geometry such as Berkovich or another suitable geometry.
- Actuator: applies a controlled force or displacement.
- Load sensor: measures applied force.
- Displacement sensor: measures indentation depth.
- Specimen stage: holds and positions the sample.
- Control and analysis software: records the load–displacement curve and calculates properties.

2.3 Typical Test Cycle

Prepare a clean, stable and sufficiently flat specimen.
Position the indenter over the selected test region.
Apply a controlled loading sequence.
Hold the maximum load when required.
Unload while continuously recording displacement.
Generate the load–displacement curve.
Analyze the unloading response to obtain hardness and modulus-related quantities.
Repeat at multiple locations when spatial variation is important.

2.4 Load–Displacement Curve

A typical nanoindentation curve contains a loading portion and an unloading portion. Maximum load Pmax corresponds to maximum penetration hmax. The unloading slope is related to contact stiffness. The exact calculation depends on the indenter geometry, calibration and analysis model.

2.5 Hardness

Indentation hardness is commonly expressed as the maximum applied load divided by the projected contact area:

$H = Pmax / A$
where H is indentation hardness, Pmax is maximum indentation load and A is the projected contact area.

2.6 Indentation Modulus

The unloading stiffness can be used with an appropriate contact-mechanics model to estimate reduced modulus and, with suitable assumptions about indenter and specimen elastic properties, the specimen indentation modulus.

2.7 Factors Affecting Nanoindentation

- Surface roughness and cleanliness.
- Specimen thickness and substrate effects.
- Indenter geometry and tip calibration.
- Loading rate and hold time.
- Thermal drift.
- Instrument compliance.
- Pile-up or sink-in around the indentation.
- Material anisotropy, porosity and microstructural heterogeneity.

2.8 Advantages

- Very small test volumes.
- Local property mapping is possible.
- Useful for thin films and coatings.
- Can compare different microstructural regions.
- Requires relatively small specimens.

2.9 Limitations

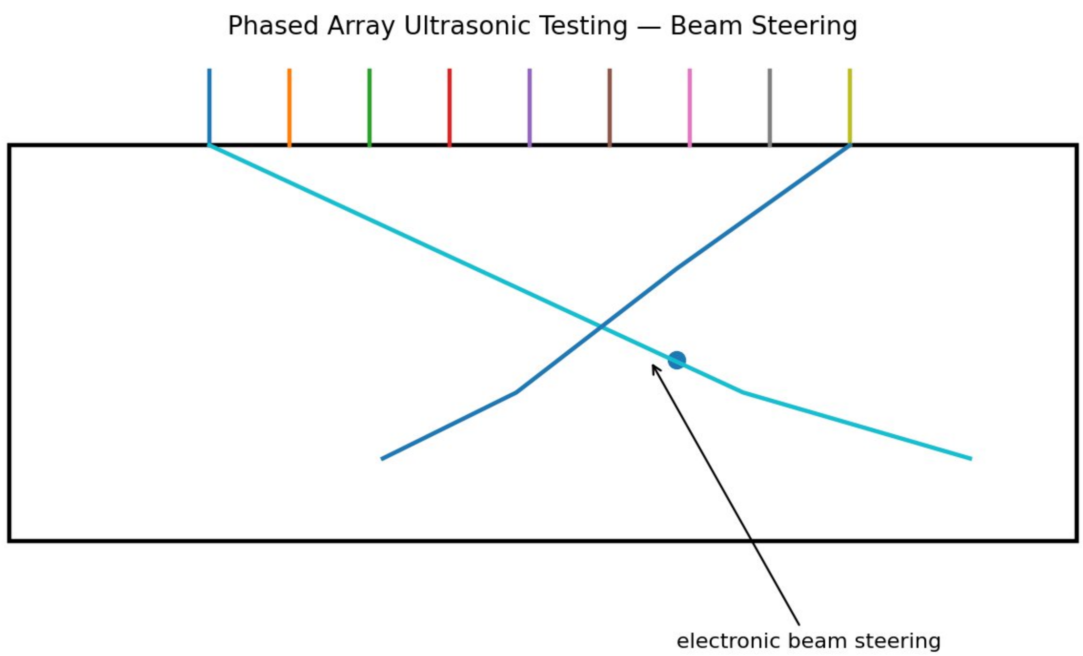
- Results can be sensitive to surface preparation.
- Very thin layers may be influenced by the substrate.
- Interpretation requires careful calibration and analysis.
- Viscoelastic, plastic, porous or time-dependent materials may need specialized analysis.

Real-World Example

A hard protective coating on a machine component may be only a few micrometres thick. A conventional tensile specimen cannot isolate the coating, but nanoindentation can measure localized hardness and modulus while limiting the indentation depth to the coating region.

3. Advanced NDT — Phased Array Ultrasonic Testing (PAUT)

Phased Array Ultrasonic Testing (PAUT) is an advanced ultrasonic method that uses an array of small transducer elements. By controlling the timing of excitation and reception of individual elements, the ultrasonic beam can be electronically steered, focused and shaped.



3.1 Principle
Instead of relying on one fixed ultrasonic beam, PAUT controls multiple elements with programmed time delays. Different delay patterns produce different beam angles and focal positions. The probe can therefore scan a region electronically as well as mechanically.

3.2 Phased Array Probe
- Array elements: multiple small piezoelectric elements arranged in a line or matrix.
- Wedge or coupling arrangement: transfers ultrasound into the component and can provide refraction.
- Pulser/receiver electronics: controls excitation and receives echoes.
- Phased-array instrument: applies time delays and processes signals.
- Display/software: presents A-scan and commonly sectorial or encoded views.

3.3 Beam Steering
If adjacent elements are fired with carefully selected time delays, the resulting wavefront can be tilted. Changing the delay pattern changes the beam angle. This is called electronic beam steering.

3.4 Beam Focusing
Time delays can also be selected so wavefronts converge toward a selected focal point. Focusing can improve sensitivity and resolution within the chosen region.

3.5 Basic PAUT Procedure
11. Define the inspection objective and expected defect types.
Select a suitable phased-array probe and wedge.
Prepare the surface and establish coupling.
Create or load an appropriate focal law.
Calibrate the system using the required reference standard.
Scan the component using the planned coverage pattern.
Record and analyze ultrasonic indications.
Compare results with the applicable acceptance criteria.
Prepare the inspection report.

3.6 Common Display Concepts

A-scan
Amplitude is plotted against time or sound path. It shows echoes along one beam.

Sectorial scan
A set of beam angles is displayed to show coverage over a sector.

Linear scan
The focal position or beam is moved along the component to create a coverage image.

Encoded scan
Probe position is recorded so the inspection response can be mapped spatially.

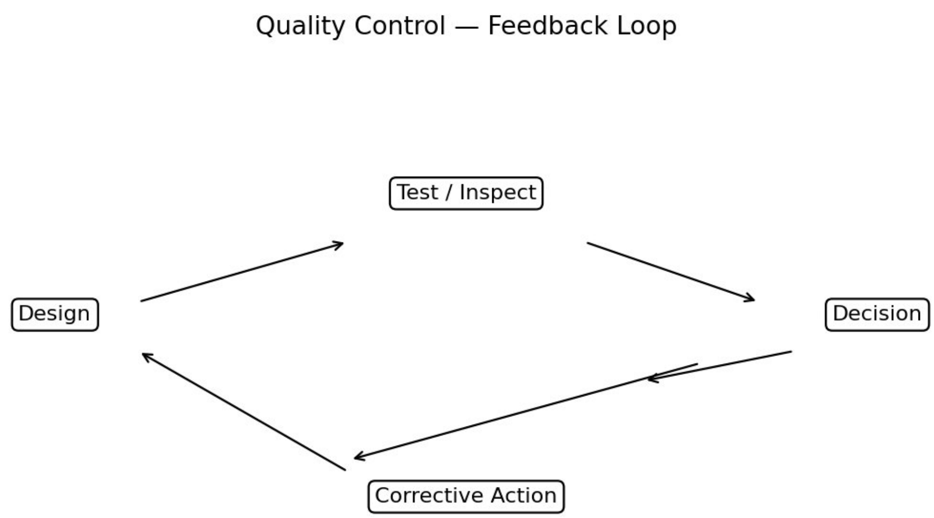
3.7 Advantages
- Electronic beam steering reduces the need for multiple fixed-angle probes in many applications.
- Beam focusing can improve sensitivity in selected regions.
- Large inspection volumes can be represented as imaging data.
- Useful for weld and complex-component inspection.
- Inspection coverage can be planned with multiple focal laws.

3.8 Limitations
- Equipment and probes are more complex than conventional single-element UT.
- Requires qualified setup, calibration and interpretation.
- Geometry, material attenuation and defect orientation affect results.
- Incorrect focal laws or calibration can produce misleading results.

PAUT vs Conventional UT

Feature	Conventional UT	PAUT	Importance
Beam	Usually fixed or manually changed	Electronically steered/focused	Greater coverage flexibility
Probe	Single or limited elements	Multiple elements	More control
Imaging	Often A-scan	Can produce sectorial/encoded views	Better visualization
Setup	Simpler	More complex	Requires training

4. Quality Control (QC) in Material Testing
Quality control is the systematic process of checking materials, processes and products against specified requirements. In material testing, QC converts test data into decisions about acceptance, rejection, process adjustment and corrective action.



4.1 Objectives of Quality Control

- Ensure raw materials meet specifications.
- Detect manufacturing defects early.
- Maintain consistent mechanical and physical properties.
- Reduce scrap, rework and failure costs.
- Support traceability and documentation.
- Protect safety and reliability.
- Provide evidence that products meet applicable specifications.

4.2 Quality Control Workflow

- Define requirements and acceptance criteria.
- Receive and identify material.
- Inspect and test samples.
- Compare results with specifications.
- Accept, reject or investigate.
- Apply corrective action when required.
- Verify effectiveness and maintain records.

4.3 Role of Material Testing in QC

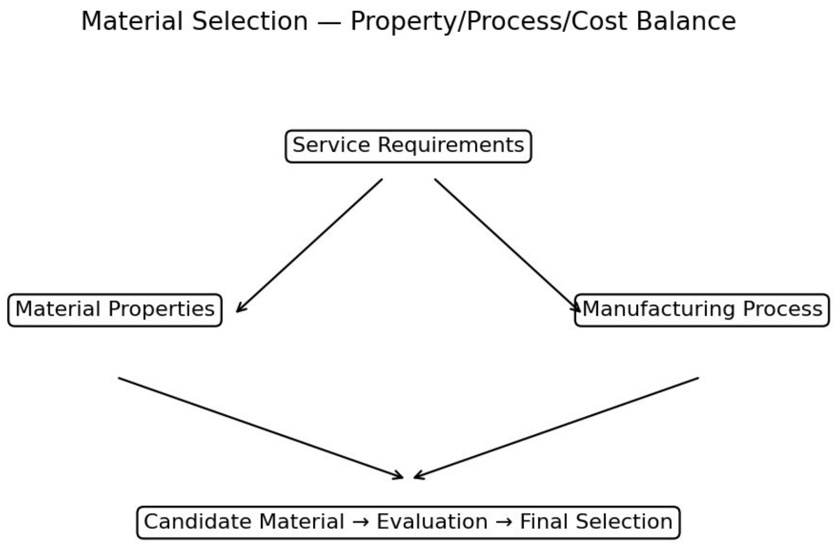
- Tensile tests verify strength and ductility.
- Hardness tests support process and material verification.
- Impact tests evaluate toughness under dynamic loading.
- Fatigue/creep tests support service-life assessment.
- NDT checks components without destroying them.
- Advanced methods such as nanoindentation and PAUT can address localized or complex inspection problems.

4.4 Quality Control vs Quality Assurance

Quality control focuses on inspection, measurement and correction of outputs and processes. Quality assurance is the broader planned system intended to prevent quality problems and ensure that processes consistently meet requirements.

5. Material Selection

Material selection is the systematic choice of a material that can safely and economically perform its intended function under the expected service conditions.



5.1 Important Selection Criteria

- Mechanical properties: strength, stiffness, hardness, toughness, fatigue resistance and creep resistance.
- Physical properties: density, thermal conductivity, electrical conductivity and thermal expansion.
- Chemical/environmental resistance: corrosion, oxidation and chemical compatibility.
- Manufacturability: casting, forging, rolling, machining, welding, forming or additive manufacturing suitability.
- Service temperature and thermal stability.
- Availability and supply reliability.
- Cost over the complete life cycle.
- Safety, reliability and regulatory requirements.
- Sustainability, recyclability and environmental considerations where applicable.

5.2 Material Selection Procedure

1. Define the component function.

Identify service loads and environment.
Establish required properties.
List candidate materials.
Eliminate unsuitable candidates.
Compare performance, manufacturing and cost.
Test or validate the selected material.
Finalize material specification and quality requirements.

5.3 Property Trade-Offs

Material selection rarely maximizes every property simultaneously. For example, increasing hardness may affect toughness; increasing strength may affect ductility; low density may come with higher material or processing cost. The engineer therefore selects a balanced solution.

5.4 Example — Shaft Material

A rotating shaft may require adequate yield strength, fatigue resistance, toughness, wear resistance, machinability and dimensional stability. The final choice should be based on the actual load, environment, manufacturing route, required heat treatment and cost—not on a single property such as hardness.

6. Integration of Advanced Testing with Industrial Decision-Making

- Nanoindentation → local mechanical-property characterization → coating/microstructure assessment.
- PAUT → advanced internal inspection and imaging → weld/component integrity assessment.
- Conventional material tests → bulk properties → specification verification.
- QC → combines inspection results, process data and acceptance criteria.
- Material selection → uses verified property data and service requirements to choose the appropriate material.

7. Industrial Applications

Aerospace

Advanced NDT can support inspection of critical structures and welds, while localized property measurement can help evaluate coatings and small material regions.

Automotive

Nanoindentation can characterize coatings and localized microstructural regions; advanced ultrasonic inspection can support weld/component quality.

Power and energy

Ultrasonic inspection is useful for welds and critical components; material selection must consider temperature, fatigue, creep and corrosion.

Manufacturing

QC integrates dimensional checks, mechanical testing, NDT and material certification to control product quality.

Surface engineering

Nanoindentation is particularly useful for evaluating thin hard coatings where conventional bulk tests are unsuitable.

8. Case Studies

Case Study 1 — Thin Protective Coating

Problem: A coated engineering component requires verification of local hardness without measuring the substrate-dominated bulk property.

Approach: Prepare the surface, perform nanoindentation at controlled depth, examine the load–displacement response and compare hardness/modulus with the coating specification.

Learning: The test must control indentation depth and account for substrate influence.

Case Study 2 — Weld Inspection with PAUT

Problem: A critical welded joint requires volumetric inspection with controlled coverage.

Approach: Define expected defect orientations, select an array probe and suitable focal laws, calibrate using a reference block, scan the weld and evaluate encoded/sectorial indications.

Learning: Probe position, beam angle, calibration and defect orientation are essential to reliable interpretation.

Case Study 3 — Material Selection for a Machine Component

Problem: A component experiences repeated loading, wear and a corrosive environment.

Approach: Translate service conditions into property requirements, shortlist candidate materials, compare fatigue/toughness/hardness/corrosion performance, check manufacturability and cost, and validate the final choice by testing.

Learning: Material selection is a multi-criteria engineering decision, not simply a search for the strongest material.

9. Important Formulae and Concepts

- Nanoindentation hardness: H = Pmax / A.
- Load–displacement curve: loading gives increasing penetration with load; unloading provides contact-stiffness information.
- PAUT focal law: a programmed set of element time delays used to steer/focus the ultrasonic beam.
- QC: specification → measurement → comparison → decision → corrective action → verification.
- Material selection: service requirement → required properties → candidates → manufacturing/cost evaluation → validation → final selection.

10. Advantages and Limitations — Quick Revision

Technique	Advantages	Limitations
Nanoindentation	Localized properties; tiny volumes; thin films/coatings	Sensitive to surface, substrate, calibration and analysis
PAUT	Beam steering/focusing; imaging; broad coverage	Complex setup; calibration and operator skill
Quality Control	Consistency, defect reduction, traceability	Requires standards, reliable measurements and process discipline
Material Selection	Balances performance, manufacturing and cost	Trade-offs and incomplete data can complicate decisions

11. Short Questions

1. Define nanoindentation.
2. State the basic principle of nanoindentation.
3. What is an indenter?
4. What is a load–displacement curve?
5. Define indentation hardness.
6. What is contact stiffness?
7. Mention two applications of nanoindentation.
8. Why is surface preparation important in nanoindentation?
9. What is substrate effect?
10. State two limitations of nanoindentation.
11. Define phased-array ultrasonic testing.
12. What is a phased-array probe?
13. What is beam steering?
14. What is beam focusing?
15. What is a focal law?
16. What is an A-scan?
17. What is a sectorial scan?
18. State two advantages of PAUT.
19. State two limitations of PAUT.
20. Why is calibration necessary in PAUT?
21. Define quality control.
22. State four objectives of quality control.
23. What is an acceptance criterion?
24. Differentiate quality control and quality assurance.
25. What is traceability?
26. What is material selection?

27. List six factors considered in material selection.
28. Why is service environment important?
29. Why is manufacturability considered?
30. Why should life-cycle cost be considered?
31. How can material testing support quality control?
32. How can NDT support quality control?
33. Give one industrial application of nanoindentation.
34. Give one industrial application of PAUT.
35. Why is material selection a trade-off problem.

12. Long Questions

1. Explain nanoindentation with principle, schematic diagram, components, test cycle, load–displacement curve, hardness, indentation modulus, advantages and limitations.
2. Explain the working principle of nanoindentation and discuss the factors affecting the accuracy of nanoindentation results.
3. Explain Phased Array Ultrasonic Testing (PAUT) with a neat diagram. Discuss array elements, beam steering, beam focusing, focal laws and inspection procedure.
4. Compare conventional ultrasonic testing and phased-array ultrasonic testing.
5. Explain the important display concepts in PAUT, including A-scan and sectorial scanning.
6. Explain quality control in material testing. Discuss objectives, workflow, testing role, acceptance criteria, traceability and corrective action.
7. Explain material selection and discuss mechanical, physical, environmental, manufacturing, economic and safety criteria.
8. Describe a systematic procedure for selecting a material for an engineering component.
9. Discuss the integration of nanoindentation, PAUT and conventional material testing in industrial quality control.
10. Write detailed case studies showing how advanced testing techniques can support aerospace, automotive or manufacturing applications.

13. Viva Questions

- Why is nanoindentation useful for thin coatings?
- Why must indentation depth be controlled?
- What does the unloading curve provide?
- What is substrate effect?
- Why are multiple indentations sometimes required?
- What is the purpose of phased-array elements?
- How does electronic beam steering work?
- What is a focal law?
- Why is PAUT calibration important?
- What is the difference between A-scan and sectorial imaging?
- What is quality control?
- Why are acceptance criteria needed?
- What is traceability?
- Why is material selection not based only on strength?
- Why should manufacturing process be considered during material selection?