Course: Concrete Technology

Lecture 7: Hardened Concrete Properties

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Session Objectives

- Study hardened concrete properties and performance factors
- Analyze strength development mechanisms and material interactions
- Review standardized testing methods and procedures
- Evaluate durability, permeability, and long-term behavior

Content

- Study hardened concrete properties: mechanical, physical, and durability aspects
- Analyze strength development: paste hydration, aggregates, and interface behavior
- Review key factors: w/cm ratio, materials, admixtures, curing, and age
- Examine testing methods and durability, including predictive tools and evaluation techniques

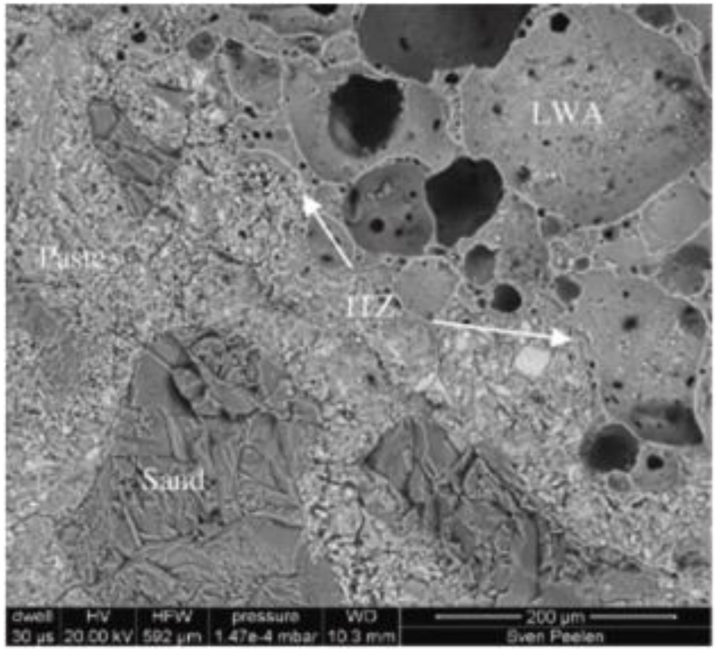
Concrete States and Performance

- Hardened concrete behavior depends on mechanical, thermal, electrical, acoustic, and visual properties
- Performance governed by paste strength, aggregates, and interfacial transition zone
- Strength refers to resistance to compression, tension, flexure, and shear
- Classified by compressive strength: normal (<42 MPa), high (42–100 MPa), ultra-high (>100 MPa)

Strength Development

Cement Hydration and Strength Development

- Strength originates from cement hydration process
- C-S-H gel formation strengthens hardened paste
- Capillary pores enable continued hydration reactions
- Hydration reduces porosity, increases strength



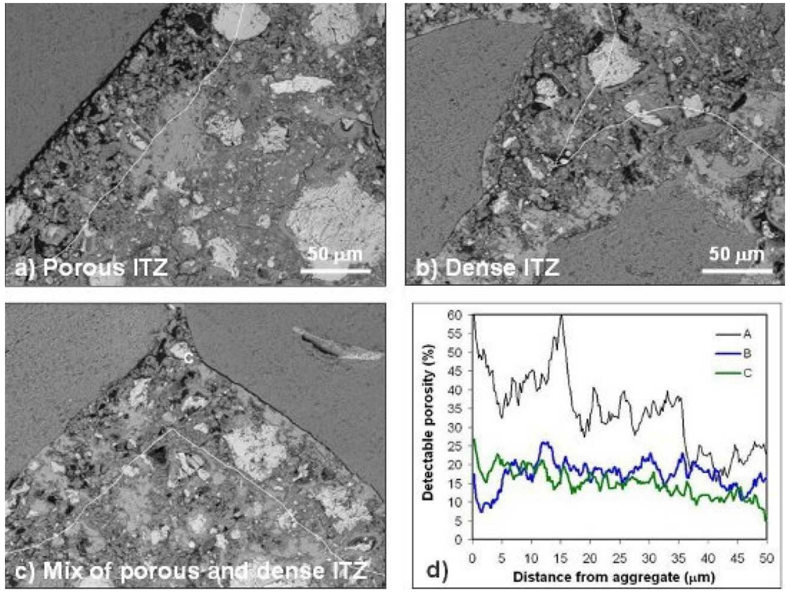
SEM image of the light-weight composite Source: Yu et al. (2013)

Aggregate Contribution to Strength

- Aggregate contribution to strength depends on intrinsic properties such as strength, shape, and texture.
- These characteristics remain constant over time and are independent of hydration processes.
- Typically, aggregates are stronger than hardened cement paste under normal conditions.
- Exceptions occur in lightweight aggregates or very high-strength concrete mixtures.
- In such cases, paste strength may equal or exceed aggregate mechanical resistance.

Interfacial Transition Zone Importance

- Interface bond ensures internal concrete cohesion
- Transition zone is weakest concrete region
- Failure typically initiates at interface zone
- Aggregate–paste interaction controls structural performance

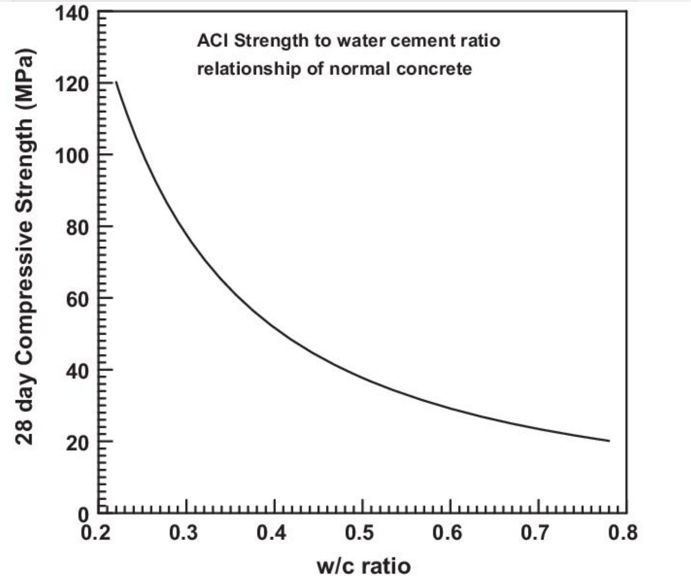


Porosity distribution plot showing three different ITZ morphologies
Source: Imperial College London. (n.d.)

Key Factors

Water–Cement Ratio and Strength

- Strength inversely proportional to water–cement ratio
- Excess water increases porosity, reduces strength
- Abrams' law defines strength relationship
- Low ratios require proper compaction techniques



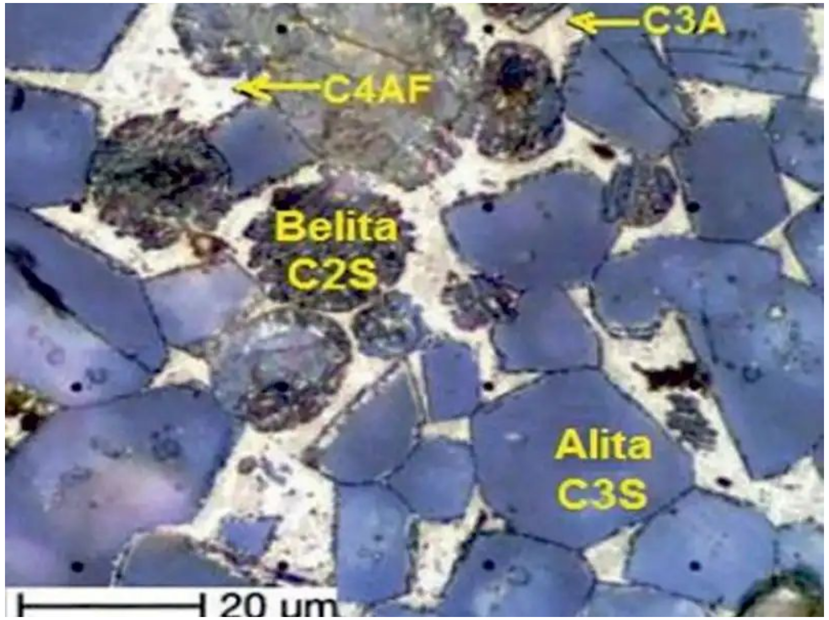
Source: Dinakar, P., & Nadesan, M. S. (2014)

Cement Content and Type Effects

- Increasing cement content generally increases strength if water–cement ratio remains constant.
- Cement is the primary reactive component responsible for strength development in concrete.
- However, excessive cement content may lead to incomplete hydration at low water ratios.
- Unhydrated cement behaves as inert filler without contributing to mechanical strength.
- High cement contents may induce shrinkage stresses, causing microcracking and bond loss.

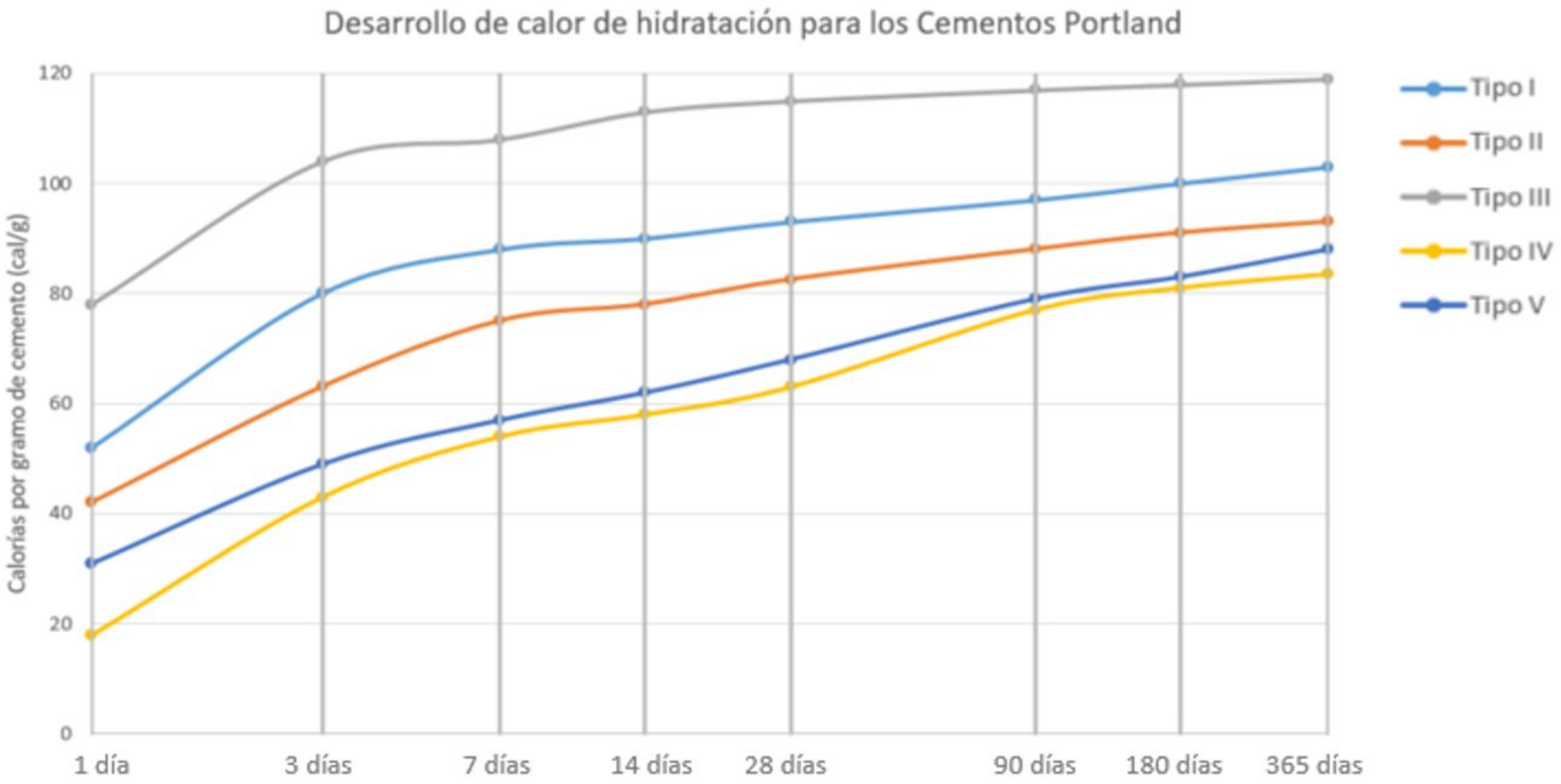
Cement Composition and Strength Development

- Cement phases control mechanical behavior
- Alite and belite influence strength evolution
- Type III cement gains early strength rapidly
- Type IV cement improves long-term strength



Micrograph of cement phases Source: NBM Media Pvt Ltd. (n.d.).

Strength Gain and Heat of Hydration



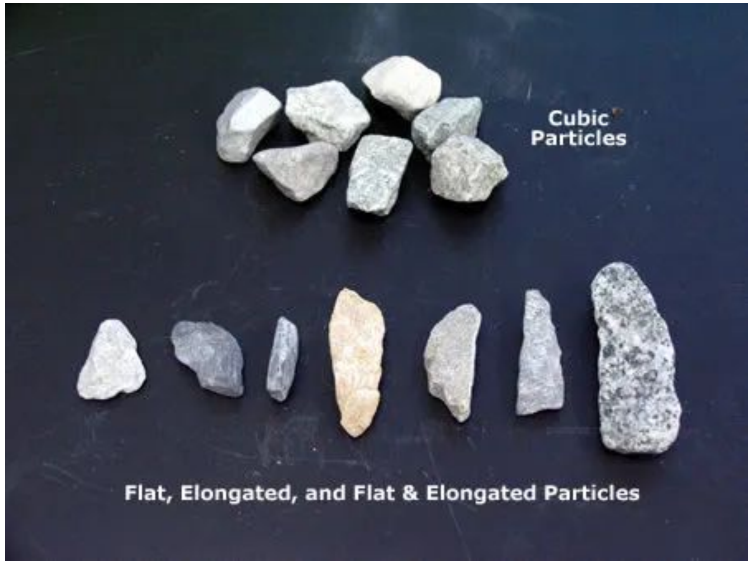
Source: Pasquel. (1998)

Aggregate Characteristics and Strength

- Aggregate characteristics significantly influence concrete strength and mechanical performance.
- Key properties include shape, surface texture, gradation, and intrinsic strength.
- Angular and rough aggregates improve bonding and mechanical interlock with paste.
- These characteristics enhance strength compared to smooth and rounded aggregates.
- However, they typically require more water to maintain adequate workability.

Aggregate Shape and Texture Effects

- Shape influences workability and strength
- Rounded aggregates reduce mechanical interlock
- Rough texture increases water absorption
- Texture impacts mix design and performance



Aggregates of different shape. Source: CivilBlog. (2014)

Aggregate Gradation and Strength

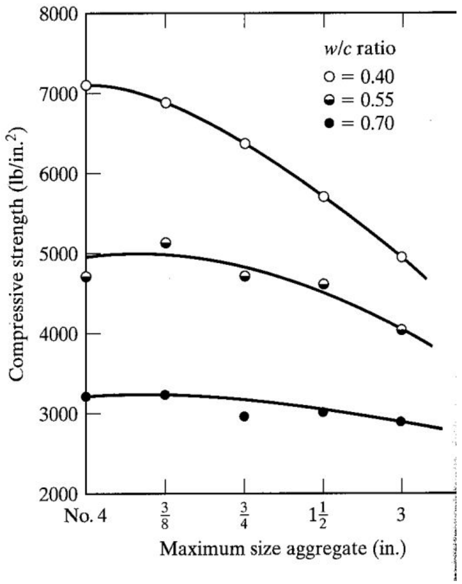
- Proper aggregate gradation ensures balanced distribution of particle sizes within the mixture.
- Continuous grading improves packing density and reduces internal void content.
- This leads to better cohesion and overall mixture stability.
- Adequate gradation prevents segregation during handling and placement processes.
- Denser mixtures generally result in improved mechanical strength and durability.

Aggregate Strength and Durability

- Aggregate strength directly contributes to the overall strength of concrete material.
- Dense, strong aggregates enhance compressive strength and structural performance.
- Hardness and toughness are critical for resisting wear and mechanical degradation.
- Durable aggregates maintain integrity under abrasion and service conditions.
- These properties improve long-term performance and durability of concrete structures.

Maximum Aggregate Size Effects

- Larger aggregates reduce water demand
- Larger size may reduce compressive strength
- High-strength concrete uses smaller aggregates
- Size selection depends on strength requirements



Effect of maximum size of aggregate on compressive strength
Source: Cordon and Gillespie (1963)

Admixtures: Positive Effects

- Admixtures significantly influence concrete strength depending on type and dosage used.
- Water-reducing admixtures improve workability without increasing water content in mixtures.
- Accelerating admixtures promote early strength development and faster construction processes.
- Admixtures can modify setting time to suit specific project requirements.
- Lower water–cement ratios achieved through admixtures enhance mechanical strength development.

Admixtures: Negative Effects

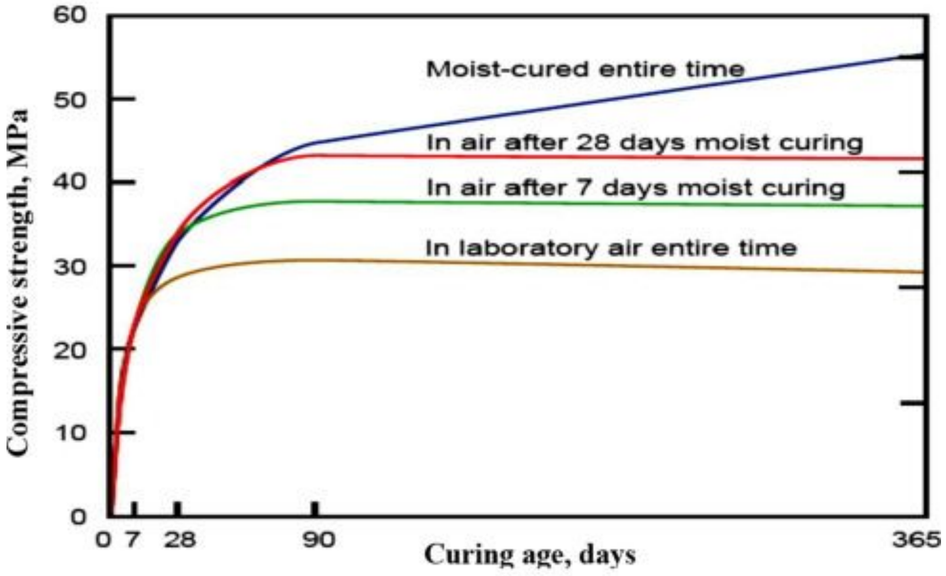
- Improper use of admixtures can negatively affect concrete strength and durability.
- Early strength gain may reduce long-term strength performance in some cases.
- Overdosing admixtures can significantly reduce workability and mixture stability.
- Excessive shrinkage and internal stresses may lead to cracking and durability issues.
- Strict adherence to manufacturer recommendations and testing is essential for proper performance.

Setting Process and Temperature

- Concrete setting behavior is strongly influenced by environmental temperature conditions.
- Cold climates delay hydration and may prevent proper setting below approximately 4°C.
- Slow setting reduces early strength development and may compromise performance.
- Hot climates accelerate hydration, increasing early strength gain significantly.
- However, rapid hydration leads to more porous microstructures and reduced long-term strength.

Importance of Concrete Curing

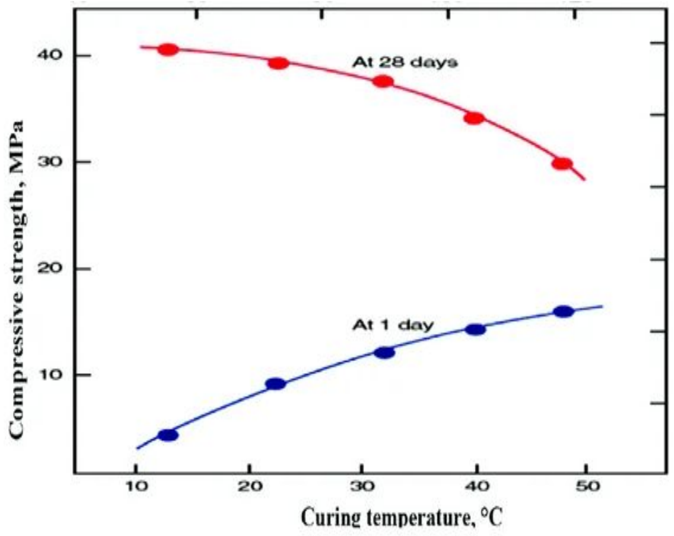
- Curing maintains moisture during hardening
- Prevents premature drying of concrete
- Ensures continued cement hydration process
- Minimum curing ensures adequate strength



Effect of moist curing time on strength of concrete.
Source: Kosmatka et al. (2002).

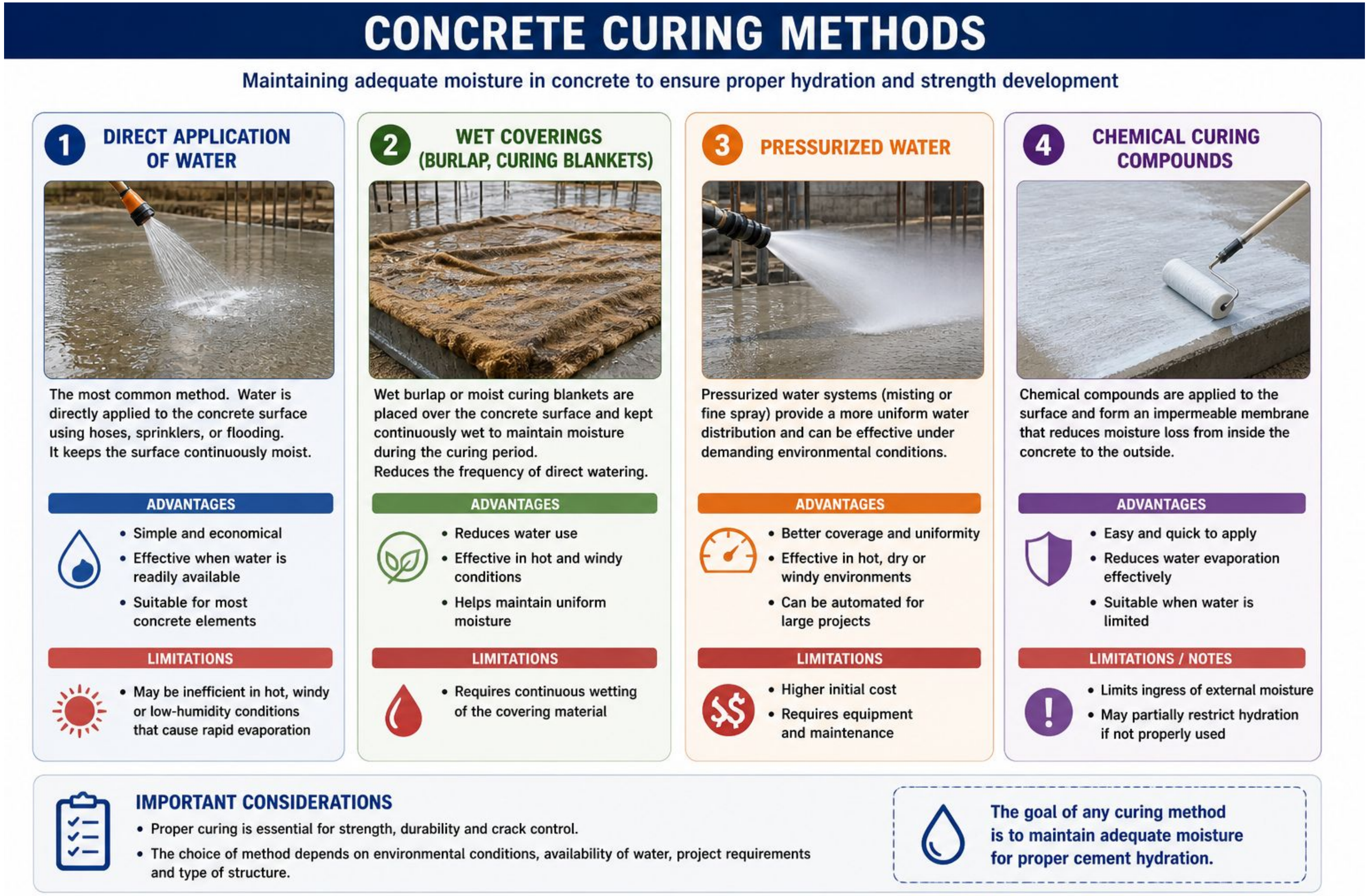
Temperature Effects During Curing

- High temperature accelerates hydration reactions
- Early strength increases with higher temperatures
- Excess heat reduces long-term strength
- Poor curing prevents full strength development



Effect of curing temperature on strength of concrete.
Source: Kosmatka et al. (2002).

Concrete Curing Methods



Source: OpenAI. (2026)

Quality Control in Curing Materials

- Quality of curing water and materials must be carefully evaluated before application.
- Ponding methods require knowledge of chemical composition of water and retaining materials.
- Harmful agents may penetrate concrete at early ages if not properly controlled.
- Such ingress can compromise durability and long-term performance of concrete structures.
- Material control during curing is essential for quality assurance in construction processes.

Age and Strength Development

- Concrete strength increases progressively with age after initial setting occurs.
- Design compressive strength is typically achieved at 28 days for conventional concrete.
- Strength continues increasing beyond 28 days if proper moisture conditions are maintained.
- High-strength concretes may reach full strength at 56 or even 90 days.
- Aging improves density and durability while reducing permeability, though shrinkage may occur.

Testing Methods and Durability

Specimen Preparation Standards

- Specimens prepared under ASTM standards
- Samples taken from field and laboratory
- Tested at predefined curing ages
- Laboratory results define acceptance criteria

Source: HP Engineering. (2024)

Field vs Laboratory Specimens

- Field-cured specimens are used to determine formwork removal or service timing.
- They simulate actual structure conditions in temperature, humidity, and protection.
- These specimens are not suitable for determining mechanical properties of concrete.
- Mechanical properties must be evaluated under controlled laboratory curing conditions.
- Laboratory conditions ensure reproducibility and reliability of strength test results.

Sampling Equipment and Materials

- Sampling requires cylindrical molds, typically PVC or metal, for specimen preparation.
- A tamping rod with specified dimensions is used for proper compaction.
- Additional tools include mallet, scoop, strike-off bar, and finishing trowel.
- Mold interiors must be coated with release agent before casting concrete.
- Proper equipment ensures consistent specimen quality and accurate test results.

Specimen Molding Procedure

- Concrete placed in three equal layers
- Each layer compacted with 25 strokes
- Rubber mallet removes entrapped air
- Surface finished and specimen covered

Source: The Constructor. (n.d.)

Demolding and Curing Process

- Demolding depends on mold type, either metallic or plastic materials.
- Metallic molds are opened mechanically, sometimes leaving surface imperfections.
- Plastic molds require compressed air for specimen extraction.
- Demolding must occur within 24 ± 8 hours after casting.
- Specimens are then placed in lime-saturated water for controlled curing.

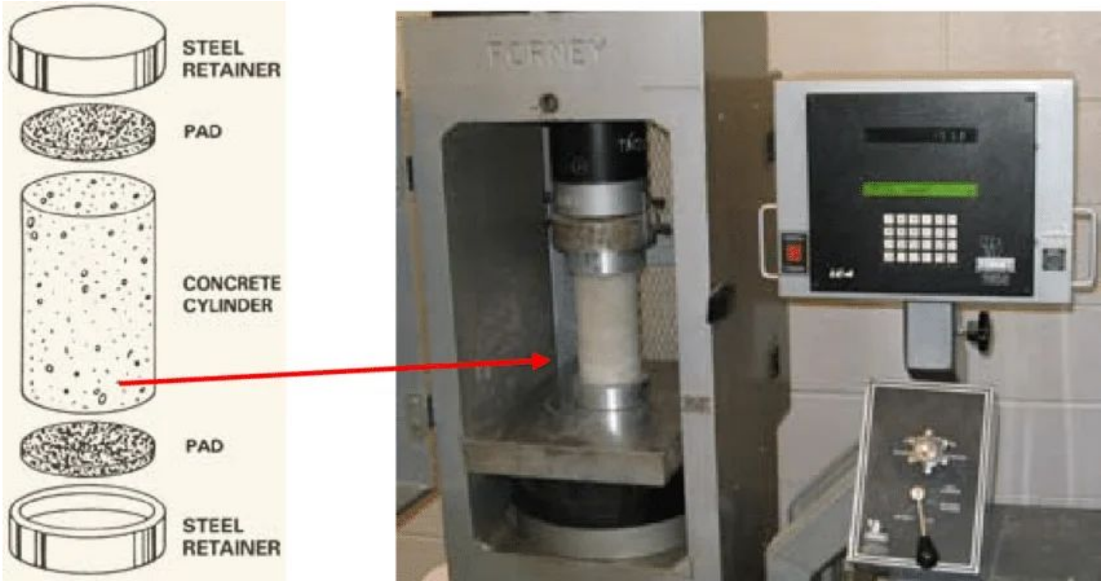
4" x 8" Specimen Procedure Variations

- Use three specimens per test age
- Two layers instead of three
- Smaller diameter tamping rod required
- Apply strokes and external mallet blows

Source: U.S. Department of Transportation.. (n.d.)

Compressive Strength Test

- Test follows ASTM C39 standard
- Use hydraulic compression testing machine
- Measure diameter for area calculation
- Neoprene pads ensure uniform load distribution

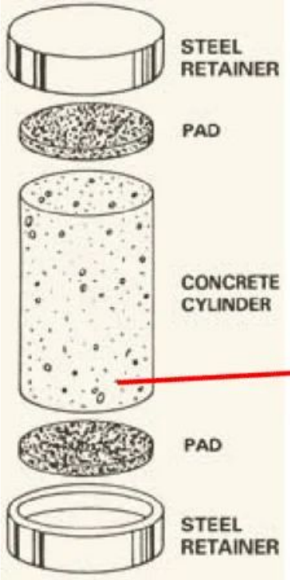


Compression test configuration (concrete cylinder).
Source: ASTM International.. (n.d.)

Compressive Strength Test

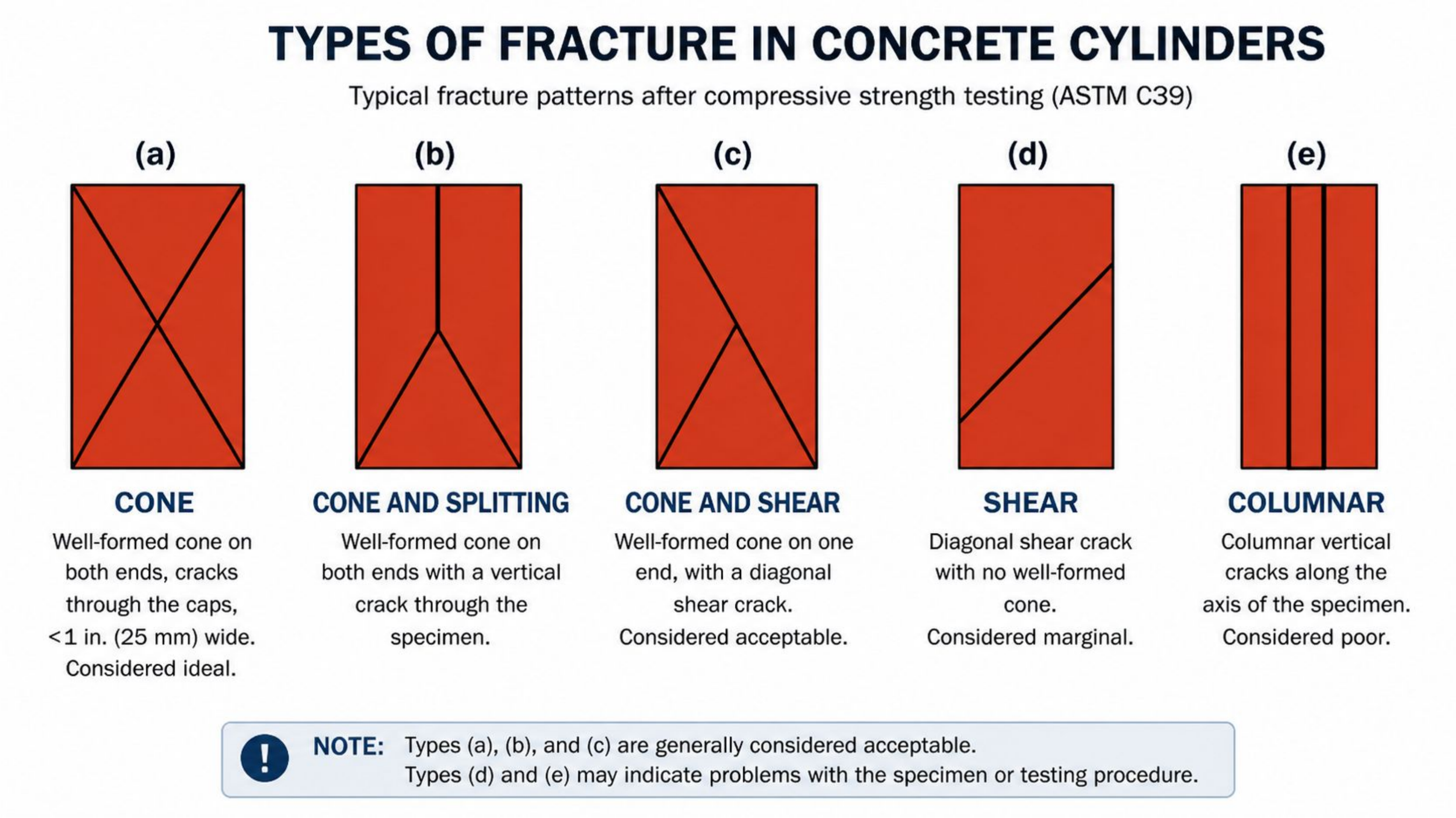
- Specimens removed at specified testing ages
- Surface-dry, label, measure average diameter
- Apply axial load at controlled rate
- Verify strength using actual specimen area

$$f'_c = \frac{P}{A}$$



Compression test configuration (concrete cylinder).
Source: ASTM International.. (n.d.)

Fracture Type Evaluation



Source: Pasquel. (1998)

Testing Age and Tolerances

- Testing age affects strength development
- Standards define allowable time tolerances
- Accurate molding time must be recorded
- Ensures representative strength evaluation

AGE OF TESTING AND PERMISSIBLE TOLERANCE

AGE OF TEST	PERMISSIBLE TOLERANCE
1 day	± 0.5 hr
3 days	± 2 hr
7 days	± 6 hr
28 days	± 20 hr
90 days	± 2 days

Source: Author’s own ellaboration

Variability and Acceptance Criteria

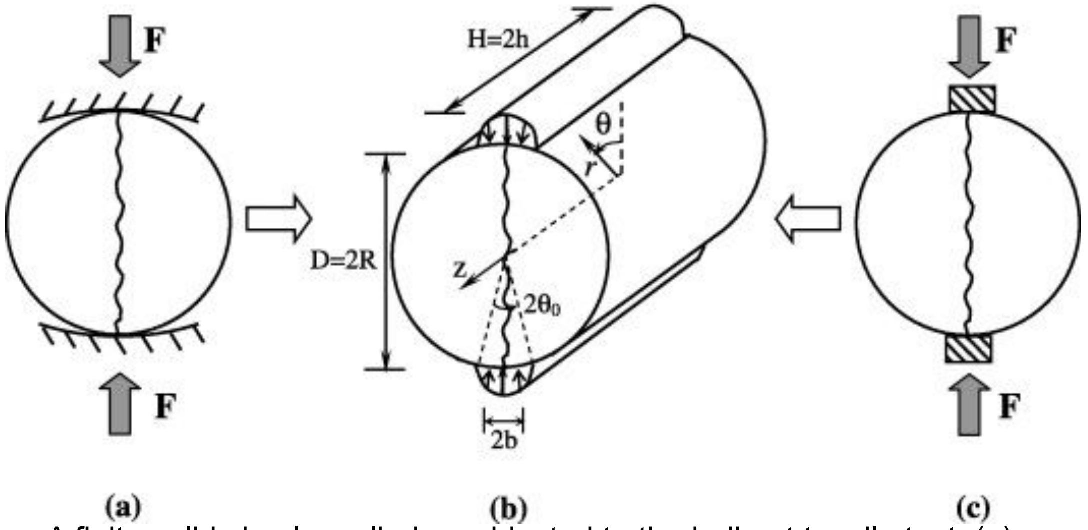
Source: OpenAI. (2026)

Factors Affecting Test Results

- Multiple variables influence concrete behavior throughout its entire lifecycle.
- Improper sampling leads to non-representative and unreliable test results.
- Errors in molding, curing, or transport introduce significant variability.
- Incorrect testing procedures affect accuracy of measured strength values.
- Skilled personnel and calibrated equipment are essential for reliable evaluation.

Indirect Tensile Strength Test

- Direct tensile testing is difficult
- Brazilian test measures indirect tension
- Load applied along cylinder diameter
- Tensile strength from standard equation

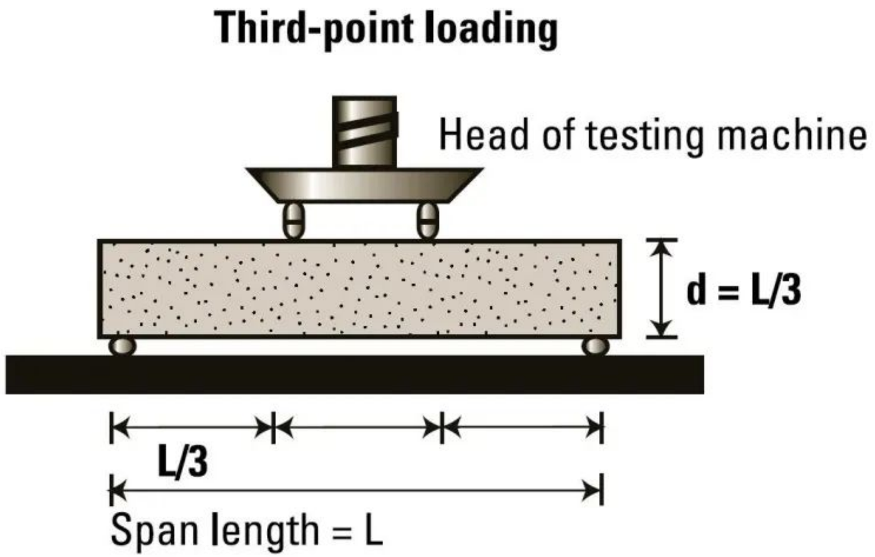


A finite solid circular cylinder subjected to the indirect tensile test: (a) ISRM Brazilian test; (b) Mathematical model; and (c) ASTM test..
Source: Mindess, Sidney, Young, J. Francis, & Darwin, David. (2013)

$$f_{ct} = \frac{2P}{\pi LD}$$

Flexural Strength Test

- Evaluates modulus of rupture
- Beam tested under controlled loading
- Failure location determines calculation method
- Rough aggregates increase flexural strength



Source: CivilBlog. (2015)

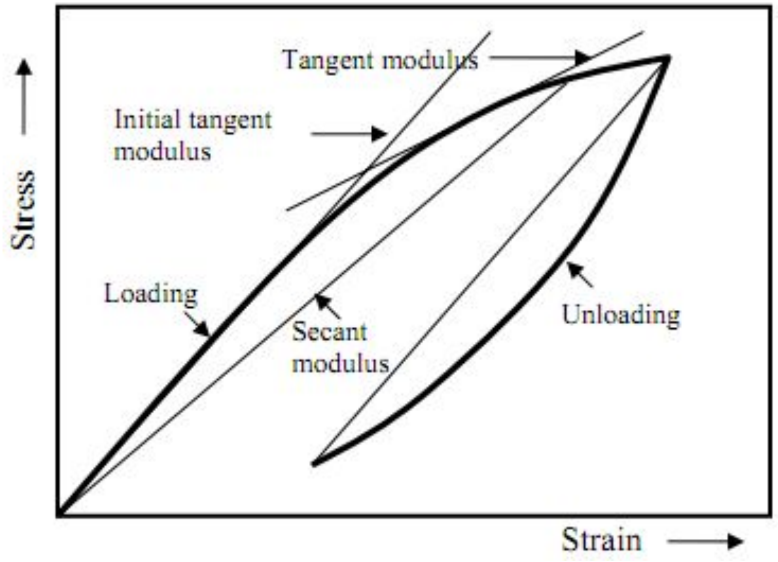
$$FR = \frac{PL}{bd^2}$$

Shear Strength Considerations

- No standardized method exists for direct and reliable measurement of concrete shear strength.
- Tests using short beams produce combined stress states, complicating pure shear evaluation.
- Simultaneous tensile and compressive stresses make interpretation of results difficult.
- Reported shear strength values vary widely depending on testing conditions and assumptions.
- Engineers rely on empirical models and design codes instead of direct testing.

Elastic Modulus and Poisson's Ratio

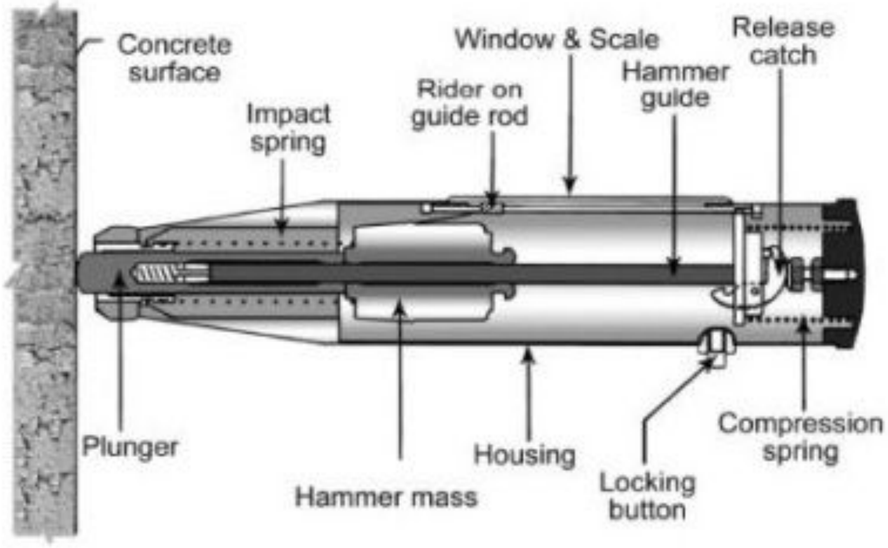
- Determined following ASTM C469
- Measures longitudinal and transverse strains
- Secant modulus based on stress–strain curve
- Initial tangent modulus estimated indirectly



Stress–strain diagram for concrete under loading and unloading. Source: Vikram Anand. (2017)

Non-Destructive Testing Methods - Rebound Hammer test

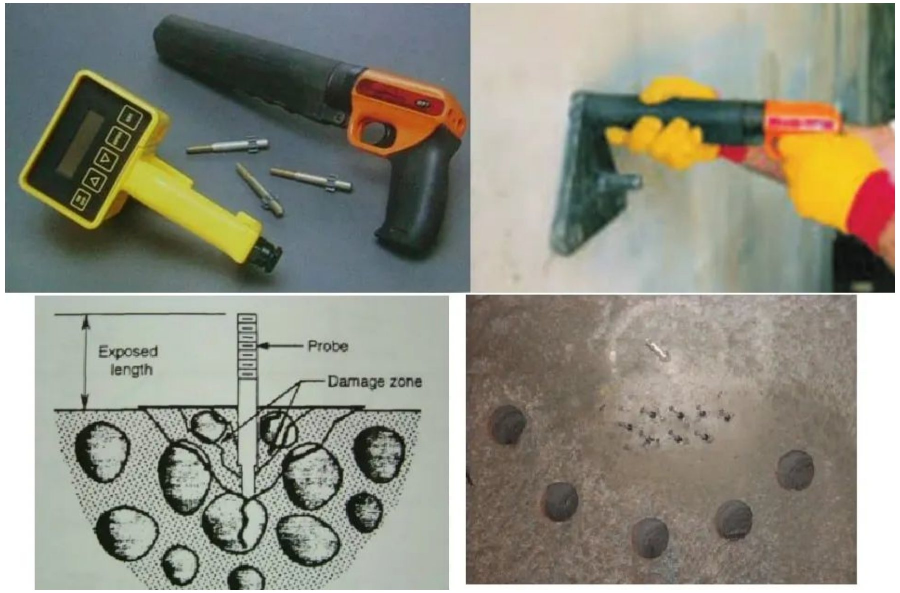
- Evaluate concrete without structural damage
- Estimate strength and uniformity indirectly
- Includes rebound, penetration, vibration techniques
- Results affected by surface and conditions



Source: Eurofins. (n.d.)

Penetration Resistance Test

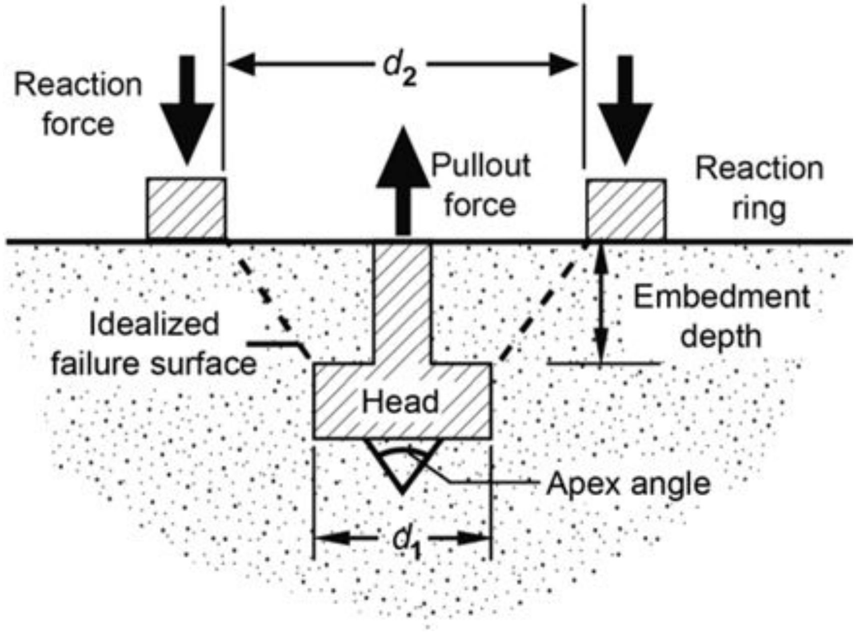
- Windsor method estimates concrete strength
- Steel probe driven into concrete
- Penetration depth correlates with strength
- Provides rapid field comparative results



Source: The Constructor. (n.d.)

Pull-Out Test Method

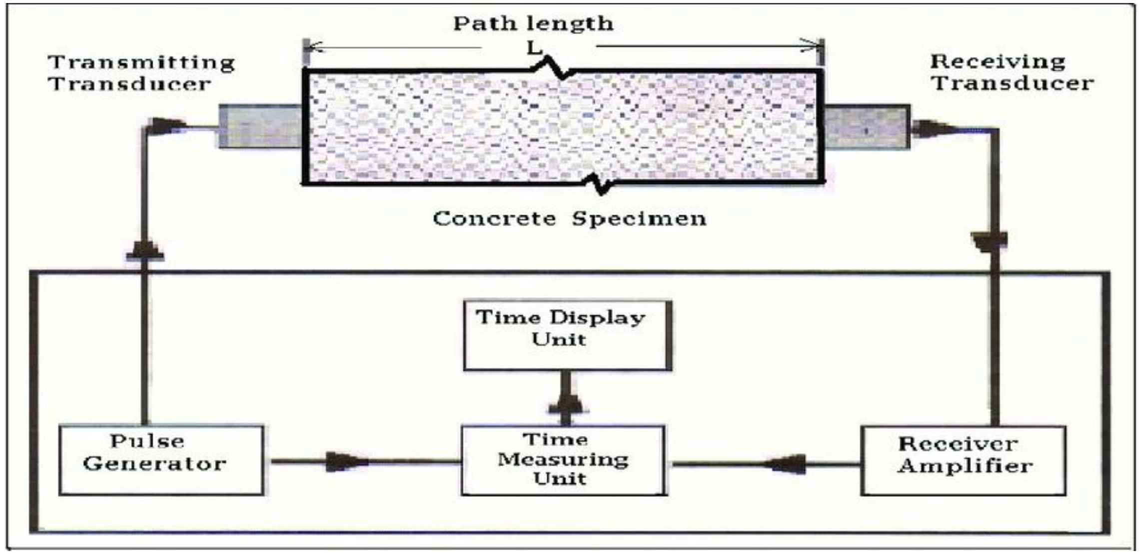
- Steel insert embedded into concrete
- Force required for extraction measured
- Correlates with shear and compressive strength
- Useful for existing structure evaluation



Source: Amphora Consulting. (n.d.)

Ultrasonic Pulse Velocity Test

- Measures ultrasonic wave propagation velocity
- High velocity indicates dense concrete
- Low velocity suggests internal defects
- Assesses uniformity without damaging structure



Schematic Diagram of Ultrasonic Pulse Velocity Test..
Source: Rao, K. J. (2018)

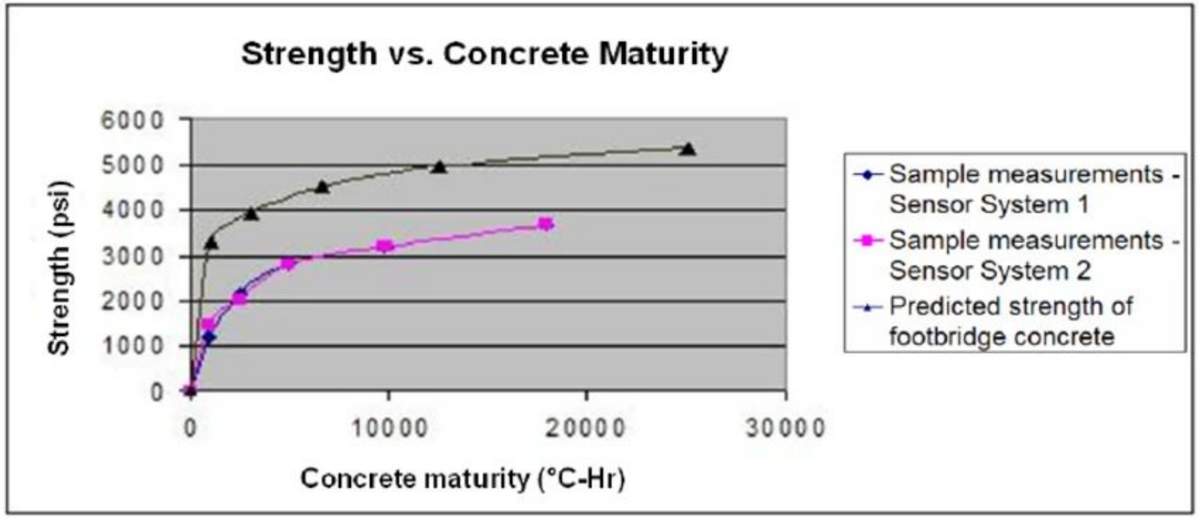
Core Extraction Test

- Direct evaluation of in-situ strength
- Used when specimen results are doubtful
- Cores tested under compression
- Results affected by extraction conditions

Source: Hilti Corporation. (n.d.)

Maturity Method

- Strength depends on time and temperature
- Maturity integrates curing conditions
- Equal maturity yields similar strengths
- Nurse–Saul equation commonly applied



Source: Carino, Nicholas J.. (n.d.).

$$M = \sum (T - T_0) \cdot \Delta t$$

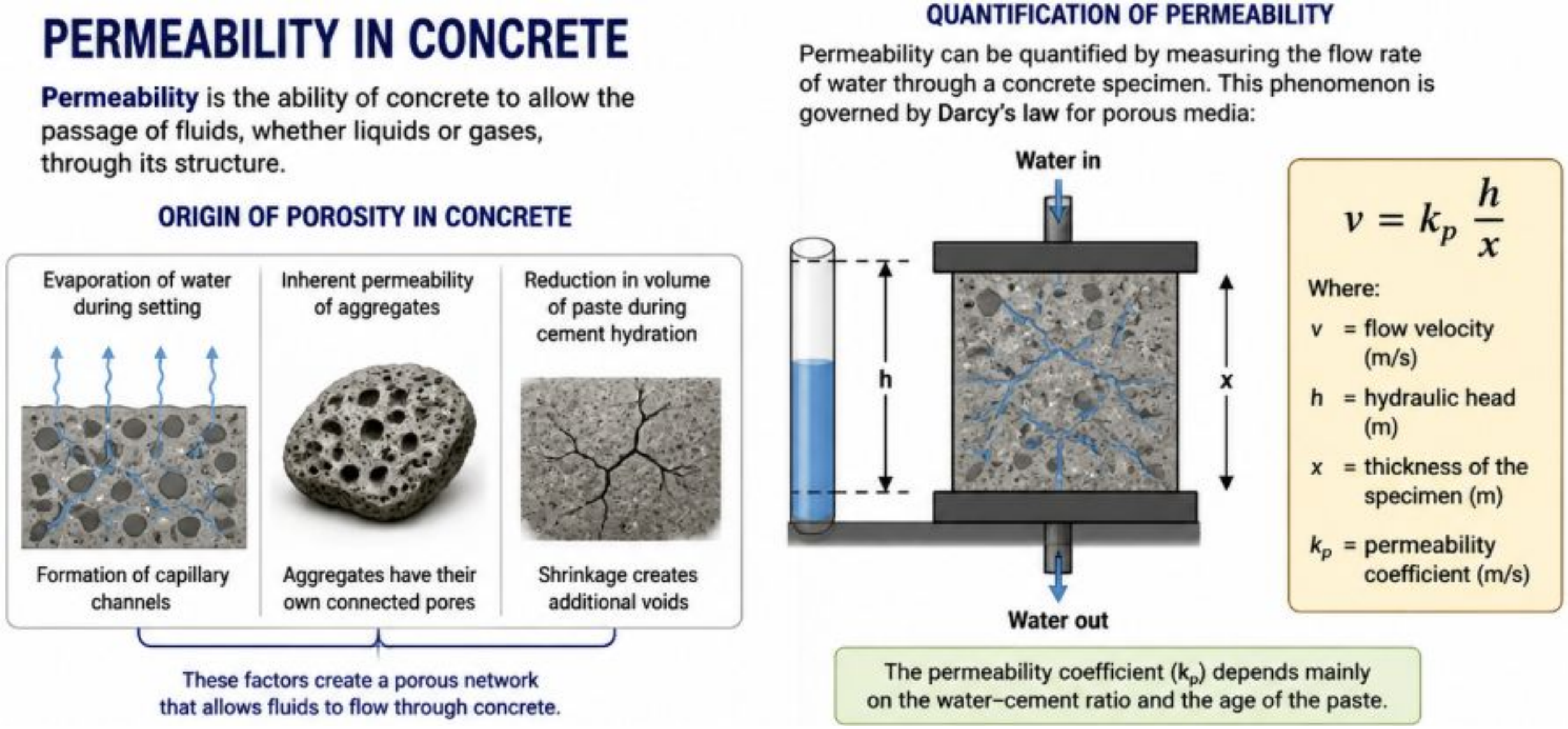
Unit Weight of Concrete

- Unit weight is defined as mass excluding evaporable water from concrete mixture.
- Remaining water includes chemically bound and non-evaporable retained moisture.
- Evaporable water represents approximately 2.5% of total concrete mass.
- Concrete is classified as lightweight, normal-weight, or heavyweight based on density.
- Unit weight mainly depends on aggregate type and composition used.

Concrete Durability Concept

- Durability is ability of concrete to resist environmental and service conditions over time.
- Includes resistance to chemical attack, abrasion, and weathering effects.
- Durability is as important as mechanical strength in structural design.
- Concrete can deteriorate if exposure conditions are not properly considered.
- Proper design must account for environmental conditions and loading scenarios.

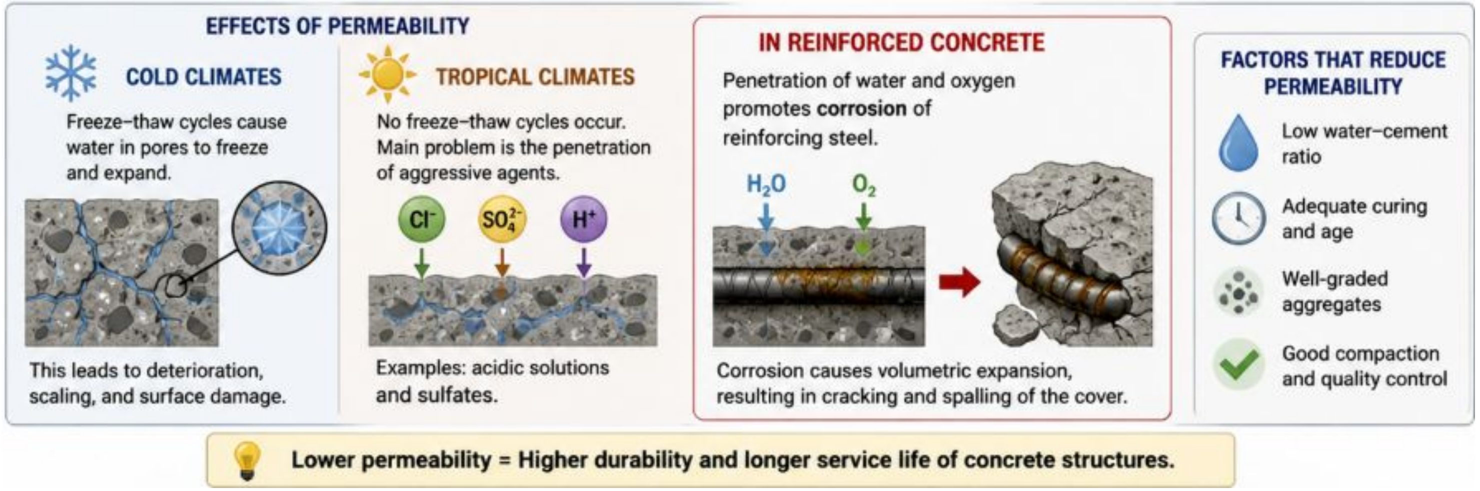
Concrete Permeability



Source: OpenAI. (2026)

Reducing Permeability for Durability

- Reduce permeability for aggressive exposure durability
- Depends on pressure, porosity, exposure duration
- Low water–cement ratio reduces pore connectivity
- Curing, gradation, treatments improve impermeability



Source: OpenAI. (2026)

Conclusions

- Performance depends on multiple interrelated properties, not only compressive strength alone
- Strength governed by paste quality, aggregates, and interfacial transition zone characteristics
- Proper curing ensures hydration continuity, reducing porosity and improving strength and durability
- Durability requires permeability control and proper design against environmental and chemical exposure

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Course: Concrete Technology

Lecture 7: Hardened Concrete Properties

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