Course: Concrete Technology

Lecture 3: Aggregates: Classification and Properties

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Session Objectives

- Analyze physical, chemical, and mechanical properties of aggregates
- Understand influence on:
  - Fresh concrete behavior (workability)
  - Hardened concrete (strength, durability, density)
- Review standards and laboratory testing methods:
  - Gradation, specific gravity, absorption, abrasion, fines
- Develop practical skills:
  - Proper execution of tests (ASTM)

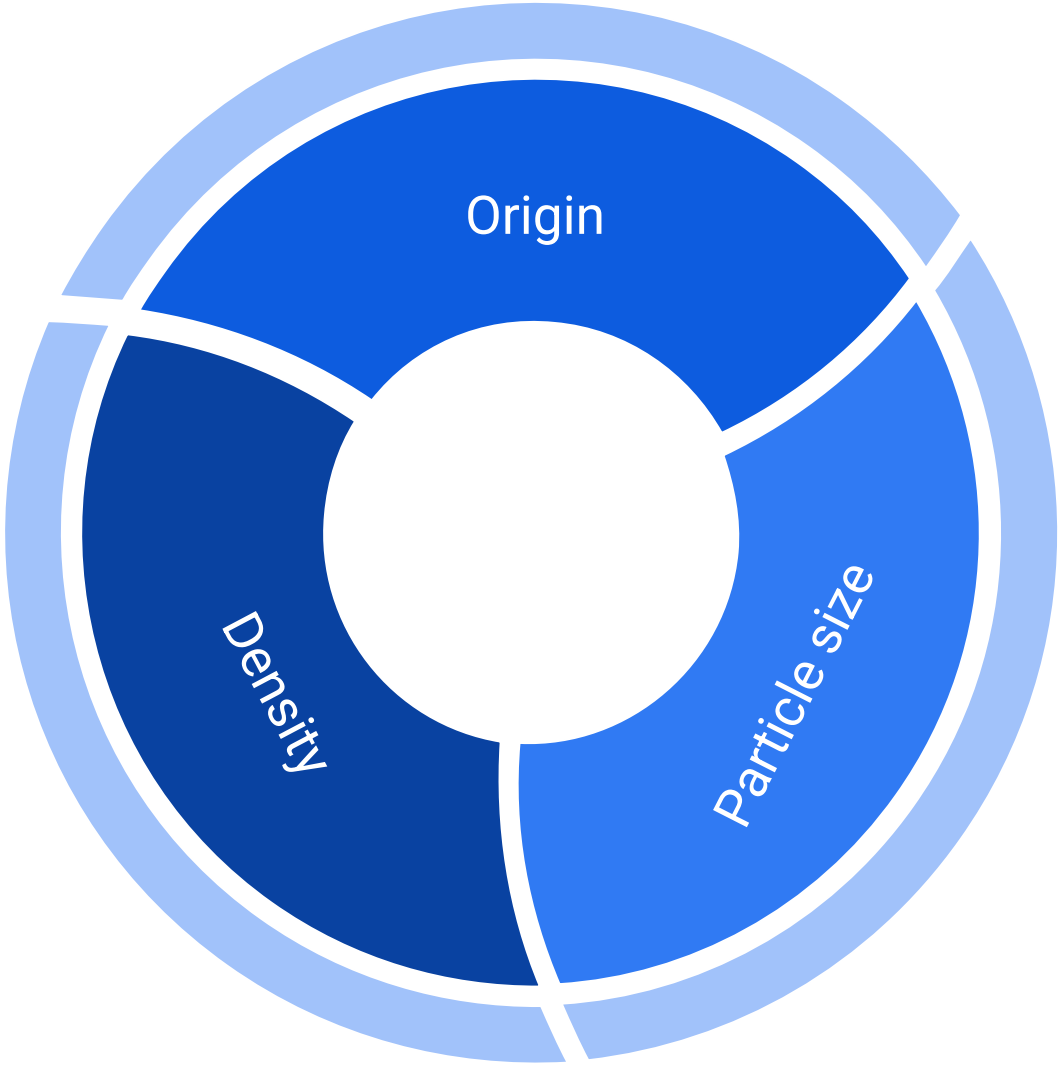
Content

- Introduction to quarry operations:
  - Extraction principles
  - Site selection criteria (technical, economic, environmental)
- Study of aggregate properties:
  - Mechanical: strength, hardness, abrasion
  - Physical: density, absorption, shape, texture
  - Chemical: reactivity, durability
- Quality assurance & control:
  - Laboratory testing importance
  - Key parameters linked to concrete performance

Aggregate Classification

Aggregate Classification

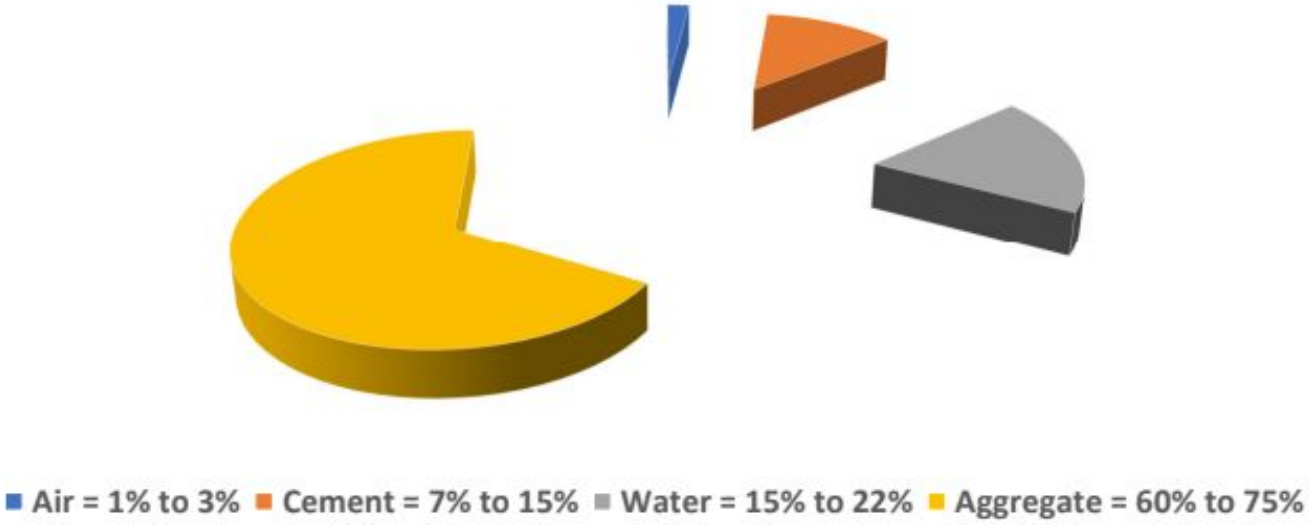
- Multiple classification criteria exist
- Focus on three main criteria:
  - Origin
  - Particle size (gradation)
  - Density (specific gravity)



Source: Author´s own elaboration

Importance

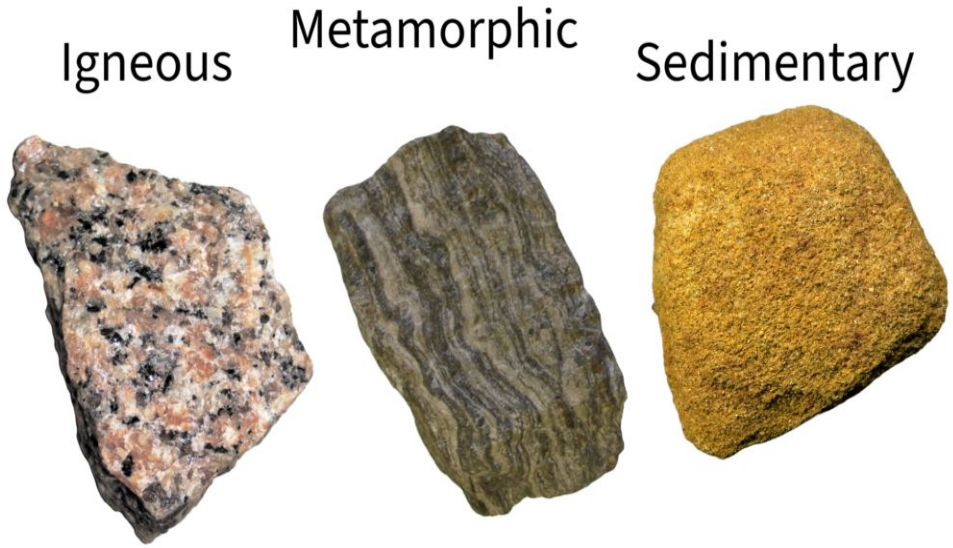
- Aggregates = 60–75% of concrete
- Control:
  - Strength, durability
  - Workability, density
- Key for mix design



Source: Author´s own elaboration

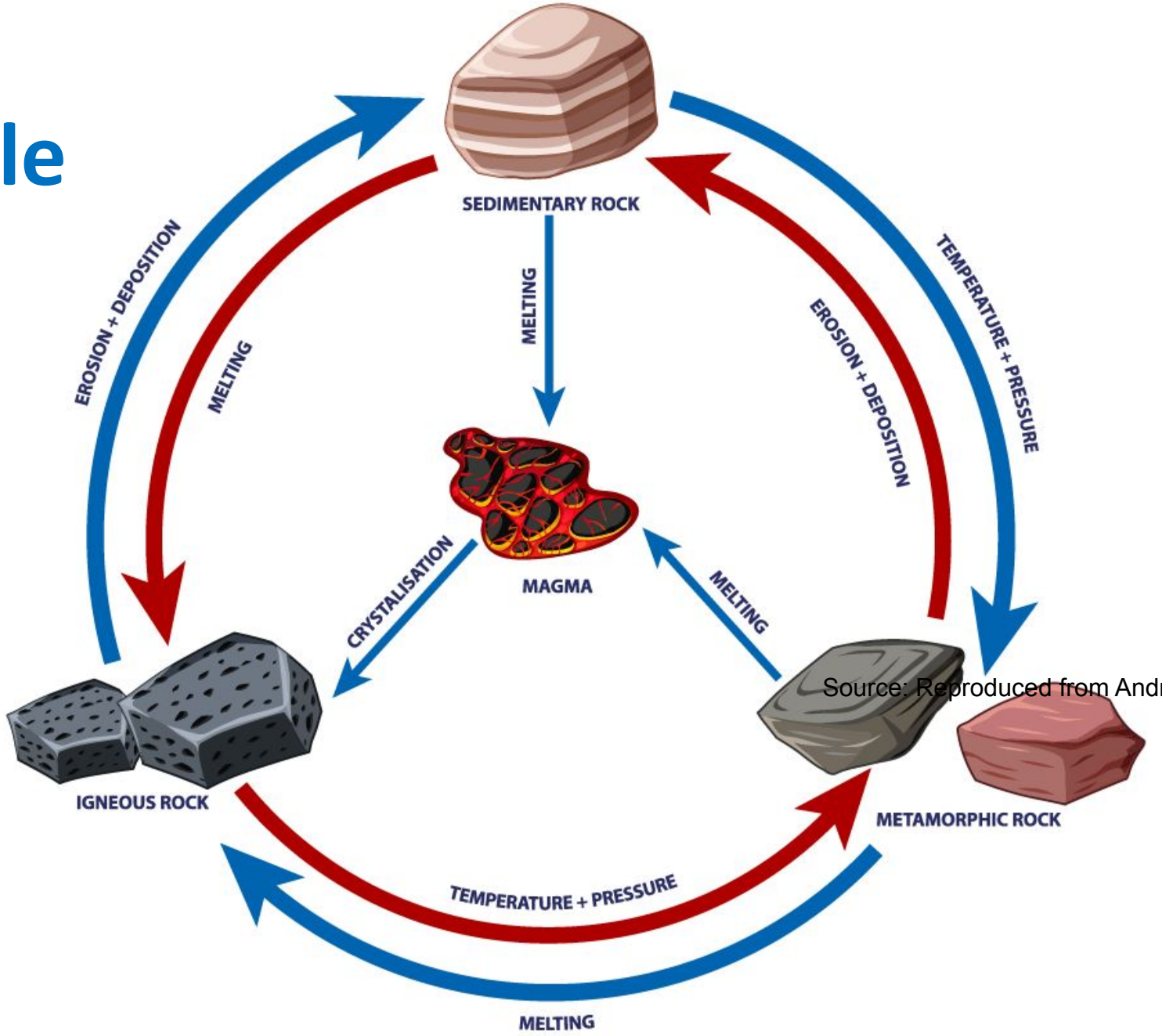
Origin Types

- Igneous: strong, durable
- Sedimentary: lower strength
- Metamorphic: altered, improved properties



Source: Reproduced from Andrei (2024)

Rock Cycle



Source: Reproduced from Andrei (2024)

Source: Cropped from GeeksforGeeks (2025)

Artificial Aggregates

- From industrial processes
- Examples: slag, expanded clay, recycled concrete
- Benefits:
  - Sustainability
  - Reduced environmental impact

(a) (b) (c)

Source: Reproduced from Tataranni & Sangiorgi (2019)

Size Classification

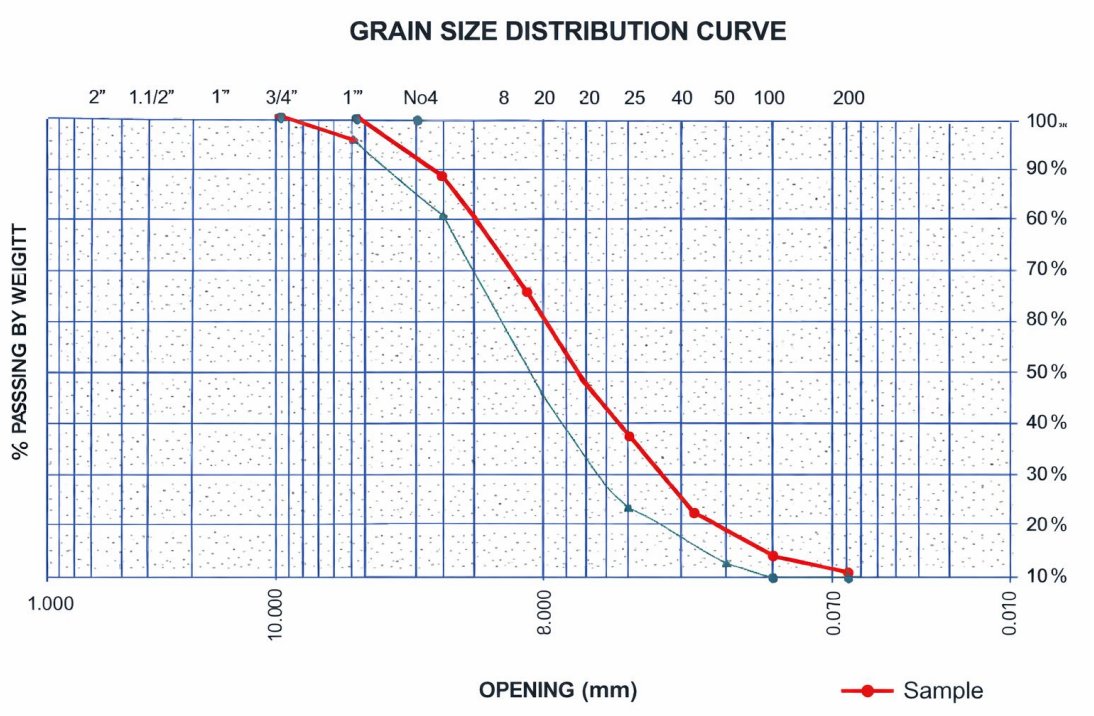
- Fine fraction (< No. 200)
- Fine aggregate (sand)
- Coarse aggregate (gravel, stone)

(a) Fine aggregate (Sand) (b) Coarse aggregate (Gravel)

Source: Reproduced from Shukur et al. (2023)

Sieve Analysis

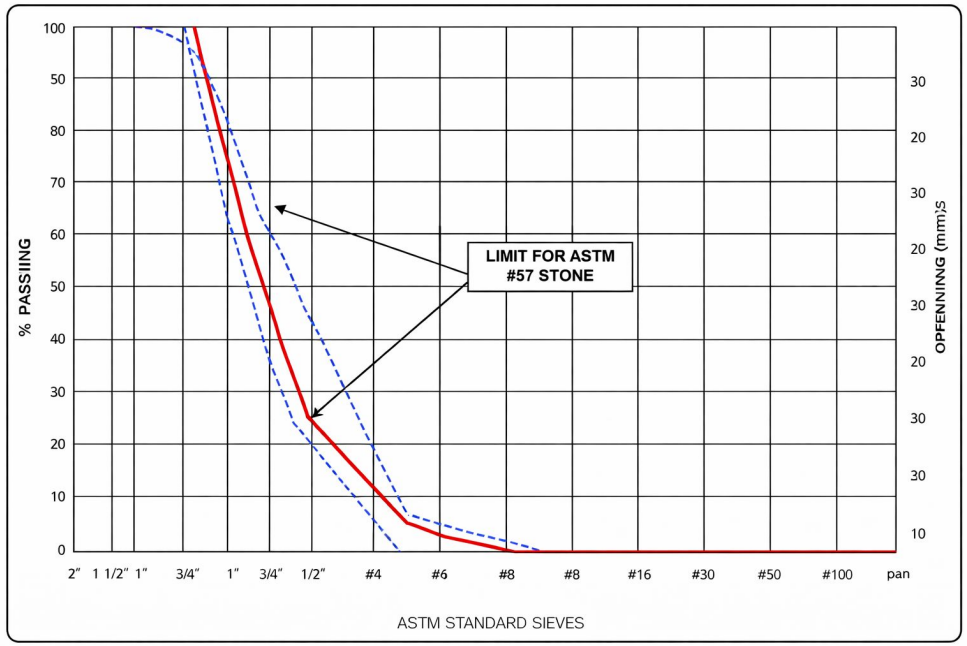
- Determines gradation curve
- Ensures:
  - Workability
  - Cohesion
- Simplifies quality control



Source: Author´s own elaboration

Coarse Aggregate Gradation

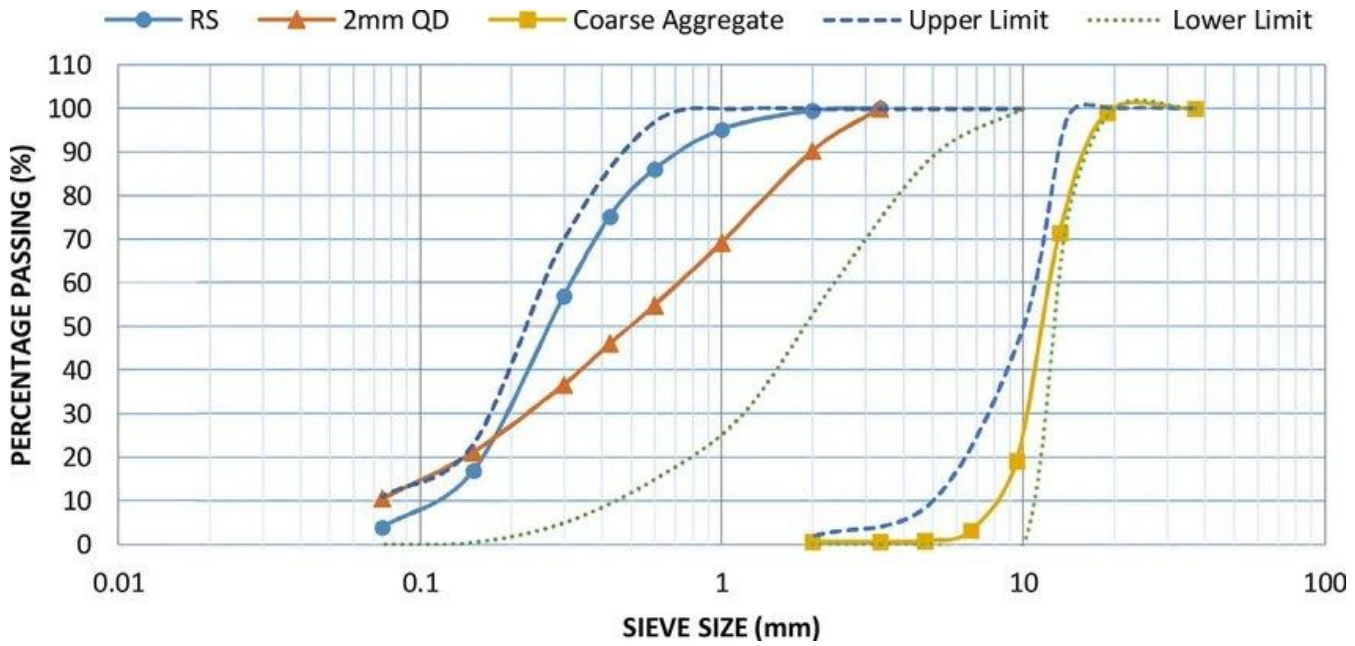
- Multiple grading bands (e.g., No. 57)
- Controls:
  - Compaction
  - Void reduction
  - Cement demand



Source: Source: Author´s own elaboration

Gradation Curves

- Semi-log graph:
  - Y: % passing
  - X: size (log scale)
- Used to assess:
  - Quality
  - Compatibility



Source: Reproduced from Meisuh et al. (2017)

Density Classification

- Lightweight (< 2.5)
- Normal (2.5–2.75)
- Heavyweight (> 2.75)
- Linked to rock origin (with exceptions)

Source: Reproduced from Taiheiyo Cement Corporation (n.d.)

Applications

- Lightweight → insulation, non-structural
- Normal → general concrete
- Heavyweight → radiation shielding, special uses

Source: Reproduced from The Civil Studies (2025)

Aggregate quarry

Quarry Key Factors

- Capacity (material volume)
- Production rate
- Transport distance (cost)

Source: Reproduced from Aggressive Hydraulics (2026)

Quarry Selection

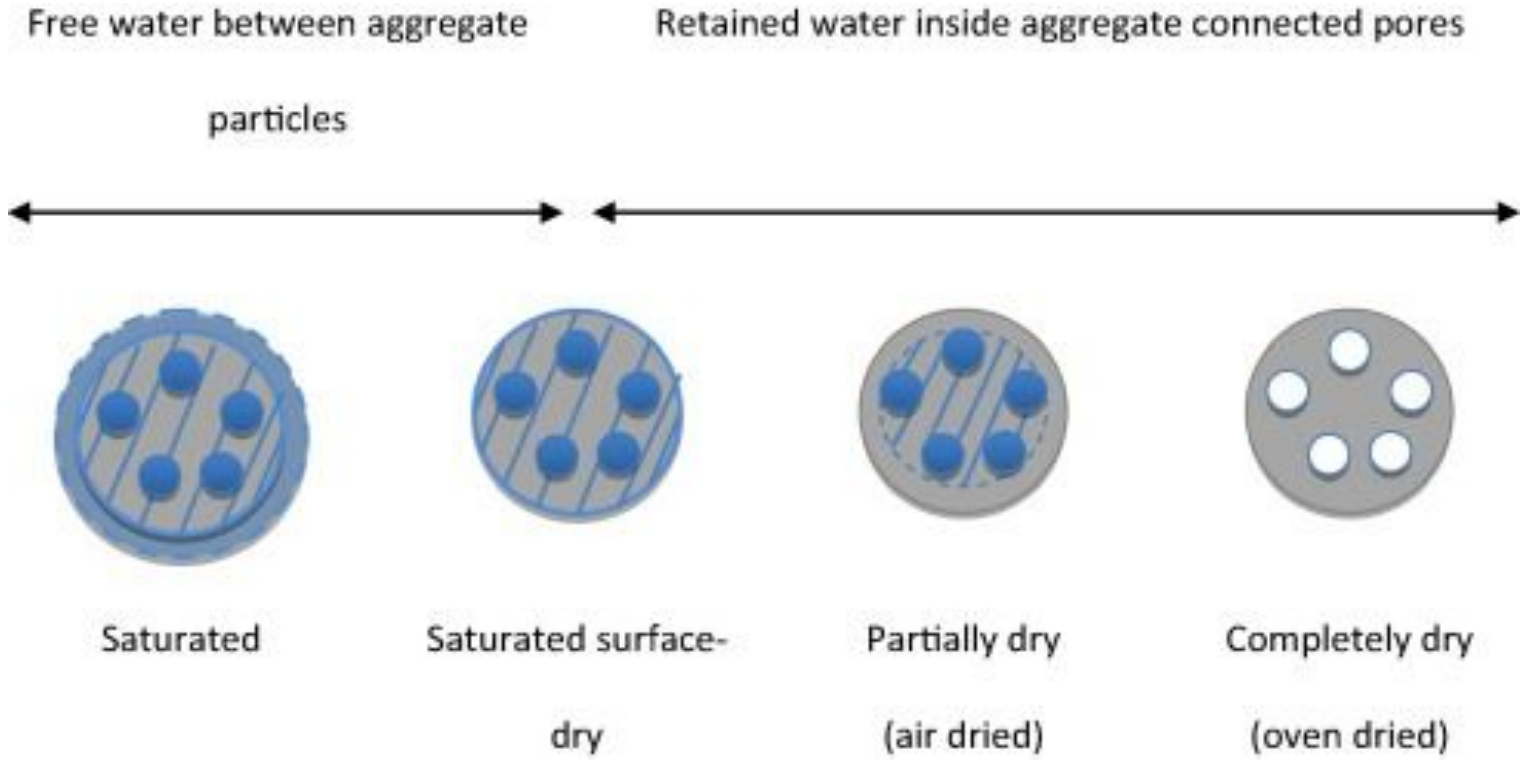
- Use test pits
- Plan layout:
  - Access, crushing, stockpiles
- Control gradation & fines
- Consider:
  - Water access
  - Environmental impact

Source: Reproduced from Booth Ventures (2023)

Aggregate properties
Physical properties

Saturation States

- Oven-dry
- Air-dry
- SSD (key for design)
- Wet (surface water)



Source: Reproduced from Gentilini et al. (2015)

Specific Gravity

- Mass / volume (no voids)
- ASTM C127 / C128
- Typical: 2500–2750 kg/m³

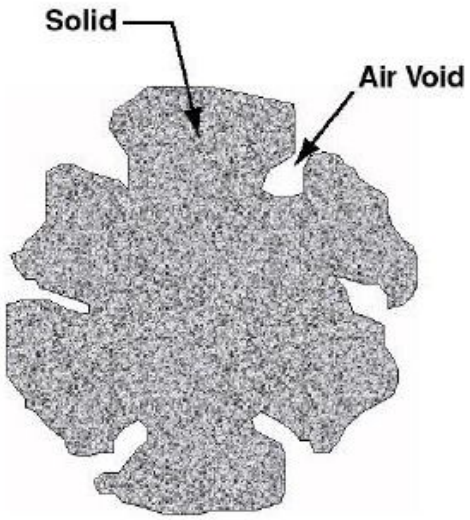


Figure 1. Dry aggregate.

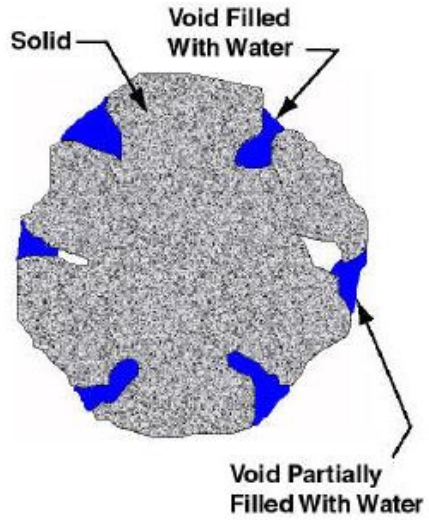


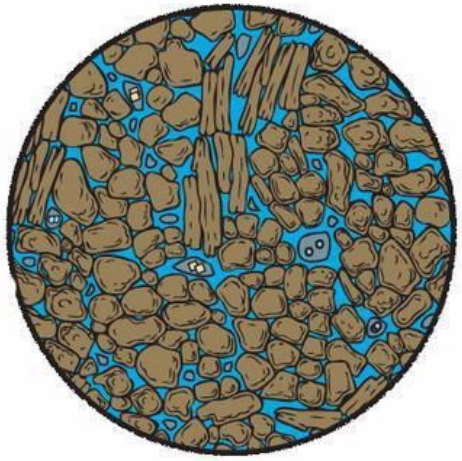
Figure 2. Wet aggregate.

Source: Reproduced from Pavement Interactive (n.d.)

Bulk Density (Unit Weight)

- Weight-to-volume ratio including voids
- Depends on compaction and particle arrangement
- Determined by ASTM C29 (loose & compacted)
- Typical range: 1500–1700 kg/m³
- Key parameter for mix design (real field condition)

Lower bulk density
Lower weight
More pore space

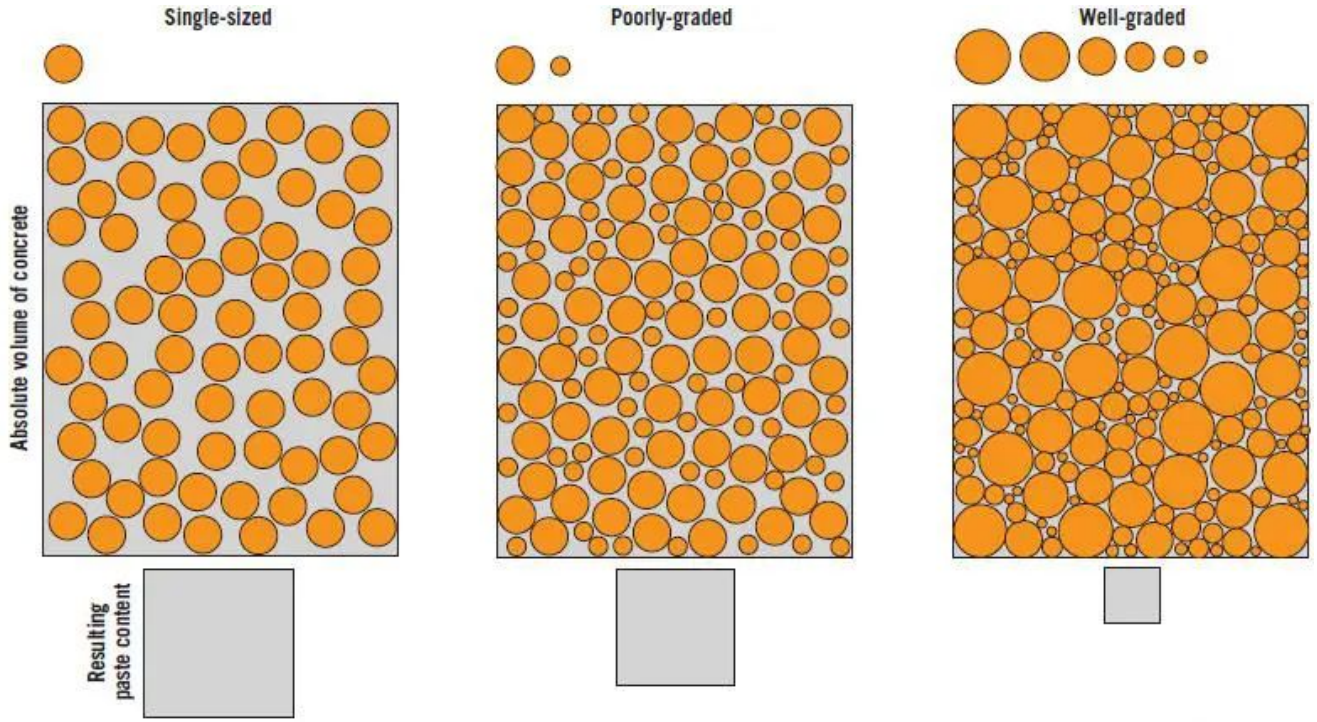


Higher bulk density
Higher weight
Less pore space

Source: Cropped from Afsar (2012)

Voids Content

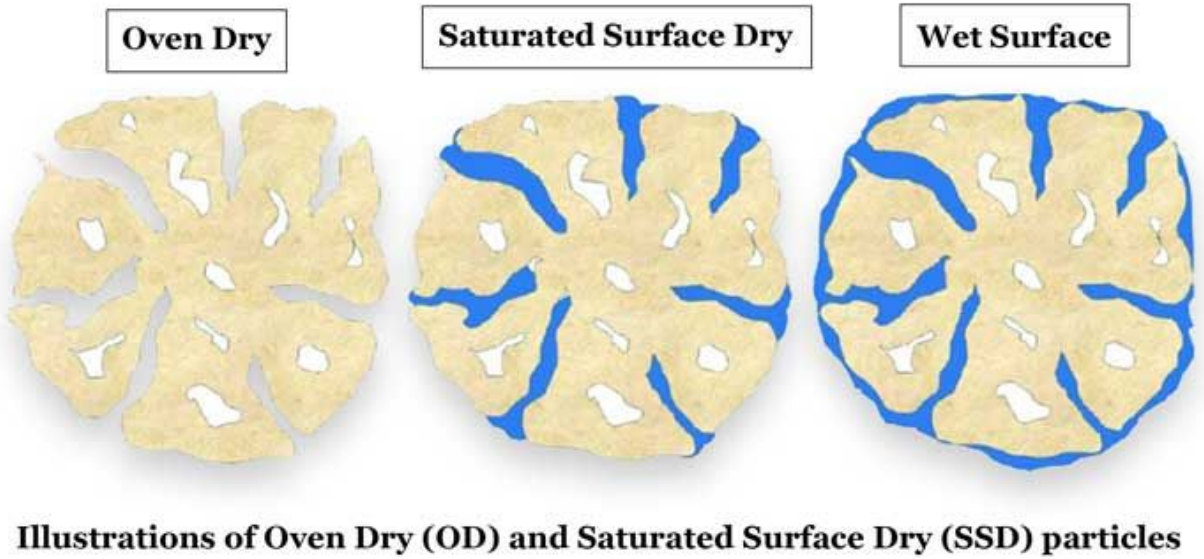
- % of voids between particles (relative property)
- Depends on compaction and test method
- Related to specific gravity and bulk density
- Controls paste demand and concrete density



Source: Reproduced from Bay-Lynx Manufacturing (2026)

Absorption

- Water retained in aggregate pores
- Affects water–cement ratio and durability
- Determined by ASTM C127 / C128
- Related to saturation condition

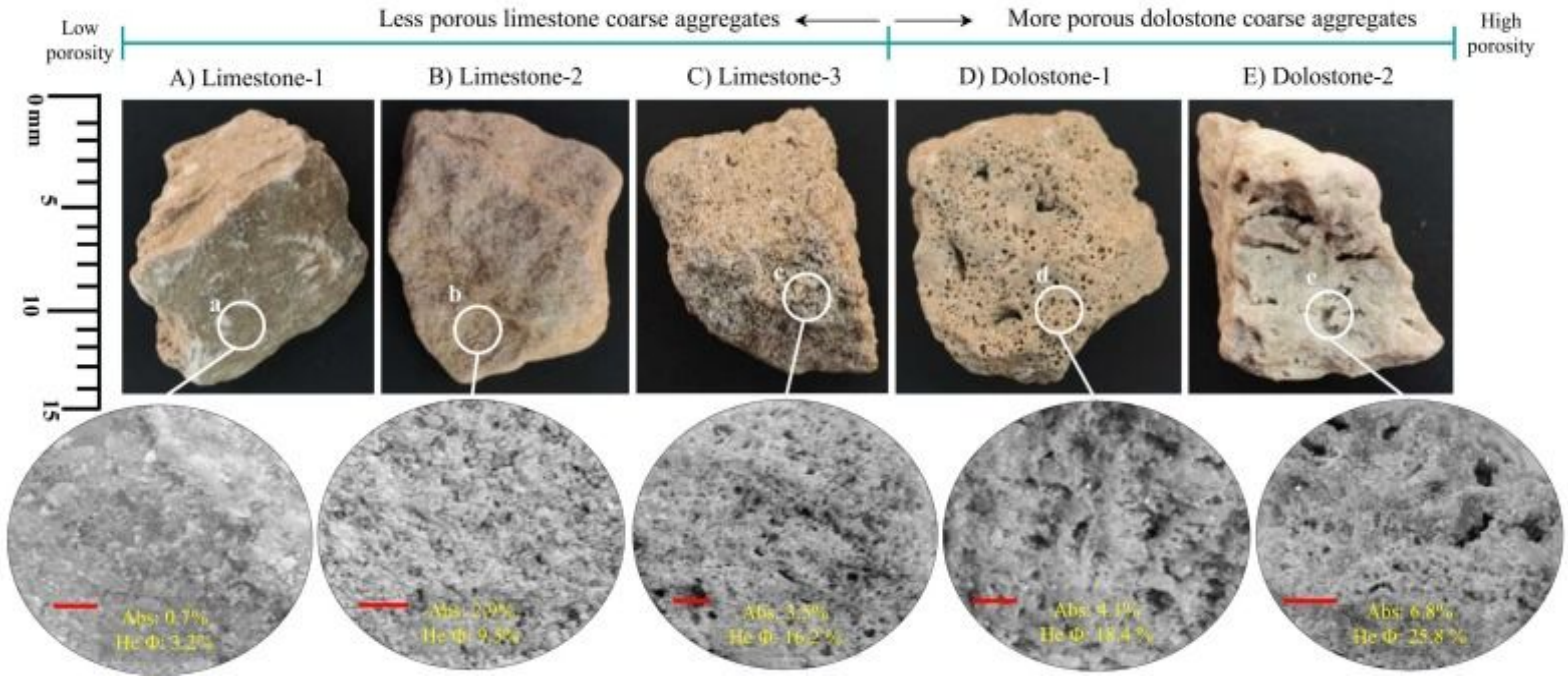


Illustrations of Oven Dry (OD) and Saturated Surface Dry (SSD) particles

Source: Reproduced from GlobalGilson (2026)

Porosity

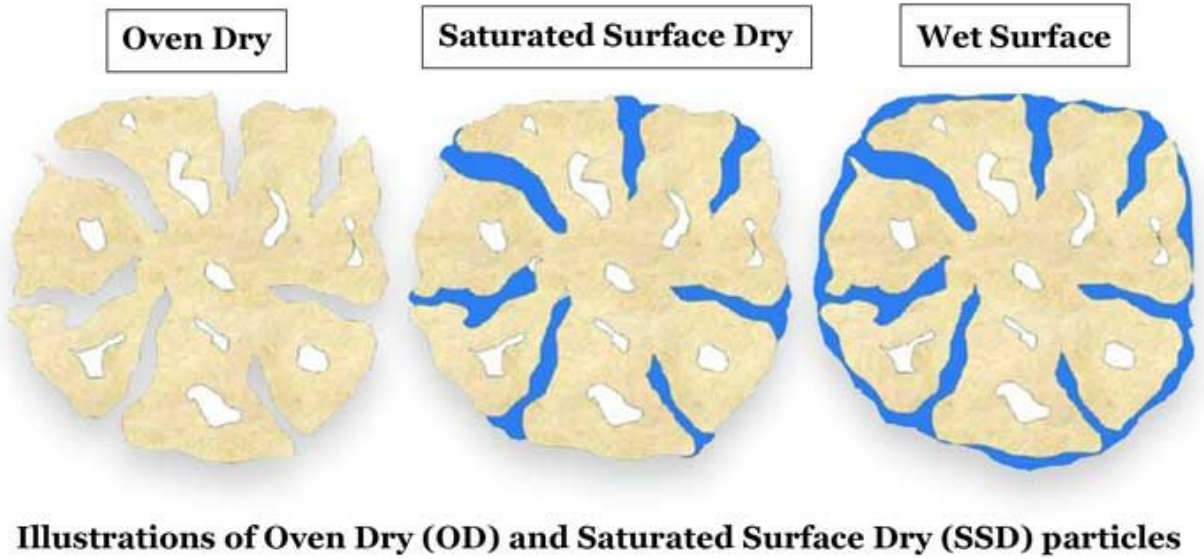
- Internal voids within particles
- Normal: 1–5% | Lightweight: 15–20%



Source: Reproduced from Melugiri Shankaramurthy et al. (2025)

Moisture Content

- Water in surface + pores
- Affects effective water–cement ratio
- Determined by ASTM C566 (oven-dry method)
- Requires correction in mix design

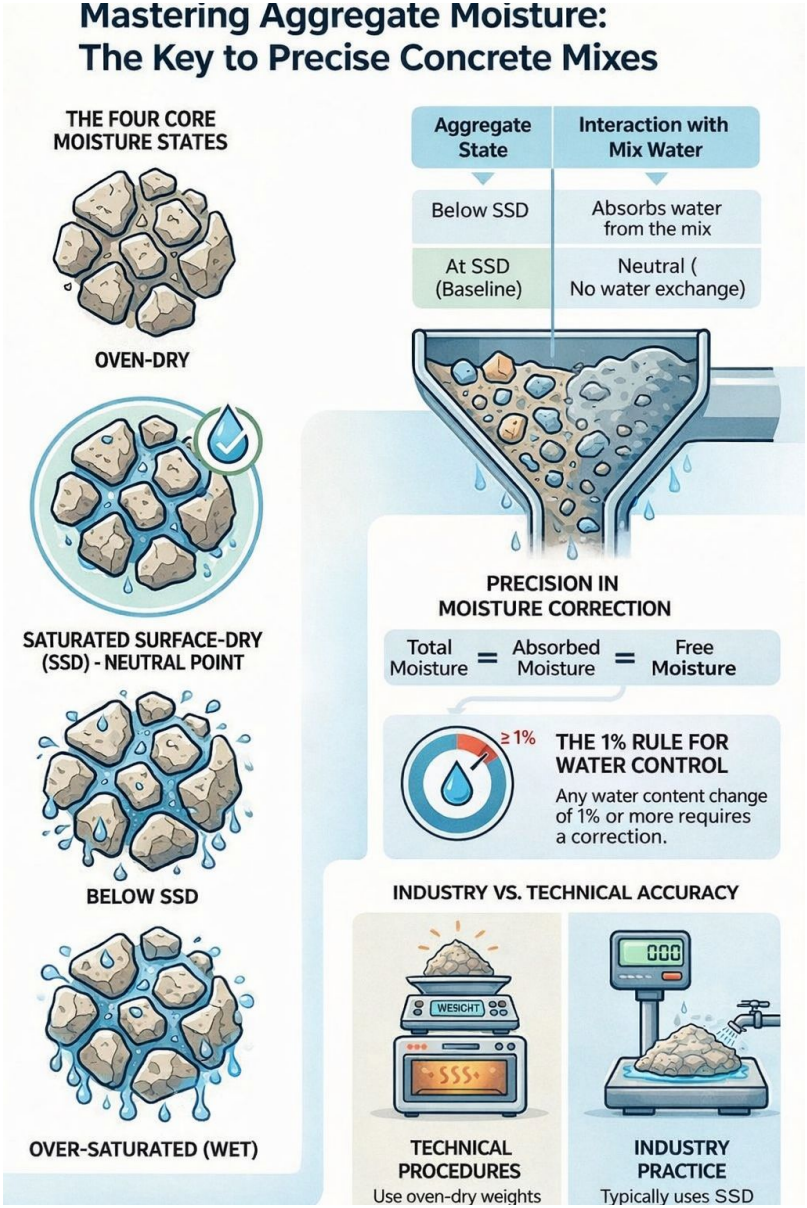


Illustrations of Oven Dry (OD) and Saturated Surface Dry (SSD) particles

Source: Reproduced from GlobalGilson (2026)

Moisture Control

- Impacts strength, durability, workability
- Excess water → weaker concrete
- Low water → poor workability
- Critical for quality control

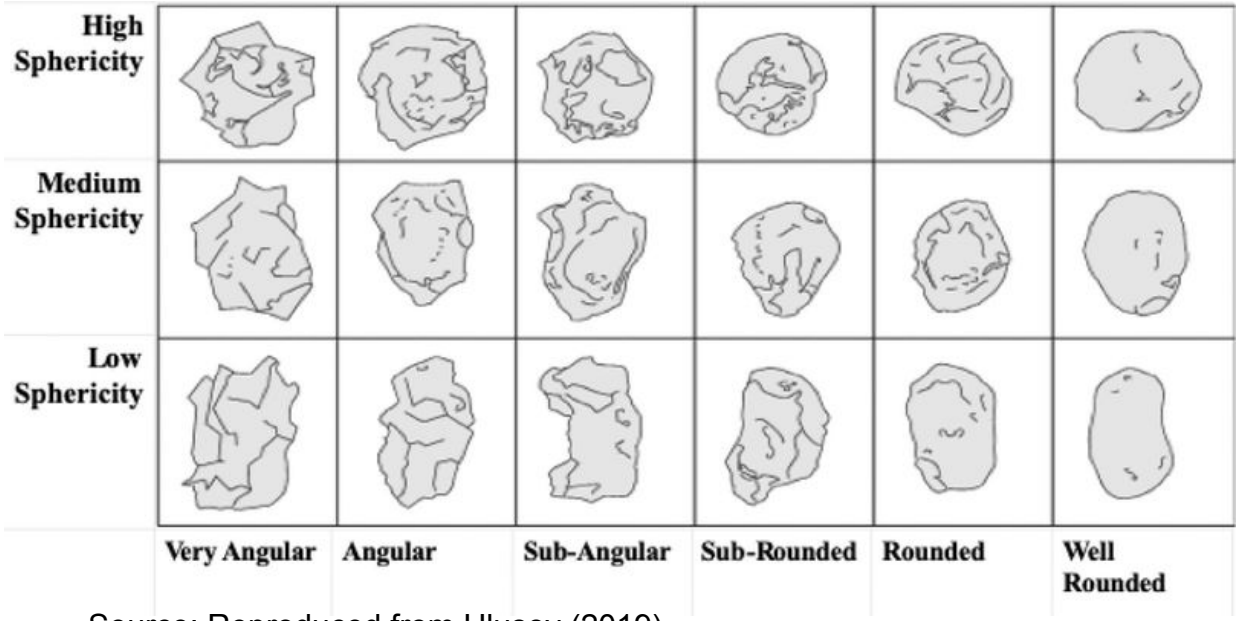


Source: OpenAI (2026)

Shape and texture

Shape: Roundness & Sphericity

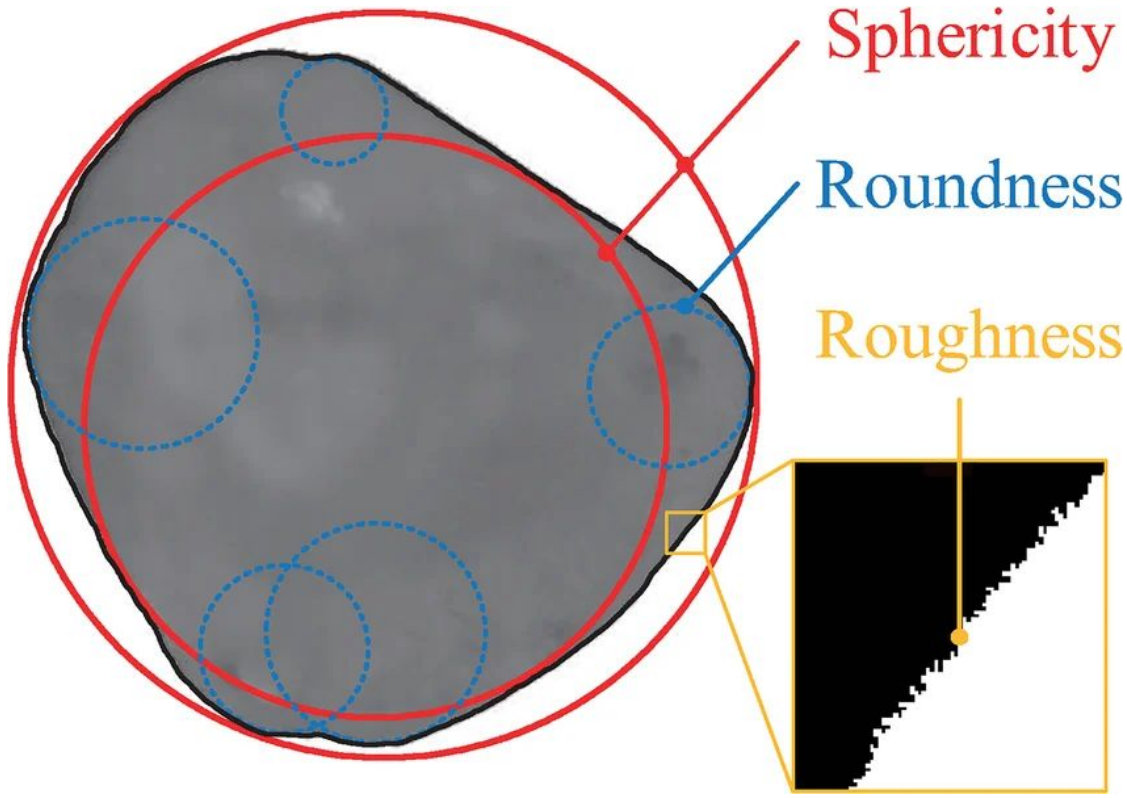
- Equidimensional particles → better packing
- Angular → better bonding, lower workability
- Rounded → better flow, lower adhesion



Source: Reproduced from Ulusoy (2019)

Shape Effects

- Equidimensional → fewer voids, less paste needed
- Classification: angular → rounded (by wear)
- Smooth/rounded → weaker bond
- Sphericity → crushing; roundness → abrasion

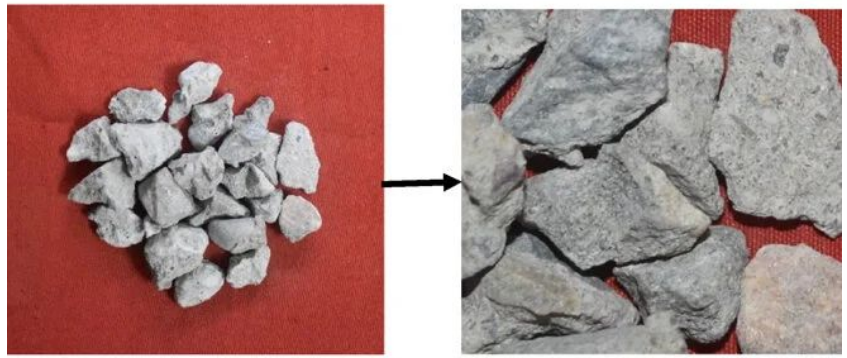


Source: Reproduced from Mo (2020)

Surface Texture

- Smooth vs. rough particles
- Rough ⟶ higher absorption, lower workability
- Improves mechanical bond (interlock)
- Requires water control

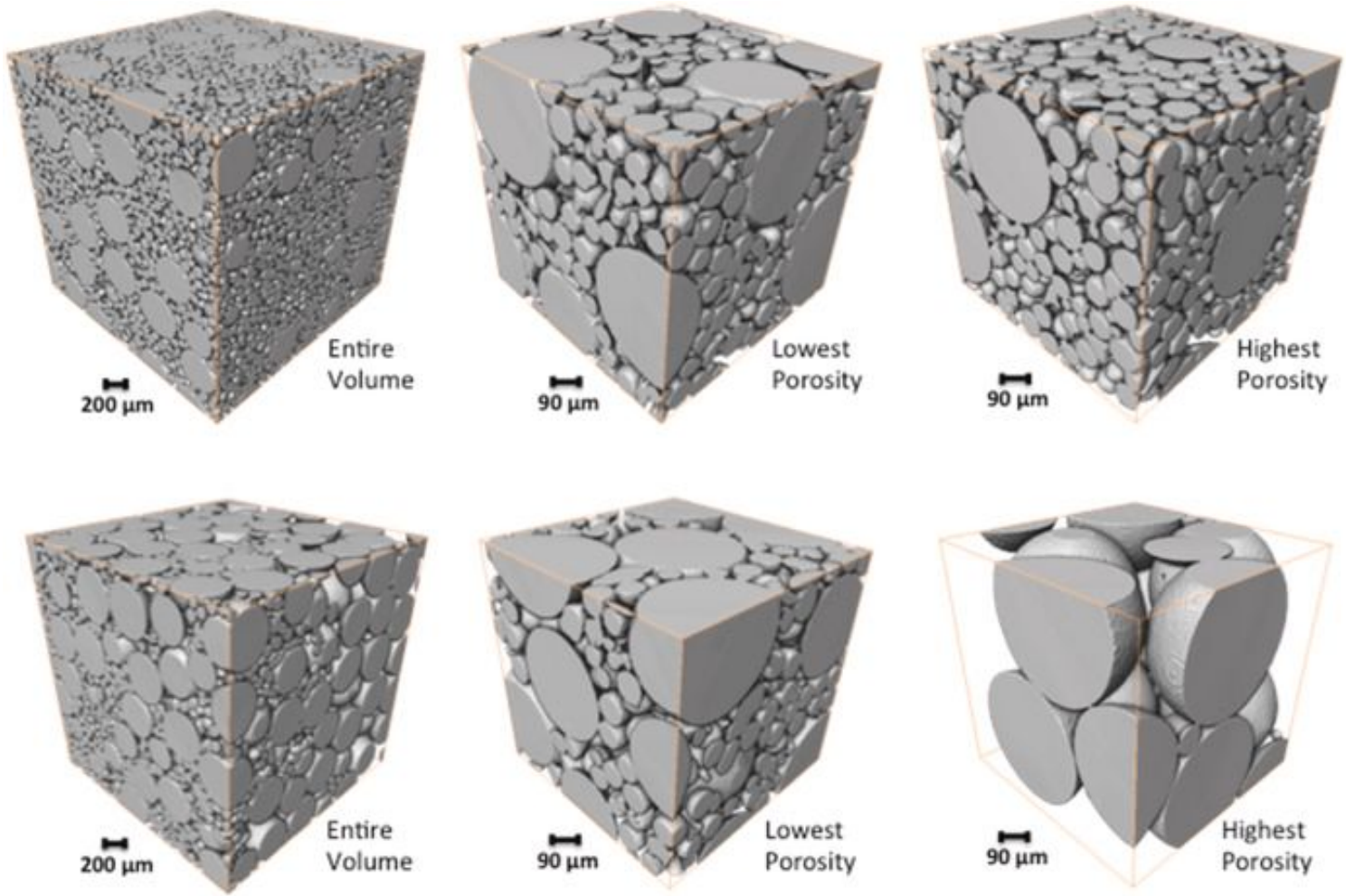
Rounded/irregular shape and smooth surface texture of the NCA



Angular/irregular shape and rough surface texture of the RCA

Source: Reproduced from Singh et al. (2018)

Specific Surface



Source: Reproduced from Hussaini & Dvorkin (2021)

Chemical properties

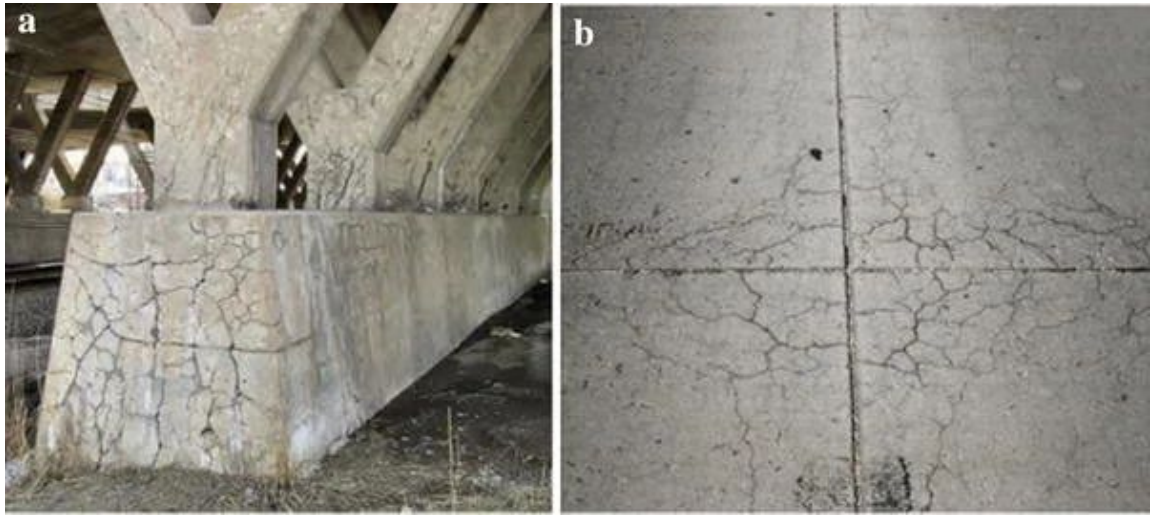
Epitaxy

- Favorable reaction in calcareous aggregates
- Improves bond over time
- Enhances strength and durability

Source: Neptunerover. (n.d.)

Alkali–Silica Reaction (ASR)

- Reactive silica + alkalis → expansive gel
- Causes cracking and deterioration
- Affects siliceous & volcanic rocks
- Evaluated by ASTM C289, C227, C586, C295
- Must be controlled for durability



Source: Reproduced from Lima da Costa, F. (2016)

Mechanical properties

Strength

- Coarse aggregate controls concrete strength
- Failure modes: aggregate, paste, or ITZ
- Aggregate must be stronger than hardened paste
- Critical for durability and performance

Failure modes during uniaxial compression tests. Adapted from Zhou et al.(2025)

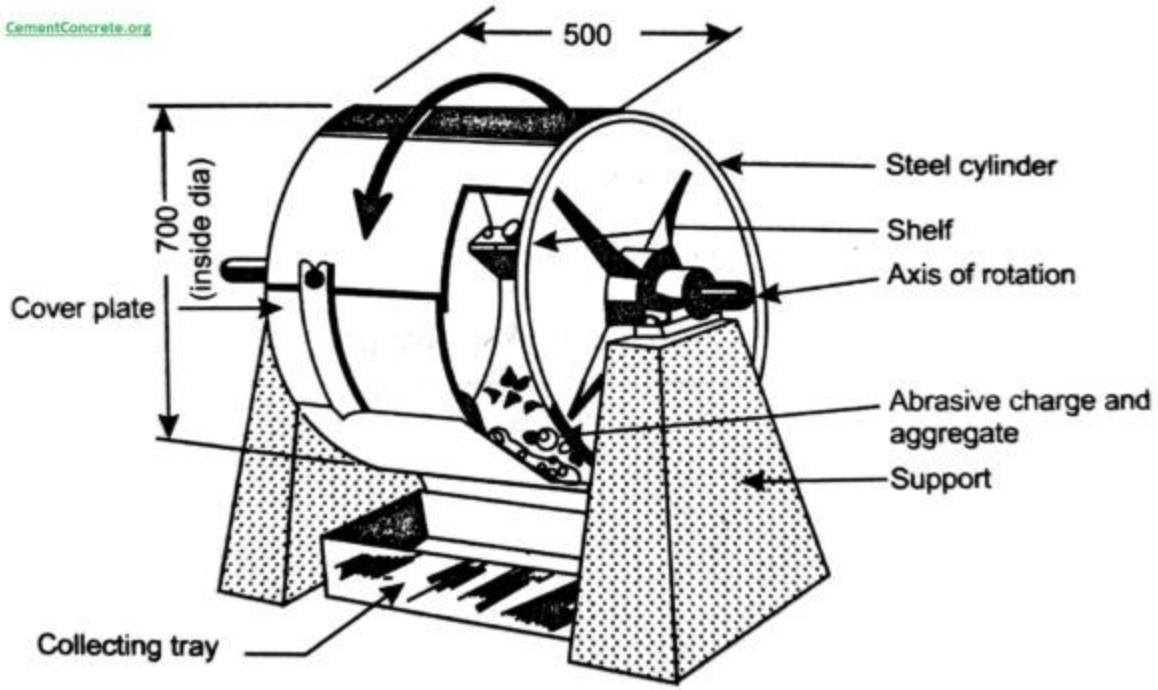
Toughness

- Ability to resist impact and dynamic loads
- Depends on origin and internal structure
- Low toughness → particle breakage, poor gradation
- Measured by impact test (BS 812) ASTM D5874

Source: Impact Testing Machine For Aggregate. Adapdted from Civiconcepts. (2024)

Hardness

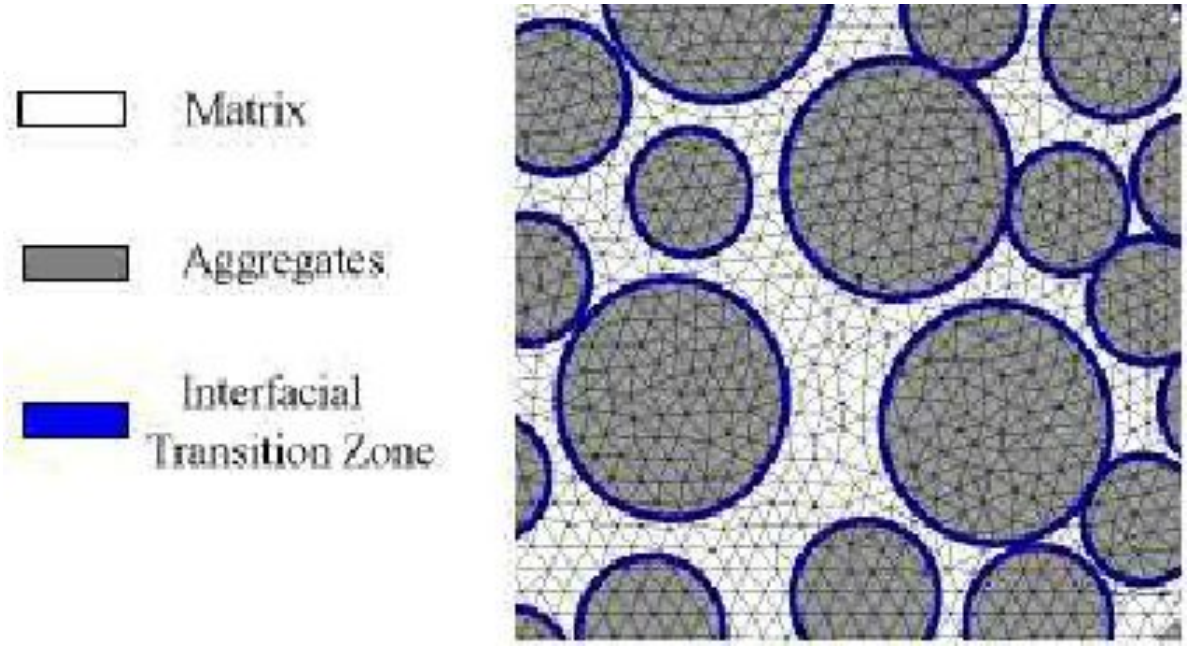
- Resistance to abrasion, impact, polishing
- Key in pavements and hydraulic works
- Measured by Los Angeles test (ASTM C131/C535)
- Acceptable wear: < 50%



Source: LA abrasion testing machine. Adapdted from CementConcrete. (2024)

Adhesion

- Bond between aggregate and paste (ITZ)
- Mechanisms: friction, interlock, hydration
- Higher adhesion → better strength (tension/flexure)
- Depends on size, shape, texture, stiffness

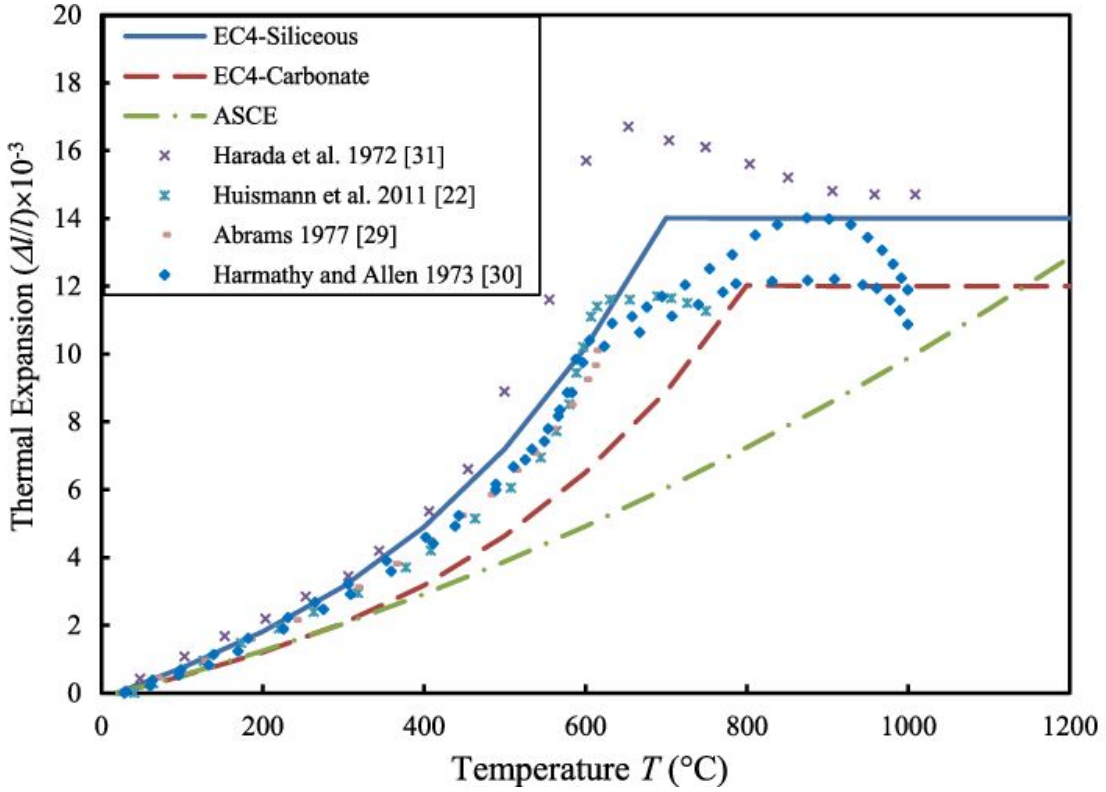


Source: Reproduced from Grondin, F., Mounajed, G., Hamida, A., & Dumontet, H. (2003)

Thermal properties

Thermal properties

- Coefficient of Thermal Expansion
- Specific Heat
- Thermal Conductivity
- Thermal Diffusivity



Thermal expansion for concrete with Siliceous Coarse aggregate. Adapted from Ghannam, M. (2019)

Conclusions

- Aggregates are the main component of concrete (60–75%) and their properties strongly influence key behaviors such as strength, durability, workability, and density.
- They are classified by origin, size (gradation), and density, with their geological formation and quarrying processes playing a key role in material selection and performance.
- Their properties include physical, morphological, chemical, mechanical, and thermal characteristics, all of which affect concrete behavior and require evaluation through standardized tests.
- Proper quality control, moisture management, and prevention of harmful reactions (e.g., ASR) are essential to ensure durable, high-performance concrete.

References

- Pasquel, E. (1998). *Tópicos de Tecnología de Concreto en el Perú.* Lima: Colegio de Ingenieros del Perú - Consejo Nacional
- Gomezjurado, J., Osorio, J., & Niño, J. (2014). *Tecnología del Concreto: Materiales, propiedades y diseño de mezclas.* Bogotá: Asociación Colombiana de Productores de Concreto
- Mihai Andrei. (2024, January 4). *What are the most common types of rocks?* ZME Science. https://www.zmescience.com/feature-post/natural-sciences/geology-and-paleontology/rocks-and-minerals/marble/
- GeeksforGeeks. (2025, August 21). *Rock cycle*. https://www.geeksforgeeks.org/social-science/rock-cycle/
- Tataranni, P., & Cesare Sangiorgi. (2019). Synthetic aggregates for the production of innovative low impact porous layers for urban pavements. *Infrastructures*, 4(3), 48. https://doi.org/10.3390/infrastructures4030048

References

- Shukur, M., Ibrahim, K., Al-Darzi, S., & Salih, O. (2023). Mechanical properties of concrete using different types of recycled plastic as an aggregate replacement. *Cogent Engineering*, 10. https://doi.org/10.1080/23311916.2023.2243735
- Nick Turner. (2025, October 11). *Understanding aggregate grading & gradation reports: A comprehensive guide*. Machinery Partner. https://www.machinerypartner.com/blog/mastering-aggregate-grading-and-gradation-reports-everything-you-need-to-know
- Meisuh, B., Kankam, C., & Buabin, T. (2017). Effect of quarry rock dust on the flexural strength of concrete. *Case Studies in Construction Materials*, 8. https://doi.org/10.1016/j.cscm.2017.12.002
- Taiheiyo Cement Corporation. (n.d.). *Heavyweight aggregate and heavyweight concrete*. https://www.taiheiyo-cement.co.jp/english/service_product/aggregate/jc/index.html
- The Civil Studies. (2025). *Radiation-shielding concrete (RSC): Engineering design, materials, applications, and practical challenges*. https://thecivilstudies.com/radiation-shielding-concrete-design-materials/

References

- Aggressive Hydraulics, Inc.. (2026). *Mining, quarry & aggregates*. https://www.aggressivehydraulics.com/markets/mining-quarry-aggregates/
- Booth Ventures. (2023, November 21). *A to Z of quarrying*. https://boothventures.co.uk/news/a-to-z-of-quarrying/
- Gentilini, O., Yazoghli-Marzouk, V., Delmotte, V., & Descantes, Y. (2015). *Determination of the water content of fillerised fine aggregates in the saturated surface dry state*. *Construction and Building Materials, 98*, 662–670. https://doi.org/10.1016/j.conbuildmat.2015.08.131
- Pavement Interactive. (n.d.). *Aggregate specific gravity*. https://pavementinteractive.org/reference-desk/materials/aggregate/aggregate-specific-gravity/
- Afsar, J. (2012, July 30). *Bulk density of aggregates*. Engineering Intro. https://engineeringintro.com/concrete/concrete-strength/bulk-density-of-aggregates-loose-and-compact-bulk-density/
- Bay-Lynx Manufacturing Ltd. (2026). *Understanding the role of aggregates in concrete*. https://baylynx.co.uk/education/understanding-the-role-of-aggregates-in-concrete/

References

- GlobalGilson.com. (2026). *Relative density/specific gravity of fine and coarse aggregate*. https://www.globalgilson.com/blog/fine-coarse-specific-gravity-of-aggregate
- Melugiri Shankaramurthy, B., Hasiuk, F., Wang, K., Sargam, Y., & Li, W. (2025). *Influence of coarse aggregate pore structure on the pore structure and water absorption of concrete*. *Construction and Building Materials, 491*, 142751. https://doi.org/10.1016/j.conbuildmat.2025.142751
- OpenAI. (2026). *Mastering aggregate moisture: The key to precise concrete mixes* [AI-generated infographic]. DALL·E.
- Ulusoy, U. (2019). *Quantifying of particle shape differences of differently milled barite using a novel technique: Dynamic image analysis*. *Materialia, 8*, 100434. https://doi.org/10.1016/j.mtla.2019.100434
- Mo, P.-Q. (2020). *Internal rolling method for particle shape evaluation and reconstruction*. *PLOS ONE, 15*(11), e0242162. https://doi.org/10.1371/journal.pone.0242162
- Singh, R. B., Singh, B., & Kumar, N. (2018). *Thixotropy of self-compacting concrete containing recycled aggregates*. *Magazine of Concrete Research, 71*(1), 14–25. https://doi.org/10.1680/jmacr.17.00273

References

- Hussaini, S. R., & Dvorkin, J. (2021). *Specific surface area versus porosity from digital images: High-porosity granular samples*. *Journal of Petroleum Science and Engineering, 206*, 108961. https://doi.org/10.1016/j.petrol.2021.108961
- Neptunerover. (n.d.). *Calcite crystals on the matrix* [Photograph]. Wikimedia Commons. https://commons.wikimedia.org/w/index.php?curid=8394995
- Lima da Costa, F. (2016). Analysis of concrete structures deteriorated by alkali-aggregate reaction: Case study. *Journal of Building Pathology and Rehabilitation, 1*(1), 13. https://doi.org/10.1007/s41024-016-0016-3
- Zhou, J., Hao, S., Chen, Y., et al. (2025). Multiscale investigation of thermally activated coal gangue aggregate concrete interfacial transition zone evolution and failure mechanisms. *Scientific Reports, 15*, 28663. https://doi.org/10.1038/s41598-025-14014-y
- Civiconcepts. (2024). *7 aggregate test: Method & procedure*. https://civiconcepts.com/blog/aggregate-testing
- CementConcrete. (2024). *Los Angeles abrasion test (LA abrasion test) on aggregates*. https://cementconcrete.org/transportation/los-angeles-abrasion-test-la-on-aggregate/2377/

References

- Grondin, F., Mounajed, G., Hamida, A., & Dumontet, H. (2003). Digital concrete: A multi-scale approach for the concrete behavior. In *Proceedings of the International Conference on Computational Methods in Sciences and Engineering* (pp. 205–208). https://doi.org/10.1142/9789812704658_0046
- Ghannam, M. (2019). Proposed models for concrete thermal expansion with different aggregate types and saturation conditions. *SN Applied Sciences, 1*, 1–11. https://doi.org/10.1007/s42452-019-0452-1

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