HORIBA Scientific

Application Note

PSD of Cement, Concrete, Aggregates
AN147

Measurement of Particle Size of Cement and Concrete Components

Concrete is the hard, strong construction material we all know. This consists of sand, gravel, pebbles, broken stone, or slag in a mortar or cement matrix. Cement is the powder that is mixed with water to bind it all together. The final properties of the concrete body are determined by a number of properties including the quantity and quality of the aggregate, the amount of cement in the mixture, and the fineness of the cement itself.

While chemical composition of the cement, proportions of the different components, and conditions of the mixing and setting may have a significant effect on final performance, this paper will address the effects of particle size in manufacturing and in the final product.

Summary

The properties and value of cement are largely determined by particle size distribution. Quick-setting cement contains a higher percentage of fine particles than regular cement and is more expensive since more grinding is required to produce it. Particle size analysis will enable a manufacturer to make sure fine sized cement is not sold at a low price, and will enable users to determine if they are paying too high a price for coarser cement.

The percentage of cement particles larger than 100 micron is important since large particles act more as a filler than contributing to final binder strength. Particle size analysis can also be used to predict the properties of a particular batch of cement. The amount of material in the 3 to 30 micron range has been found to be a good indicator of potential strength development. The percentage of cement particles finer than 7 microns has a major influence on water demand, bleeding characteristics, and stiffening problems. HORIBA's particle size analyzers have been used to analyze problem cement samples and determine what preparation steps should be changed to produce a high quality cement.

Cements set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a stone like mass, called paste. When the paste (cement and water) is added to aggregates (sand and gravel, crushed stone, or other granular material) it acts as an adhesive and binds the aggregates together to form concrete.

Manufacturing Methods

Portland cement, the functional ingredient of concrete, is made from materials that contain appropriate amounts of calcium compounds, silica, alumina and iron oxide that are crushed, screened and placed in a rotating cement kiln. Ingredients used in this process are typically materials such as limestone, marl, shale, iron ore, clay, and fly ash.

The rotating kiln can be up to 300 feet long and is heated to a temperature between 2700 and 3000 Fahrenheit (1480 and 1650 Celsius). This high heat drives off, or calcines, the chemically combined water and carbon dioxide from the raw materials and forms new compounds (tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite). The discharge is clinker, in the form of marble sized pellets. The clinker is then very finely ground to produce Portland cement. A small amount of gypsum is added during the grinding process to control the cement's set or rate of hardening.

Each step in manufacture of Portland cement is checked by frequent chemical and physical tests in plant laboratories. The finished product is also analyzed and tested to ensure that it complies with all specifications.

ASTM Methods

Because of the huge amount of cement produced and the wide number of producers, there has been a long history of specifications produced by bodies such as ASTM. These include ASTM C 150, Standard Specification for Portland Cement, which recognizes eight types of portland cement with different characteristics.

ASTM C 595, Specification for Blended Hydraulic Cements, recognizes five primary classes of blended cement: Blended hydraulic cements are produced by intimately and uniformly intergrinding or blending two or more types of fine materials. The primary materials are Portland cement, ground granulated blast furnace slag, fly ash, silica fume, calcined clay, other pozzolans, hydrated lime, and pre-blended combinations of these materials.

All Portland and blended cements are hydraulic cements. “Hydraulic cement” is merely a broader term. ASTM C 1157, *Performance Specification for Hydraulic Cements*, is a performance specification that includes Portland cement, modified Portland cement, and blended cements.

Aggregates

Aggregates are classified by ASTM C 33 (AASHTO M 6/M 80) as fine or coarse. Fine aggregate consists of natural sand, manufactured sand, or a combination thereof with particles that are typically smaller than 5 mm (0.2 in.). Coarse aggregate consists of either (or a combination of) gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed concrete, with particles generally larger than 5 mm (0.2 in.). The maximum size of the coarse aggregates is generally in the range of 9.5 to 37.5 mm (? to 1½ in.).

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories-fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch (9.5-mm) sieve. Coarse aggregates are any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1.5 inches (9.5 mm to 37.5 mm) in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular sub-bases, soil-cement, and in new concrete.

Aggregate processing consists of crushing, screening, and washing the aggregate to obtain proper cleanliness and gradation. If necessary, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality. Once processed, the aggregates are handled and stored in a way that minimizes segregation and degradation and prevents contamination. Aggregates strongly influence concrete’s freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process.

Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include:

- grading
- durability
- particle shape and surface texture
- abrasion and skid resistance
- unit weights and voids
- absorption and surface moisture

Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

Shape and Size Matter

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio.

Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete. The void content between particles affects the amount of cement paste required for the mix. Angular aggregate increase the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content.

Absorption and surface moisture of aggregate are measured when selecting aggregate because the internal structure of aggregate is made up of solid material and voids that may or may not contain water. The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate.

Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

Effects of Particle Size on Cement Performance

Cement, together with water, creates the paste that binds aggregate together to form concrete. Concrete quality depends upon the quantity and quality of the aggregate and the paste, as well as the bond between the two. Therefore, the properties of concrete are influenced by the properties of cement. Whether it is the clinker composition, the fineness of the individual cement grains, or the amount with which it is used in the concrete, the type and proportion of cement affect both the fresh and hardened properties of concrete. An understanding of cement characteristics can provide insight to many of the issues arising in concrete construction.

Hydraulic cements set and harden, not by drying, but through a chemical reaction between the cement grains and water. During this process (called “hydration”), the calcium silicates from the Portland cement form calcium hydroxide and a gel-like calcium silicate hydrate (C-S-H). The rate of this reaction is dependent on many factors including the type and proportion of Portland cement components (C_3S, C_2S, C_3A, and C_4AF), the fineness and particle size distribution of the cement grains, and the placing and curing conditions of the concrete.

The strength of a concrete structure is essentially dependent on three factors - water to cement ratio, the particle size distribution of the cement powder used and the hardening time allowed. Generally, for a fixed cement content, a reduction in the median particle size results in increased hydration and a higher compressive strength.

The effects of the particle size distribution on the performance properties of Portland cement-based materials were examined in a paper by D.P. Bentz, E.J. Garboczi, C.J. Haecker, and O. M. Jensen (Cement and Concrete Research volume 29, 1663 – 1671, 1999) or currently available at http://ciks.cbt.nist.gov/bentz/finetwo/. Their study concluded that no single cement particle size distribution was suitable for all applications but it could be optimized for a particular usage.

Many other papers have been written about the subject relating particle size to cement performance.

Cements differ from plant to plant due to changes in raw material properties, kiln temperatures, and fineness upon grinding. These changes can significantly affect concrete properties when different cements are used in concrete, so testing is required to adjust properties.

Measurement Methods

Measurement by sieves and the use of sedimentation systems have been common in the cement industry but the use of light scattering instruments, especially those employing laser as the light source, has been gaining popularity. This is due to the good accuracy, short analysis time, ease of use and results presentation.

HORIBA has precisely catered for this need to obtain highly accurate and repeatable particle size distribution of industrial products with the LA-series laser scattering particle size analyzers.

Some cement was tested using HORIBA’s LA-920 wet flow method (in alcohol) and the results are shown in the subsequent page.

NIST 114 Round Robin data

Example data with 950 wet and dry

CAMSIZER sand

CAMSIZER aggregate

Correlation to existing methods

Example data

Include D10, D50, D90, and mean.
With discussion (Describe why this data is representative or important)

Analytical test method

RI, dispersant fluid, sonication requirements, pump speeds [relate to which model if necessary]
Any special conditions or cautions required to properly test or analyze data.