GLOBAL EDITION

Materials for Civil and Construction Engineers

Fourth Edition in SI Units

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Pearson

MATERIALS FOR CIVIL AND CONSTRUCTION ENGINEERS

FOURTH EDITION IN SI UNITS

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TABLE 5.1 Basic Aggregate Properties (Meininger and Nichols, 1990)

Property	Relative Importance for End Use* Portland Cement Concrete	Asphalt Concrete	Base
PHYSICAL			
Particle shape (angularity)	M	V	V
Particle shape (flakiness, elongation)	M	M	M
Particle size—maximum	M	M	M
Particle size—distribution	M	M	M
Particle surface texture	M	V	V
Pore structure, porosity	V	M	U
Specific gravity, absorption	V	M	M
Soundness—weatherability	V	M	M
Unit weight, voids—loose, compacted	V	M	M
Volumetric stability—thermal	M	U	U
Volumetric stability—wet/dry	M	U	M
Volumetric stability—freeze/thaw	V	M	M
Integrity during heating	U	M	U
Deleterious constituents	V	M	M
CHEMICAL			
Solubility	M	U	U
Surface charge	U	V	U
Asphalt affinity	U	V	M
Reactivity to chemicals	V	U	U
Volume stability—chemical	V	M	M
Coatings	M	M	U
MECHANICAL			
Compressive strength	M	U	U
Toughness (impact resistance)	M	M	U
Abrasion resistance	M	M	M
Character of products of abrasion	M	M	U
Mass stability (stiffness, resilience)	U	V	V
Polishability	M	M	U

* V = Very important; M = Moderately important; U = Unimportant or importance unknown

in Table 5.1 (Meininger and Nichols, 1990). Several individual particle characteristics are important in determining if an aggregate source is suitable for a particular application. Other characteristics are measured for designing portland cement and asphalt concrete mixes (Goetz and Wood, 1960).

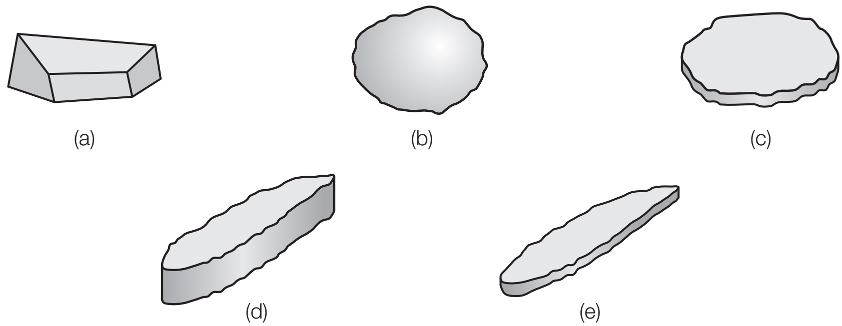

FIGURE 5.3 Particle shapes: (a) angular, (b) rounded, (c) flaky, (d) elongated, and (e) flaky and elongated.

5.5.1 Particle Shape and Surface Texture

The shape and surface texture of the individual aggregate particles determine how the material will pack into a dense configuration and also determines the mobility of the stones within a mix. There are two considerations in the shape of the material: *angularity* and *flakiness.* Crushing rocks produces angular particles with sharp corners and rough texture. Due to weathering, the corners of the aggregates break down, creating *subangular* particles and smooth texture. When the aggregates tumble while being transported in water, the corners can become completely *rounded.* Generally, angular and rough-textured aggregates produce bulk materials with higher stability than rounded, smooth-textured aggregates. However, the angular aggregates will be more difficult to work into place than rounded aggregates, since their shapes make it difficult for them to slide across each other. Due to the size differences between coarse and fine aggregates, different test methods are used for their evaluation.

Particle Shape of Coarse Aggregates Figures 5.3 and 5.4 show the different shapes of coarse aggregates: angular, rounded, flaky, elongated, and flaky and elongated. Flakiness, also referred to as flat and elongated, describes the relationship between

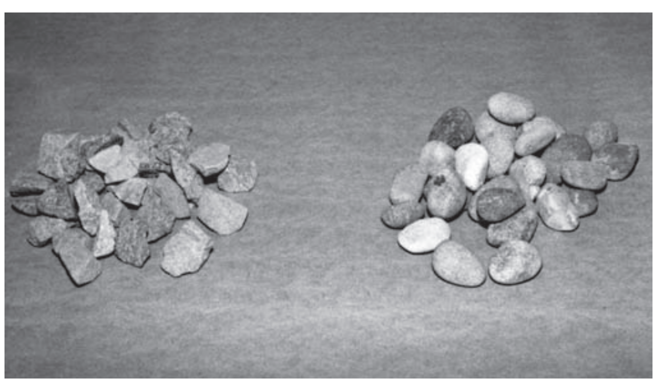

FIGURE 5.4 Angular and rounded aggregates.

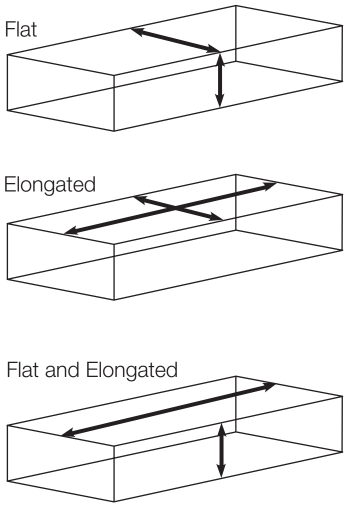

FIGURE 5.5 Concept of flakiness test.

the dimensions of the aggregate, ASTM D4791. Figure 5.5 shows the concept of the flakiness test. This is an evaluation of the coarse portion of the aggregates, but only aggregates retained on the 9.5 mm sieve are evaluated. Under the traditional definition, a flat particle is defined as one where the ratio of the "middle" dimension to the smallest dimension of the particle exceeds the 3 to 1. An elongated particle is defined as one where the ratio of the longest dimension to the middle dimension of the particle exceeds the 3 to 1. Under the Superpave criteria, particles are classified as "flat and elongated" if the ratio of the largest dimension to the smallest dimension exceeds 5 to 1. Figure 5.6 is the apparatus used for the Superpave flat and elongated test.

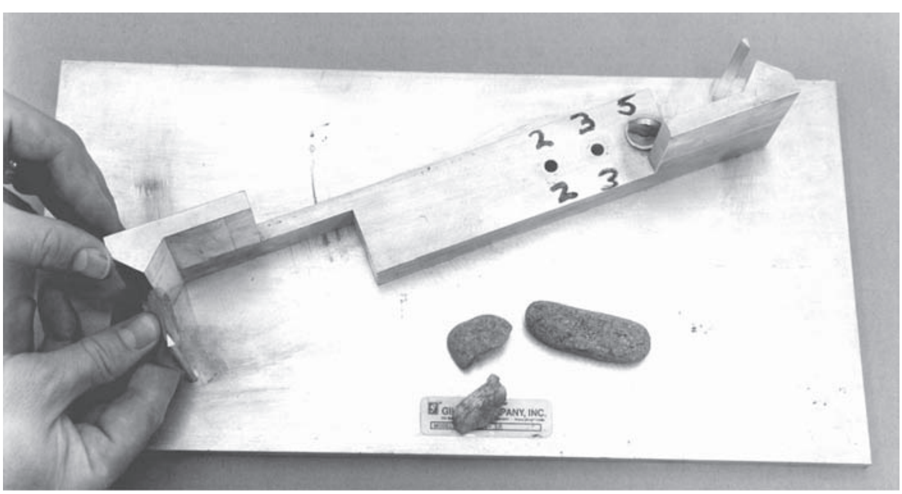

FIGURE 5.6 Superpave flat and elongated apparatus.

Texture of Coarse Aggregates The roughness of the aggregate surface plays an important role in the way the aggregate compacts and bonds with the binder material. Aggregates with a *rough* texture are more difficult to compact into a dense configuration than *smooth* aggregates. Rough texture generally improves bonding and increases interparticle friction. In general, natural gravel and sand have a smooth texture, whereas crushed aggregates have a rough texture.

Since the stability of portland cement concrete is mostly developed by the cementing action of the portland cement and by the aggregate interlock, it is desirable to use rounded and smooth aggregate particles to improve the workability of fresh concrete during mixing. However, the stability of asphalt concrete and base courses is mostly developed by the aggregate interlock. Therefore, angular and rough particles are desirable for asphalt concrete and base courses in order to increase the stability of the materials in the field and to reduce rutting. Flaky and elongated aggregates are undesirable for asphalt concrete, since they are difficult to compact during construction and are easy to break.

To meet the needs of angular aggregates with high texture, many specifications for coarse aggregates used in asphalt concrete require a minimum percentage of aggregates with crushed faces as a surrogate *angularity* and *texture requirement.* A crushed particle exhibits one or more mechanically induced fractured faces and typically has a rough surface texture. To evaluate the angularity and surface texture of coarse aggregate, the percentages of particles with one and with two or more crushed faces are counted in a representative sample, ASTM D5821.

Particle Shape and Texture of Fine Aggregates The angularity and texture of fine aggregates have a very strong influence on the stability of asphalt concrete mixes. The Superpave mix design method recognizes this by requiring a fine aggregate angularity test, ASTM C1252 method, Test Method for Uncompacted Void Content of Fine Aggregate. A sample of fine aggregate with a defined gradation is poured into a small cylinder by flowing it through a standard funnel, as shown in Figure 5.7. By determining the weight of the fine aggregate in the filled cylinder of known volume, the void content can be calculated as the difference between the cylinder volume and the fine aggregate volume collected in the cylinder. The volume of the fine aggregate is calculated by dividing the weight of the fine aggregate by its bulk density. The higher the amount of void content, the more angular and the rougher will be the surface texture of the fine aggregate. ASTM C1252 allows three different methods for the gradation of the sample, but Method A, which requires a specific gradation, is required for Superpave. It is necessary to use a specified gradation; as different gradations would alter the amount of voids between the aggregates and hence consistent criteria could not be developed.

5.5.2 Soundness and Durability

The ability of aggregate to withstand *weathering* is defined as *soundness* or *durability.* Aggregates used in various civil engineering applications must be sound and durable, particularly if the structure is subjected to severe climatic conditions. Water freezing in the voids of aggregates generates stresses that can fracture the stones.

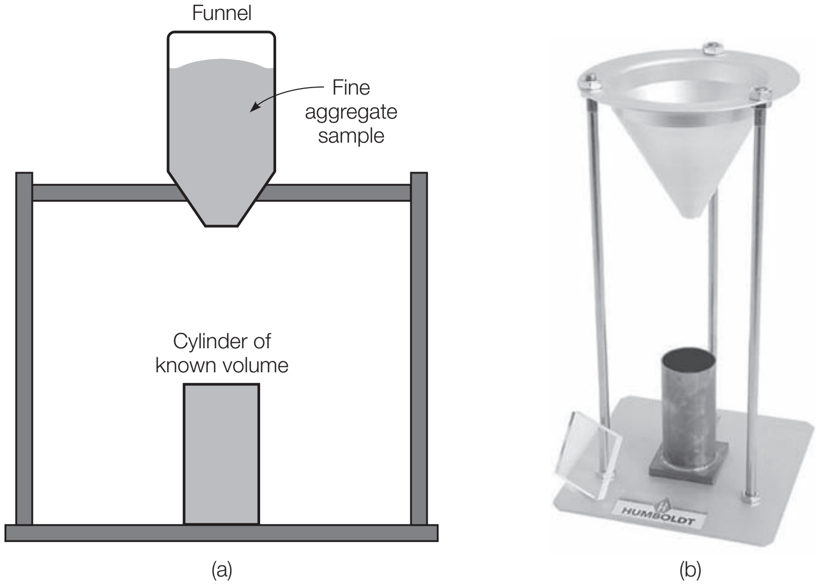

FIGURE 5.7 Apparatus used to measure angularity and surface texture of fine aggregate. (Courtesy of Humboldt Mfg. Co.)

The soundness test (ASTM C88) simulates weathering by soaking the aggregates in either a sodium sulfate or a magnesium sulfate solution. These sulfates cause crystals to grow in the aggregates, simulating the effect of freezing. The test starts with an oven-dry sample separated into different sized fractions. The sample is subjected to cycles of soaking in the sulfate for 16 hours, followed by drying. Typically, the samples are subjected to five cycles. Afterwards, the aggregates are washed and dried, each size is weighed, and the weighted average percentage loss for the entire sample is computed. This result is compared with allowable limits to determine whether the aggregate is acceptable. This is an empirical screening procedure for new aggregate sources when no service records are available.

The soundness by freeze thaw (AASHTO T103) and potential expansion from hydrated reactions (ASTM D4792) are alternative screening tests for evaluating soundness. The durability of aggregates in portland cement concrete can be tested by rapid freezing and thawing (ASTM C666), critical dilation by freezing (ASTM C671), and by frost resistance of coarse aggregates in air-entrained concrete by critical dilation (ASTM C682).

5.5.3 Toughness, Hardness, and Abrasion Resistance

The ability of aggregates to resist the damaging *effect of loads* is related to the hardness of the aggregate particles and is described as the *toughness* or *abrasion resistance*. The aggregate must resist crushing, degradation, and disintegration when stockpiled, mixed as either portland cement or asphalt concrete, placed and compacted, and exposed to loads.

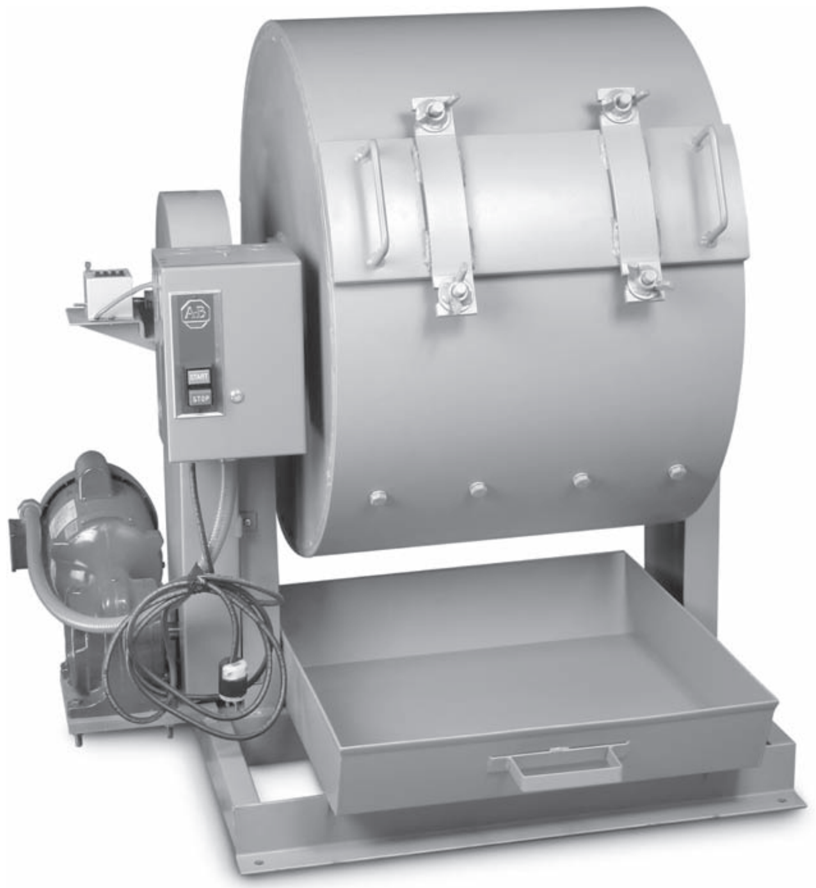

FIGURE 5.8 Los Angeles abrasion machine. (Courtesy of Humboldt Mfg. Co.)

The Los Angeles abrasion test (ASTM C131, C535) evaluates the aggregates' toughness and abrasion resistance. In this test, aggregates blended to a fixed size distribution are placed in a large steel drum with standard sized steel balls that act as an abrasive charge (see Figure 5.8). The drum is rotated, typically for 500 revolutions. The material is recovered from the machine and passed through a sieve that retains all of the original material. The percentage weight loss is the LA abrasion number. This is an empirical test; that is, the test results do not have a scientific basis and are meaningful only when local experience defines the acceptance criteria.

5.5.4 Absorption

Although aggregates are inert, they can capture water and asphalt binder in surface voids. The amount of water the aggregates absorb is important in the design of portland cement concrete, since moisture captured in the aggregate voids is not available to react with the cement or to improve the workability of the plastic concrete. There is