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Aggregates for Concrete and Asphaltic Mixes

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Overview

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Concrete and asphalt are by far the most common construction materials used today. Concrete is a composite material consisting of cement, water, air, coarse aggregate, and fine aggregates. Fine aggregates are typically sands and coarse aggregates are natural or crushed rocks. Chemical admixtures to modify certain specific properties are also commonly used (i.e., superplasticizers to make the concrete fluid during casting). Asphaltic mixes consist primarily of asphalts, coarse aggregates, and fine aggregates, in addition to a number of emulsifiers and other additives used to improve viscosity during placement.

In both concrete and asphaltic mixes, aggregates make up a very significant portion of the mix volume, as economy requires that the amount of cement and asphalt be minimized. Two types of aggregates are commonly recognized: coarse aggregates, defined as particles larger than about 4.75mm (rocks), and fine aggregates, consisting of smaller particles (sands). Other important characteristics of aggregates are that they be rigid, durable, and chemically inert with respect to the concrete mortar or asphalt. Aggregates are intended to be fillers, but they are not intended to play a key role in the behavior of either material. However, the stiffness and strength of the aggregates needs to be higher than the concrete mortar or asphalt, so as not to be the controlling phase.

For effective performance, several characteristics of the aggregates, ranging from their mechanical and chemical properties to their size distribution, need to be taken into consideration in the aggregate mix design. Moreover, both concrete mixes undergo very different behavior when being placed, with the materials resembling a Newtonian fluid, and when in their hardened configuration, with the materials resembling an elastic solid. Additionally in the case of asphalt, the service temperature range is very important, as the properties of asphalts are temperature-dependent within the usual serviceability temperature range.

In this laboratory, we will examine the basic properties of aggregates that are needed to develop successful concrete mix designs. The properties needed for asphalts are very similar, but sometimes utilize different testing techniques. The primary characteristics that we will look at are the size distribution, specific gravity, absorption, moisture content, and bulk density, all of which will be described and measured in this laboratory exercise. Other important characteristics that will not be addressed in this module are the shape and angularity of the particles, abrasion and impact resistance, chemical stability, as well as the soundness and presence of harmful organics.

Principles

As aggregates are mainly used as fillers and are relatively inexpensive, it is important that they occupy as much volume as possible to minimize the volume of the paste. In the case of concrete mixes, an appropriate size distribution must be achieved in order for the volume of paste to be minimized. A uniform distribution (particles of similar sizes) will require more paste to fill the voids than a properly graded (particles of many sizes) aggregate. A properly graded aggregate contains particles of all sizes such that very little space needs to be filled by the paste. Additionally, the size distribution of particles will have a major influence on the properties of the fresh concrete, including its flowability, or the ability to be easily placed in forms, and finishability, or the ability to obtain a flat surface with good wearability characteristics.

Through many years of field experience and laboratory testing, *gradation curves* have been developed as recommended ranges for the grading of both coarse and fine aggregates. In these curves, the horizontal axis refers to the particle size, with fine aggregates or sands being on the left and coarse aggregates (or rocks) being on the right. The vertical axis represents the cumulative percent of particles smaller than the given size. For practical reasons, the optimum distributions are specified as ranges. For example, very fine sand must have at most 85% of its particles with a no.16 size (1.18 mm) or below, while very coarse sand must have at most 55% of its particles below this size. Practical aggregate mixes thus will have about 55% to 85% of its particles passing the 1.18 mm sieve.

For both types of aggregates, these ranges are defined by running sieve tests with sieves at specified standard sizes and in descending order of sieve openings in order to determine the amounts of aggregates of a given size and their cumulative distribution. The smallest sieve through which the entire amount of aggregate passes is called the *maximum size* of the aggregate, while the sieve through which 95% of the aggregate passes gives the *nominal maximum size* of the aggregate. An important relationship that is hidden within the gradation curves is that the total surface area of the aggregates will need to be coated with water during mixing to obtain proper workability. If there are too many fine particles, the surface area will be high and a lot of water will be used up coating the particles, resulting in a stiffer concrete mix that is harder to place.

For fine aggregates, a *fineness modulus* (FM) is often computed. The fineness modulus is defined as the summation of the percentages retained by weight from the No. 4 to the No. 100 sieves, divided by 100. Typical values for the fineness modulus range from about 2.3 to 3.1, with the former consisting more of fine particles and the latter of coarser particles. The FM can vary greatly with the application. For example, the FM may be as low as 1.8 for use in masonry mortars, which contain no coarse aggregate and which require greater finishability.

Concrete mix designs are very susceptible to water content, and since coarse and fine aggregates are typically stored in the open and exposed to wind and rain, it is necessary to account for even trace amounts of water present in the aggregate. Four environmental conditions are usually recognized. The *oven dry* condition, as the name implies, occurs after the aggregate has been placed in an oven for a sufficiently long time and high temperature, such that all water has evaporated. The *air-dry* condition arises when some, but not all of the inner pores are filled. The *saturated surface dry* (SSD) condition arises when all the internal pores are saturated, but the surface is dry. The SSD condition is the one used as the reference for mix design and is achieved by immersing the aggregates in water until all internal pores are saturated and then drying the

surface of all particles. This can be done with a little effort for the coarse aggregate but is very difficult to do for fine aggregates as it is impossible to get the surface of all of the sand particles dry without drawing out the water from the internal pores. Alternately, the SSD for fine aggregate can be measured using the slump test, as described in the protocol section. For this, a conical mold is filled with sand or aggregate, and then packed. The mold is flipped over and removed. If it slumps slightly, it is in SSD condition. If the mold holds its shape, the aggregate is in *damp* or *wet* condition. The *damp* or *wet* condition occurs after the aggregate has been immersed in water for long enough that all internal pores are saturated, and the surface is wet. In practice, the aggregates will either be in a wet (too much water) or air dry (too little water) with respect to the design SSD condition. Thus, prior to mixing, the amount of water needs to be adjusted.

Although the range of moisture contents from oven dry to wet is small (mostly in the range of 4% to 6%), the amount of aggregates in a typical concrete mix are much larger than those of the water, often in the range of 25 to 1. Thus, even a small difference in the percent water content of the aggregates can have an enormous effect on the total water that needs to be added to maintain a certain water-to-cement ratio, the main variable used to control strength and durability of concrete mixes. The absorption capacity of an aggregate is defined as:

$$\% \text{ Absorption} = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100 \text{ (Eq. 1)}$$

The moisture content of a sample of weight W is defined as:

$$\% \text{ Moisture content} = \frac{W - W_{OD}}{W_{OD}} \times 100 \text{ (Eq. 2)}$$

The bulk specific gravity is defined as the ratio of the mass of a unit volume of aggregate, including the water in voids, to the mass of an equal volume of gas-free distilled water at the stated temperature. This is in contrast to the apparent specific gravity, which has a similar definition but does not include the volume of water in the voids. The bulk specific gravity is an important aggregate characteristic because mixes are often specified by either volume or weight of the constituents, and therefore it is critical to be able to go from one set of measures to the other. Values of specific gravity are referenced as being in either the oven-dry or the saturated surface dry condition. In the former case, the bulk specific gravity is the oven-dry mass divided by the mass of a volume of water equal to the SSD aggregate volume. In the latter case, the SSD bulk specific gravity is the saturated surface-dry mass divided by the mass of a volume of water equal to the SSD aggregate volume. Most aggregates have a bulk specific gravity SSD between 2.3 and 3.0.

Other key characteristics that affect the choice of aggregate sources are chemical inertness and resistance to wear. Chemical inertness is desirable to avoid problems such as sulfate attack and alkali-silicate reactions, which have resulted in substantial losses in the past, as they are problems that surface many years after the concrete was cast. Resistance to wear refers to the ability of the aggregate particles to resist the deterioration from pedestrian and vehicle traffic without undue wear or rutting. Tests for these characteristics are beyond the scope of this laboratory and will not be discussed.

Procedure

Moisture Content and Specific Gravity (for Fine Aggregate)

1. Obtain approximately 1 kg air-dry fine aggregate (sand) and place it in a flat metal pan. The sand should have been dried in an oven at temperatures above 220°F for at least 24 hours to evaporate all water.
2. Bring the fine aggregate to the SSD condition by sprinkling a few drops of water on the air-dry sand and thoroughly mixing.
3. Hold a conical mold firmly on the flat metal pan with the large diameter down.
4. Place a portion of the sand loosely in the mold by filling it to the point of overflow, then heap additional sand above the top of the mold.
5. Lightly tamp the sand into the mold with 25 light drops of the tamping rod. Start each drop about 0.2 in. above the top of the sand. Permit the rod to fall freely on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops evenly over the surface.
6. Clean loose sand from around the base and remove the mold by lifting it vertically. When the sand slumps slightly it indicates that it has reached a saturated surface dry condition. If the cone retains its mold shape, the sand is still in a wet condition and the process needs to be repeated using less water. This is a trial-and-error procedure.
7. Take approximately 400 g of the SSD aggregate. Record exact weight of SSD sample (D).
8. Fill a flask with 500 mL water and record the weight of water and the flask in grams (B). The water temperature should be about 73 ± 3°F (23 ± 1.5°C).
9. Empty the water from the flask and add the entire SSD sand sample to the flask. Fill the flask with water to about 1/2 in. above the aggregate. Apply vacuum and rolling action to eliminate the air entrapped in the aggregate. This action will take at least 5 minutes.
10. Fill the flask with water up to 500 mL mark. Record the total weight (in grams) of the flask plus the water plus the aggregate (C).
11. Calculate the Bulk Specific Gravity (SSD) based on the weights B, C, D, and compare the calculated value with the typical value to ensure that the data obtained is accurate.
12. Pour the entire contents of the flask into a pan and place it in oven. Additional tap water may be used as necessary to wash all the aggregate out of the flask. After 24 hours, return and measure the weight of the oven-dry aggregate (A).

Sieve Analysis (for Fine Aggregate)

1. Obtain the proper weight of dry aggregate. For fine aggregate, use about 400 grams.
2. Assemble 8" diameter size sieves in the following order: #4, #8, #16, #30, #50, #100, pan.

- Place the aggregates in the top of the sieve stack and cover with the lid. Properly secure the sieves in the mechanical shaker and turn on the shaker for five minutes.
- Weigh the materials that are retained on each of the sieves, including the weight retained on the pan, and record on the data sheet. If the sum of these weights is not within 0.1% times the number of sieves used (0.6%) of the original sample weight, the procedure should be repeated. Otherwise, **use the sum of the weight retained in the pan** to calculate the percentage retained on each sieve.
- Compute the cumulative percentage retained on and the percentage passing each sieve. Plot the gradation curves for the fine aggregates from the experiment on the gradation chart as shown below in the example plot below.
- Compute the Fineness Modulus for the fine aggregate.

Results

Table 1: Fine Aggregate Moisture Test Data

Oven dry weight (A)	486.0 g
Weight of flask + water (B)	617.4 g
Weight of flask + water + sample (C)	926.8 g
SSD weight in air (D)	502.3 g

From the above data (Table 1), the specific gravity values and absorption are calculated as follows (Table 2):

Apparent Specific Gravity (dry) = $A / (B + A - C)$

Bulk Specific Gravity (dry) = $A / (B + D - C)$

Bulk Specific Gravity (SSD) = $D / (B + D - C)$

Absorption = $((D - A) / A) \times 100\%$

Table 2: Summary of Moisture Test Results

Apparent Specific Gravity (dry)	2.75
Bulk Specific Gravity (dry)	2.52
Bulk Specific Gravity (SSD)	2.60
Absorption %	3.35%

Table 3 illustrates the calculation of the fineness modulus. An interpretation of the fineness modulus might be that it represents the (weighted) average sieve of the group upon which the material is retained, No. 100 being the first, No. 50 the second, etc. Thus, for sand with a FM of 3.00, sieve No. 30 (the third sieve) would be the average sieve size upon which the aggregate is retained. In our case, a fineness modulus of 2.92 indicates that there are many fine particles in our aggregate sample, as a high fineness modulus indicates that many particles were trapped in the smaller sieves.

Table 3: Sample Calculation in Determining Fineness Modulus

Sieve No.	Wt. Retained	Cumulative Wt. Retained	Cumulative % Retained
4	30	30	12.2
8	40	70	28.5
16	30	100	40.7
30	35	135	54.9
50	45	180	73.2
100	50	230	93.5
200	6	236	95.9*
Pan	10	246	100

Fineness Modulus of Sand = #Cumulative % retained/100

= $(12.2 + 28.5 + 40.7 + 54.9 + 73.2 + 93.5) / 100 = 3.02$

* #200 sieve should not be included in computing the FM.

Applications and Summary

Three important characteristics of aggregates used in concrete mixes were examined in this laboratory exercise. The first is the moisture content and absorption capacity. These quantities are needed to properly determine the amount of water to be added to a concrete mix. The second characteristic is the specific gravity. This value is needed because it is sometimes necessary to go from volumes to weights and vice versa in batching concrete mixes. The third characteristic is the size distribution or gradation. A suitable gradation of an aggregate in a Portland cement concrete mixture is desirable in order to secure workability of the concrete mix and economy in the use of cement. For asphalt concrete, suitable

gradation will not only affect the workability of the mixture and economy in the use of asphalt, but also will significantly affect the strength and other integral properties.

In the design of concrete and asphaltic mixes, it is always desirable to maximize the use of fine and coarse aggregates, as they are the least expensive component of these mixes. Concrete mixes are used in many construction projects, ranging from building bridges to power plants and industrial facilities. Appropriate use of gradation, moisture content, and the fineness modulus will result in durable and efficient infrastructure projects.