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TechNote

Aggregate Suspension Mixture Proportioning Method

Keywords: durability; optimal grading; packing density; proportioning; shape-angularity factor; water-powder ratio; workability.

Introduction

This document describes the aggregate suspension mixture proportioning method. The method is suitable for normalweight concrete with workability ranging from zero-slump to self-consolidating. This method may not be suitable for mass concrete mixture proportioning. It is adapted from a method originally published by Koehler and Fowler (2007).

The aggregate suspension mixture proportioning method is based on the representation of concrete as a suspension of aggregates in paste and air, as depicted schematically in Fig. 1. All solid material finer than the No. 200 (75 µm) sieve is considered to be part of the powder and, subsequently, the paste.

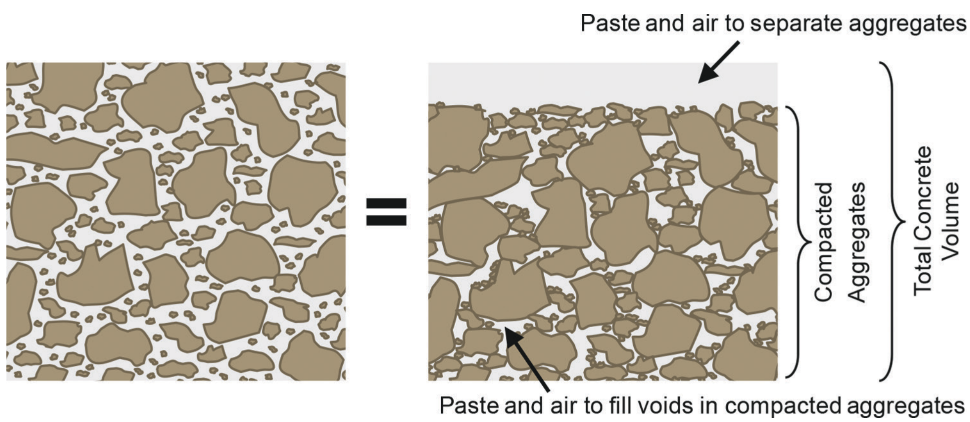

Fig. 1—Concrete as a suspension of aggregate in paste and air.

To proportion a concrete mixture, the optimal combination of aggregates for the application is selected based on grading, size, shape, angularity, and texture. Next, the total volume of paste and air required for the selected aggregates is determined. Then, the composition of paste and air—namely the relative amounts of water, each powder material, and air—is optimized to achieve the desired concrete rheology and hardened properties. Lastly, trial batches are used to make adjustments. Although this document discusses concrete rheology, measurements of rheology are not required to perform this method. Guidance on measuring rheology is available in ACI 238.1R.

Key features of the method include:

a) The aggregates are selected on a combined basis, rather than individually.

b) The volumes of aggregates and of paste and air are selected based on the properties of the combined aggregates. Aggregates with desired grading, shape, angularity, and texture for the application will typically result in less volume of paste needed.

c) All material finer than the No. 200 (75 µm) sieve is considered part of the powder content and, thus, part of the paste. This material includes fines from the aggregate and separately added fines, such as ground limestone filler.

d) The water-powder ratio (w/p) is considered when adjusting workability and the water-cementitious materials ratio (w/cm) is considered when aiming to achieve desired hardened properties. The difference between w/p and w/cm is attributable to noncementitious fines such as ground limestone filler and other mineral fillers.

Calculations should be performed in a computer application. Use of this method results in proportions based on aggregates in saturated surface-dry (SSD) condition. The user should make corrections for aggregate moisture content when making trial or production batches.

Use of this proportioning method may result in otherwise acceptable but different proportions than those determined in ACI 211.1.

Definitions

angularity—sharpness of corners and edges of a particle.

packing density—volume of solid particles divided by total bulk volume.

paste volume—volume of water and powder, excluding air.

passing ability—ease with which concrete can pass among various obstacles and narrow spacing in the formwork without blockage.

plastic viscosity—for Bingham materials, such as most concretes, the difference between shear stress and yield stress divided by shear rate.

powder—solid materials finer than approximately the No. 200 (75 μm) sieve, including cement, supplementary cementitious materials (SCMs), mineral fillers, and aggregate fines.

segregation resistance (stability)—ability of a material to maintain homogeneous distribution of its various constituents during its flow and setting.

shape—relative dimensions of a particle; common descriptors include flatness, elongation, and sphericity.

slump flow—a measure of workability of self-consolidating concrete determined by filling a slump cone with concrete, removing the slump cone, and measuring the horizontal diameter that concrete flows.

texture—roughness of a particle on a scale smaller than that used for shape and angularity.

yield stress—a critical shear stress value below which an ideal plastic or viscoplastic material behaves like a solid (that is, will not flow); once the yield stress is exceeded, a plastic material yields, whereas a viscoplastic material flows like a liquid.

Notation

$DRBD$ = dry-rodded bulk density, lb/ft^3 (kg/m^3)
m_{cement} = mass of cement, lb (kg)
m_{cm} = mass of cementitious materials, lb (kg)
m_{filler} = mass of filler, lb (kg)
m_{powder} = mass of powder, lb (kg)
m_{SCM} = mass of SCM, lb (kg)
p_i = volume of aggregate fraction i divided by the total aggregate volume
SG = specific gravity
SG_{cement} = specific gravity of cement
SG_{filler} = specific gravity of filler
SG_{OD} = oven-dry specific gravity
SG_{SCM} = specific gravity of supplementary cementitious material
SG_{SSD} = saturated surface-dry specific gravity
$SG_{SSD\text{-}coarse}$ = saturated surface-dry specific gravity of coarse aggregate
$SG_{SSD\text{-}fine}$ = saturated surface-dry specific gravity of fine aggregate
$SG_{SSD\text{-}intermediate}$ = saturated surface-dry specific gravity of intermediate aggregate
V_{air} = volume percentage of air, %
V_{coarse} = volume percentage of coarse aggregate, %
V_{fine} = volume percentage of fine aggregate, %
$V_{intermediate}$ = volume percentage of intermediate aggregate, %
$V_{minimum\ paste+air}$ = minimum volume percentage of paste and air, %
$V_{minimum\ spacing\ paste+air}$ = minimum volume percentage of spacing paste and air, %
V_{paste} = volume percentage of paste, %
V_{water} = volume percentage of water, %
w/c = water-cement ratio
w/cm = water-cementitious materials ratio
w/p = water-powder ratio
ρ_{water} = density of water, lb/ft^3, kg/m^3
$\%_{coarse\text{-}to\text{-}total\ aggregate}$ = coarse aggregate as a percent of total aggregate volume, %
$\%_{fine\text{-}to\text{-}total\ aggregate}$ = fine aggregate as a percent of total aggregate volume, %
$\%_{intermediate\text{-}to\text{-}total\ aggregate}$ = intermediate aggregate as a percent of total aggregate volume, %
$\%voids_{compacted\ aggregate}$ = percentage voids in compacted aggregate, %

Design criteria

Determine all relative design criteria before selecting proportions. Design criteria include performance requirements for workability, strength, dimensional stability, and durability; and prescriptive requirements such as limits on *w/cm* and cementitious materials content.

Methodology

Step 1: Select the maximum size of aggregate

Select the largest maximum size of aggregate that is practical for the application. As required by ACI 318, the nominal maximum size of aggregate should not exceed:

a) One-fifth of the narrowest dimension between sides of forms;

b) One-third the depth of slabs; or

c) Three-fourths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands.

Increased maximum size of aggregate typically results in increased packing density of the combined aggregate, reduced concrete plastic viscosity, increased concrete slump and slump flow, increased segregation potential, and reduced passing ability.

Step 2: Select combined aggregates

Select the relative amounts of fine, intermediate, and coarse aggregates based on grading, shape, angularity, and texture. The selection of aggregates should balance each of these factors. For example, adding a poorly shaped aggregate to improve grading could have an overall negative effect on concrete. In most cases, the combination of aggregates resulting in maximum packing density is not optimal for workability. Instead, a slightly finer grading is typically preferred.

If the combined aggregates contain less than 5 percent passing the No. 200 (75 µm) sieve, this fine material can be considered negligible to the volume of paste and accounted for as part of the combined aggregate. Otherwise, include all aggregate material passing the No. 200 (75 µm) sieve as part of the powder.

Grading—There is no universally optimal grading for concrete, or even a particular type of concrete, such as self-consolidating concrete (SCC). The best grading for a mixture depends on the application and the aggregate. As a starting point, select a blend of fine and coarse aggregate best matching the 0.45 power curve or finer and without an excess or deficiency of material on two consecutive sieves.

The 0.45 power curve, which is shown in Fig. 2, is a plot of percent passing on the vertical axis and sieve sizes raised to the 0.45 power on the horizontal axis. A straight line is drawn from the minimum aggregate size (No. 200 [75 µm] sieve) to the maximum aggregate size (size with approximately 85 percent of the combined material passing). Gradings finer than the 0.45 power curve are also usually preferred to coarser gradings because they reduce harshness. Finer grading targets are achieved by reducing the exponent to less than 0.45. Exponents of 0.35 and 0.40 are used to achieve satisfactory workability and paste volume.

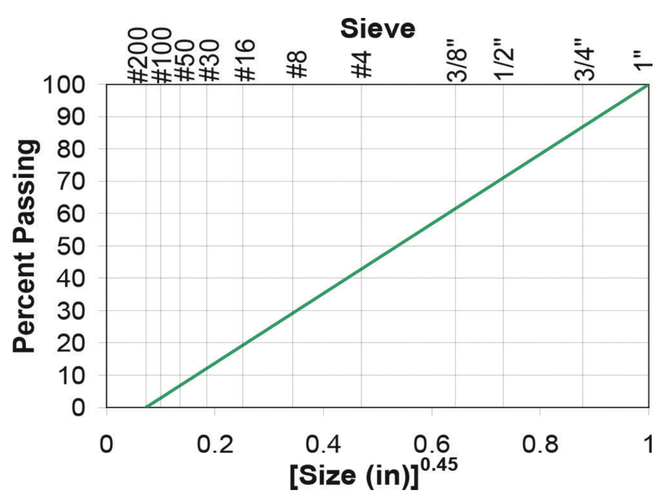

Fig. 2—0.45 power curve for combined aggregate. (The curve passes through the No. 200 [75 µm] sieve.) (1 in. = 25.4 mm.)

In addition, the sum of material retained on any two consecutive sieves should not be less than 10 percent or greater than 35 percent, with the exception of the combination of the No. 200 (75 µm) sieve and pan. The use of gap gradings, where the amount of material on two consecutive sieves is less than 10 percent, can result in increased packing density and reduced water or admixture demand. Such gradings, however, should be used with caution because they may increase segregation potential.

Shape, angularity, and texture—Aggregates that are equidimensional (cubical shaped) and well-rounded (low angularity) result in requiring less water, admixture, paste, and air volume, or combination thereof to reach a given workability. Aggregates that are more angular and have rough texture typically result in higher compressive strength for a given *w/cm*. The choice among different aggregate sources varying in shape, angularity, and texture depends on the application and the specific materials.