Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete

Reported by ACI Committee 221

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This guide presents information on selection and use of normal weight and heavyweight aggregates in concrete. The selection and use of aggregates in concrete should be based on technical criteria as well as economic considerations and knowledge of types of aggregates generally available in the area of construction. The properties of aggregates and their processing and handling influence the properties of both plastic and hardened concrete. The effectiveness of processing, stockpiling, and aggregate quality control procedures will have an effect on batch-to-batch and day-to-day variation in the properties of concrete. Aggregates that do not comply with the specification requirements may be suitable for use if the properties of the concrete using these aggregates are acceptable. This is discussed under the topic of marginal aggregates (Chapter 6). Materials that can be recycled or produced from waste products are potential sources of concrete aggregates; however, special evaluation may be necessary.

Keywords: aggregate grading; aggregate shape and texture; air entrainment; blast-furnace slag; bleeding (concrete); coarse aggregates; concretes; crushed stone; degradation resistance; density (mass/volume); fine aggregates; mix proportioning; modulus of elasticity; pumped concrete; quality control; recycling; shrinkage; strength; tests; workability.

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CHAPTER 1—INTRODUCTION

Aggregates, the major constituent of concrete, influence the properties and performance of both freshly mixed and hardened concrete. In addition to serving as an inexpensive filler, they impart certain positive benefits that are described in this guide. When they perform below expectation, unsatisfactory concrete may result. Their important role is frequently overlooked because of their relatively low cost as compared to that of cementitious materials.

This guide is to assist the designer in specifying aggregate properties. It also may assist the aggregate producer and user in evaluating the influence of aggregate properties on concrete, including identifying aspects of processing and handling that have a bearing on concrete quality and uniformity. The report is limited primarily to natural aggregates, crushed stone, air-cooled blast-furnace slag, and heavyweight aggregate. It does not include lightweight aggregates. The types of normal weight and heavyweight aggregates listed are those covered by ASTM C 33, ASTM C 63, and other standardized specifications. In most cases, fine and coarse aggregate meeting ASTM C 33 will be regarded as adequate to insure satisfactory material. Experience and test results of those materials are the basis for discussion of effects on concrete properties in this guide. Other types of slag, waste materials, and marginal or recycled materials may require special investigations for use as concrete aggregate. Definitions and classifications of concrete aggregates are given in ACI 116R.

This guide is divided into six major parts: (1) properties of hardened concrete influenced by aggregate properties, (2) properties of freshly mixed concrete influenced by aggregate properties, (3) aspects of processing and handling which have a bearing on concrete quality and uniformity, (4) quality control, (5) marginal and recycled aggregates, and (6) heavyweight aggregate.

While a designer or user does not normally specify the methods and equipment to be used in aggregate processing or beneficiation, processing may influence properties important to performance. Therefore, Chapter 4 is included not only as a guide for aggregate producers but for the benefit of anyone who must frequently handle aggregates.

Aggregate selection should be based on technical criteria and economic considerations. When available in sufficient detail, service records are a valuable aid to judgment. They are most useful when the structures, concrete proportions, and exposure are similar to those anticipated for the proposed work. Petrographic analysis can be used to determine whether the aggregate to which the service record applies is sufficiently similar to the proposed aggregate for the service record to be meaningful. It also provides useful information on acceptability of aggregate from a new source. As circumstances change or as experience increases, it may be desirable to reexamine acceptance criteria and to modify or change them accordingly.

Poor performance of hardened concrete discussed in Chapter 2 may not be the fault of the aggregate. For example, an improper air void system in the cement paste can result in failure of a saturated concrete exposed to freezing and thawing conditions. Chemical agents, such as sulfate, may cause serious deterioration even though the aggregate used is entirely satisfactory.

Table 1.1 lists concrete properties and relevant aggregate properties that are discussed in this guide.

Test methods are indicated in Table 1.1 and are listed with their full title and source in Chapter 8. In many cases, the aggregate properties and test methods listed are not routinely used in specifications for aggregates. Their use may be needed only for research purposes, for investigation of new sources, or when aggregate sources are being investigated for a special application. Typical values are listed only for guidance. Acceptable aggregates may have values outside the ranges shown, and conversely, not all aggregates within these limits may be acceptable for some uses. Therefore, service records are an important aspect in evaluating and specifying aggregate sources. Some of the more routinely performed tests are described in ACI Education Bulletin E1.

A summary of data on aggregate properties and their influence on the behavior of concrete is contained in *Significance of Tests and Properties of Concrete and Concrete Making Materials* (ASTM, 1994). Information on exploration of aggregate sources, production, and rock types is in Chapter 2 of the *Concrete Construction Handbook* (Waddell, 1974).

Table 1.1—Properties of concrete influenced by aggregate properties

Relevant aggregate property	Standard test	Typical values	Text reference	Comments
Concrete property—Durability: Resistance to freezing and thawing				
Sulfate soundness	ASTM C 88	Fine agg - 1 to 10% Coarse agg - 1 to 12%	2.1.1	Magnesium sulfate ($MgSO_4$) gives higher loss percentages than sodium sulfate ($NaSO_4$); test results have not been found to relate well to aggregate performance in concrete.
Resistance to freezing and thawing	ASTM C 666 and CRD-C-114 - Performance of aggregate in air-entrained concrete by rapid cycles	Durability factor of 10 to 100%	2.1.1	Normally only performed for coarse aggregate since fine aggregate does not affect concrete freezing and thawing to any large extent; results depend on moisture conditioning of coarse aggregates and concrete.
	ASTM C 682 - Aggregate in concrete, dilation test with slow freeze	Period of frost immunity from 1 to more than 16 weeks		Results depend on moisture conditioning of aggregate and concrete. For specimens that do not reach critical dilation in the test period, no specific value can be assigned.
	AASHTO T 103 - Test of unconfined aggregate in freeze-thaw	—		Used by some U.S. Departments of Transportation; test is not highly standardized between agencies. Results may help judge quality of aggregate in regional area.
Absorption	ASTM C 127 - Coarse aggregate	0.2 to 4%	2.1.1	Typical values are for natural aggregates. Most blast-furnace slag coarse aggregates are between 4 and 6%, fine aggregate about one percent less.
	ASTM C 128 - Fine aggregate	0.2 to 2%		Some researchers have found a general trend of reduced durability for natural coarse aggregate in concrete exposed to freezing and thawing with increased absorption.
Porosity	None	1 to 10% by volume for coarse aggregate	2.1.1	Porosity - The ratio, usually expressed as a percentage, of the volume of voids in a material to the total volume of the material, including the voids.
Pore structure	None	—	2.1.1	Mercury intrusion methods and gas or vapor absorption techniques can be used to estimate pore size distribution and internal surface area of pore spaces.
Permeability	None	—	2.1.1	Permeability of aggregate materials to air or water is related to pore structure.
Texture and structure and lithology	ASTM C 295 - Petrographic examination	Quantitative report of rock type and minerals present		Estimation of the resistance of the aggregate to freezing damage; type of particles that may produce popouts or disintegration
Presence of clay and fines	ASTM C 117 - Amount by washing	Fine agg - 0.2 to 6% Coarse agg - 0.2 to 1%	3.70	Larger amounts of material finer than the 75 µm sieve can be tolerated if free of clay minerals. Does not include clay balls.
	ASTM D 2419 - Sand equivalent	50 to 90%		Used only for fine aggregate; the presence of active clay may increase water demand or decrease air entrainment.
Resistance to degradation	ASTM C 131 and C 535	15 to 50% loss	2.1.4	These tests impart a good deal on impact to the aggregate as well as abrasion; therefore, results not directly related to abrasion test of concrete.
	C 1137			Degradation of fine aggregate
Abrasion resistance	ASTM C 418 - Sand blasting	Volume of concrete removed per unit area	2.1.4	These tests are performed on concrete samples containing the aggregate(s) under investigation and may provide the user with a more direct answer.
	ASTM C 779 - Three procedures	Depth of wear with time		No limit established. Test provides relative differences.
	ASTM C 944 - Rotating cutter	Amount of loss in time abraded		No limit established. Test provides relative differences.
	ASTM C 1138 - Underwater method	Abrasion loss vs. time		
Durability index	ASTM D 3744	Separate values are obtained for fine and coarse aggregate ranging from 0 to 100		This test was developed in California and indicates resistance to the production of clay-like fines when agitated in the presence of water.
Concrete property—Durability: Alkali-aggregate reactivity				
Aggregate reactivity	ASTM C 295 - Petrographic examination	Presence and amount of potentially reactive minerals	2.1.5	For important engineering works. Tests for potential expansion due to aggregate reactivity in moist exposure are often conducted using the cement-aggregate combinations expected on the project.
	ASTM C 227 - Mortar bar expansion	0.01 to 0.20% or more after 6 months	2.1.5.1	Both fine and coarse aggregate can be tested. Coarse aggregates must be crushed to fine aggregate sizes.