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Aggregates for Concrete

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Aggregates for Concrete

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Aggregates for Concrete

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Aggregate properties and gradation significantly affect workability and finishability of freshly placed concrete and properties of hardened concrete including compressive strength, durability and abrasion resistance. Properties and accepted test methods discussed in this bulletin include: aggregate gradation; fine and coarse aggregate fineness moduli; relative bulk densities of wet, saturated surface dry, air-dry, and oven-dry aggregates; moisture absorption; shape angularity and surface texture; abrasion and impact resistance; permeability resistance to freeze thaw cycles and alkali-silica reaction; and chemical stability. Aggregate types including normalweight, lightweight and heavyweight natural aggregate; blast furnace slag aggregates; and recycled aggregates from crushed reclaimed concrete pavements are covered. Examples are provided on how to calculate and evaluate fineness modulus, batch mixture proportions adjusted for aggregate absorption, batch mixing water proportions, water cementitious ratios and bulk densities. Sampling aggregate methods to estimate average aggregate properties of large volumes or stockpiles, batches, or truck-loads of aggregates are also covered.

Keywords: abrasion resistance, absorption, aggregate angularity, aggregate gradation, aggregate surface texture, air-dry bulk density, alkali-silica reaction, batch mixture proportioning, blast-furnace slag aggregate, bulk density, compaction, fineness modulus, heavyweight aggregate, lightweight aggregate, mixing water, normalweight aggregate, oven-dry bulk density, recycled aggregate, relative bulk density, saturated surface-dry bulk density, sampling, surface moisture, water-cementitious ratio.

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CHAPTER 1—INTRODUCTION

Concrete is a mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials. Aggregates are granular materials such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag. Coarse aggregate is that portion retained on the 4.75 mm (No. 4) sieve. Fine aggregate is that portion passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 μ m (No. 200) sieve. Aggregate classifications include normalweight, lightweight, or heavyweight. The selection of aggregate to be used for concrete mixtures depends on the intended concrete properties. For instance, heavyweight aggregates such as barite, magnetite, hematite, limonite, ilmenite, iron, or steel are used in heavyweight concrete mixtures. Heavyweight concrete is used for applications such as radiation shielding, ballast for offshore pipelines, or other similar applications. Lightweight aggregate, such as expanded or sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, slag, pumice, scoria, volcanic cinders, tuff, diatomite, sintered fly ash, or industrial cinders, are used in lightweight concrete applications.

Coarse and fine aggregate constitute approximately 60 to 75 percent of the concrete mixture. Therefore, the properties of the aggregates have a significant influence on the properties of the concrete mixture. Aggregate properties significantly affect the workability of plastic concrete, and the durability, strength, volume stability, thermal properties, and density of hardened concrete.

This bulletin describes types of aggregates normally used in concrete, aggregate properties affecting performance of the concrete, tests used to measure aggregate properties, and methods used to obtain test samples. Normalweight, lightweight, and heavyweight aggregates are discussed.

CHAPTER 2—CLASSIFICATION OF AGGREGATES

Aggregates may be broadly classified as natural or manufactured, both with respect to source and method of preparation. Natural sands and gravels are the product of weathering and the action of wind or water whereas manufactured crushed fine aggregate and crushed stone are produced by crushing natural stone. Screening and washing may be used to process either natural or manufactured aggregates. Aggregates may be produced from igneous, sedimentary, or metamorphic rocks, but the presence or absence of any geological type does not, by itself, make an aggregate suitable or unsuitable for use in concrete. The acceptance of an aggregate for use in concrete on a particular job or in a specification should be based on specific information obtained from tests used to measure the aggregate quality, its service record, or both. A typical consensus specification for both fine and coarse concrete aggregate is [ASTM C33/C33M](#).

Manufactured aggregates may be either by-products of an industrial process, such as blast-furnace slag, or products of processes developed to manufacture aggregates with special properties, such as expanded clay, shale, or slate that are used for lightweight aggregates. Some lightweight aggregates such as pumice or scoria also occur naturally.

Other classifications of aggregates may be based on bulk density (previously termed unit weight) ([ASTM C33/C33M](#); [ASTM C330/C330M](#); and [ASTM C637](#)), mineralogical composition ([ASTM C294](#)), and particle shape; these, as well as the ones previously discussed, serve mainly as aids in describing an aggregate. To understand the role played by aggregate in the performance of concrete, it is necessary to define specific aggregate properties and show their effect on concrete properties.

CHAPTER 3—AGGREGATE PROPERTIES AND TEST METHODS

3.1—Grading

3.1.1 Definition and test method—Grading refers to the distribution of particle sizes present in an aggregate. The grading is determined in accordance with [ASTM C136/C136M](#), “Sieve Analysis of Fine and Coarse Aggregates.” A representative sample of the aggregate that has been properly prepared is shaken through a series of sieves nested one above the other in order of size, with the sieve having the largest openings on top and the one having the smallest openings at the bottom ([Fig. 3.1.1a](#)). These wire-cloth sieves have square openings. A pan is used to catch material passing the smallest sieve. Sieve sizes commonly used for concrete aggregates are detailed in [Table 3.1.1a](#), and various physical properties of normalweight aggregates, with typical range values, are shown in [Table 3.1.1b](#).

Coarse and fine aggregates are generally sieved separately. That portion of an aggregate passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 μ m (No. 200) sieve is called fine aggregate or sand, and larger aggregate is called coarse aggregate. Coarse aggregate may be available in several different size groups, such as 19 to 4.75 mm (3/4 in. to No. 4), or 37.5 to 19 mm (1-1/2 to 3/4 in.). [ASTM C33/C33M](#), “Standard Specification for Concrete Aggregates,” lists several such size groups using the simplified practice

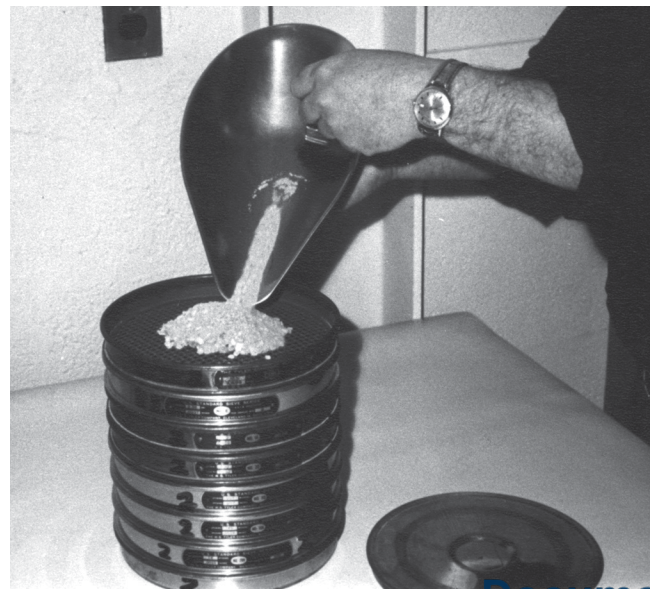


Fig. 3.1.1a—Nest of sieves.

Table 3.1.1a—Sieves commonly used for concrete aggregate sieve analysis

ASTM E11 sieve designation		Nominal sieve opening	
		mm	in.
Coarse sieves			
75.0 mm	3 in.	75.0	3
63.0 mm	2-1/2 in.	63.0	2.5
50.0 mm	2 in.	50.0	2
37.5 mm	1-1/2 in.	37.5	1.5
25.0 mm	1 in.	25.0	1
19.0 mm	3/4 in.	19.0	0.75
12.5 mm	1/2 in.	12.5	0.5
9.5 mm	3/8 in.	9.5	0.375
Fine sieves			
4.75 mm	No. 4	4.75	0.1870
2.36 mm	No. 8	2.36	0.0937
1.18 mm	No. 16	1.18	0.0469
600 μm^*	No. 30	0.60	0.0234
300 μm	No. 50	0.30	0.0117
150 μm	No. 100	0.15	0.0059
75 μm	No. 200	0.075	0.0029

*Note: 1000 μm = 1 mm.

Table 3.1.1b—Ranges in physical properties for normalweight aggregates used in concrete

Property		Typical ranges
Fineness modulus of fine aggregate		2.0 to 3.1
Nominal maximum size of coarse aggregate		37.5 to 9.5 mm (1-1/2 to 3/8 in.)
Absorption		0 to 8 percent
Bulk relative density (bulk specific gravity)		2.30 to 2.90
Dry-rodded bulk density* of coarse aggregate		1280 to 1920 kg/m ³ (80 to 120 lb/ft ³)
Surface moisture content	Coarse aggregate	0 to 2 percent
	Fine aggregate	0 to 10 percent

*Previously dry-rodded unit weight.

recommendation (SPR) number designation. The number and size of sieves selected for a sieve analysis depends on the particle sizes present in the sample and the grading requirements specified. After sieving, the mass of material retained on each sieve and in the pan is obtained using a balance accurate to 0.1 percent of the test-sample mass. Results are recorded in tabular form and typically reported as mass retained on each sieve, individual percent retained on each sieve, cumulative percent retained, and cumulative percent passing each sieve. For an accurate determination of the amount of material finer than the 75 μm (No. 200) sieve, a specimen is tested in accordance with **ASTM C117**.

Grading charts are drawn to show the results of a sieve analysis graphically. The percent passing is usually plotted on the vertical axis whereas the sieve sizes are plotted on the horizontal axis. Upper and lower limits specified for the allowable percentage of material passing each sieve may also be included on the grading chart. **Figure 3.1.1b** shows a typical grading chart for coarse and fine aggregates having grading calculated in **3.1.1.1** and **3.1.1.2**. Combined gradation charts, which illustrate the particle size distribution for a mixture of fine and coarse aggregate, are useful in concrete mixture optimization. Combined gradation charts can identify gaps or deficiencies and an excess in a particular size range.

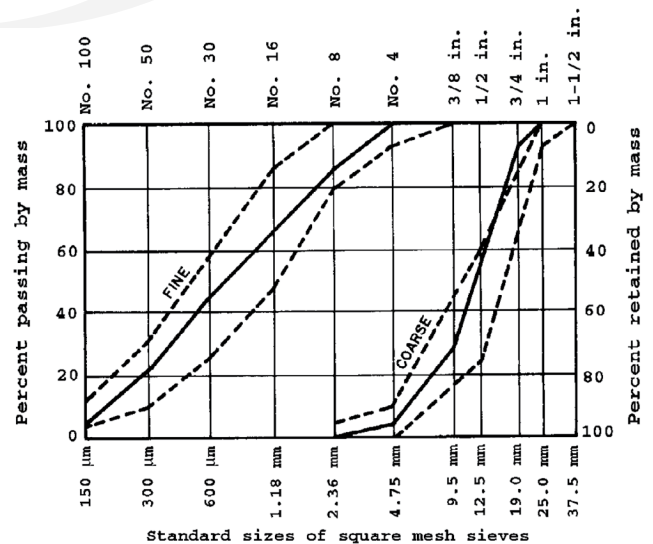


Fig. 3.1.1b—Typical grading chart. Dashed lines indicate limits specified in **ASTM C33/C33M for fine aggregates and for 25.0 mm (1 in.) coarse aggregate.**

3.1.1.1 Example calculation for sieve analysis of fine aggregate—A sample of fine aggregate with a mass of

Table 3.1.1.1—Example calculation for sieve analysis of fine aggregate

Sieve size	Individual mass retained, g (lb)	Individual percent retained	Cumulative percent retained	Cumulative percent passing
9.50 mm (3/8 in.)	0 (0)	0	0	100
4.75 mm (No. 4)	9.2 (0.020)	2	2	98
2.36 mm (No. 8)	67.6 (0.149)	13	15	85
1.18 mm (No. 16)	101.2 (0.223)	20	35	65
600 μ m (No. 30)	102.2 (0.225)	20	55	45
300 μ m (No. 50)	120.5 (0.266)	24	79	21
150 μ m (No. 100)	93.1 (0.205)	18	97	3
75 μ m (No. 200)	10.2 (0.022)	2	99	1
Pan	4.5 (0.010)	1	100	0
Total	508.5 (1.120)	100	—	—

Notes: Total of masses retained may differ from original sample mass. Because mass of material on each sieve is determined to within 0.1 percent of the total sample mass, maximum difference should not exceed 0.1 percent times the number of mass determinations. In this example, seven mass determinations were made, so the difference should not exceed 0.7 percent. The total of masses retained differs from the mass of the original sample by 2 g, or only 0.4 percent. If the difference was too great, a check would have been made for possible errors in mass determination, calculation, accidental spillage loss, or material stuck in sieve openings. Normally, sieve analysis calculations are recorded to the nearest 0.1 percent and then reported to the nearest 1 percent, except for the percent passing the No. 200 (75 μ m), which is reported to the nearest 0.1 percent.

Table 3.1.1.2—Example calculation for sieve analysis of coarse aggregate

Sieve size	Individual mass retained, g (lb)	Individual percent retained	Cumulative percent retained	Cumulative percent passing
25.0 mm (1 in.)	0 (0)	0	0	100
19.0 mm (3/4 in.)	405 (0.89)	5	5	95
12.5 mm (1/2 in.)	2850 (6.28)	35	40	60
9.5 mm (3/8 in.)	2435 (5.37)	30	70	30
4.75 mm (No. 4)	2030 (4.48)	25	95	5
2.36 mm (No. 8)	375 (0.83)	5	100	0
Pan	35 (0.08)	0	100	0
Total	8130 (17.93)	100	—	—

510.5 g (1.125 lb) is passed through the sieves shown in [Table 3.1.1.1](#) and the masses retained on each sieve are as shown.

The total mass of the material after sieving should check closely with the original mass of the sample placed on the sieves. If the amounts differ by more than 0.3 percent, based on the original dry sample mass, the results should not be used for acceptance purposes.

Individual percent retained is the percentage of material contained between successive sieves, recorded to the nearest whole percent. It is calculated by dividing the mass retained on each sieve by the sum of the masses retained on each sieve and the pan and multiplying by 100.

Cumulative percent retained is calculated by successively summing the numbers in the individual percent retained column. The cumulative percent passing is calculated by subtracting the cumulative percent retained from 100.

3.1.1.2 Example calculation for sieve analysis of coarse aggregate—A sample of coarse aggregate with a mass of 8145 g (17.96 lb) is passed through the sieves shown in [Table 3.1.1.2](#) and the masses retained on each sieve are as shown.

The total of masses retained differs from the original sample mass. Six mass determinations were made so the difference should not exceed 0.6 percent of the total sample mass. The total of masses retained differs from the original sample mass by 15 g (0.033 lb) or only 0.2 percent. Refer to [3.1.1.1](#) for steps to be taken if the difference was too great. All other calculations are carried out in a manner identical to that shown in [3.1.1.1](#).

If the test sample was first tested by the [ASTM C117](#) test method, include the mass of material finer than the 75 μ m

(No. 200) size that was obtained by washing in the sieve analysis calculation. Use the total dry sample mass prior to washing as the basis for calculating all the percentages.

3.1.2 Fineness modulus—Fineness modulus is often computed using the sieve analysis results. The fineness modulus is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100. The specified sieves are the 75.0, 37.5, 19.0, and 9.5 mm (3, 1-1/2, 3/4, and 3/8 in.) and 4.75 mm, 2.36 mm, 1.18 mm, 600 μ m, 300 μ m, and 150 μ m (No. 4, 8, 16, 30, 50, and 100). Note that the lower limit of the specified series of sieves is the 150 μ m (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve in the following. The coarser the aggregate, the higher the fineness modulus. For sands used in concrete, the fineness modulus generally ranges from 2.3 to 3.1 per [ASTM C33/C33M](#). In some regions, finer or coarser sands are used in concrete mixtures with fineness modulus of 2.0 and 3.1, respectively.

3.1.2.1 Example calculation of fineness modulus for fine aggregate—Although fineness modulus is most commonly computed for fine aggregates ([Table 3.1.2.1](#)), the fineness modulus of coarse aggregate is needed for some proportioning methods. It is calculated in the same manner but care must be taken to exclude sieves that are not specified in the definition (for example, 25.0 and 12.5 mm [1 and 1/2 in.] sieves) and to include all of the specified finer sieves.

3.1.2.2 Example calculation of fineness modulus for coarse aggregate is shown in [Table 3.1.2.2a](#). The 25 and 12.5 mm (1 and 1/2 in.) sieves were used in the sieve

Table 3.1.2.1—Example calculation of fineness modulus of fine aggregate

Sieve size	Total percent retained
9.5 mm (3/8 in.)	0
4.75 mm (No. 4)	2
2.36 mm (No. 8)	15
1.18 mm (No. 16)	35
600 μ m (No. 30)	55
300 μ m (No. 50)	79
150 μ m (No. 100)	97
Sum	283

Notes: Fineness modulus = $283/100 = 2.83$.

All of the sieve sizes for determining fineness modulus below the maximum size (in this case nothing retained on the 9.50 mm [3/8 in.]) should be included and all other sieves not used for determining fineness modulus should be excluded. For example, if a 75 μ m (No. 200) or 12.5 mm (1/2 in.) sieve were included in the sieve analysis, the cumulative percent retained on those sieves would not be included in the fineness modulus calculation.

analysis, they are not included in the calculation. Because the total percent retained on the 2.36 mm (No. 8) sieve was 100 percent, 100 percent will also be retained on the smaller sieves specified in the fineness modulus definition. Thus, the calculation is as shown in Table 3.1.2.2b.

3.1.2.3 Example calculation of grading when two or more aggregates are combined—Three aggregates as shown in Table 3.1.2.3a are combined in the mass percentages indicated. For the given individual aggregate grading, determine the grading of the combined aggregate.

The combined grading is shown in Table 3.1.2.3b. The percent passing is calculated for each of the sieve sizes as follows. Using the 9.5 mm (3/8 in.) sieve as an example, 100 percent of Aggregate 1 passes the 9.5 mm (3/8 in.) sieve, but only 35 percent of this aggregate is used in the mixture. Similarly, only 25 and 40 percent of Aggregate 2 and 3, respectively, are used. Therefore,

- Percent passing of Aggregate 1 in the combined aggregate = 35 percent $\times$ 100 = 35 percent
- Percent passing of Aggregate 2 in the combined aggregate = 25 percent $\times$ 89 = 22 percent
- Percent passing of Aggregate 3 in the combined aggregate = 40 percent $\times$ 2 = 1 percent
- Percent passing the 9.5 mm (3/8 in.) sieve in the combined aggregate = 58 percent
- Percent retained on the 9.5 mm (3/8 in.) sieve in the combined aggregate = $100 - 58 = 42$ percent

The fineness modulus of the combined aggregate can be determined by adding the percentage retained on the specified series of sieves. In this case, the total percentage retained on the 50.0 mm (2 in.), 25.0 mm (1 in.), 12.5 mm (1/2 in.), and 75 μ m (No. 200) sieves should not be included in the calculation. Therefore

$$\text{Fineness modulus} = 560/100 = 5.60$$

The individual percentage of material between successive sieves is sometimes of interest. This can be determined from the grading of the combined aggregate as follows:

- Percent passing the 25.0 mm (1 in.) sieve = 80 percent
- Percent passing the 19.0 mm (3/4 in.) sieve = 70 percent

Table 3.1.2.2a—Example calculation of fineness modulus of coarse aggregate

Sieve size	Cumulative percent retained
25.0 mm (1 in.)	0
19.0 mm (3/4 in.)	5
12.5 (1/2 in.)	40
9.5 mm (3/8 in.)	70
4.75 mm (No. 4)	95
2.36 mm (No. 8)	100

Table 3.1.2.2b—Example calculation of cumulative percent retained of coarse aggregate

Sieve size	Cumulative percent retained
19.0 mm (3/4 in.)	5
9.5 mm (3/8 in.)	70
4.75 mm (No. 4)	95
2.36 mm (No. 8)	100
1.18 mm (No. 16)	100
600 μ m (No. 30)	100
300 μ m (No. 50)	100
150 μ m (No. 100)	100
Sum	670

Note: Fineness modulus = $670/100 = 6.70$.

- Percent of material between the 25.0 and 19.0 mm (1 and 3/4 in.) sieves = $80 - 70 = 10$ percent
10 percent would be the individual percent retained on the 19.0 mm (3/4 in.) sieve.

3.1.3 Maximum size and nominal maximum size—ACI defines the maximum size as the smallest sieve opening through which the entire amount of aggregate is required to pass. The nominal maximum size of aggregate is defined as the smallest sieve opening through which the entire amount of the aggregate is permitted to pass. Aggregate meeting the specification limits in Table 3.1.3 would have a maximum size of 37.5 mm (1-1/2 in.) and a nominal maximum size of 25.0 mm (1 in.).

3.1.4 Significance of aggregate grading—There are several reasons for specifying both grading limits and maximum aggregate size. The aggregate gradation and content will impact properties such as finishability, workability, pumpability, strength, permeability, and shrinkage. Aggregates having a smooth grading curve and neither a deficiency nor an excess of any one particle size will generally produce mixtures with fewer voids between particles. Because cementitious materials are typically more expensive than aggregates, and the cementitious paste requirement for concrete increases with increasing void content of the combined aggregates, it is desirable to keep the void content as low as possible. If there is not enough fine aggregate to fill the voids between coarse aggregate particles, the space must be filled with cementitious paste. These under-sanded mixtures also tend to be harsh and difficult to finish. On the other hand, aggregate combinations with excessive amounts of fine aggregate or excessively fine sands may produce undesirable concretes because of the large space filled by the area of finer particles.

Table 3.1.2.3a—Example grading of aggregates to be combined

Sieve size	Cumulative percent passing		
	Aggregate 1	Aggregate 2	Aggregate 3
50 mm (2 in.)	100	100	100
37.5 mm (1-1/2 in.)	100	100	95
25.0 mm (1 in.)	100	100	51
19.0 mm (3/4 in.)	100	100	25
12.5 mm (1/2 in.)	100	99	8
9.5 mm (3/8 in.)	100	89	2
4.75 mm (No. 4)	99	24	0
2.36 mm (No. 8)	85	3	—
1.18 mm (No. 16)	65	0	—
600 μ m (No. 30)	38	—	—
300 μ m (No. 50)	15	—	—
150 μ m (No. 100)	4	—	—
Sieve size	% Passing		
	Aggregate 1	Aggregate 2	Aggregate 3
75 μ m (No. 200)	1	—	—
Percentage by mass	35	25	40

Table 3.1.2.3b—Calculations for determining mixture proportions from aggregate given in Table 3.1.2.3a

Sieve size	Aggregate 1	Aggregate 2	Aggregate 3	Combined cumulative percent passing	Combined cumulative percent retained	Individual percent retained for combined aggregate
50 mm (2 in.)	35	25	40	100	0 (not included in fineness modulus calculation)	0
37.5 mm (1-1/2 in.)	35	25	38	98	2	2
25.0 mm (1 in.)	35	25	20	80	20 (not included in fineness modulus calculation)	18
19.0 mm (3/4 in.)	35	25	10	70	30	10
12.5 mm (1/2 in.)	35	25	3	63	37 (not included in fineness modulus calculation)	7
9.5 mm (3/8 in.)	35	22	1	58	42	12
4.75 mm (No. 4)	35	6	0	41	59	17
2.36 mm (No. 8)	30	1	—	31	69	10
1.18 mm (No. 16)	23	0	—	23	77	8
600 μ m (No. 30)	13	—	—	13	87	9
300 μ m (No. 50)	5	—	—	5	95	8
150 μ m (No. 100)	1	—	—	1	99	4
75 μ m (No. 200)	0	—	—	0	100 (not included in fineness modulus calculation)	1
				Sum	560	

To understand how surface area increases with increasing aggregate fineness, visualize a 25 mm (1 in.) cube of aggregate. As shown in Fig. 3.1.4a, this cube has a surface area of 3750 mm² (6 in.²) and a volume of 15,625 mm³ (1 in.³). If it is cut into eight 12.5 mm (0.5 in.) cubes, the volume does not

change, but the surface area increases to 7500 mm² (12 in.²). By reducing a large coarse aggregate particle to particles one-half its original size, the surface area of an equal volume (or mass) is twice as great. If it were further reduced to sand size particles, the same volume of 15,625 mm³ (1 in.³)

Table 3.1.3—Typical specification limits for percent passing of aggregates

Sieve size	Specification limits, percent passing
37.5 mm (1-1/2 in.)	100
25.0 mm (1 in.)	95 to 100
12.5 mm (1/2 in.)	25 to 60
4.75 mm (No. 4)	0 to 10
2.36 mm (No. 8)	0 to 5

would have a surface area perhaps 100 times greater than that of the original cube.

When the surface area increases, more cement paste is needed to coat the additional surface; otherwise, the concrete would be too stiff. We might visualize the problem of excessive fineness of the aggregate as being similar to the problem faced by a painter who finds that he has forgotten to paint one side of a house and has only a liter of paint left. He has three choices: 1) he can put the paint on in a thinner coat; 2) he can extend the paint by adding cheap diluents; or 3) he can buy more paint. Each of these options has at least one disadvantage. It takes more effort to paint the side with a thinner layer, the cheap diluents will reduce the quality of the paint, and buying more paint will increase the cost. Similarly, when the aggregate surface area increases, if the cement paste content is left constant, the thinner layers of paste surrounding the aggregate particles results in a stiffer concrete that is harder to place and compact. If the paste is made more fluid by adding water, the concrete strength and durability will suffer, whereas if more cement and water are added, the cost of the concrete increases. Consequently, it is best to avoid adding too much fine aggregate to a concrete mixture and to avoid using extremely fine sand.

The maximum size of coarse aggregate used in concrete also has an effect on surface area and economy. Usually, as the maximum size of well-graded coarse aggregate increases, the amount of paste required to produce concrete of a given slump or consistency decreases. To see why this is true, refer to Fig. 3.1.4b. Shown on the left is a container filled with well-graded aggregate with a maximum size of 12.5 mm (1/2 in.). If some of this material is replaced with 19.0 and 25.0 mm (3/4 and 1 in.) particles, the surface area and the void content decrease. This is because a number of smaller particles and the voids between them are replaced by a single larger particle. If too many larger particles were added, however, there would not be enough fines to fill the voids between them and voids would increase again due to the poor grading. An intermediate aggregate can be used to fill gaps that exist in combined coarse and fine aggregates. The nominal maximum size of aggregate that can be used will be determined by the size and shape of the concrete member and by the clear spacing between reinforcing bars. In general, the nominal maximum aggregate should not be more than one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, or three-fourths of the minimum clear spacing between reinforcing bars. Use of the largest possible maximum size, consistent with placing requirements, is sometimes recommended to

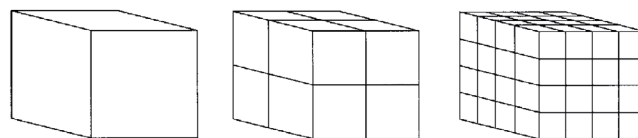
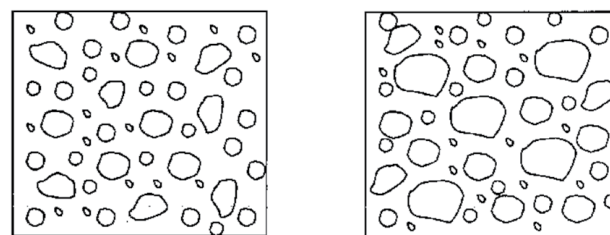


Fig. 3.1.4a—Effect of particle size on aggregate surface area: (a) one 25.0 mm (1 in.) cube of aggregate (surface area = $6 \times 25.0 \times 25.0 = 3750 \text{ mm}^2$ [6 in.²]); (b) eight 12.5 mm (1/2 in.) cubes of aggregate (surface area = $6 \times 12.5 \times 12.5 \times 8 = 7500 \text{ mm}^2$ [12 in.²]); and (c) sixty-four 6.25 mm (1/4 in.) cubes of aggregate (surface area = $6 \times 6.25 \times 6.25 \times 64 = 15,000 \text{ mm}^2$ [24 in.²]).



Well-graded aggregate
12.5 mm (1/2 in.) maximum size Well-graded aggregate
25 mm (1 in.) maximum size

Fig. 3.1.4b—Effect of increasing maximum size on void content of well-graded aggregate.

minimize the amount of cement required and to minimize shrinkage of the paste.

Aggregates of different maximum sizes, however, may give different concrete strengths for the same water-cementitious materials ratio (w/cm). In many instances, at the same w/cm , concrete with smaller maximum size aggregate has the higher compressive strength. This is especially true in higher strength ranges. If compressive strengths in excess of 35 MPa (5100 psi) are required, an aggregate having a maximum size of 19.0 mm (3/4 in.) or smaller may be the most efficient in that its use will require the least amount of cement to produce the required strength. Larger aggregate sizes, however, can be used in these instances if the combined aggregate gradation is optimized by using intermediate sizes to fill void spaces between coarse aggregates.

One of the most important characteristics of the fine aggregate grading is the amount of material passing the 300 and 150 μm (No. 50 and 100) sieves. Inadequate amounts of material in these size ranges can cause excessive bleeding, difficulties in pumping concrete, and difficulties in obtaining smooth troweled surfaces. Most specifications allow 10 to 30 percent to pass the 300 μm (No. 50) sieve, and 2 to 10 percent to pass the 150 μm (No. 100) sieve. **ASTM C33/C33M** permits the lower limits for percent passing the 300 and 150 μm (No. 50 and 100) sieves to be reduced to 5 and 0, respectively. A precautionary note in **ASTM C33/C33M** states that the addition of entrained air, additional cement, or the addition of an approved supplemental cementitious material to supply the deficient fines is a technique used to alleviate potential problems with decreased fines.