operation gives at least false information on the amount of cement in the mixture, and there are possibilities of the shortage being sufficient to have an effect on the strength The number of men assigned to this operation by the contractor should be enough to assure the thorough emptying of the sacks as far as practicable.

The amount of cement remaining in the so-called empty bags is given recognition by contractors, who have equipment for cleaning bags and reclaiming the cement for use in concrete work This practice has not become common enough to have any standard procedure established relative to its control, but it can be readily seen that the practice might increase to such an extent that it would become an incentive to encourage careless emptying of sacks.

Bulk cement should be proportioned by weight

FINE AGGREGATES

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QUALITY

Desirable Characteristics and Properties In order that proper field control may be exercised over fine aggregate, a true appreciation must be had of the requisite qualities and their relative importance to the securing of a satisfactory concrete for road-building The definition[1] tentatively adopted by the American Society for Testing Materials states:

> "Fine aggregate shall consist of sand, stone, screenings, or other inert materials with similar characteristics, or a combination thereof having clean, hard, strong, durable, uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances"

For pavement construction, the inherent qualities which are of prime importance are uniformity, durability, and a reasonable degree of hardness and toughness Hence, inspectors should be continually watchful to see that satisfactory standards in these qualities are maintained

Although comprehensive test data on the effect of silt inclusions on the strength and wear resistance of concrete are lacking, the committee believes, from evidence furnished by the poor surfaces of pave-

[1] See A S T M Tentative Standards, Ser Des C33-26T

ments made with dirty aggregate, that an excessive amount (over 3 per cent by weight) of fine dust or silt is a decided detriment to the concrete-making qualities of an aggregate The deleterious effect of organic matter in sands has been determined quantitatively by Abrams [2] and others, and its presence is properly restricted in specifications Nevertheless, it should be appreciated that the test for determining organic matter [3] is purely qualitative, and that a true estimate of its weakening influence can only be had from physical tests of mortar or concrete made with the aggregate

Kinds of Fine Aggregate In considering various sources of supply, the following more or less general characterizations of the principal classes of fine aggregate may be of assistance·

Natural sands found in glacial deposits or in river beds form the most valuable of present-day supplies of fine aggregate From the standpoint of road-building, a high content of quartz grains is desirable, though sands consisting largely of hard, tough dolomite, or of igneous material often make first-class concrete Grains which are badly elongated or flattened do not compact readily into dense concrete The glacial and river sands are usually better graded for making concrete than are the marine or lake sands, or the artificial fine aggregates, screenings, slag sands, and mine tailings

Screenings of hard, durable rock particles may be made into satisfactory fine aggregates by suitable manufacturing processes Often these aggregates, unless specially prepared, are too coarsely graded and contain too much fine dust for most effective use as concrete aggregates Such aggregates are likely to produce concretes which are more difficult to finish than those made with natural sands In some localities construction costs can be reduced by combining fine-grained quartz sand with coarsely graded screenings for the fine aggregate. In order to avoid segregation, such mixtures of fine sand and coarse screenings should not be combined until they are charged into the batch box or mixing tray.

Mine tailings from lead and zinc mines have been used to some extent as fine aggregates in the producing districts Some of these supplies are contaminated with objectionable amounts of marcasite, shale, and badly weathered rock particles In many instances the grading also is too coarse In some cases, where other suitable aggre-

[2] See Bulletin 7, Structural Materials Research Laboratory, Lewis Institute, Chicago—contains bibliography

[3] See A S T M Standards, Ser Des C40-22T

gates are not available, tailings may be combined with fine sands to form usable aggregates In other similar cases it is possible to overcome grading difficulties by carefully studying the working qualities and physical properties of trial batches of concrete made with abnormally high proportions of fine aggregate (tailings) and low proportions of coarse aggregate

Sampling of Fine Aggregate Fine aggregate supplies of questionable quality should be thoroughly examined prior to use In such examinations a sufficient number of samples should be collected and tested separately to insure that the range in quality is determined If necessary, test pits should be dug both to secure adequate samples and to determine the size and the range in quality of the deposit.

The standard methods of sampling[4] indicate the importance of proper procedure, also methods The following supplementary remarks are pertinent.

In general, sampling is preferably done at the producing plant as the material is discharged from a bin or conveyor In order to secure information regarding the range in quality of the material, numerous equal individual samples should be taken with a tube or scoop at regular intervals in such manner that the entire consignment is represented. If the supply is fairly uniform in quality, the individual samples may be mixed, quartered, and formed into a composite sample prior to testing; if non-uniform, individual samples should be tested separately to ascertain the magnitude and the effect of the non-uniformity The desirable size of the composite sample in the first case will be dependent upon the nature of the tests to be run Usually, for routine testing of the fine aggregate alone, a 10-pound sample for each 50 tons of aggregate is sufficient If only field tests are to be run, such sample can be reduced to approximately 2½ pounds by quartering.

Often it is necessary to sample a carload of fine aggregate after loading. In such cases sampling tubes, taking approximately a pound of material per sample, can be pushed downward into the material at representative points in the top of the carload. If tubes are not available, pits two feet deep (more if there is evidence of non-uniformity in loading) should be dug in the center of each cone or pile of material Then, beginning at the bottom of each pit, a scoop or small bucket should be drawn up the inclined surface of pit in such manner that scoop or bucket will be filled at a uniform rate At least three such samples should be secured per carload.

[4] See A S T M Standards, Ser Des D75-22

It is extremely difficult to secure representative samples from stockpiles To obtain the best representation of material so stored, samples should be collected as the material is loaded into the car or truck from the stockpile Occasionally such procedure is not feasible In such cases the method outlined for sampling of carloads may be employed.

Testing of Fine Aggregate All fine aggregate for use in highway construction should be carefully controlled by regular inspection during the entire period of use

Field Tests In field control the most significant tests are: Visual inspection, sieve analysis, colorimetric test, clay and silt test.

Though there are no standards for procedure in making visual examinations of fine aggregates, the skilful use of a hand lens and pocket knife will often furnish valuable qualitative information regarding the shape, grading, mineral constituents, and hardness Occasionally visual inspection will reveal the presence of components, such as mica, shale, marcasite, or badly weathered rock particles, which might seriously impair the strength and durability of the mortar or concrete made from such aggregate Hence, inspectors should be encouraged to use these simple aids and should be given definite standards for rejection of aggregate of questionable quality

The sieve analysis test of fine aggregate when properly made furnishes an accurate measure of grading, and, being readily made, is a very useful field acceptance test It also serves to determine the range in grading of the material shipped Some state highway departments specify grading limits based upon four sieves For purpose of field control, it would appear feasible to reduce the number of sieves to three

The colorimetric test is a much-used field test in explorations and for checking uniformity in shipments It is of lesser value as a preliminary test in the laboratory Absence of discoloration in the colorimetric test indicates that tannic acid, a common organic acid, is not present Since certain other substances, notably lignite, cause marked discoloration, this test does not always indicate a serious defect in the aggregate

The silt indication afforded by the colorimetric test serves to maintain a rough check on uniformity of shipments, but is an unreliable basis for rejection If an accurate determination of clay and silt is desirable, the inspector should be provided with apparatus for making the decantation test,[5] or the samples should be shipped to a laboratory

[5] See A S T M Standards, Serial Des D72-21

for such tests In localities where shale inclusions are common in fine aggregates, field inspectors may be provided with special equipment for detecting the proportions of shale A simple test, in which the low specific gravity of the shale serves as a basis for detection, is in use by the State Highway Departments of Iowa and Minnesota

Laboratory Tests In conjunction with field inspection, there should be laboratory check tests run at regular intervals on samples furnished by the field inspector Besides checks on the field tests, additional mortar strength tests, and such other physical tests on the fine aggregate or mortar, as conditions may dictate, should be run

Mortar-strength tests of fine aggregate when properly conducted are the most informative of the simple tests ordinarily made However, the present use of tensile tests of mortars of 1 . 3 proportions, by weight, in determining the ratio of the strength of mortar made with a given sand to that made with standard Ottawa sand gives misleading information regarding the concrete-making qualities of the fine aggregate in question This is due to the fact that poor correlation exists between the tensile strength of a 1 3 mortar and the compressive strength of a concrete of ordinary proportions made of the same sand as the mortar For determining such qualifications, the type of mortar-strength test used should be governed by the kind of stress the material is to receive in service Furthermore, the mortar proportions used should approximate the ratio of cement to fine aggregate in the specified concrete Hence, if one wishes to ascertain the value of a fine aggregate for making concrete of high crushing strength, a logical procedure would be to use a compression test with a mortar approaching the proportions of the mortar in the concrete, say 1 : 2 In such tests the consistency of the mortar should be the same as that proposed for the concrete This conclusion is reinforced by research,[6] which has shown that compressive tests of 1 2 and 1 2½ mixes yield more concordant results than tests of other proportions

Additional researches should be undertaken to establish what correlation exists between the strengths of mortars and of concretes containing the mortars (a) when both have the same water-cement ratios, (b) when both have the same workability, but differ in water-cement ratio Data from such tests should indicate better methods of proportioning the mixing water in order to secure the best correlation between mortar and concrete strength tests

[6] Bulletin No 5, Technology Expt Sta , University of Maine

More definite and conclusive evidence of the concrete-making qualities of a fine aggregate of doubtful value may be obtained by making the more cumbersome concrete-strength tests In such procedure the fine aggregate under test should be mixed with a standard coarse aggregate, cement and water in proportions which produce a workable concrete, containing a fixed quantity of cement Acceptance may be conditioned by the attainment of a certain fixed strength at a given age, as practiced in Arkansas, Louisiana, Nebraska, and Texas, or laboratory variations may be eliminated by providing a second set of concrete specimens of a standard cement, a standardized sand and coarse aggregate made simultaneously with the mix in question to serve as a basis of comparison

QUANTITY OF FINE AGGREGATE

Bulking of Fine Aggregate. The volume which a given amount of sand will occupy when poured loosely into a container is dependent on the amount of compacting it receives and upon the moisture content A variation of 3 or 4 per cent in moisture may cause a change of 15 to 20 per cent in the weight of a well-graded sand which can be poured into a given measure On a fine-grained sand the effect is still greater Owing to this and other inaccuracies in volumetric measurement, the committee recommends the adoption of more exact methods of measurement.

Inundation and Weight Methods of Measurement. Marked improvement in accuracy of measurement may be had by the use of either the inundation or weight methods of measurement

The inundation method[1] is based on the principle that if successive batches of sand be dropped from constant height into a receptacle containing enough water to inundate the sand until the measure is filled with sand and water, the volumes of sand and the volumes of water in the batches will be practically constant, provided the voids in the successive batches are constant This scheme of measurement obviates the necessity of making moisture determinations on the sand Also, by suitable arrangement of the measuring receptacle it is possible to correct automatically for fluctuations in moisture content of the fine aggregate Obviously, factors such as changes in grading, or variations in shapes of particles which influence the voids in aggregate, will cause variations in the quantity of fine aggregate and water

[1] For description and data concerning use, see Proc A S T M, Vol 22, Pt 2, p 404, also Proc A C I, Vol 21, p 216

in the measuring receptacle If the fine aggregate is running uniformly in voids, these variations will be negligible

To practice the weight method[8] with accuracy, the percentage of free moisture in the aggregate must be known within 1 per cent and allowance made for it in weighing the aggregate and in measuring the mixing water Moisture determinations may be easily made by finding the difference between the apparent specific gravity of the damp sand and the specific gravity of the dried sand in a suitable specific-gravity flask,[9] or in a brass tube equipped with a graduated water gage[10] If such apparatus is not available, the moisture may be determined somewhat less rapidly by drying several 200-gram samples and weighing on scales or balance accurate and sensitive to a gram Usually a moisture determination made on every 50 tons is sufficient to insure requisite control Where weight measurement is used it is well to have the indicator of the water-measuring device on the mixer also graduated to read in pounds in order to avoid conversion difficulties in dealing with the moisture correction.

COARSE AGGREGATES

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Control of coarse aggregates in concrete highway construction should aim at conditions whereby, in so far as the coarse aggregate is the affecting agent, uniformly good concrete is furnished to the job

The tentative definition[1] for coarse aggregate adopted by the American Society for Testing Materials is as follows.

"Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag or other approved inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated pieces free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali organic or other deleterious matter"

KINDS OF COARSE AGGREGATES

Crushed Stone In general a crushed stone is suitable if it consists mainly of particles approximately cubical in shape Hard stones with

[8] See descriptions of usage, Proc of Wis Engr Soc, Vol 19, p 87, also Symposium on Field Control of the Quality of Concrete, Proc A S T M, 1927

[9] For method of operation see A S T M Tentative Standard, Serial Des C70-27

[10] See *Concrete Highways,* pub by Portland Cement Assoc, Oct 1927

[1] See A S T M Tentative Standards, Serial Designation C33-26T