For Production of well Shaped and well Graded Aggregates.
Barmac Rock on Rock VSI Crusher

3
CHAPTER

Aggregates and Testing of Aggregates

- General • Classification • Source
- Aggregates from Igneous Rocks
- Aggregates from Sedimentary Rocks • Aggregates from Metamorphic Rocks
- Size • Shape • Texture
- Strength • Aggregatte Crushing Value • Aggregate Impact Value
- Aggregate Abrasion Value
- Deval Attrition Test
- Dorry Abrasion Test • Los Angeles Test
- Modulus of Elasticity
- Bulk Density • Specific Gravity
- Absorption and Moisture Content
- Bulking of Aggregates
- Measurement of Moisture Content of Aggregates • Cleanliness
- Soundness of Aggregate
- Alkali Aggregate Reaction
- Thermal Properties
- Grading of Aggregates
- Specific Surface and Surface Index
- Standard Grading Curve
- Crushed Sand • Gap grading
- Test for Determination of Flakiness Index • Test for Determination of Elongation Index • Test for Determination of clay, fine silt and fine dust • Test for Determination of Organic Impurities
- Test for Determination of Specific Gravity • Test for Determination of Bulk Density and Voids

General

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Earlier, aggregates were considerd as chemically inert materials but now it has been recognised that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that the aggregates occupy 70–80 per cent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. To know more about the concrete it is very essential that one should know more about the aggregates which constitute major volume in concrete. Without the study of the aggregate in depth and range, the study of the concrete is incomplete. Cement is the only factory made standard component in concrete. Other ingredients, namely, water and aggregates are natural materials and can vary to any extent in many of their properties. The depth and range of studies that are required to be made in respect of aggregates to *understand their widely varying effects and influence on the properties of concrete cannot be underrated.*

Concrete can be considered as two phase materials for convenience; paste phase and aggregate phase. Having studied the paste phase of concrete in the earlier chapters, we shall now study the aggregates and aggregate phase in concrete in this chapter. The study of aggregates can best be done under the following sub-headings:

(*a*) Classification	(*b*) Source
(*c*) Size	(*d*) Shape
(*e*) Texture	(*f*) Strength
(*g*) Specific gravity and bulk density	(*h*) Moisture content
(*i*) Bulking factor	(*j*) Cleanliness
(*k*) Soundness	(*l*) Chemical properties
(*m*) Thermal properties	(*n*) Durability
(*o*) Sieve analysis	(*p*) Grading

Classification

Aggregates can be classified as (i) Normal weight aggregates, (ii) Light weight aggregates and (iii) Heary weight aggregates. Light weight aggregate and heavy weight aggregate will be discussed elsewhere under appropriate topics. In this chapter the properties of normal weight aggregates will only be discussed.

Normal weight aggregates can be further classified as natural aggregates and artificial aggregates.

Natural	***Artificial***
Sand, Gravel, Crushed	Broken Brick,
Rock such as Granite,	Air-cooled Slag.
Quartzite, Basalt,	Sintered fly ash
Sandstone	Bloated clay

Aggregates can also be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate.

Source

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks. It may be recalled that igneous rocks are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite). The sedimentary rocks are formed originally below the sea bed and subsequently lifted up. Metamorphic rocks are originally either igneous or sedimentary rocks which are subsequently metamorphosed due to extreme heat and pressure. The concrete making properties of aggregate are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alteration. Within the main rock group, say granite group, the quality of aggregate may vary to a very great extent owing to changes in the structure and texture of the main parent rock from place to place.

Aggregates from Igneous Rocks

Most igneous rocks make highly satisfactory concrete aggregates because they are normally hard, tough and dense. The igneous rocks have massive structure, entirely crystalline or wholly glassy or in combination in between, depending upon the rate at which they were cooled during formation. They may be acidic or basic depending upon the percentage of silica content. They may occur light coloured or dark coloured. The igneous rocks as a class are the most chemically active concrete aggregate and show a tendency to react with the alkalies in cement. This aspect will be discussed later. As the igneous rock is one of the widely occurring type of rocks on the face of the earth, bulk of the concrete aggregates, that are derived, are of igneous origin

Aggregates from Sedimentary Rocks

Igneous rocks or metamorphic rocks are subjected to weathering agencies such as sun, rain and wind. These weathering agencies decompose, fragmantise, transport and deposit the particles of rock, deep beneath the ocean bed where they are cemented together by some of the cementing materials. The cementing materials could be carbonaceous, siliceous or argillaceous in nature. At the same time the deposited and cemented material gets subjected to static pressure of water and becomes compact sedimentary rock layer.

The deposition, cementation and consolidation takes place layer by layer beneath the ocean bed. These sedimentary rock formations subsequently get lifted up and becomes continent. The sedimentary rocks with the stratified structure are quarried and concrete aggregates are derived from it. The quality of aggregates derived from sedimentary rocks will vary in quality depending upon the cementing material and the pressure under which these rocks are originally compacted. Some siliceous sand stones have proved to be good concrete aggregate. Similarly, the limestone also can yield good concrete aggregate.

The thickness of the stratification of sedimentary rocks may vary from a fraction of a centimetre to many centimetres. If the stratification thickness of the parent rock is less, it is likely to show up even in an individual aggregate and thereby it may impair the strength of the aggregate. Such rocks may also yield flaky aggregates. Sedimentary rocks vary from soft to hard, porous to dense and light to heavy. The degree of consolidation, the type of cementation, the thickness of layers and contamination, are all important factors in determining the suitability of sedimentary rock for concrete aggregates.

Aggregates from Metamorphic Rocks

Both igneous rocks and sedimentary rocks may be subjected to high temperature and pressure which causes metamorphism which changes the structure and texture of rocks. Metamorphic rocks show foliated structure. The thickness of this foliation may vary from a few centimetres to many metres. If the thickness of this foliation is less, then individual aggregate may exhibit foliation which is not a desirable characteristic in aggregate. However, many metamorphic rocks particularly quartizite and gneiss have been used for production of good concrete aggregates.

It may be mentioned that many properties of aggregates namely, chemical and mineral composition, petro-graphic description, specific gravity, hardness, strength, physical and chemical stability, pore structure etc. depend mostly on the quality of parent rock. But there are some properties possessed by the aggregates which are important so far as concrete making is concerned which have no relation with the parent rock, particularly, the shape and size. While it is to be admitted that good aggregates from good parent rocks can make good *concrete, it may be wrong to conclude that good concrete cannot be made from slightly inferior aggregates obtained from not so good parent rocks. Aggregates which are not so good can be used for making satisfactory concrete owing to the fact that a coating of cement paste on aggregates bring about improvement in respect of durability and strength characteristics. Therefore, selection of aggregates is required to be done judiciously taking the economic factor into consideration. Several factors may be considered in making the final selection of aggregates where more than one source is available. The relative cost of material in the several sources is the most important consideration that should weigh in making a choice. Records of use of aggregate from a particular source, and examination of concrete made with such aggregates, if such cases are there, provide valuable information.*

The study will include appraisal of location and the amount of processing which each source may require. The aggregate which can be delivered to the mixing plant directly may not be the most economical one. It may require a cement content more than that of another source. Also very often the cost of some processing, such as correction of aggregate, may be fully recovered, when the processing accomplishes the reduction in cement content of the concrete. In general, that aggregate which will bring about the desired quality in the concrete with least overall expense, should be selected.

Size

The largest maximum size of aggregate practicable to handle under a given set of conditions should be used. Perhaps, 80 mm size is the maximum size that could be conveniently used for concrete making. Using the largest possible maximum size will result in (i) reduction of the cement content (ii) reduction in water requirement (iii) reduction of drying shrinkage. However, the maximum size of aggregate that can be used in any given condition may be limited by the following conditions:

(i) Thickness of section; *(ii) Spacing of reinforcement;*

(iii) Clear cover; *(iv) Mixing, handling and placing techniques.*

Generally, the maximum size of aggregate should be as large as possible within the limits specified, but in any case not greater than one-fourth of the minimum thickness of the member. Rubbles 160 mm size or upto any reasonable size may be used in plain concrete. In such concrete, called plum concrete, the quantity of rubble up to a maximum limit of 20 per cent by volume of the concrete, is used when specially permitted. The rubbles are placed on about 60 cm thick plastic concrete at certain distance apart and then the plastic concrete is vibrated by powerful internal vibrators. The rubbles sink into the concrete. This method of incorporating large boulders in the concrete is also called displacement concrete. This method is adopted in the construction of Koyna dam in Maharashtra. For heavily reinforced concrete member the nominal maximum size of aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement, whichever is smaller. But from various other practical considerations, for reinforced concrete work, aggregates having a maximum size of 20 mm are generally considered satisfactory.

Aggregates are divided into two categories from the consideration of size (i) Coarse aggregate and (ii) Fine aggregate. The size of aggregate bigger than 4.75 mm is considered as coarse aggregate and aggregate whose size is 4.75 mm and less is considered as fine aggregate.

Shape

The shape of aggregates is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregate which are derived from various rocks. Not only the characteristic of the parent rock, but also the type of crusher used will influence the shape of aggregates, e.g., the rocks available round about Pune region are found to yield slightly flaky aggregates, whereas, good granite rock as found in Banglore will yield cubical aggregate. The shape of the aggregate is very much influenced by the type of crusher and the reduction ratio i.e., the ratio of size of material fed into crusher to the size of the finished product. Many rocks contain planes of parting or jointing which is characteristic of its formation. It also reflects the internal petrographic structure. As a consequence of these tendencies, schists, slates and shales commonly produce flaky forms, whereas, granite, basalt and quartzite usually yield more or less equidimensional particles. Similarly, quartizite which does not posses cleavage planes produces cubical shape aggregates.

From the standpoint of economy in cement requirement for a given water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of the interlocking texture of the hardened concrete and higher bond characteristic between aggregate and cement paste.

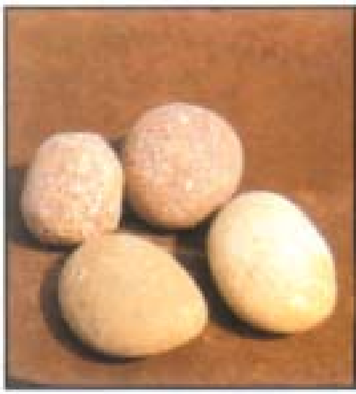
Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flaky aggregate makes very poor concrete.

Classification of particles on the basis of shape of the aggregate is shown in Table 3.1.

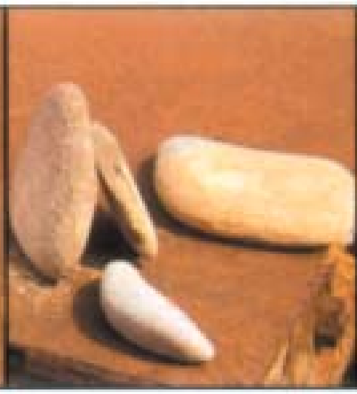
One of the methods of expressing the angularity qualitatively is by a figure called Angularity Number, as suggested by Shergold [3.1]. This is based on the percentage voids in the aggregate after compaction in a specified manner. The test gives a value termed the angularity number. The method of determination is described in IS: 2386 (Part I) 1963.

Table 3.1 Shape of Particle

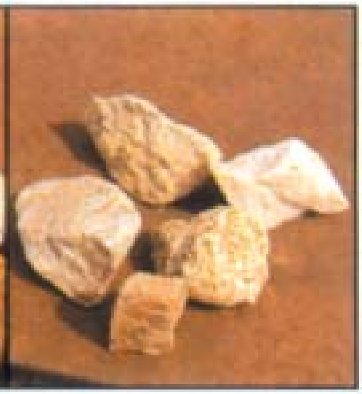
Classification	*Description*	*Examples*
Rounded	*Fully water worn or completely shaped by attrition*	*River or seashore gravels; desert, seashore and wind-blown sands*
Irregular or Partly rounded	*Naturally irregular or partly shaped by attrition, having rounded edges*	*Pit sands and gravels; land or dug flints; cuboid rock*
Angular	*Possessing well-defined edges formed at the intersection of roughly planar faces*	*Crushed rocks of all types; talus; screes*
Flaky	*Material, usually angular, of which the thickness is small relative to the width and/or length*	*Laminated rocks*



Round (spherical) concrete aggregate.



Flaky concrete aggregate.



Crushed concrete aggregate.

A quantity of single sized aggregate is filled into metal cylinder of three litre capacity. The aggregates are compacted in a standard manner and the percentage of void is found out. The void can be found out by knowing the specific gravity of aggregate and bulk density or by pouring water to the cylinder to bring the level of water upto the brim. If the void is 33 per cent the angularity of such aggregate is considered zero. If the void is 44 per cent the angularity number of such aggregate is considered 11. In other words, if the angularity number is zero, the solid volume of the aggregate is 67 per cent and if angularity number is

Poorly shapped crushed aggregate. It will make poor concrete.

Barmac crushed 20 mm cubical aggregate. It will make good concrete.

Good aggregate resulted from Barmac crusher.

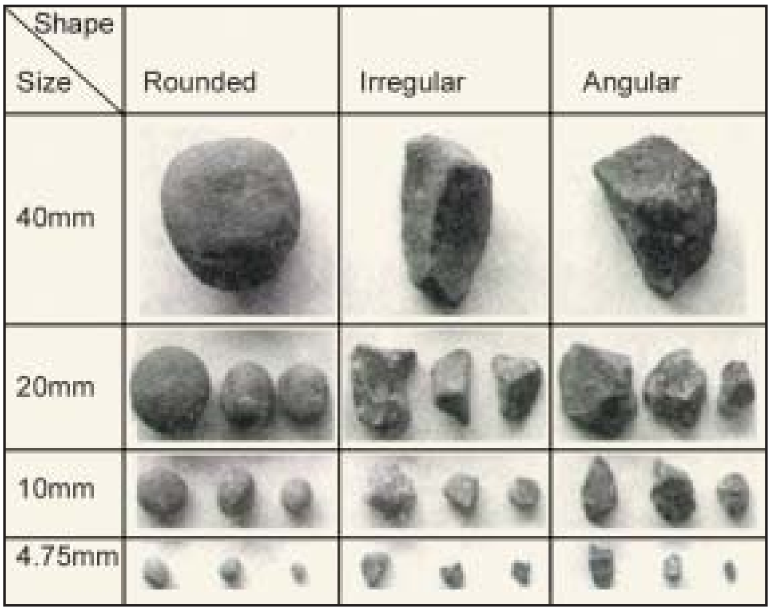
20 mm crushed angular aggregates not so good for concrete.

Courtesy : Durocrete Pune

11, the solid volume of the aggregate is 56 per cent. The normal aggregates which are suitable for making the concrete may have angularity number anything from zero to 11. Angularity number zero represents the most practicable rounded aggregates and the angularity number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.

Murdock suggested a different method for expressing the shape of aggregate by a parameter called Angularity Index 'fA'.[3.2]

Angularity Index $fA = \dfrac{3\,fH}{20} + 1.0$ *where fH is the Angularity number.*



Shape and size of aggregates
Courtesy : Ambuja Cement

There has been a lot of controversy on the subject whether the angular aggregate or rounded aggregate will make better concrete. While discussing the shape of aggregate, the texture of the aggregate also enters the discussion because of its close association with the shape. Generally, rounded aggregates are smooth textured and angular aggregates are rough textured. Some engineers, prohibit the use of rounded aggregate on the plea that it yields poor concrete, due to lack of bond between the smooth surface of the aggregate and cement paste. They suggest that if at all the rounded aggregate is required to be used for economical reason, it should be broken and then used. This concept is not fully justified for the reason that even the so called, the smooth surface of rounded aggregates is rough enough for developing a reasonably good bond between the surface and the submicroscopic cement gel. But the angular aggregates are superior to rounded aggregates from the following two points of view:

(a) Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.

(b) The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregate with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregate gives higher strength. Superimposing plus and minus points in favour and against these two kinds of aggregates it can be summed up as follows:

For water/cement ratio below 0.4 the use of crushed aggregate has resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate gets reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate has been observed.

The shape of the aggregates becomes all the more important in case of high strength and high performance concrete where very low water/cement ratio is required to be used. In such cases cubical shaped aggregates are required for better workability. To produce mostly cubical shaped aggregate and reduce flaky aggregate, improved versions of crushers are employed, such as Hydrocone crushers, Barmac rock on rock VSI crusher etc. Sometimes ordinarily crushed aggregates are further processed to convert them to well graded cubical aggregates.

In the years to come natural sand will not be available in large quantity for big infrastructural projects. One has to go for manufactured sand. When rock is crushed in the normal way it is likely to yield flaky fine aggregate. Improved version of crushers are used to produce cubical shaped well graded fine aggregate. This method of production of good fine aggregate is being practised for high rise building projects at Mumbai and for construction of Mumbai-Pune express highway. On realising the importance of shape of aggregates for producing high strength concrete the improved version of crushers are being extinsively employed in India.

Texture

Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough. Surface texture depends on hardness, grain size, pore structure, structure of the rock, and the degree to which forces acting on the particle surface have smoothed or roughend it. Hard, dense, fine-grained materials will generally have smooth fracture surfaces. Experience and laboratory experiments have shown that the adhesion between cement paste and aggregate is influenced by several complex factors in addition to the physical and mechanical properties.

As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume. A smooth particle, however, will require a thinner layer of paste to lubricate its movements with respect to other aggregate particles. It will, therefore, permit denser packing for equal workability and hence, will require lower paste content than rough particles. It has been also shown by experiments that rough textured aggregate develops higher bond strength in tension than smooth textured aggregate. The beneficial effects of surface texture of aggregate on flexural strength can be seen from Table 3.2.

Table 3.2. Influence of Texture on Strength[3.3]

Per cent of Particles		Water/Cement Ratio	Strength 28 days MPa	
Smooth	Rough		Flexural	Compressive
100	0	0.54	4.3	34.8
50	50	0.57	4.6	32.1
0	100	0.60	4.8	29.5

Surface texture characteristics of the aggregate as classified in IS: 383: 1970 is shown below.

Table 3.3. Surface Characteristics of Aggregate

Group	Surface Texture	Examples
1.	Glassy	Black flint
2.	Smooth	Chert; slate; marble; some rhyolite
3.	Granular	Sandstone; oolites
4.	Crystalline	Fine : Basalt; trachyte; medium : Dolerite; granophyre; granulite; microgranite; some limestones; many dolomites. Coarse : Gabbro; gneiss; granite; granodiorite; syenite
5.	Honeycombed and porous	Scoria; Pumice, trass.

Measurement of Surface Texture

A large number of possible methods are available and this may be divided broadly into direct and indirect methods. Direct methods include (i) making a cast of the surface and magnifying a section of this, (ii) Tracing the irregularities by drawing a fine point over the surface and drawing a trace magnified by mechanical, optical, or electrical means, (iii) getting a section through the aggregates and examining a magnified image. Indirect methods include: (i) measurement of the degree of dispersion of light falling on the surface, (ii) determining the weight of a fine powder required to fill up the interstices of the surface to a truly smooth surface, (iii) the rock surface is held against rubber surface at a standard pressure and the resistance to the flow of air between the two surfaces is measured.

Aggregate Crushing Value Apparatus.

Strength

When we talk of strength we do not imply the strength of the parent rock from which the aggregates are produced, because the strength of the rock does not exactly represent the strength of the aggregate in concrete. Since concrete is an assemblage of individual pieces of aggregate bound together by cementing material, its properties are based primarily on the quality of the cement paste. This strength is dependant also on the bond between the cement paste and the aggregate. If either the strength of the paste or the bond between the paste and aggregate is low, a concrete of poor quality will be obtained irrespective of the strength of the rock or aggregate. But when cement paste of good quality is provided and its bond *with the aggregate is satisfactory, then the mechanical properties of the rock or aggregate will influence the strength of concrete. From the above it can be concluded that while strong aggregates cannot make strong concrete, for making strong concrete, strong aggregates are an essential requirement. In other words, from a weak rock or aggregate strong concrete cannot be made. By and large naturally available mineral aggregates are strong enough for making normal strength concrete. The test for strength of aggregate is required to be made in the following situations:*

(i) *For production of high strength and ultra high strength concrete.*

(ii) *When contemplating to use aggregates manufactured from weathered rocks.*

(iii) *Aggregate manufactured by industrial process.*

Aggregatte Crushing Value

Strength of rock is found out by making a test specimen of cylindrical shape of size 25 mm diameter and 25 mm height. This cylinder is subjected to compressive stress. Different rock samples are found to give different compressive strength varying from a minimum of about 45 MPa to a maximum of 545 MPa. As said earlier, the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in a standardised manner. This test is known as aggregate crushing value test. Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. Generally, this test is made on single sized aggregate passing 12.5 mm and retained on 10 mm sieve. The aggregate is placed in a cylindrical mould and a load of 40 ton is applied through a plunger. The material crushed to finer than 2.36 mm is separated and expressed as a percentage of the original weight taken in the mould. This percentage is referred as aggregate crushing value. The crushing value of aggregate is restricted to 30 per cent for concrete used for roads and pavements and 45 per cent may be permitted for other structures.

Aggregate Impact Value Apparatus.

The crushing value of aggregate is rather insensitive to the variation in strength of weaker aggregate. This is so because having been crushed before the application of the full load of 40 tons, the weaker materials become compacted, so that the amount of crushing during later stages of the test is reduced. For this reason a simple test known as "10 per cent fines value" is introduced. When the aggregate crushing value become 30 or higher, the result is likely to be inaccurate, in which case the aggregate should be subjected to "10 per cent fines value" test which gives a better picture about the strength of such aggregates.

This test is also done on a single sized aggregate as mentioned above. Load required to produce 10 per cent fines (particles finer than 2.36 mm) is found out by observing the *penetration of plunger. The 10 per cent fines value test shows a good correlation with the standard crushing value test for strong aggregates while for weaker aggregates this test is more sensitive and gives a truer picture of the differences between more or less weak samples.*

It should be noted that in the 10 per cent fines value test unlike the crushing value test, a higher numerical result denotes a higher strength of the aggregate. The detail of this test is given at the end of this chapter under testing of aggregate.

Aggregate Impact Value

With respect to concrete aggregates, toughness is usually considered the resistance of the material to failure by impact. Several attempts to develop a method of test for aggregates impact value have been made. The most successful is the one in which a sample of standard aggregate kept in a mould is subjected to fifteen blows of a metal hammer of weight 14 Kgs. falling from a height of 38 cms. The quantity of finer material (passing through 2.36 mm) resulting from pounding will indicate the toughness of the sample of aggregate. The ratio of the weight of the fines (finer than 2.36 mm size) formed, to the weight of the total sample taken is expressed as a percentage. This is known as aggregate impact value IS 283-1970 specifies that aggregate impact value shall not exceed 45 per cent by weight for aggregate used for concrete other than wearing surface and 30 per cent by weight, for concrete for wearing surfaces, such as run ways, roads and pavements.

Aggregate Abrasion Value

Apart from testing aggregate with respect to its crushing value, impact resistance, testing the aggregate with respect to its resistance to wear is an important test for aggregate to be used for road constructions, ware house floors and pavement construction. Three tests are in common use to test aggregate for its abrasion resistance. (i) Deval attrition test (ii) Dorry abrasion test (iii) Los Angels test.

Deval Attrition Test

In the Deval attrition test, particles of known weight are subjected to wear in an iron cylinder rotated 10000 times at certain speed. The proportion of material crushed finer than 1.7 mm size is expressed as a percentage of the original material taken. This percentage is taken as the attrition value of the aggregate. This test has been covered by IS 2386 (Part IV) – 1963. But it is pointed out that wherever possible Los Angeles test should be used.

Dorry Abrasion Test

This test is not covered by Indian Standard Specification. The test involves in subjecting a cylindrical specimen of 25 cm height and 25 cm diameter to the abrasion against rotating metal disk sprinkled with quartz sand. The loss in weight of the cylinder after 1000 revolutions of the table is determined. The hardeness of the rock sample is expressed in an empirical formula

Los Angeles Abrasion Testing Machine.

$$\text{Hardness} = 20 - \frac{\text{Loss in Grams}}{3}$$

Good rock should show an abrasion value of not less than 17. A rock sample with a value of less than 14 would be considered poor.

Los Angeles Test

Los Angeles test was developed to overcome some of the defects found in Deval test. Los Angeles test is characterised by the quickness with which a sample of aggregate may be tested. The applicability of the method to all types of commonly used aggregate makes this method popular. The test involves taking specified quantity of standard size material along with specified number of abrasive charge in a standard cylinder and revolving if for certain specified revolutions. The particles smaller than 1.7 mm size is separated out. The loss in weight expressed as percentage of the original weight taken gives the abrasion value of the aggregate. The abrasion value should not be more than 30 per cent for wearing surfaces and not more than 50 per cent for concrete other than wearing surface. Table 3.4 gives average values of crushing strength of rocks, aggregate crushing value, abrasion value, impact value and attrition value for different rock groups.

Modulus of Elasticity

Modulus of elasticity of aggregate depends on its composition, texture and structure. The modulus of elasticity of aggregate will influence the properties of concrete with respect to shrinkage and elastic behaviour and to very small extent creep of concrete. Many studies have been conducted to investigate the influence of modulus of elasticity of aggregate on the properties of concrete. One of the studies indicated that the 'E' of aggregate has a decided effect on the elastic property of concrete and that the relation of 'E' of aggregate to that of the concrete is not a linear function, but may be expressed as an equation of exponential type.[3.4]

Table 3.4. Average Test Values For Rocks of Different Groups

Rock Group	Crushing Strength MPa	Aggregate crushing value	Abrasion value	Impact value	Attrition value		Specific gravity
					Dry	Wet	
Basalt	207	12	17.6	16	3.3	5.5	2.85
Flint	214	17	19.2	17	3.1	2.5	2.55
Gabbro	204	-	18.7	19	2.5	3.2	2.95
Granite	193	20	18.7	13	2.9	3.2	2.69
Gritstone	229	12	18.1	15	3.0	5.3	2.67
Hornfels	354	11	18.8	17	2.7	3.8	2.88
Limestone	171	24	16.5	9	4.3	7.8	2.69
Porphyry	239	12	19.0	20	2.6	2.6	2.66
Quartizite	339	16	18.9	16	2.5	3.0	2.62
Schist	254	-	18.7	13	3.7	4.3	2.76

Bulk Density

The bulk density or unit weight of an aggregate gives valuable informations regarding the shape and grading of the aggregate. For a given specific gravity the angular aggregates show a lower bulk density. The bulk density of aggregate is measured by filling a container of known volume in a standard manner and weighing it. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles. One of the early methods of mix design make use of this parameter bulk density in proportioning of concrete mix. The higher the bulk density, the lower is the void content to be filled by sand and cement. The sample which gives the minimum voids or the one which gives maximum bulk density is taken as the right sample of aggregate for making economical mix. The method of determining bulk density also gives the method for finding out void content in the sample of aggregate.

For determination of bulk density the aggregates are filled in the container and then they are compacted in a standard manner. The weight of the aggregate gives the bulk density calculated in kg/litre or kg/m^3*. Knowing the specific gravity of the aggregate in saturated and surface-dry condition, the void ratio can also be calculated.*

$$\text{Percentage voids} = \frac{Gs - \gamma}{Gs} \times 100$$

where Gs *= specific gravity of the aggregate and* γ *= bulk density in kg/litre.*

Bulk density of aggregate is of interest when we deal with light weight aggregate and heavy weight aggregate. The parameter of bulk density is also used in concrete mix design for converting the proportions by weight into proportions by volume when weigh batching equipments is not available at the site.

Specific Gravity

In concrete technology, specific gravity of aggregates is made use of in design calculations of concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements. Similarly, specific gravity of aggregate is required to be considered when we deal with light weight and heavy weight concrete. Average specific gravity of the rocks vary from 2.6 to 2.8.

Absorption and Moisture Content

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as percentage is known as absorption of aggregate. But when we deal with aggregates in concrete the 24 hours absorption may not be of much significance, on the other hand, the percentage of water absorption during the time interval equal of final set of cement may be of more significance. The aggregate absorbs water in concrete and thus affects the workability and final volume of concrete. The rate and amount of absorption within a time interval equal to the final set of the cement will only be

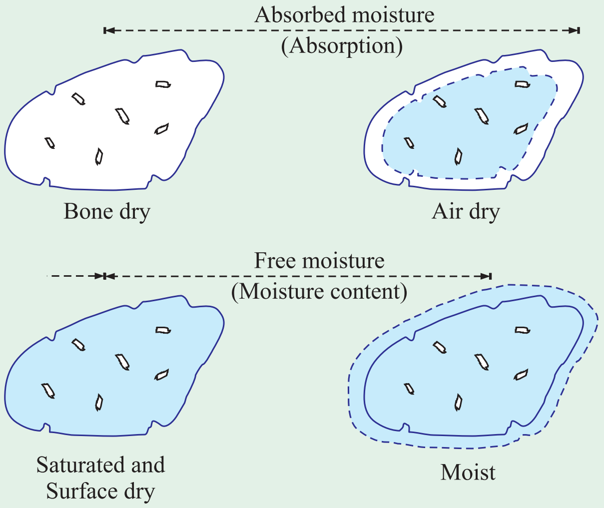


Fig. 3.1. Diagrammatic representation of Moisture in Aggregate.

a significant factor rather than the 24 hours absorption of the aggregate. It may be more realistic to consider that absorption capacity of the aggregates which is going to be still less owing to the sealing of pores by coating of cement particle particularly in rich mixes. In allowing for extra water to be added to a concrete mix to compensate for the loss of water due to absorption, proper appreciation of the absorption in particular time interval must be made rather than estimating on the basis of 24 hours absorption.

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry. But in practice, aggregates in such ideal condition is rarely met with. Aggregates are either dry and absorptive to various degrees or they have surface moisture. The aggregates may have been exposed to rain or may have been washed in which case they may contain surface moisture or the aggregates may have been exposed to the sun for a long time in which case they are absorptive. Fine aggregates dredged from river bed usually contains surface moisture. When stacked in heap the top portion of the heap may be comparatively dry, but the lower portion of the heap usually contains certain amount of free moisture. It should be noted that if the aggregates are dry they absorb water from the mixing water and thereby affect the workability and, on the other hand, if the aggregates contain surface moisture they contribute extra water to the mix and there by increase the water/cement ratio. Both these conditions are harmful for the quality of concrete. In making quality concrete, it is very essential that corrective measures should be taken both for absorption and for free moisture so that the water/cement ratio is kept exactly as per the design.

Very often at the site of concrete work we may meet dry coarse aggregate and moist fine aggregate. The absorption capacity of the coarse aggregate is of the order of about 0.5 to 1 per cent by weight of aggregate. A higher absorption value may be met with aggregates derived from sand stone or other soft and porous rocks. Recently it was observed that the rocks excavated in the cuttings of Pune-Mumbai express highway, showed absorption of around 4% unusualy high for rock of the type Deccan trap. The high absorption characteristic has presented plenty of problems for using such stone aggregate for 40 MPa Pavement Quality

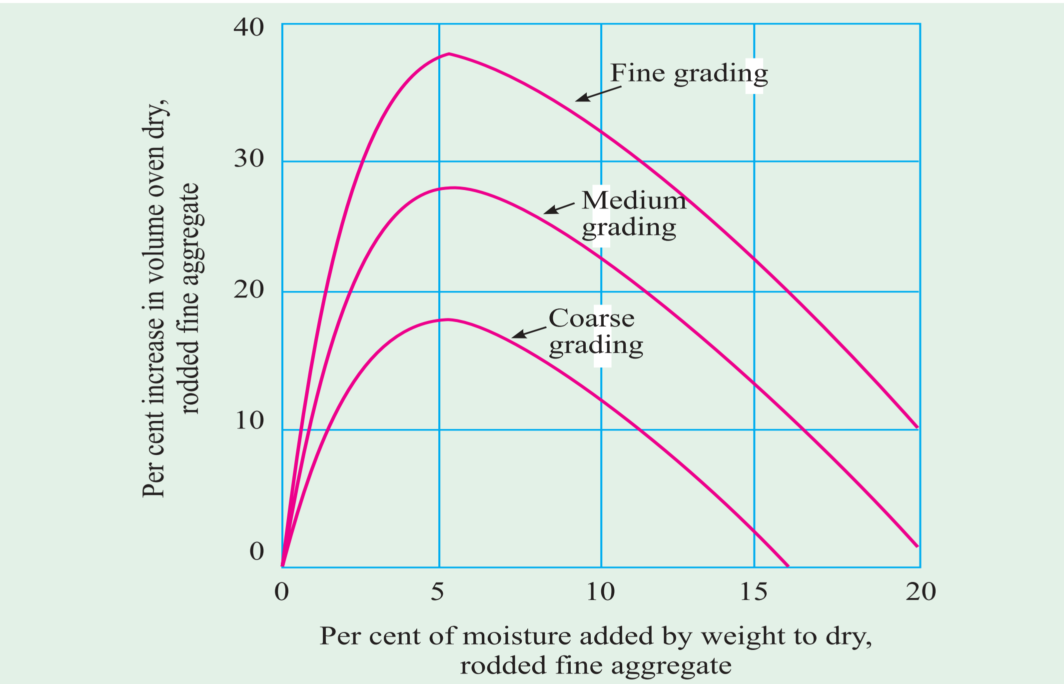
Concrete (PQC). The natural fine aggregates often contain free moisture anything from one to ten per cent or more. Fig. 3.1 shows a diagrammatic representation of moisture in aggregates.

Free moisture in both coarse aggregate and fine aggregate affects the quality of concrete in more than one way. In case of weigh batching, determination of free moisture content of the aggregate is necessary and then correction of water/cement ratio to be effected in this regard. But when volume batching is adopted, the determination of moisture content of fine aggregate does not become necessary but the consequent bulking of sand and correction of volume of sand to give allowance for bulking becomes necessary.

Bulking of Aggregates

The free moisture content in fine aggregate results in bulking of volume. Bulking phenomenon can be explained as follows:

Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no point contact is possible between the particles. This causes bulking of the volume. The extent of surface tension and consequently how far the adjacent particles are kept away will depend upon the percentage of moisture content and the particle size of the fine aggregate. It is interesting to note that the bulking increases with the increase in moisture content upto a certain limit and beyond that the further increase in the moisture content results in the decrease in the volume and at a moisture content representing saturation point, the fine aggregate shows no bulking. It can be seen from Fig. 3.2 that fine sand bulks more and coarse sand bulks less. From this it follows that the coarse aggregate also bulks but the bulking is so little that it is always neglected. Extremely fine sand and particularly the manufactured fine aggregate bulks as much as about 40 per cent.



Due to the bulking, fine aggregate shows completely unrealistic volume. Therefore, it is absolutely necessary that consideration must be given to the effect of bulking in proportioning the concrete by volume. If cognisance is not given to the effect of bulking, in case of volume batching, the resulting concrete is likely to be undersanded and harsh. It will also affect the yield of concrete for a given cement content.

The extent of bulking can be estimated by a simple field test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. Note down the level, say h_1*. Pour water into the measuring cylinder and completely inundate the sand and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the inundated sand completely offsets the bulking effect. Note down the level of the sand say,* h_2*. Then* $h_1 - h_2$ *shows the bulking of the sample of sand under test.*

$$\text{Percentage of bulking} = \frac{h_1 - h_2}{h_2} \times 100$$

In a similar way the bulking factor can be found out by filling the wet sand in a water tight measuring box (farma) up to the top and then pour water to inundate the sand. Then measure the subsidence of sand and express it as a percentage. This gives a more realistic picture of the bulking factor.

The field test to find out the percentage of bulking is so simple that this could be conducted in a very short time interval and the percentage of bulking so found out could be employed for correcting the volume of fine aggregate to be used. This can be considered as one of the important methods of field control to produce quality concrete. Since volume batching is not adopted for controlled concrete, the determination of the percentage of moisture content is not normally required. The quantity of water could be controlled by visual examination of the mix and by experience. The percentage of free moisture content is required to be determined and correction made only when weigh batching is adopted for production of quality concrete.

Measurement of Moisture Content of Aggregates

Determination of moisture content in aggregate is of vital importance in the control of the quality of concrete particularly with respect to workability and strength. The measurement of the moisture content of aggregates is basically a very simple operation. But it is complicated by several factors. The aggregate will absorb a certain quantity of water depending on its porosity. The water content can be expressed in terms of the weight of the aggregate when absolutely dry, surface dry or when wet. Water content means the free water, or that held on the surface of the aggregate or the total water content which includes the absorbed water plus the free water, or the water held in the interior portion of aggregate particles.

The measurement of the moisture content of aggregate in the field must be quick, reasonably accurate and must require only simple appartus which can be easily handled and used in the field. Some of the methods that are being used for determination of moisture content of aggregate are given below:

(i) Drying Method *(ii) Displacement Method*

(iii) Calcium Carbide Method *(iv) Measurement by electrical meter.*

(v) Automatic measurement

Drying Method

The application of drying method is fairly simple. Drying is carried out in a oven and the loss in weight before and after drying will give the moisture content of the aggregate. If the drying is done completely at a high temperature for a long time, the loss in weight will include not only the surface water but also some absorbed water. Appropriate corrections may be made for the saturated and surface dry condition. The oven drying method is too slow for field use. A fairly quick result can be obtained by heating the aggregate quickly in an open pan. The process can also be speeded up by pouring inflammable liquid such as methylated spirit or acetone over the aggregate and igniting it.

Displacement Method

In the laboratory the moisture content of aggregate can be determined by means of pycnometer or by using Siphon-Can Method. The principle made use of is that the specific gravity of normal aggregate is higher than that of water and that a given weight of wet aggregate will occupy a greater volume than the same weight of the aggregate when dry. By knowing the specific gravity of the dry aggregate, the specific gravity of the wet aggregate can be calculated. From the difference between the specific gravities of the dry and wet aggregates, the moisture content of the aggregate can be calculated.

Calcium Carbide Method

A quick and reasonably accurate method of determining the moisture content of fine aggregate is to mix it with an excess of calcium carbide in a strong air-tight vessel fitted with pressure gauge. Calcium carbide reacts with surface moisture in the aggregate to produce acetylene gas. The pressure of acetylene gas generated depends upon the moisture content of the aggregates. The pressure gauge is calibrated by taking a measured quantity of aggregate of known moisture content and then such a calibrated pressure gauge could be used to read the moisture content of aggregate directly. This method is ofen used to find out the moisture content of fine aggregate at the site of work. The equipment consists of a small balance, a standard scoop and a container fixed with dial gauge. The procedure is as follows: Weigh 6 grams of representative sample of wet sand and pour it into the container. Take one scoop full of calcium carbide powder and put it into the container. Close the lid of the container and shake it rigorously. Calcium carbide reacts with surface moisture and produces acetylene gas, the pressure of which drives the indicator needle on the pressure gauge. The pressure gauge is so calibrated, that it gives directly percentage of moisture. The whole job takes only less than 5 minutes and as such, this test can be done at very close intervals of time at the site of work.

Electrical Meter Method

Recently electrical meters have been developed to measure instantaneous or continuous reading of the moisture content of the aggregate. The principle that the resistance gets changed with the change in moisture content of the aggregate has been made use of. In some sophisticated batching plant, electrical meters are used to find out the moisture content and also to regulate the quantity of water to be added to the continuous mixer.

Automatic Measurement

In modern batching plants surface moisture in aggregates is automatically recorded by means of some kind of sensor arrangement. The arrangement is made in such a way that the quantity of free water going with aggregate is automatically recorded and simultaneously that *much quantity of water is reduced. This sophisticated method results in an accuracy of ± 0.2 to 0.6%.*

Cleanliness

The concrete aggregates should be free from impurities and deletrious substances which are likely to interfere with the process of hydration, prevention of effective bond between the aggregates and matrix. The impurities sometimes reduce the durability of the aggregate.

Generally, the fine aggregate obtained from natural sources is likely to contain organic impurities in the form of silt and clay. The manufactured fine aggregate does not normally contain organic materials. But it may contain excess of fine crushed stone dust. Coarse aggregate stacked in the open and unused for long time may contain moss and mud in the lower level of the stack.

Sand is normally dredged from river beds and streams in the dry season when the river bed is dry or when there is not much flow in the river. Under such situation along with the sand, decayed vegetable matter, humus, organic matter and other impurities are likely to settle down. But if sand is dredged when there is a good flow of water from very deep bed, the organic matters are likely to get washed away at the time of dredging. The organic matters will interfere with the setting action of cement and also interfere with the bond characteristics with the aggregates. The presence of moss or algae will also result in entrainment of air in the concrete which reduces its strength.

To ascertain whether a sample of fine aggregate contains permissible quantity of organic impurities or not, a simple test known as colorimetric test is made. The sample of sand is mixed with a liquid containing 3 per cent solution of sodium hydroxide in water. It is kept for 24 hours and the colour developed is compared with a standard colour card. If the colour of the sample is darker than the standard colour card, it is inferred that the content of the organic impurities in the sand is more than the permissible limit. In that case either the sand is rejected or is used after washing.

Sometimes excessive silt and clay contained in the fine or coarse aggregate may result in increased shrinkage or increased permeability in addition to poor bond characteristics. The excessive silt and clay may also necessitate greater water requirements for given workability.

The quantity of clay, fine silt and fine dust are determined by sedimentation method. In this method, a sample of aggregate is poured into a graduated measuring jar and the aggregate is nicely rodded to dislodge particles of clay and silt adhering to the aggregate particles. The jar with the liquid is completely shaken so that all the clay and silt particles get mixed with water and then the whole jar is kept in an undisturbed condition. After a certain time interval, the thickness of the layer of clay and silt standing over the fine aggregate particles will give a fair idea of the percentage of clay and silt content in the sample of aggregate under test. The limits of deleterious materials as given in IS 383-1970 are shown in Table 3.5.

Fine aggregate from tidal river or from pits near sea shore will generally contain some percentage of salt. The contamination of aggregates by salt will affect the setting properties and ultimate strength of concrete. Salt being hygroscopic, will also cause efflorescence and unsightly appearance. Opinions are divided on the question whether the salt contained in aggregates would cause corrosion of reinforcement. But studies have indicated that the usual percentage of salt generally contained in the fine aggregate will not cause corrosion in any appreciable manner. However, it is a good practice to wash sand containing salt more than 3 per cent.

Table 3.5. Limits of Deleterious Materials (IS: 383-1970)

Sr. No. (1)	Deleterious substances (2)	Method of test (3)	Fine aggregate percentage by weight , max		Coarse aggregate percentage by weight, max	
			uncrushed (4)	crushed (5)	uncrushed (6)	crushed (7)
(*i*)	Coal and lignite	IS:2386 (Part II)-1963	1.00	1.00	1.00	1.00
(*ii*)	Clay lumps	IS:2386 (Part II)-1963	1.00	1.00	1.00	1.00
(*iii*)	Materials finer than 75-micron IS Sieve	IS:2386 (Part I)-1963	3.00	15.00	3.00	3.00
(*iv*)	Soft fragments	IS:2386 (Part II)-1963	-	-	3.00	-
(*v*)	Shale	IS:2386 (Part II)-1963	1.00	-	-	-
(*vi*)	Total of percentages of all deleterious materials (except mica) including Sr. No. (*i*) to (*v*) for col. 4, 6 and 7 and Sr. No. (*i*) and (*ii*) for col. 5 only	-	5.00	2.00	5.00	5.00

Notes:

(*i*) The presence of mica in the fine aggregate has been found to reduce considerably the durability and compressive strength of concrete and further investigations are underway to determine the extent of the deleterious effect of mica. It is advisable, therefore, to investigate the mica content of fine aggregate and make suitable allowances for the possible reduction in the strength of concrete or mortar.

(*ii*) The aggregate shall not contain harmful organic impurities (tested in accordance with IS:2386 (Part II-1963) in sufficient quantities to effect adversely the strength or durability of concrete. A fine aggregate which fails in the test for organic impurities may be used, provided that, when tested for the effect of organic impurities on the strength of mortar, the relative strength at 7 and 28 days, reported in accordance with clause 7 of IS:2386 (Part VI)-1963 is not less than 95 per cent.

Aggregates from some source may contain iron pyrites, clay nodules, soft shale particles and other impurities which are likely to swell when wetted. These particles also get worn out when concrete is subjected to abrasion and thereby cause pitting in concrete. Such unsound particles cause damage to the concrete particularly, when subjected to alternate freezing and thawing or wetting and drying. A limitation to the quantity of such impurities is already shown in Table 3.5.

Soundness of Aggregate

Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect the soundness of aggregate are the freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions and wetting and drying in salt water. Aggregates which are porous, weak and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregates which undergo more than the specified amount of volume change is said to be unsound aggregates. If concrete is liable to be exposed to the action of frost, the coarse and fine aggregate which are going to be used should be subjected to soundness test.

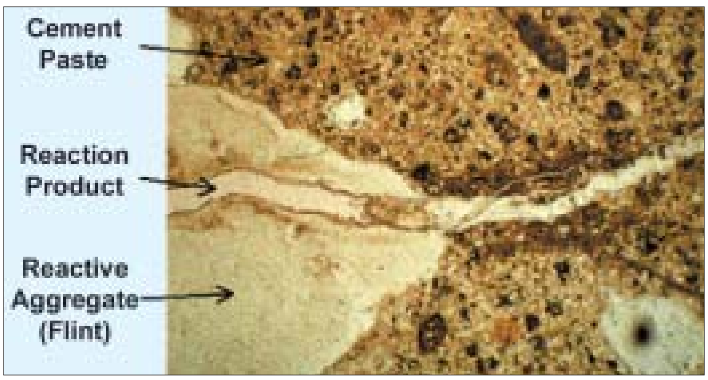
The soundness test consists of alternative immersion of carefully graded and weighed test sample in a solution of sodium or magnesium sulphate and oven drying it under specified conditions. The accumulation and growth of salt crystals in the pores of the particles is thought to produce disruptive internal forces similar to the action of freezing of water or crystallisation of salt. Loss in weight, is measured for a specified number of cycles. Soundness test is specified in IS 2386 (Part V). As a general guide, it can be taken that the average loss of weight after 10 cycles should not exceed 12 per cent and 18 per cent when tested with sodium sulphate and magnesium sulphate respectively.

It may be pointed out that the sulphate soundness test might be used to accept aggregates but not to reject them, the assumption being that aggregates which will satisfactorily withstand the test are good while those which breakdown may or may not be bad. Unfortunately, the test is not reliable. Certain aggregates with extremely fine pore structure show almost no loss of weight. Conversely, certain aggregates that disintegrate readily in the sulphate test but produce concrete of high resistance to freezing and thawing. A low loss of weight usually. but not always, an evidence of good durability, whereas a high loss of weight places the aggregate in questionable category.

Alkali Aggregate Reaction

For a long time aggregates have been considered as inert materials but later on, particularly, after 1940's it was clearly brought out that the aggregates are not fully inert. Some of the aggregates contain reactive silica, which reacts with alkalies present in cement i.e., sodium oxide and potassium oxide.

In the United States of America it was found for the first time that many failures of concrete structures like pavement, piers and sea walls could be attributed to the alkali-aggregate reaction. Since then a systematic study has been made in this regard and now it is proved beyond doubt that certain types of reactive aggregates are responsible for promoting alkali-aggregate reaction.

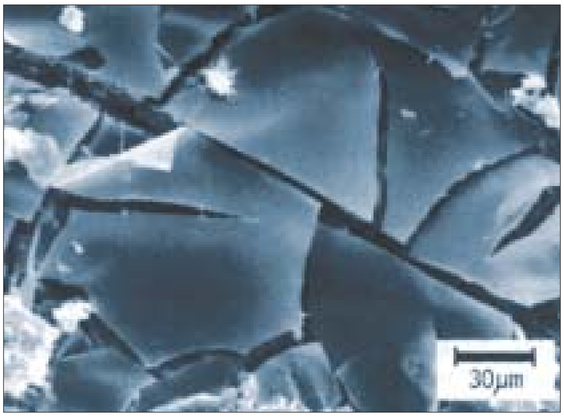


Typical Alkali - Aggregate reaction. Alkali silicate gels of unlimited swelling type are formed under favourable conditions.

The types of rocks which contain reactive constituents include traps, andesites, rhyolites, siliceous limestones and certain types of sandstones. The reactive constituents may be in the form of opals, cherts, chalcedony, volcanic glass, zeolites etc. The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalies in cement. As a result, the alkali silicate gels of unlimited swelling type are formed. When the conditions are congenial, progressive manifestation by swelling takes place, which results in disruption of concrete with the spreading of pattern cracks and eventual failure of concrete structures. The rate of deterioration may be slow or fast depending upon the conditions. There were cases where concrete has become unserviceable in about a year's time. In India, the basalt rocks occurring in the Deccan plateau, Madhya Pradesh, Kathiawar, Hyderabad, Punchal Hill (Jammu and Kashmir), Bengal and Bihar should be viewed with caution.[3.6]

Similarly, limestones and dolomites containing chert nodules would be highly reactive. Indian limestones of Bijawar series are known to be highly cherty. Regions of occurrence include Madhya Pradesh, Rajasthan, Punjab and Assam.

Sandstones containing silica minerals like chalcedony, crypto to microcrystalline quartz or opal are found to be reactive. Regions of occurrence include Madhya Pradesh, Bengal, Bihar and Delhi. Some of the samples obtained from Madhya Pradesh, West Bengal and Kashmir were found to be containing reactive constituents which could be identified by visual examination. These contain substantial quantities of minerals like opals, chalcedony and amorphous silica. Quartzite samples of rock obtained from Kashmir were also found to be highly reactive.



Typical example of the alkali-aggregate reaction product (swellable gel).

Geographically India has a very extensive deposit of volcanic rocks. The Deccan traps covering the western part of Maharashtra and Madhya Pradesh, the dolomites of Madhya Pradesh, Punjab and Rajasthan, limestones of Jammu and Kashmir would form extensive source of aggregate for concrete construction. The aggregates from these rocks should be studied cautiously to see how far reactive are they. It is interesting to note that only such aggregates which contain reactive silica in particular proportion and in particular fineness are found to exhibit tendencies for alkali-aggregates reaction. It is possible to reduce its tendency by altering either the proportion of reactive silica or its fineness.

Factors Promoting the Alkali-Aggreate Reaction

(i) Reactive type of aggregate; *(ii) High alkali content in cement;*

(iii) Availability of moisture; *(iv) Optimum temperature conditions.*

It is not easy to determine the potential reactivity of the aggregates. The case history of aggregates may be of value in judging whether a particular source of aggregate is deleterious or harmless. The petrographic examination of thin rock sections may also immensely help to asses the potential reactivity of the aggregate. This test often requires to be supplemented by other tests.

Mortar Bar Expansion Test devised by Stanton has proved to be a very reliable test in assessing the reactivity or otherwise of the aggregate. A specimen of size 25 mm x 25 mm and 250 mm length is cast, cured and stored in a standard manner as specified in IS : 2386 (Part VII 1963). Measure the length of the specimen periodically, at the ages of 1, 2, 3, 6, 9, and 12 months. Find out the difference in the length of the specimen to the nearest 0.001 per cent and record the expansion of the specimen. The aggregate under test is considered harmful if it expands more than 0.05 per cent after 3 months or more than 0.1 per cent after six months.

The potential reactivity of aggregate can also be found out by chemical method. In this method the potential reactivity of an aggregate with alkalies in Portland cement is indicated by the amount of reaction taking place during 24 hours at 80°C between sodium hydroxide solution and the aggregate that has been crushed and sieved to pass a 300 micron IS Sieve and retained on 150 micron IS Sieve. The solution after 24 hours is analysed for silica dissolved and reduction in alkalinity, both expressed as millimoles per litre. The values are plotted as shown in Fig 3.3 reproduced from IS : 2386 (Part VII 1963). Generally, a potentially deleterious reaction is indicated if the plotted test result falls to the right of the boundary line of Fig. 3.3 and if plotted result falls to the left side of the boundary line, the aggregate may be considered as innocuous. The above chemical test may also be employed for finding out the effectiveness of adding a particular proportion of pozzolanic material to offset the alkali-aggregate reaction. Table 3.6 shows dissolved silica and reduction in alkalinity of some Indian aggregates.

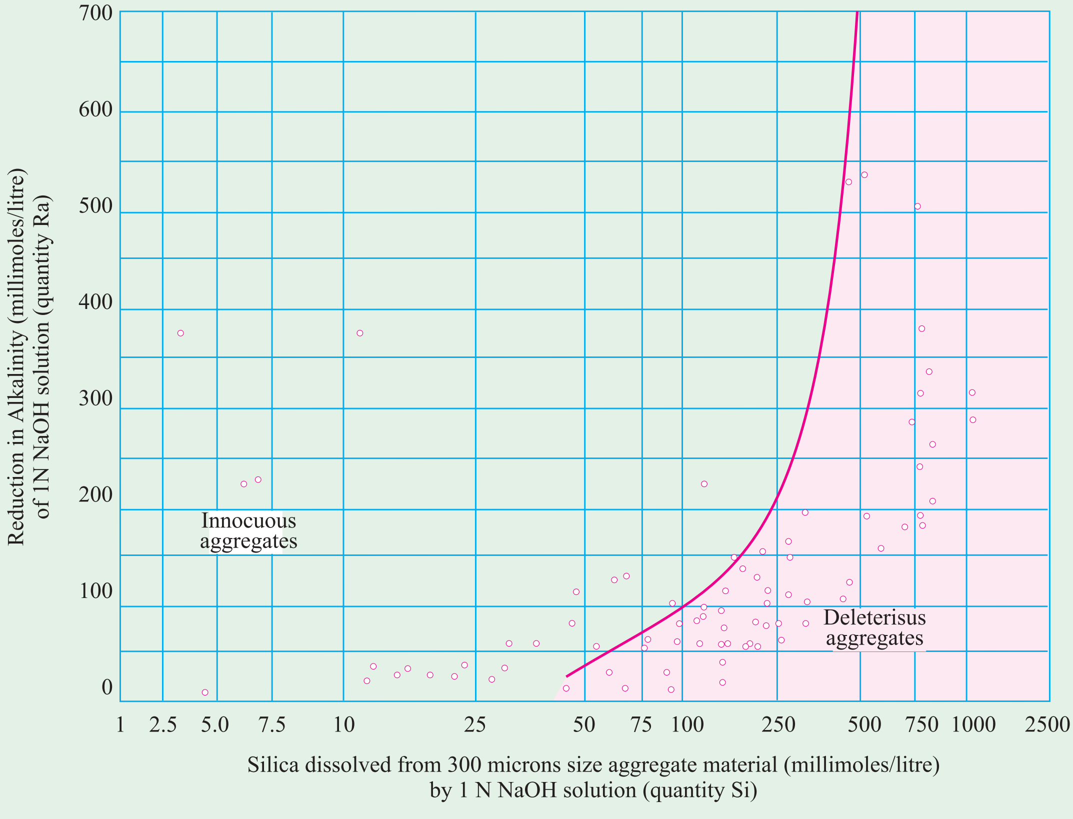


Fig. 3.3. Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test.

High Alkali Content in Cement

The high alkali content in cement is one of the most important factors contributing to the alkali-aggregate reaction. Since the time of recognition to the importance of alkali-aggregate reaction phenomena, a serious view has been taken on the alkali content of cement. Many specifications restrict the alkali content to less than 0.6 per cent. Their total amount, expressed as Na_2O equivalent (Na_2O + 0.658 K_2O). A cement, meeting this specification is designated as a low alkali cement. Field experience has never detected serious deterioration of concrete through the process of alkali-aggregate reaction when cement contained alkalies less than 0.6 per cent. In exceptional cases, however, cement with even lower alkali content have caused objectionable expansion. Generally, Indian cements do not contain high alkalies as in U.S.A. and U.K. The result of investigations done to find out the alkali content in the sample of Indian cement is shown in Table 3.7. Table 3.7 shows that 11 out of 26 Indian cement samples have total alkali content higher than 0.6 per cent. This is the statistics of cement manufactured prior to 1975. The present day cement manufactured by modern sophisticated methods will have lower alkali content than what is shown in Table 3.7.

Table 3.6. Dissolved silica and reduction in alkalinity of some Indian aggregates[3.5]

Sl. No.	Description of Aggregate	Reduction in Alkalinity millimoles per litre — Ra	Dissolved Silica Millimoles Per litre Si	Ratio Si/Ra
1.	Banihal Trap	16	42	2.63
2.	Deccan Trap (Nagpur)	320	177	0.55
3.	Rajmahal Trap (West Bengal)	252	210	0.83
4.	Banihal Quartizite	16	57	3.56
5.	Limestone	24	Nil	Nil
6.	Limestone (Balasore)	96	Nil	Nil
7.	Limestone (Banswara)	32	Nil	Nil
8.	Ennore Sand	4	Nil	Nil
9.	Grevelly Sand No. 1 (Banihal)	68	Nil	Nil
10.	Gravelly Sand No. 2 (Banihal)	100	Nil	Nil
11.	Pyrex Glass	160	926	5.79
12.	Opal	120	721	6.01

Table 3.7. Alkali Content in Indian Cement

No. of samples	Alkali content per cent	Percentage of number of sample to the total
8	Below – 0.40	30.8
7	0.40 – 0.60	26.9
5	0.60 – 0.80	19.2
6	0.80 – 1.00	23.1
Nil	Above – 1.00	Nil

Availability of Moisture

Progress of chemical reactions involving alkali-aggregate reaction in concrete requires the presence of water. It has been seen in the field and laboratory that lack of water greatly reduces this kind of deterioration. Therefore, it is pertinent to note that deterioration due to alkali-aggregate reaction will not occur in the interior of mass concrete. The deterioration will be more on the surface. It is suggested that reduction in deterioration due to alkali-aggregate reaction can be achieved by the application of waterproofing agents to the surface of the concrete with a view to preventing additional penetration of water into the structure.

Temperature Condition

The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C. If the temperatures condition is more than or less than the above, it may not provide an ideal situation for the alkali-aggregate reaction.

Mechanism of Deterioration of Concrete Through the Alkali-Aggregate Reaction

The mechanism of alkali aggregate reaction has not been perfectly understood. However, from the known information, the mechanism of deterioration is explained as follows:

The mixing water turns to be a strongly caustic solution due to solubility of alkalies from the cement. This caustic liquid attacks reactive silica to form alkali-silica gel of unlimited swelling type. The reaction proceeds more rapidly for highly reactive substances. If continuous supply of water and correct temperature is available, the formation of silica gel continues unabated. This silica gels grow in size. The continuous growth of silica gel exerts osmotic pressure to cause pattern cracking particularly in thinner sections of concrete like pavements. Conspicuous effect may not be seen in mass concrete sections.

The formation of pattern cracks due to the stress induced by the growth of silica gel results in subsequent loss in strength and elasticity. Alkali-aggregate reaction also accelerates other process of deterioration of concrete due to the formation of cracks. Solution of dissolved carbon dioxide, converts calcium hydroxide to calcium carbonate with consequent increase in volume. Many destructive forces become operative on the concrete disrupted by alkali-aggregate reaction which will further hasten the total disintegration of concrete.

Control of Alkali-Aggregate Reaction

From the foregoing discussion it is apparent that alkali-aggregate reaction can be controlled by the following methods:

(i) Selection of non-reactive aggregates;

(ii) By the use of low alkali cement;

(iii) By the use of corrective admixtures such as pozzolanas;

(iv) By controlling the void space in concrete;

(v) By controlling moisture condition and temperature.

It has been discussed that it is possible to identify potentially reactive aggregate by petrographic examination, mortar bar test or by chemical method. Avoiding the use of the reactive aggregate is one of the sure methods to inhibit the alkali-aggregate reaction in concrete.

In case avoidance of suspicious reactive aggregate is not possible due to economic reasons, the possibility of alkali-aggregate reaction can be avoided by the use of low alkali cement. restricting the alkali content in cement to less than 0.6 per cent or possibly less than 0.4 per cent, is another good step.

In the construction of nuclear power project at Kaiga in Karnataka, initially, they did not make proper investigation about the coarse aggregate they are likely to use in the power project. When they investigated, they found that the coarse aggregate was showing a tendency for alkali-aggregate reaction. They could not change the source for economical reason. Therefore, they have gone for using, special low-alkali cement. with alkali content less than 0.4 per cent.

It has been pointed out earlier that generally the aggregate is found to be reactive when it contains silica in a particular proportion and in particular fineness. It has been seen in the laboratory that if this optimium condition of silica being in particular proportion and fineness is disturbed, the aggregate will turn to be innocuous. This disturbance of optimum content and fineness of silica can be disturbed by the addition of pozzolanic materials such as crushed stone dust, diatomaceous earth, fly ash or surkhi. The use of pozzolanic mixture has been found to be one of practical solutions for inhibiting alkali-aggregate reaction.

It has been said that development of osmotic pressure on the set-cement gel by the subsequently formed alkali-silica gel is responsible for the disruption of concrete. If a system is introduced to absorb this osmotic pressure, it is probable that the disruption could be reduced. The use of air-entraining agent has frequently been recommended as a means of absorbing the osmotic pressure and controlling expansion due to alkali-aggregate reaction in mortar and concrete.

For the growth of silica gel a continuous availability of water is one of the requirements. If such continuous supply is not made available, the growth of silica gel is reduced. Similarly, if the correct range of temperature is not provided, the extent of expansion is also reduced.

Thermal Properties

Rock and aggregate possesses three thermal properties which are significant in establishing the quality of aggregate for concrete constructions. They are:

(i) Coefficient of expansion; (ii) Specific heat; (iii) Thermal conductivity.

Out of these, specific heat and conductivity are found to be important only in mass concrete construction where rigorous control of temperature is necessary. Also these properties are of consequence in case of light weight concrete used for insulation purpose. When we are dealing with the aggregate in general it will be sufficient at this stage to deal with only the coefficient of expansion of the aggregate, since it interacts with the coefficient of thermal expansion of cement paste in the body of the set-concrete.

An average value of the linear thermal coefficient of expansion of concrete may be taken as 9.9×10^{-6} per °C, but the range may be from about 5.8×10^{-6} per °C to 14×10^{-6} per °C depending upon the type and quantities of the aggregates, the mix proportions and other factors. The range of coefficient of thermal expansion for hydrated cement paste may vary from 10.8×10^{-6} Per °C to 16.2×10^{-6} per °C. Similarly, for mortar it may range from 7.9×10^{-6} per °C to 12.6×10^{-6} per °C.

The linear thermal coefficient of expansion of common rocks ranges from about 0.9×10^{-6} per °C to 16×10^{-6} per °C. From the above it could be seen that while there is thermal compatibility between the aggregate and concrete or aggregate and paste at higher range, there exists thermal incompatibility between aggregate and concrete or aggregate and paste at the lower range. This thermal incompatibility between the aggregate and concrete at the lower range causes severe stress which has got damaging effect on the durability and integrity of concrete structures.

Many research workers have studied the interaction of aggregates with different coefficient of thermal expansion with that of concrete. The result of the experiments does not present a very clear cut picture of the effects that may be expected, and some aspects of the problem are controversial. However, there seems to be a fairly general agreement that the thermal expansion of the aggregate has an effect on the durability of concrete, particularly under severe exposure conditions or under rapid temperature changes. Generally, it can be taken that, where the difference between coefficient of expansion of coarse aggregate and mortar is larger, the durability of the concrete may be considerably lower than would be predicted from the results of the usual acceptance tests. Where the difference between these coefficients exceeds 5.4×10^{-6} per °C caution should be taken in the selection of the aggregate for highly durable concrete.

If a particular concrete is subjected to normal variation of atmospheric temperature, the thermal incompatibility between the aggregates and paste or between the aggregate and matrix may not introduce serious differential movement and break the bond at the interface of aggregate and paste or aggregate and matrix. But if a concrete is subjected to high range of temperature difference the adverse effect will become acute. If quartz is used as aggregate for concrete that is going to be subjected to high temperature the concrete is sure to undergo disruption as quartz changes state and suddenly expands 0.85 per cent at a temperature of 572.7°C. It is also necessary to take care of the peculiar anisotropic behavior *i.e.*, the property of expanding more in one direction or parallel to one crystallographic axis than another. The most notable example is calcite which has a linear thermal coefficient expansion of 25.8×10^{-6} per °C parallel to its axis and -4.7×10^{-6} per °C perpendicular to this direction[3.7]. Potash feldspars are another group of minerals exhibiting anisotropic behaviour.

Therefore, in estimating the cubical expansion of concrete, care must be taken to this aspect of anisotropic behaviour of some of the aggregates. The study of coefficient of thermal expansion of aggregate is also important, in dealing with the fire resistance of concrete.

Grading of Aggregates

Aggregate comprises about 55 per cent of the volume of mortar and about 85 per cent volume of mass concrete. Mortar contains aggregate of size of 4.75 mm and concrete contains aggregate upto a maximum size of 150 mm.

Thus it is not surprising that the way particles of aggregate fit together in the mix, as influenced by the gradation, shape, and surface texture, has an important effect on the workability and finishing characteristic of fresh concrete, consequently on the properties of hardened concrete. Volumes have been written on the effects of the aggregate grading on the properties of concrete and many so called "ideal" grading curves have been proposed. In spite of this extensive study, we still do not have a clear picture of the influence of different types of aggregates on the plastic properties of concrete. It has been this much understood that there is nothing like "ideal" aggregate grading, because satisfactory concrete can be made with various aggregate gradings within certain limits.

It is well known that the strength of concrete is dependent upon water/cement ratio provided the concrete is workable. In this statement, the qualifying clause "provided the concrete is workable" assumes full importance. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum *paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater durability.*

The advantages due to good grading of aggregates can also be viewed from another angle. If concrete is viewed as a two phase material, paste phase and aggregate phase, it is the paste phase which is vulnerable to all ills of concrete. Paste is weaker than average aggregate in normal concrete with rare exceptions when very soft aggregates are used. The paste is more permeable than many of the mineral aggregates. It is the paste that is susceptible to deterioration by the attack of aggressive chemicals. In short, it is the paste which is a weak link in a mass of concrete. The lesser the quantity of such weak material, the better will be the concrete. This objective can be achieved by having well graded aggregates. Hence the importance of good grading.

Many research workers in the field of concrete technology, having fully understood the importance of good grading in making quality concrete in consistent with economy, have directed their studies to achieve good grading of aggregate at the construction site.

Fuller and Thompson[3.8] concluded that grading for maximum density gives the highest strength, and that the grading curve of the best mixture resembles a parabola. Talbot and Richart from their works found that aggregate graded to produce maximum density gave a harsh mixture that is very difficult to place in ordinary concreting operations. Edwards and Young proposed a method of proportioning based on the surface area of aggregate to be wetted. Other things being equal, it was concluded that the concrete made from aggregate grading having least surface area will require least water which will consequently be the strongest.

Abrams and others in course of their investigations have also found that the surface area of the aggregate may vary widely without causing much appreciable difference in the concrete strength, and that water required to produce a given consistency is dependent more on other characteristics of aggregate than on surface area. Therefore, Abrams introduced a parameter known as "fineness modulus" for arriving at satisfactory gradings. He found that any sieve analysis curve of aggregate that will give the same fineness modulus will require the same quantity of water to produce a mix of the same plasticity and gives concrete of the same strength, so long as it is not too coarse for the quantity of cement used. The fineness modulus is an index of the coarseness or fineness of an aggregate sample, but, because different grading can give the same fineness modulus, it does not define the grading.

Waymouth introduced his theory of satisfactory grading on the basis of "particle interference" considerations[3.9]. He found out the volume relationships between successive size groups of particles based on the assumption that particles of each group are distributed throughout the concrete mass in such a way that the distance between them is equal to the mean diameter of the particles of the next smaller size group plus the thickness of the cement film between them. He stated that particle interference occurred between two successive sizes when the distance between particles is not sufficient to allow free passage of the smaller particles. The determination of grading by Waymouth method usually results in finer gradings.

Many other methods have been suggested for arriving at an optimum grading. All these procedures, methods and formulae point to the fact that none is satisfactory and reliable for field application. At the site, a reliable satisfactory grading can only be decided by actual trial and error, which takes into consideration the characteristics of the local materials with respect to size fraction, shape, surface texture, flakiness index and elongation index. The widely varying peculiarities of coarse and fine aggregates cannot be brought under formulae and set procedure for practical application.

One of the practical methods of arriving at the practical grading by trial and error method is to mix aggregates of different size fractions in different percentages and to choose the one sample which gives maximum weight or minimum voids per unit volume, out of all the alternative samples. Fractions which are actually available in the field, or which could be made available in the field including that of the fine aggregate will be used in making samples.

Sieve Analysis

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation.

Set of Sieves assembled for conducting Sieve analysis.

A convenient system of expressing the gradation of aggregate is one which the consecutive sieve openings are constantly doubled, such as 10 mm, 20 mm, 40 mm etc. Under such a system, employing a logarithmic scale, lines can be spaced at equal intervals to represent the successive sizes.

The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron. The aggregate fraction from 80 mm to 4.75 mm are termed as coarse aggregate and those fraction from 4.75 mm to 150 micron are termed as fine aggregate. The size 4.75 mm is a common fraction appearing both in coarse aggregate and fine aggregate (C.A. and F.A.).

Grading pattern of a sample of C.A. or F.A. is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top. The material retained on each sieve after shaking, represents the fraction of aggregate coarser than the sieve in question and finer than the sieve above. Sieving can be done either manually or mechanically. In the manual operation the sieve is shaken giving movements in all possible direction to give


Set of Sieves.

chance to all particles for passing through the sieve. Operation should be continued till such time that almost no particle is passing through. Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than hand-sieving. For assessing the gradation by sieve analysis, the quantity of materials to be taken on the sieve is given Table 3.8.

Table 3.8. Minimum weight of sample for Sieve Analysis (IS: 2386 (Part I) – 1963)

Maximum size present in substantial proportions	Minimum weight of sample to be taken for sieving
mm	kg
63	50
50	35
40 or 31.5	15
25	5
20 or 16	2
12.5	1
10	0.5
6.3	0.2
4.75	0.2
2.36	0.1

From the sieve analysis the particle size distribution in a sample of aggregate is found out. In this connection a term known as "Fineness Modulus" (F.M.) is being used. F.M. is a ready index of coarseness or fineness of the material. Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material. Table No. 3.9 shows the typical example of the sieve analysis, conducted on a sample of coarse aggregate and fine aggregate to find out the fineness modulus.

Many a time, fine aggregates are designated as coarse sand, medium sand and fine sand. These classifications do not give any precise meaning. What the supplier terms as fine sand may be really medium or even coarse sand. To avoid this ambiguity fineness modulus could be used as a yard stick to indicate the fineness of sand.

The following limits may be taken as guidance:

Fine sand	:	Fineness Modulus	:	2.2 - 2.6
Medium sand	:	F.M.	:	2.6 - 2.9
Coarse sand	:	F.M.	:	2.9 - 3.2

A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Combining Aggregates to Obtain Specified Gradings

Sometimes aggregates available at sites may not be of specified or desirable grading. In such cases two or more aggregates from different sources may be combined to get the desired

Table 3.9. The typical Example of the Sieve Analysis

IS Sieve Size	Coarse Aggregate				Fine Aggregate			
	Weight retained weight kg	Cumulative weight retained kg	Cumulative percentage retained	Cumulative percentage passing	Weight retained gm	Cumulative weight retained gm	Cumulative percentage weight retained	Comulative percentage passing
80 mm	0	0	0	100	-	-	-	-
40 mm	0	0	0	100	-	-	-	-
20 mm	6	6	40	60	-	-	-	-
10 mm	5	11	73.3	26.7	0	0	0	100
4.75 mm	4.0	15.00	100	00	10	10	2	98
2.36 mm	-	-	100	00	50	60	12	88
1.18 mm	-	-	100	00	50	110	22	78
600 micron	-	-	100	00	95	205	41	59
300 micron	-	-	100	00	175	380	76	24
150 micron	-	-	100	00	85	465	93	7
lower than 150 micron	-	-	-	00	35	500	-	-
Total	15 kg		713.3		500 gm	—	246	
	$F.M. = \frac{713.3}{100} = 7.133$				$F.M. = \frac{246}{100} = 2.46$			

grading. Often, mixing of available fine aggregate with available coarse aggregate in appropriate percentages may produce desirable gradings. But sometimes two or more fractions of coarse aggregate is mixed first and then the combined coarse aggregate is mixed with fine aggregate to obtain the desired gradings. Knowing the grading of available aggregates, proportions of mixing different sizes can be calculated, either graphically or arithmetically. This aspect will be dealt in more detail under the chapter Mix Design. At this stage a simple trial and error arithmetical method of combining coarse and fine aggregate is illustrated. Table 3.10 shows the grading pattern of the available coarse and fine aggregate at site. This table also shows the specified combined grading.

Table 3.11 shows the grading of different combination of fine and coarse aggregate for first trial and second trial. The combined grading of first trial and second trial is compared with the specified combined grading. Whichever trial gives the combined aggregate grading equal or nearly equal to the specified grading is adopted.

Specific Surface and Surface Index

The importance of a good grading of the coarse and fine aggregate has already been discussed. The quantity of water required to produce a given workability depends to a large extent on the surface area of the aggregate.

Table 3.10. Shows the grading pattern of the available coarse and fine aggregate and specified combined grading

I.S. Sieve size	Percentage passing		
	C.A.	F.A.	Specified combined aggregate (From Table No. 3.11)
40	100	100	100
20	96	100	98
10	35	100	61
4.75	6	92	42
2.36	0	85	35
1.18	0	75	28
600	0	60	22
300	0	10	5
150	0	0	0

The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading. Specific surface increases with the reduction in the size of aggregate particle so that fine aggregate contributes very much more to the surface area than does the coarse aggregate. Greater surface area requires more water for lubricating the mix to give workability. The workability of a mix is, therefore, influenced more by finer fraction than the coarser particles in a sample of aggregates.

The foregoing paragraph gives the impression that smaller particles of aggregate contribute more surface area and hence require more water for wetting the surface of aggregates; and for a given quantity of water, the presence of smaller particles reduces the workability. This impression is correct upto a certain extent of the finer fraction. This will not hold good for very fine particles in F.A. The every fine particles in F.A. i.e., 300 micron and 150 micron particles, being so fine, contribute more towards workability. Their over-riding influence

Table 3.11. Showing the Grading of Different Combination of Fine and Coarse Aggregate for Different Trials

I.S. Sieve	Percentage passing								
	C.A.	F.A.	Specified combined grading	1st Trial			2nd Trial		
				70% C.A.	30% F.A.	Combined grading	60% C.A.	40% F.A.	Combined grading
1	2	3	4	5	6	7	8	9	10
40	100	100	100	70	30	100	60	40	100
20	96	100	98	67.2	30	97.2	60	40	97.6
10	35	100	61	24.5	30	54.5	57.6	40	61.0
4.75	6	92	42	4.2	27.6	31.8	21.0	36.8	40.6
2.36	0	85	35	-	25.5	25.5	3.6	34.0	34.0
1.18	0	75	28	-	22.5	22.5	-	30.0	30.0
600	0	60	22	-	18.00	18.00	-	24.0	24.0
300	0	10	5	-	3.00	3.00	-	4.0	4.0
150	0	0	0	-	-	-	-	-	-

It is seen that the combined grading obtained by the mixture of C.A. and F.A. in the ratio of 60:40 closely conform the specified grading shown in column 4.

in contributing to the better workability by acting like ball bearings to reduce the internal friction between coarse particles, far out-weigh the reduction in workability owing to the consumption of mixing water for wetting greater surface area.

Consideration of specific surface gives a somewhat misleading picture of the workability to be expected. To overcome this difficulty Murdock has suggested the use of "Surface Index" which is an empirical number related to the specific surface of the particle with more weightage given to the finer fractions. The empirical numbers representing the surface index of aggregate particles within the set of sieve size are given in Table 3.12.

The total surface index (fx) of a mixture of aggregate is calculated by multiplying the percentage of material retained on its sieve by the corresponding surface index and to their sum is added a constant of 330 and the result is divided by 1000. The method of computing the total surface for any given grading is shown in Table 3.13

Table 3.12. Surface Index of Aggregate Particles[3.2]

Sieve size within which particles lie	*Surface Index for Particles within Sieve Size indicated*
80–40 mm	– 2.5
40–20 mm	– 2
20–10 mm	– 1
10–4.75 mm	+ 1
4.75–2.36 mm	4
2.36–1.18 mm	7
1.18–600 micron	9
600–300 micron	9
300–150 micron	7
Smaller than 150 micron	2

Table 3.13. Surface Index of Combined Grading

Sieve size within which Particles lie	*Percentage of particles within sieve size*	*Surface Index for particles within sieve size*	*Surface Index (fx)*
20—10 mm	55	–1	–55
10—4.75 mm	15	1	15
4.75—2.36 mm	7	4	28
2.36—1.18 mm	7	7	49
1.18—600 micron	7	9	63
600—300 micron	7	9	63
300—150 micron	2	7	14
		Total	177
		Add constant	330
			507

$$\text{Surface Index } (fx) = \frac{507}{1000} = \mathbf{0.507}$$

Similarly, surface index can be calculated for standard grading curve, and this value of surface index can be taken as the desirable surface index of the combined aggregate.

This parameter of surface index can be made use of for finding out the proportion of fine aggregate to coarse aggregate available in the field to obtain specified or desirable surface index in the following way.

Let x = surface index of fine aggregate

y = surface index of coarse aggregate

z = surface index of combined aggregate

a = proportion of fine to coarse aggregate

$$\text{Then } a = \frac{(z - y)}{(x - z)}$$

The following example will show how to combine the available fine aggregate with available coarse aggregate whose grading patterns are known to get the desirable surface index of the combined aggregate. The desirable surface index of the combined aggregate could be calculated from the grading pattern of the standard grading curve.

Sieve size within which particles lie	Percentage of particles within sieve size	Surface index for partcles for sieve size	Surface Index (fx)
Coarse Aggregate			
20 mm — 10 mm	65	–1	–65
10 mm — 4.75	35	1	35
			Total = –30
			Add constant = 330
			= 300
Surface Index of Corase Aggregate = $\frac{300}{1000}$ = 0.30			
Fine Aggregate			
4.75 mm — 2.36	10	4	40
2.36 mm — 1.18	20	7	140
1.18 mm — 600 micron	20	9	180
600 micron — 300 micron	30	9	270
300 micron — 150 micron	15	7	105
			Total = 735
			Add constant = 330
			= 1065

$$\text{Surface Index of fine Aggregate} = \frac{1065}{1000} = 1.065$$

Let the surface index of combined aggregate required = 0.6.

x = surface index of F.A. = 1.065

y = surface index of C.A. = 0.30

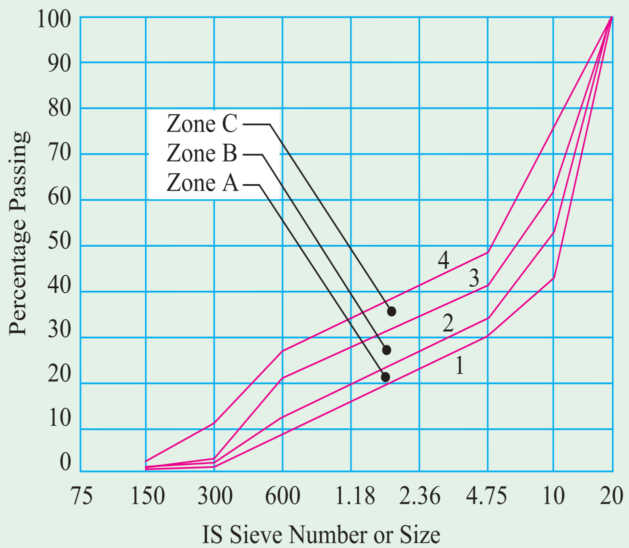
z = surface index of combined aggregate = 0.60

If a = proportion of fine to coarse aggregate, $a = \frac{(z-y)}{(x-z)} = \frac{(0.60-0.30)}{(1.065-0.60)} = \frac{1}{1.55}$

Therefore, F.A. : C.A. = 1 : 1.55

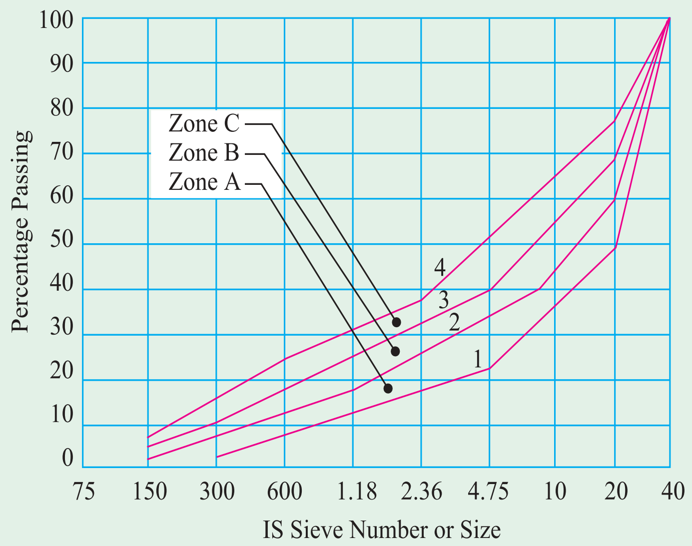
Standard Grading Curve

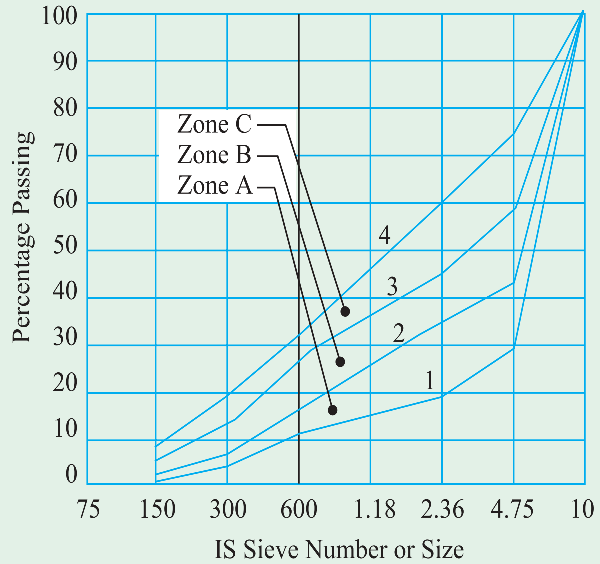
The grading patterns of aggregate can be shown in tables or charts. Expressing grading limits by means of a chart gives a good pictorial view. The comparison of grading pattern of a number of samples can be made at one glance. For this reason, often grading of aggregates is shown by means of grading curves. One of the most commonly referred practical grading curves are those produced by Road Research Laboratory (U.K.).[3.10] On the basis of large number of experiments in connection with bringing out mix design procedure, Road Research



Laboratory has prepared a set of type grading curve for all-in aggregates graded down from 20 mm and 40 mm. They are shown in figure 3.4 and Fig 3.5 respectively. Similar curves for aggregate with maximum size of 10 mm and downward have been prepared by McIntosh and Erntory. It is shown in Fig. 3.6. Fig. 3.7 shows the desirable grading limit for 80 mm aggregate.

Four curves are shown for each maximum size of aggregate except 80 mm size. From values of percentage passing it can be seen that the lowest curve *i.e.*, curve No. 1 is the coarsest grading and curve No. 4 at the top represents the finest grading. Between the curves No. 1 to 4 there are three zones: A, B, C. In practice the coarse and fine aggregates are supplied separately. Knowing their gradation it will be possible to mix them up to get type grading conforming to any one of the four grading curves.



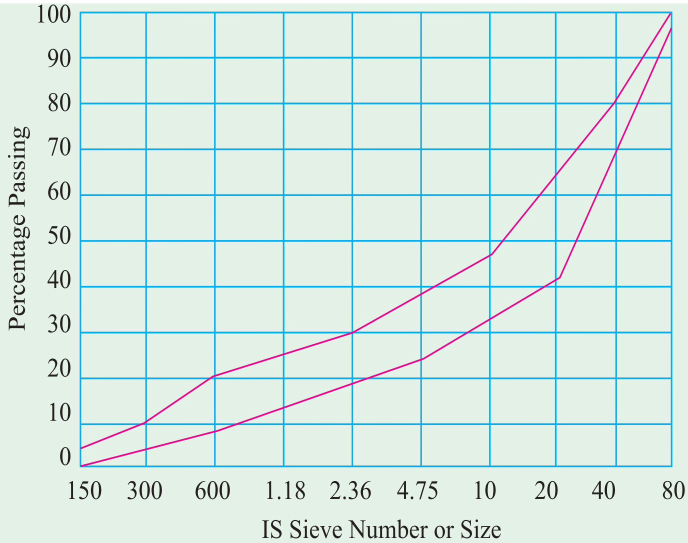


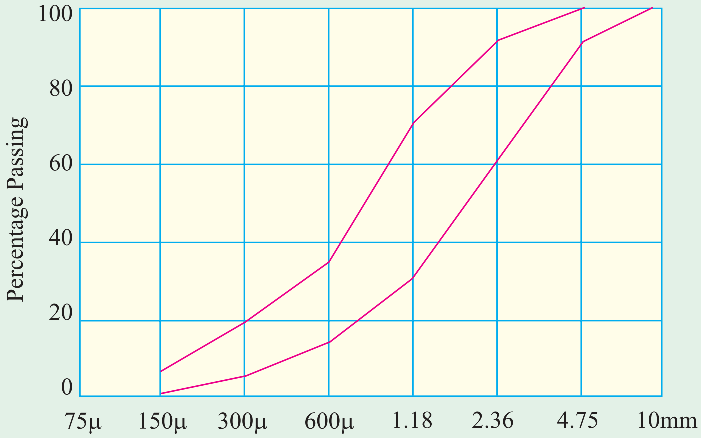
In practice, it is difficult to get the aggregate to conform to any one particular standard curve exactly. If the user insists on a particular pattern of grading, the supplier may quote very high rates. At the same time the user also cannot accept absolutely poor grading pattern of aggregates. As a via media, grading limits are laid down in various specifications rather than to conform exactly to a particular grading curve. Table 3.14 shows the grading limits of coarse aggregates.

Table 3.15 shows the grading limits of fine aggregates. Table 3.16 shows the grading limits of all-in-aggregate.

It should be noted that for crushed stone sands, the permissible limit on 150 micron I.S. Sieve is increased to 20 per cent. Figs. 3.8 a, b, c and d show the grading limits of F.A.

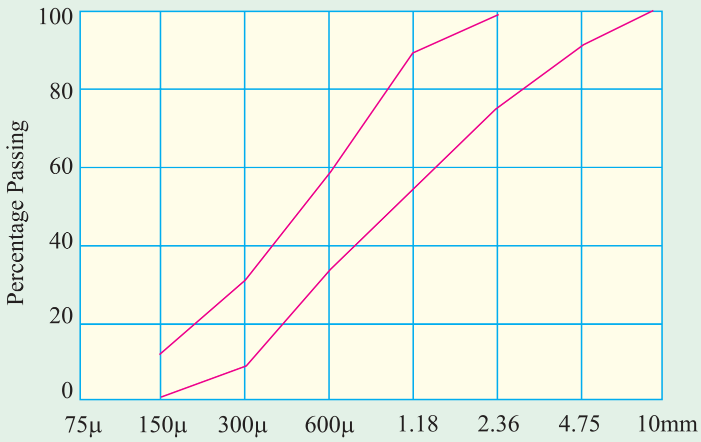
Fine aggregate complying with the requirements of any grading zone in Table 3.15 is suitable for concrete but the quality of concrete produced will depend upon a number of factors including proportions.





Zone - 1

(*a*)



Zone - 2

(*b*)

Fig. 3.8. Grading limits for sand in zones 1 and 2 of I.S. : 383-1970. (Contd.)

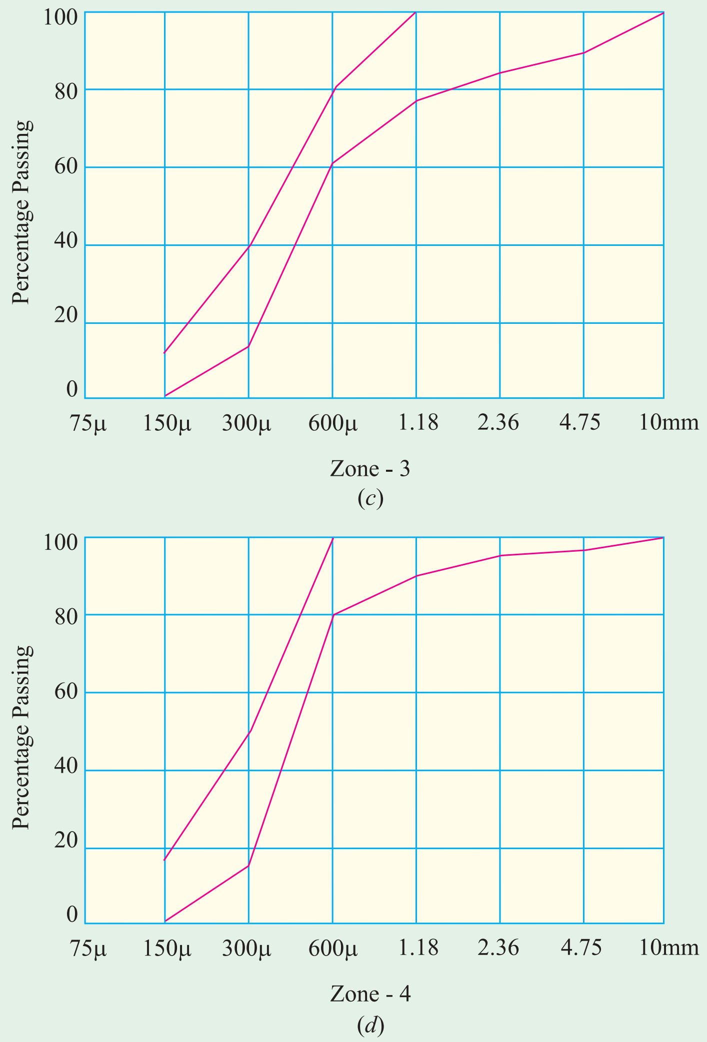


Fig. 3.8. Grading limits for sand in zones 3 and 4 of I.S. : 383-1970.

Where concrete of high strength and good durability is required, fine aggregate conforming to any one of the four grading zones may be used, but the concrete mix should be properly designed. As the fine aggregate grading becomes progressively finer, that is from Grading Zones I to IV, the ratio of the fine aggregate to coarse aggregate should be progressively reduced. The most suitable fine to coarse ratio to be used for any particular mix will, however, depend upon the actual grading, particle shape and surface texture of both fine and coarse aggregates.

It is recommended that fine aggregate conforming to Grading Zone IV should not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions.

Table 3.14. Grading Limits for Coarse Aggregate IS: 383-1970

IS Sieve Designation	*Percentage passing for single-sized aggregate nominal size (by weight)*						*Percentage passing for Graded aggregate of nominal size (by weight)*			
	63 mm	*40 mm*	*20 mm*	*16 mm*	*12.5 mm*	*10 mm*	*40 mm*	*20 mm*	*16 mm*	*12.5 mm*
80 mm	100	–	–	–	–	–	100	–	–	–
63 mm	85–100	100	–	–	–	–	–	–	–	–
40 mm	0–30	85–100	100	–	–	–	95–100	100	–	–
20 mm	0–5	0–20	85–100	100	–	–	30–70	95–100	100	100
16 mm	–	–	–	85–100	100	–	–	–	90–100	–
12.5 mm	–	–	–	–	85–100	100	–	–	–	90–100
10 mm	–	0–5	0–20	0–30	0–45	85–100	10–35	25–55	30–70	40–85
4.75 mm	–	–	0–5	0–5	0–10	0–20	0–5	0–10	0–10	0–10
2.36 mm	–	–	–	–	–	0–5	–	–	–	–

Table 3.15. Grading limits of fine aggregates IS: 383-1970

I.S. Sieve Designation	Percentage passing by weight for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–70	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15

Table 3.16. Grading limits of all-in-aggregates

I.S. Sieve Designation	Percentage by weights passing for all in-aggragrate of	
	40 mm Nominal size	20 mm Nominal size
80 mm	100	–
40 mm	95–100	100
20 mm	45–75	95–100
4.75 mm	25–45	30–50
600 micron	8–30	10–35
150 micron	0–6	0–6

It must be remembered that the grading of fine aggregates has much greater effect on workability of concrete than does the grading of coarse aggregate. Experience has shown that usually very coarse sand or very fine sand is unsatisfactory for concrete making. The coarse sand results in harshness bleeding and segregation, and the fine sand requires a comparatively greater amount of water to produce the necessary fluidity. For fine aggregates, a total departure of 5 per cent from zone limits may be allowed. But this relaxation is not permitted beyond the coarser limit of zone I or the finer limit of zone IV.

Crushed Sand

All along in India, we have been using natural sand. The volume of concrete manufactured in India has not been much, when compared to some advanced countries. The infrastructure development such as express highway projects, power projects and industrial developments have started now. Availability of natural sand is getting depleted and also it is becoming costly. Concrete industry now will have to go for crushed sand or what is called manufactured sand.

Advantages of natural sand is that the particles are cubical or rounded with smooth surface texture. The grading of natural F.A. is not always ideal. It depends on place to place. Being cubical, rounded and smooth textured it gives good workability.

So far, crushed sand has not been used much in India for the reason that ordinarily crushed sand is flaky, badly graded rough textured and hence they result in production of harsh concrete for the given design parameters. We have been also not using superplasticizer *widely in our concreting operations to improve the workability of harsh mix. For the last about 4–5 years the old methods of manufacturing ordinary crushed sand have been replaced by modern crushers specially designed for producing, cubical, comparatively smooth textured, well graded sand, good enough to replace natural sand.*

Many patented equipments are set up in India to produce crushed sand of acceptable quality at project site. Pune-Mumbai express highway is one of the biggest projects undertaken in India recently. Enough quantities of natural sand is not available in this region. The total quantity of concrete involved is more than 20,000,00 m^3 of concrete. The authorities have decided to use crushed sand.

A company by name Svedala is one of the concrete aggregate manufacturers who have been in the forefront for supplying crusher equipments by trade name Jaw master crusher, or Barmac Rock on Rock VSI crushers incorporating rock-on-rock crushing technology that has revolutionised the art of making concrete aggregates. This imported technology has been used for producing coarse and fine aggregates of desired quality in terms of shape, texture and grading.

Dust is a nuisance and technically undesirable in both coarse aggregate and more so in fine aggregate. Maximum permissible particles of size finer than 75µ is 15% in fine aggregate and 3% in coarse aggregate. There are provision available in these equipments to control and seal the dust.

Barmac Rock-On-Rock VSI Crusher.

In one of the high rise building sites in western suburb of Mumbai, M 60 concrete was specified. The required slump could not be achieved by natural sand with the given parameter of mix design. But with the use of manufactured sand with proper shape, surface texture, desirable grading to minimise void content, a highly workable mix with the given parameter of mix design, was achieved.

The following is the grading pattern of a sample collected from a sand crushing plant on a particular date and time at Pune-Mumbai Road Project:

Table 3.17. Grading Pattern of Crushed Sand (Typical)

I.S. Sieve mm	Percentage passing			Remarks
	As per actual test	IS Requirements for		
		Zone I	Zone II	
10	100	100	100	
4.75	97.58	90–100	90–100	Falling in Zone II
2.36	82.36	60–95	75–100	
1.18	55.27	30–70	55–90	
600	40.56	15–34	35–59	
300	29.33	5–20	8–30	
150	18.78	0–20	0–20	
75	10.09	Max 15	Max 15	

The introduction of modern scientifically operated crushers which are operating all over the world, will go a long way for making quality aggregates in all cities in India. Ordinary crushers cannot give the desired shape, surface texture or grading of both coarse and fine aggregate.

Cone Crushers.

Gap grading

So far we discussed the grading pattern of aggregates in which all particle size are present in certain proportion in a sample of aggregate. Such pattern of particle size distribution is also referred to as continuous grading.

Originally in the theory of continuous grading, it was assumed that the voids present in the higher size of the aggregate are filled up by the next lower size of aggregate, and similarly, voids created by the lower size are filled up by one size lower than those particle and so on. It was realised later that the voids created by a particular fraction are too small to accommodate the very next lower size. The next lower size being itself bigger than the size of the voids, it will create what is known as "particle size interference", which prevents the large aggregates compacting to their maximum density.

It has been seen that the size of voids existing between a particular size of aggregate is of the order of 2 or 3 size lower than that fraction. In other words, the void size existing between 40 mm aggregate is of the size equal to 10 mm or possibly 4.75 mm or the size of voids occurring when 20 mm aggregate is used will be in the order of say 1.18 mm or so. Therefore, along with 20 mm aggregate, only when 1.18 mm aggregate size is used, the sample will contain least voids and concrete requires least matrix. The following advantages are claimed for gap graded concrete:

- *(i)* *Sand required will be of the order of about 26 per cent as against about 40 per cent in the case of continuous grading.*
- *(ii)* *Specific surface area of the gap graded aggregate will be low, because of high percentage of C.A. and low percentage of F.A.*
- *(iii)* *Requires less cement and lower water/cement ratio.*
- *(iv)* *Because of point contact between C.A. to C.A. and also on account of lower cement and matrix content, the drying shrinkage is reduced.*

It was also observed that gap graded concrete needs close supervision, as it shows greater proneness to segregation and change in the anticipated workability. In spite of many claims of the superior properties of gap graded concrete, this method of grading has not become more popular than conventional continuous grading.

TESTING OF AGGREGATES

Test for Determination of Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm.

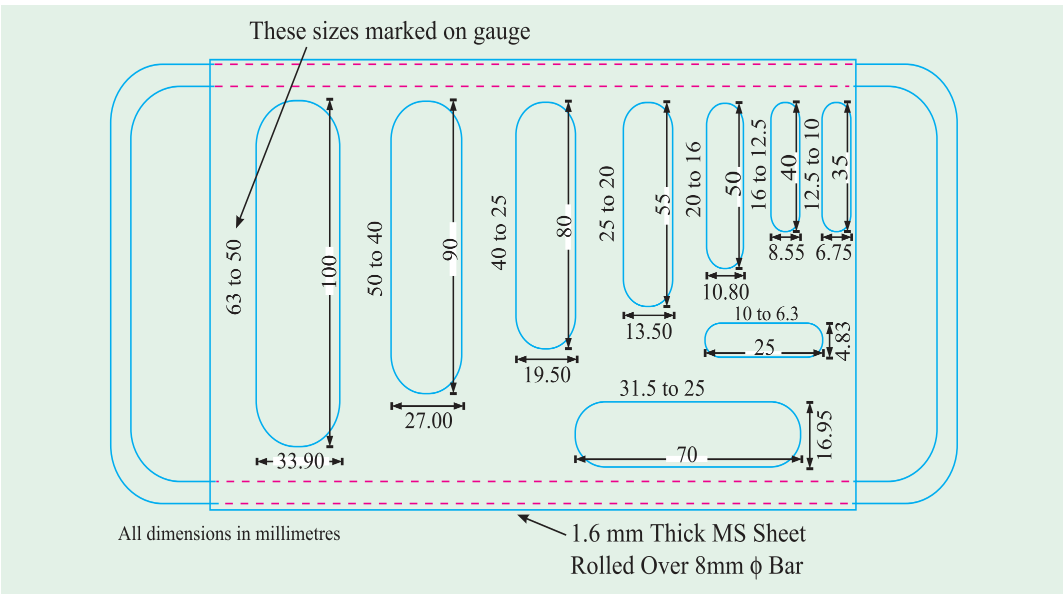
This test is conducted by using a metal thickness gauge, of the description shown in Fig. 3.9. A sufficient quantity of aggregate is taken such that a minimum number of 200 pieces of any fraction can be tested. Each fraction is gauged in turn for thickness on the metal gauge. The total amount passing in the guage is weighed to an accuracy of 0.1 per cent of the weight of the samples taken. The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken. Table 3.18 shows the standard dimensions of thickness and length gauges.

Table 3.18. Shows Dimensions of Thickness and Length Gauges (IS: 2386 (Part I) – 1963)

Size of Aggregate Thickness		*Length of Gauge* mm*	*Gauge† mm*
Passing through IS Sieve	*Retained on IS Sieve*		
63 mm	50 mm	33.90	–
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	–
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10.0 mm	6.75	20.2
10.0 mm	6.3 mm	4.89	14.7

* This dimension is equal to 0.6 times the mean Sieve size.

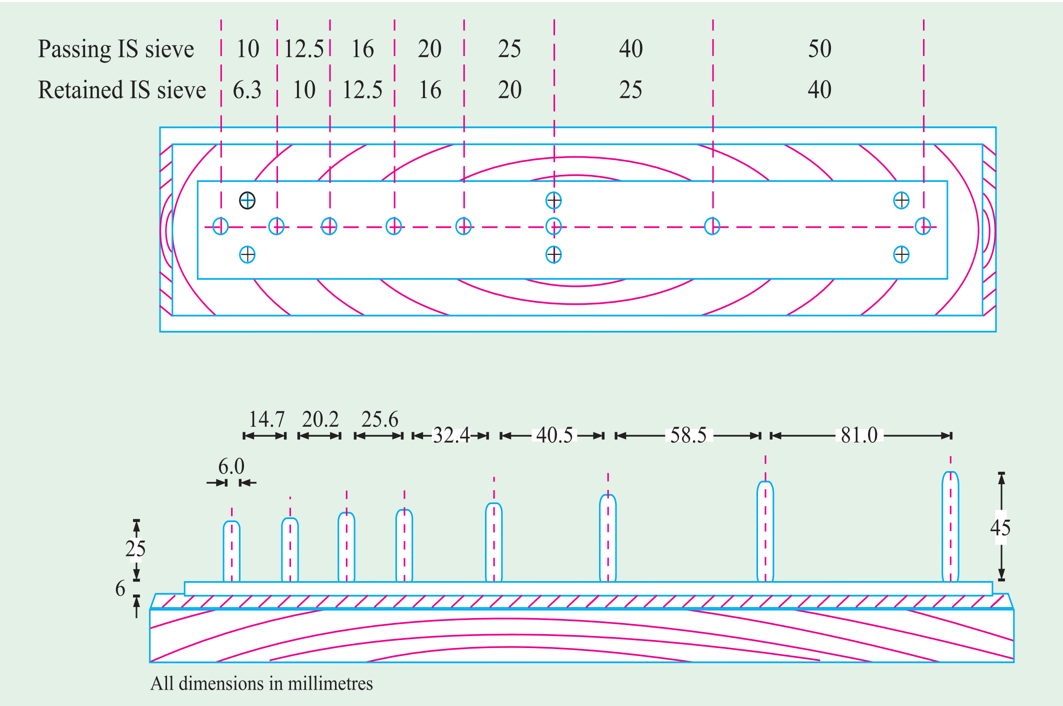
† This dimension is equal to 1.8 times the mean Sieve size.



Test for Determination of Elongation Index

The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using metal length guage of the description shown in Fig. 3.10. A sufficient quantity of aggregate is taken to provide a minimum number of 200 pieces of any fraction to be tested. Each fraction shall be gauged individually for length on the metal guage. The guage length used shall be that specified in column of 4 of Table 3.18 for the appropriate size of material. The total amount retained by the guage length shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test samples taken. The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recoganised limits are laid down.



Length Gauge.

Indian standard explain only the method of calculating both Flakiness Index and Elongation Index. But the specifications do not specify the limits. British Standard BS 882 of 1992 limits the flakiness index of the coarse aggregate to 50 for natural gravel and to 40 for crushed corase aggregate. However, for wearing surfaces a lower values of flakiness index are required.

Test for Determination of clay, fine silt and fine dust

This is a gravimetric method for determining the clay, fine silt and fine dust which includes particles upto 20 microns.

The sample for test is prepared from the main sample, taking particular care that the test sample contains a correct proportion of the finer material. The amount of sample taken for the test is in accordance with Table 3.19.

Table 3.19. Weight of Sample for Determination of Clay, Fine Silt and Fine Dust

Maximum size present in substantial proportions mm	Approximate weight of sample for Test kg
63 to 25	6
20 to 12.5	1
10 to 6.3	0.5
4.75 or smaller	0.3

Sedimentation pipette of the description shown in Fig. 3.11 is used for determination of clay and silt content. In the case of fine aggregate, approximately 300 gm. of samples in the air-dry condition, passing the 4.75 mm IS Sieve, is weighed and placed in the screw topped glass jar, together with 300 ml of diluted sodium oxalate solution. The rubber washer and cap are fixed. Care is taken to ensure water tightness. The jar is then rotated about its long axis, with this axis horizontal, at a speed of 80 ± 20 revolutions per minute for a period of 15 minutes. At the end of 15 minutes the suspension is poured into 1000 ml measuring cylinder and the residue washed by gentle swirling and decantation of successive 150 ml portions of sodium oxalate solution, the washings being added to the cylinder until the volume is made upto 1000 ml.

In the case of coarse aggregate the weighed sample is placed in a suitable container, covered with a measured volume of sodium oxalate solution (0.8 gm per litre), agitated vigorously to remove all fine material adhered and the liquid suspension transferred to the 1000 ml measuring cylinder. This process is repeated till all clay material has been transferred to the cylinder. The volume is made upto 1000 ml with sodium oxalate solution.

The suspension in the measuring cylinder is thoroughly mixed. The pipette A is then gently lowered until the pipette touches the surface of the liquid, and then lowered a further 10 cm into the liquid. Three minutes after placing the tube in position, the pipette A and the bore of tap B is filled by opening B and applying gentle suction at C. A small surplus may be drawn up into the bulb between tap B and tube C, but this is allowed to run away and any solid matter is washed out with distilled water from E. The pipette is then removed from the measuring cylinder and its contents run into a weighed container. The contents of the container is dried at 100°C to 110°C to constant weight, cooled and weighed.

The percentage of the fine slit and clay or fine dust is calculated from the formula.

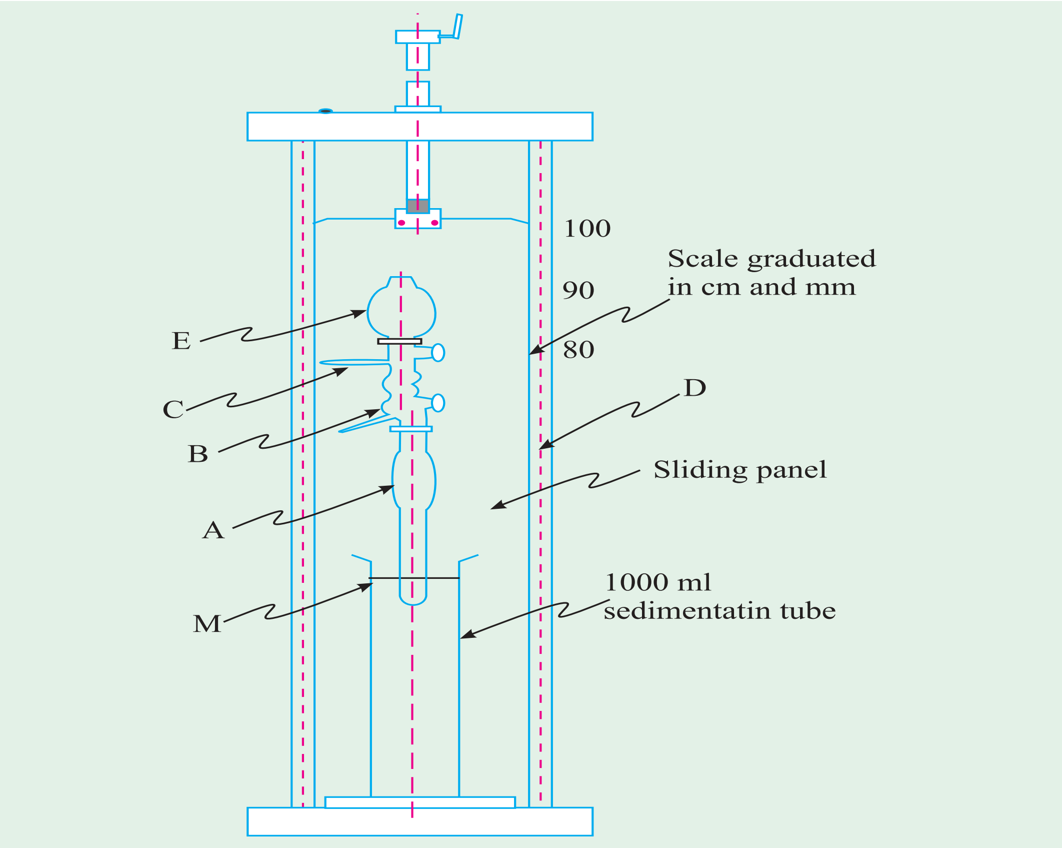
$$\frac{100}{W_1}\left(\frac{1000\,W_2}{V}-0.8\right)$$

where W_1 = *weight in gm of the original sample.*

W_2 = weight in gm of the dried residue

V = volume in ml of the pipette and

0.8 = weight in gm of sodium oxalate in one litre of diluted solution.



Test for Determination of Organic Impurities

This test is an approximate method for estimating whether organic compounds are present in the natural sand in an objectionable quantity or within the permissible limit. The sand from the natural source is tested as delivered and without drying. A 350 ml graduated clear glass bottle is filled to the 75 ml mark with 3 per cent solution of sodium hydroxide in water. The sand is added gradually until the volume measured by the sand layer is 125 ml. The volume is then made up to 200 ml by adding more solution. The bottle is then stoppered and shaken vigorously. Roding also may be permitted to dislodge any organic matter adhering to the natural sand by using glass rod. The liquid is then allowed to stand for 24 hours. The colour of this liquid after 24 hours is compared with a standard solution freshly prepared, as follows:

Add 2.5 ml of 2 per cent solution of tannic acid in 10 per cent alcohol, to 97.5 ml of a 3 per cent sodium hydroxide solution. Place in a 350 ml. bottle, stopper, shake vigorously and allow to stand for 24 hours before comparison with the solution above and described in the preceding paragraph. Alternatively, an instrument or coloured acetate sheets for making the comparison can be obtained, but it is desirable that these should be verified on receipt by comparison with the standard solution.

Test for Determination of Specific Gravity

Indian Standard Specification IS : 2386 (Part III) of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. The following procedure is applicable to aggregate size larger than 10 mm.

A sample of aggregate not less than 2 kg is taken. It is thoroughly washed to remove the finer particles and dust adhering to the aggregate. It is then placed in a wire basket and immersed in distilled water at a temperature between 22° to 32°C. Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per sec. During the operation, care is taken that the basket and aggregate remain completely immersed in water. They are kept in water for a period of 24 ± 1/2 hours afterwards. The basket and aggregate are then jolted and weighed (weight A_1) in water at a temperature 22° to 32° C. The basket and the aggregate are then removed from water and allowed to drain for a few minutes and then the aggregate is taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth. The aggregate is transferred to the second dry cloth and further dried. The empty basket is again immersed in water, jolted 25 times and weighed in water (weight A_2). The aggregate is exposed to atmosphere away from direct sunlight for not less than 10 minutes until it appears completely surface dry. Then the aggregate is weighed in air (weight B). Then the aggregate is kept in the oven at a temperature of 100 to 110°C and maintained at this temperature for 24 ± 1/2 hours. It is then cooled in the air-tight container, and weighed (weight C).

$$\text{Specific Gravity} = \frac{C}{B-A}; \quad \text{Apparent Sp. Gravity} = \frac{C}{C-A}$$

$$\text{Water absorption} = \frac{100\,(B-C)}{C}$$

Where, A = the weight in gm of the saturated aggregate in water $(A_1 - A_2)$,

B = the weight in gm of the saturated surface-dry aggregate in air, and

C = the weight in gm of oven-dried aggregate in air.

Test for Determination of Bulk Density and Voids

Bulk density is the weight of material in a given volume. It is normally expressed in kg per litre. A cylindrical measure preferably machined to accurate internal dimensions is used for measuring bulk density. The size of the container for measuring bulk density is shown in Table, 3.20.

Table 3.20. Size of Container for Bulk Density Test

Size of Largest Particles	Nominal Capacity	Inside Diameter	Inside Height	Thickness of Metal
	litre	cm	cm	mm
4.75 mm and under	3	15	17	3.15
Over 4.75 mm				
to 40 mm	15	25	30	4.00
Over 40 mm	30	35	31	5.00

The cylindrical measure is filled about 1/3 each time with thoroughly mixed aggregate and tamped with 25 strokes by a bullet ended tamping rod, 16 mm diameter and 60 cm long. The measure is carefully struck off level using tamping rod as a straight edge. The net weight of the aggregate in the measure is determined and the bulk density is calculated in kg/litre.

$$\text{Bulk dinsity} = \frac{\text{net weight of the aggregate in kg}}{\text{capacity of the container in litre}}\text{;} \qquad \text{Percentage of voids} = \frac{G_s - \gamma}{G_s} \times 100$$

where, G_s *= specific gravity of aggregate and* γ *= bulk dinsity in kg/litre.*

Mechanical Properties of Aggregates
IS: 2386 Part IV – 1963

Test for determination of aggregate crushing value

The "aggregate crushing value" gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. With aggregates of 'aggregate crushing value' 30 or higher, the result may be anomalous and in such cases the "ten per cent fines value" should be determined and used instead.

The standard aggregate crushing test is made on aggregate passing a 12.5 mm I.S. Sieve and retained on 10 mm I.S. Sieve. If required, or if the standard size is not available, other sizes upto 25 mm may be tested. But owing to the nonhomogeneity of aggregates the results will not be comparable with those obtained in the standard test.

About 6.5 kg material consisting of aggregates passing 12.5 mm and retained on 10 mm sieve is taken. The aggregate in a surface dry condition is filled into the standard cylindrical measure in three layers approximately of equal depth. Each layer is tamped 25 times with the tamping ord and finally levelled off using the tamping rod as straight edge. The weight of the sample contained in the cylinder measure is taken (A). The same weight of the sample is taken for the subsequent repeat test.

The cylinder of the test appartus with aggregate filled in a standard manner is put in position on the base-plate and the aggregate is carefully levelled and the plunger inserted horizontally on this surface. The plunger should not jam in the cylinder.

Aggregate Crushing Value Apparatus.

The appartus, with the test sample and plunger in position, is placed on the compression testing machine and is loaded uniformly upto a total load of 40 tons in 10 minutes time. The load is then released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed (B),

$$\text{The aggregate crushing value} = \frac{B}{A} \times 100$$

where, *B* = weight of fraction passing 2.36 mm sieve,

A = weight of surface-dry sample taken in mould.

The aggregate crushing value should not be more than 45 per cent for aggregate used for concrete other than for wearing surfaces, and 30 per cent for concrete used for wearing surfaces such a runways, roads and air field pavements.

Test for determination of 'ten per cent fines value'

The sample of aggregate for this test is the same as that of the sample used for aggregate crushing value test. The test sample is prepared in the same way as described earlier. The cylinder of the test appartus is placed in position on the base plate and the test sample added in thirds, each third being subjected to 25 strokes by tamping rod. The surface of the aggregate is carefully levelled and the plunger inserted so that it rests horizontally on this surface.

The appartus, with the test sample and plunger in position is placed in the compression testing machine. The load is applied at a uniform rate so as to cause a total penetration of the plunger in 10 minutes of about:

15.00 mm for rounded or partially rounded aggregates (for example uncrushed gravels)

20.0 mm for normal crushed aggregates, and

24.0 mm for honeycombed aggregates (for example, expanded shales and slags).

These figure may be varied according to the extent of the rounding or honeycombing.

After reaching the required maximum penetration, the load is released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve. The fines passing the sieve is weighed and the weight is expressed as a percentage of the weight of the test sample. This percentage would fall within the range 7.5 to 12.6, but if it does not, a further test shall be made at a load adjusted as seems appropriate to bring the percentage fines with the range of 7.5 to 12.5 per cent. Repeat test is made and the load is found out which gives a percentage of fines within the range of 7.5 to 12.5

$$\text{Load required for 10 per cent fines} = \frac{14 \times X}{Y + 4}$$

where, *X* = load in tons, causing 7.5 to 12.5 per cent fines.

Y = mean percentage fines from two tests at *X* tons load.

Test for determination of aggregate impact value

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact. Which in some aggregates differs from its resistance to a slow compressive load.

Aggregate Impact Value Apparatus.

The test sample consists of aggregate passing through 12.5 mm and retained on 10 mm I.S. Sieve. The aggregate shall be dried in an oven for a period of four hours at a temperature of 100°C to 110°C and cooled. The aggregate is filled about one-third full and tamped with 25 strokes by the tamping rod. A further similar quantity of aggregate is added and tamped in the standard manner. The measure is filled to over-flowing and then struck off level. The net weight of the aggregate in the measure is determined (weight *A*) and this weight of aggregate shall be used for the duplicate test on the same material.

The whole sample is filled into a cylindrical steel cup firmly fixed on the base of the machine. A hammer weighing about 14 kgs. is raised to a height of 380 mm above the upper surface of the aggregate in the cup and allowed to fall freely on the aggregate. The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed to an accuracy of 0.1 gm. (weight *B*). The fraction retained on the sieve is also weighed (weight *C*). If the total weight (*B* + *C*) is less than the initial weight *A* by more than one gm the result shall be discarded and a fresh test made. Two tests are made.

The ratio of the weight of fines formed to the total sample weight in each test is expressed as percentage.

Therefore, Aggregate Impact Value = $\frac{B}{A} \times 100$

where, B = weight of fraction passing 2.36 mm I.S. Sieve.

A = weight of oven-dried sample.

The aggregate impact value should not be more than 45 per cent by weight for aggregates used for concrete other than wearing surfaces and 30 per cent by weight for concrete to be used as wearing surfaces, such as runways, roads and pavements.

Test for determination of aggregate abrasion value

Indian Standard 2386 (Part IV) of 1963 covers two methods for finding out the abrasion value of coarse aggregates: namely, by the use of Deval abrasion testing machine and by the use of Los Angeles abrasion testing machine. However, the use of Los Angeles abrasion testing machine gives a better realistic picture of the abrasion resistance of the aggregate. This method is only described herein.

Table 3.21 gives the detail of abrasive charge which consists of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 to 445 gm.

Table 3.21. Specified Abrasive Charge

Grading	Number of spheres	Weight of charge (gm)
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

The test sample consist of clean aggregate which has ben dried in an oven at 105°C to 110°C and it should conform to one of the gradings shown in Table 3.22.

Table 3.22. Gradings of Test Samples

Sieve Size		Weight in gm. of Test Sample For Grade						
Passing	Retained on	A	B	C	D	E	F	G
mm	mm							
80	63	-	-	-	-	2500	-	-
63	50	-	-	-	-	2500	-	-
50	40	-	-	-	-	5000	5000	-
40	25	1250	-	-	-	-	5000	5000
25	20	1250	-	-	-	-	-	5000
20	12.5	1250	2500	-	-	-	-	-
12.5	10	1250	2500	-	-	-	-	-
10	6.3	-	-	2500	-	-	-	-
6.3	4.75	-	-	2500	-	-	-	-
4.75	2.36	-	-	-	5000	-	-	-

Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and the machine is rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine is rotated for 500 revolutions. For gradings E, F and G, it is rotated 1000 revolutions. At the completion of the above number of revolution, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.7 mm IS Sieve. Finer portion is then sieved on a 1.7 mm IS Sieve. The material coarser than 1.7 mm IS Sieved is washed, dried in an oven at 105° to 110°C to a substantially constant weight and accurately weighed to the nearest gram.

The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample. This value is reported as the percentage of wear. The percentage of wear should not be more than 16 per cent for concrete aggregates.

Typical properties of some of the Indian aggregate sample are shown in table 3.23.

Los Angeles Abrasion Testing Machine.

Table 3.23. Typical Properties of Some of the Indian Aggregates[3.11]

		Characteristics								
Sr. No. (1)	Name of Place (2)	Flakiness Index % (3)	Elongation Index % (4)	Specific gravity (5)	Water Absorption (6)	Crushing Value % (7)	Impact Value % (8)	Abrasion Value % (9)	Soundness % (10)	Remarks (11)
1.	Kirkee	16.8	20.8	2.84	1.20	16.97	18.65	18.54	4.2	20 mm aggregate
2.	Uterlai	22.8	23.9	2.79	0.80	—	17.80	21.0	2.4	40 mm aggregate
	Rajasthan	28.0	25.2	2.76	0.60	23.0	25.47	19.7	3.1	20 mm aggregate
3.	Bhatinda	20.89	17.50	2.5	1.01	22.62	31.54	29.1	10.0	40 mm aggregate
4.	Jammu	40.13	38.90	2.73	0.75	17.8	17.6	26.0	2.4	40 mm aggregate
		35.06	37.68	2.71	0.50	18.32	20.41	25.1	2.84	20 mm aggregate
5.	Bhuj	25.2	14.2	2.90	0.90	18.80	13.25	11.2	10.0	20 mm aggregate
6.	Nasik	27.8	31.3	2.67	0.75	24.83	—	21.00	4.00	40 mm aggregate
7.	Ranchi	13.28	25.28	2.69	0.50	27.47	29.58	38.9	3.0	Unreactive 20 mm
		23.60	21.0	2.66	0.50	33.68	—	18.8	1.0	40 mm aggregate
8.	Cochin	14.0	20.0	2.85	0.2	27.0	23.0	20.0	2.0	40 mm aggregate
		23.0	11.0	2.84	0.2	28.0	27.0	32.0	8.0	20 mm aggregate
9.	Wellington	30.0	19.0	2.87	0.44	26.0	21.0	19.0	6.0	40 mm aggregate
		14.0	29.0	2.85	0.50	27.6	19.0	31.3	6.0	20 mm aggregate
10.	Premnagar	39.0	25.00	2.62	1.20	27.30	27.40	31.96	3.5	20 mm aggregate
	(Dehradun)	36.30	25.70	2.60	1.25	29.90	25.00	20.00	4.0	12.5 mm aggregate
11.	Sulur	8.0	9.0	2.70	0.50	26.0	33.0	35.7	2.0	20 mm aggregate
	Coimbatore									
12.	Trivandrum	22.44	25.42	2.72	0.25	22.70	17.05	15.2	1.50	20 mm aggregate
		9.38	15.74	2.71	0.50	20.28	15.23	24.1	1.30	40 mm aggregate
13.	Muzzafarpur	14.0	18.0	2.69	0.20	23.2	22.9	17.80	3.90	20 mm aggregate
14	Belgaum	20.20	38.80	2.94	0.65	20.80	17.20	8.90	0.85	40 mm Type I aggregate
		31.80	29.20	2.98	0.47	22.30	14.80	10.10	0.87	40 mm Type II aggregate
		15.70	38.40	3.00	1.31	21.80	10.15	10.35	0.66	20 mm ,, I aggregate
		24.00	29.30.	3.00	1.00	12.40	13.10	9.95	0.63	20 mm Type II ,,

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Top