UNIT 2 AGGREGATES

Structure

2.1 INTRODUCTION

Concrete is a two-phase material and can be considered as consisting of paste phase and aggregate phase. We studied the paste phase in Unit 1, Cement, as a important materials in concrete making and now let us study the aggregate phase. This phase as the name indicates consists of aggregates which are important constituents of concrete. They give body to the concrete and occupy 70 to 80 percent of volume of concrete. Therefore, they exert considerable impact on the characteristics and properties of concrete. While cement is the only factory made component in concrete, the other two i.e. aggregates and water are natural materials whose properties can vary to any extent. It is also evident now that aggregates are not chemically inert as thought earlier and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. It is therefore essential that we study the aggregates in detail to understand their widely varying effects and influence on the properties of concrete.

Objectives

This unit will help you to understand the characteristics and properties of aggregates and their influence on concrete.

After studying this unit, you should be able to :

* describe the classification and sources of aggregates,
* distinguish the properties such as, size, shape, texture, soundness etc. of the aggregates,
* understand the importance and advantages of grading of aggregates, and
* elaborate briefly the different tests which are conducted on the aggregates to assess their suitability for various applications.

2.2 PROPERTIES OF AGGREGATES

In order to study the aggregates, in a systematic manner, we shall examine them in the following order :

ii) Source

iii) Size

iv) Shape

v) Texture

vi) Strength

vii) Bulk Density and Specific Gravity

viii) Absorption and Moisture Content

ix) Bulking Factor

x) Impurities

xi) Soundness

xii) Alkali Aggregate Reaction

xiii) Thermal Properties

2.2.1 Classification

Aggregates are broadly classified on the basis of weight. These are:

a) Normal weight

b) Light weight

c) Heavy weight

Since, normal weight aggregates are used most widely, therefore, in this unit we shall focus our attention on these. These aggregates comprise two large groups of materials.

i) **Natural aggregates,** which are modified during their preparation only with reference to size, shape, surface, texture. These are sand, gravel, crushed rock like granite, basalt, sandstone, quartzite.

ii) **Artificial or synthetic aggregates** prepared from natural materials whose physical properties have been changed in the course of their production like, crushed blast furnace slag, cinders, burned clay and coloured ceramic aggregates.

2.2.2 Source

The natural aggregates owe their origin to the three bed rocks namely Igneous, Sedimentary and Metamorphic.

i) **Aggregates from Igneous Rocks**

These rocks are formed by cooling of molten magma and normally hard, tough and dense and therefore are a highly satisfactory source of aggregates. Since they are widely occurring type of rocks, therefore bulk of aggregates are derived from them.

ii) **Aggregates from Sedimentary Rocks**

Sedimentary rocks are formed by deposition, cementation and consolidation. They vary from soft to hard, porous to dense and light to heavy. Some siliceous sand stones belonging to this source have proved to be good aggregates. The lime stone can also yield good concrete aggregates.

iii) **Aggregates from Metamorphic Rocks**

Metamorphic rocks take birth when igneous and sedimentary rocks are subjected to high temperatures and pressures which changes the structure and texture of rocks. However, due to their foliated nature, the resulting aggregate also possesses the undesirable foliation. However many metamorphic rocks like quartzite and gniess have been used for production of good concrete aggregates.

However, before selecting a particular source you must study the record of use of aggregates from that source and also examine concrete produced from the same in the past. In general you could choose that source of aggregate which will give the desired quality of concrete with least overall expense.

2.2.3 Size

The size of an aggregate is an important criterion based on which the aggregates are divided into two categories:

i) Coarse Aggregate – size greater than 4.75 mm.

ii) Fine Aggregate – size less than 4.75 mm.

In concrete, generally, 80 mm is the maximum size of aggregate which could be used conveniently. The maximum size of aggregate to be used in any situation is governed by following conditions :

i) Thickness of the member to be concreted.

ii) Spacing of reinforcement.

iii) Clear cover to reinforcement.

iv) Mixing, transportation, placing and compaction techniques.

Though it is advantageous to use the lagrest possible size of aggregate, it is limited to one fourth of the minimum thickness of the member to be concreted. However, keeping in view all practical consideration, for reinforced concrete work a maximum aggregate size of 20 mm is considered satisfactory.

2.2.4 Shape

The aggregates are classified on the basis of shape as shown in Table 2.1.

Table 2.1 : Classification of Aggregates by Shape

Sl. No.	Classification	Examples
1)	Rounded	River or seashore gravels, desert, sea-shore, and wind blown sands
2)	Irregular or partly rounded	Pit sands and gravels; land or dug flints
3)	Angular	Crushed rocks of all types
4)	Flaky	Laminated rocks

You should note the following important points while choosing any of the above aggregates :

i) From the stand point of economy in cement requirements for a given water/cement ratio; rounded aggregates are preferable to angular aggregates.

ii) On the other hand, angular aggregates have greater durability, interlocking nature, higher surface area and higher bond characteristics which results in higher strengths.

iii) Flat and flaky aggregates make very poor concrete.

2.2.5 Texture

Surface texture depends on hardness, grain size, pore structure, structure of the rock. A smooth aggregate requires a thinner layer of paste and permit denser packing for same workability. It has also been shown by experiments that rough textured aggregates develop higher bond strength in tension than smooth textured aggregates. The influence of textures on strength can be understood much better by you from the Table 2.2

Table 2.2 : Strength of Concrete

Percentage of Particals		Water/ Cement Ratio	28 Days Strength kg/cm^2	
Smooth	Rough		Flexural	Compressive
100	0	0.54	43	348
50	50	0.57	46	321
0	100	0.60	48	295

2.2.6 Strength

You will appreciate that if either the strength of the paste or bond between the paste and aggregate is low, than irrespective of the strength of aggregate, a concrete of poor quality will be obtained. However strength of aggregate will influence strength of concrete when the paste and bond strength are good. Therefore strong aggregates are an essential requirement for a strong concrete. Though naturally available aggregates are quite strong, the same may be required to be tested in certain situations like:

i) For production of high strength and ultra high strength concrete

ii) Use of aggregates from weathered rock

iii) Use of industrially processed aggregates

The assessment of strength of aggregate is made by carrying out several tests to determine values like :

i) Aggregate crushing value

ii) 10 percent fines value

iii) Aggregate impact value

iv) Aggregate abrasion value

Another strength related property is the **Modulus of Elasticity** which depends upon composition, texture and structure of the aggregate. This property of aggregate influences the shrinkage and elastic behaviour and to a small extent creep of concrete.

The tests for evaluating these values have been described briefly at the end of this unit. The aggregate crushing value of aggregates for concrete used for roads and pavements is restricted to 30 percent while 45 percent may be permitted for other structures.

IS 383-1970 specifies that aggregate impact value shall not exceed 45 percent by weight for aggregate used for concrete other than wearing surface and 30 percent by weight for concrete for wearing surfaces such as run ways, roads and pavements.

The abrasion value as determind by Los Angeles Test should not be more than 30 percent for wearing surfaces and not more than 50 percent for concrete other than wearing surface.

You may keep this information in view while selecting an aggregate for a particular situation.

2.2.7 Bulk Density and Specific Gravity

The bulk density or unit weight gives useful information regarding the shape and grading of aggregates. It shows how densely the aggregate is packed when filled in a standard manner. The higher the bulk density, the lower is the void content to be filled by the sand and cement.

The determination of bulk density is done by filling the aggregates in a standard container in a standard manner. The net weight of the aggregates in the container divided by its volume gives the bulk density in kg/litre. If we know the specific gravity of the aggregate in saturated and surface dry condition then

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

where,

γ = bulk density in kg/litre

G_s = specific gravity of the aggregate

Specific Gravity

The specific gravity of aggregates is an important factor in design of concrete mixes and as seen above in calculation of percent voids. It helps in conversion of weight of aggregate into solid volume and is also required in calculating compacting factor in connection with the workability measurements. Average specific gravity of rocks, normally, varies from 2.6 to 2.8.

2.2.8 Absorption and Moisture Content

The presence of internal pores in the aggregates affects its porosity and hence absorptivity and influences:

i) The bond between the aggregate and cement paste

ii) Water/cement ratio and hence the workability and

iii) The resistance of concrete to freezing and thawing and also when it is subjected to chemically aggressive liquids. The water absorption of aggregate is determined by conventional **Dry method** in which increase in weight of a sample when immersed in water for 24 hours divided by the weight of oven dry sample expressed as percentage is known as absorption of aggregate. However, this procedure is not realistic as the absorption capacity of the aggregates is going to be still less owing to the sealing of pores by coating of cement particles, specially in rich mixes. To give you an idea of porosity, the values of some common rocks are tabulated in Table 2.3.

Table 2.3 : Porosity of Rocks

Sl. No.	Rock Group	Porosity %
1)	Granite	0.4–3.8
2)	Lime Stone	0.0–37.6
3)	Quartzite	1.9–15.1

You will appreciate that since aggregates occupy about 75% of the volume of concrete, therefore their porosity materially contributes to the overall porosity of concrete and hence it is a very important characteristic to be taken note of.

Another anomaly which is there between theory and practice is that while proportioning the materials for concrete it is assumed that aggregates are saturated and surface dry as it is done in mix design also; however in practice, aggregates are either dry and absorptive to different extents or they have surface moisture. It therefore become essential for you to remember that corrective measures should be taken both for absorption and free moisture so that water/cement ratio as per design is not altered.

2.2.9 Bulking Factor

Another problem which is faced in volume batching is the bulking of sand and the necessary correction in volume of sand to give allowance for bulking. Fine sand bulks more than coarse sand. The bulking of extremely fine sand could be as much as 40 percent at a moisture content of about 10 percent.

You will be amazed to note that the extent of bulking can be estimated by a simple field test. In this, a sample of moist fine aggregate is filled in a measuring cylinder and its level is noted say h_1. Now pour water and completely submerge the sand and shake. Note down the new level as h_2.

$$\text{The percent of bulking} = \left(\frac{h_1 - h_2}{h_2} \right) \times 100$$

The measurement of moisture content of aggregates is usually done by some of the methods stated below :

i) Drying Method

ii) Displacement Method

iii) Calcium Carbide Method

iv) Measurement by Electrical Meter

2.2.10 Deleterious Substances

The process of hydration demands aggregate to be free from impurities and deleterious substances, so as to ensure effective bond between the aggregate and the matrix. Three broad categories of deleterious substances may be encountered in aggregates :

i) **Impurities**, which interfere with the processes of hydration of cement; like humus or organic loam found mostly in sands.

ii) **Coatings**, which prevent the development of good bond between aggregate and the matrix; like clay, silt and other fine material.

iii) **Unsound particles**, like iron pyrites, soft shale, clay nodules, mica, wood, coal.

You will find that the **Calorimetric Test** is very convenient to determine the extent of organic impurities. In this, sample of sand is mixed with a liquid containing 3 percent solution of sodium hydroxide in water. The colour developed after 24 hours is then compared with a standard colour card. If it is darker than the standard colour,than the sand is rejected, inferring that it has organic impurities which are more than permissible limit.

Another interesting field test is for determination of clay, fine silt etc. known as **Sedimentation** Method. It consists of a graduated jar having water in which the fine aggregate is put and properly rodded to dislodge the impurities. The jar is then shaken and kept in an undisturbed state. Now the thickness of clay, silt etc which collect on top, is measured to determine their percentage content.

IS 383 : 1970 has laid down **Limits of Deleterious Materials** as tabulated in Table 2.4. It is stipulated that sum of the percentage of all deleterious materials shall not exceed five.

Table 2.4 : Limits of Deleterious Materials

Sl. No.	Deleterious Substance	Fine Aggregate %		Coarse Aggregate %	
		Uncrushed	Crushed	Uncrushed	Crushed
1)	Coal and Lignite	1.00	1.00	1.00	1.00
2)	Clay Lumps	1.00	1.00	1.00	1.00
3)	Self Fragments	–	–	3.00	
4)	Material passing 75 micron IS Sieve	3.00	3.00	3.00	1.00
5)	Shale	1.00	–	–	–

2.2.11 Soundness

You may view soundness as the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. Aggregates which undergo more than the specified amount of volume change are said to be unsound. The physical conditions responsible for the unsoundness are :

i) Freezing and Thawing

ii) Thermal Changes at Temperatures above Freezing

iii) Alternating Wetting and Drying

The soundness test as specified in IS 2386 (part v) 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 aggregate is assumed to produce internal disruptive forces similar to the action of freezing of water. Loss in weight is measured for a specified number of cycles. You may note as a general guide that the average loss of weight after 10 cycles should not exceed 12 percent and 18 percent, when tested with sodium sulphate and magnesium sulphate respectively. However, an important point to note is that the soundness test is not reliable and hence it might be used to accept aggregates but not to reject them.

Let us now move on to study of an important phenomenon, called Alkali-Aggregate reaction.

2.2.12 Alkali Aggregate Reaction

It was only in 1940s that it was realised that the aggregates are not fully inert. In fact some of the aggregates contain reactive silica, which reacts with alkalies (Na_2O and K_2O; recall the oxide composition of cement studied in Unit 1 : Cements) present in the cement. The types of rocks which contain reactive constituents include traps, andesites, rhyolites, silicious limestones and certain types of sand stones. The reactive constituents may be in the form of opals, cherts, chalcedony, volanic glass, zeolites etc. The factors which promote Alkali-Aggregate reaction are :

i) Reactive type of aggregate

ii) High alkali content in cement > 0.6 percent

iii) Availiability of moisture

iv) Optimum temperature conditions.

a) **Mechanism of Alkali Aggregate Reaction**

The mechanism of deterioration is explained as follow :

The alkalies from cement dissolve to make the mixing water as alkali-silica-gel of unlimited swelling variety. The reaction proceeds rapidly for highly reactive substances. If moisture is available continuously and optimum temperature condition (usually 10 degree to 38 degree celsius) is available, the formation of silica gel exerts osmotic pressure to cause pattern cracking in thinner sections of concrete like pavements. The cracking leads to continuous deterioration and loss in strength and elasticity and eventually total disintegration of concrete.

You may well ask, then what should be done to avoid alkali-aggregate reaction ? Well the answer lies in the control of factors which cause this reaction, i.e.

i) Avoid use of reactive aggregates by examining them before use. A chemical test is detailed in IS : 2386 (Part-vii)- 1963 and also the mortar bar expansion test.

ii) Use low alkali cement; alkali content being less than 0.6 percent or possibly less than 0.4 percent.

iii) Use corrective admixtures like pozzollanic i.e material like crushed stone dust, flyash, surkhi.

iv) Control void space in concrete by use of air-entraining agents which will absorb the osmotic pressure due to swelling of gel.

b) **Mortar Bar Expansion Test**

It is not easy to determine the potential reactivity of the aggregates. However, a popular test devised by Stanton and known as mortar bar expansion test has proved to be very reliable. In this test, a specimen of size 25 mm × 25 mm length is cast, cured and stored in a standard manner as specified in IS : 2386 (Part vii)-1963. Now, the length of the specimen is measured periodically at the ages of 1, 2, 3, 6, 9 and 12 months. From these, the difference in length to the nearest 0.001 percent is worked out and the expansion of the specimen is recorded. The aggregate under test is considered harmful if the expansion is more than 0.005 percent after 3 months or more than 0.1 percent after six months.

2.2.13 Thermal Properties

The thermal properties of aggregates which are significant for establishing the quality of aggregate for use in concrete are :

i) Coefficient of expansion

ii) Specific heat

iii) Thermal conductivity

However, you will notice that it is only the coefficient of expansion which is of importance to us for our day to day concreting work, as it interacts with coefficient of thermal expansion of concrete paste. The other two thermal properties are of significance only in mass construction or light weight concrete.

The comparative values of thermal coefficients of concrete, cement paste and aggregate are given in Table 2.5.

On examination, you would observe that while at the higher range there is thermal compatibility between concrete, paste and aggregate, the incompatibility at lower range is considerable. This causes severe stress on the concrete and affects its durability. It is also to be noted that this adverse effect will become acute if concrete is subjected to high range of

Table 2.5: Coefficient of Thermal Expansion

Sl.No.	Material	Coefficient of Thermal Expansion (/ °C)
1)	Concrete	5.8×10^{-6} to 14×10^{-6}
2)	Hydrated Cement Paste	10.8×10^{-6} to 16.2×10^{-6}
3)	Mortar	7.9×10^{-6} to 12.6×10^{-6}
4)	Common Aggregate	0.9×10^{-6} to 16×10^{-6}

temperature difference. You will also appreciate that the study of coefficient of thermal expansion of aggregate is also important in judging the fire resistance of concrete.

Let us now move on to a very important fact of study of aggregates, namely Grading of Aggregates.

SAQ 1

a) Discuss mechanism of alkali-aggregate reaction ?

b) How can you classify aggregates based on weight, size and shape ?

c) What is the effect of porosity of aggregate on the concrete ?

2.2.14 Grading of Aggregates

It is well known that the strength of a concrete is dependent upon water/cement ratio **provided the concrete is workable**. One of the most important factors for producing workable concrete is good gradation of aggregates. What is a good grading ?, you may ask. Well, a good grading implies that a sample of aggregate contains all standard fractions of aggregate in required proportions such that there are minimum voids. Such a sample will require minimum cement paste to fill up these voids. And you can conclude that this will mean, less quantity of cement and water, leading to increased economy, higher strength, lower shrinkage and greater durability.

You could adopt another way of viewing the advantages due to good grading of aggregates. Concrete is generally viewed as two phase material consisting of cement paste or paste phase and the aggregate phase. It is well known that it is the paste phase that is most vulnerable and hence cause of all ills of concrete. Generally, you could say that paste is weaker than the aggregate except in rare situations where very soft aggregate may be used. Further, paste is also more permeable than many of the mineral aggregates. It is also susceptible to deterioration by the attack of aggressive chemicals. Well, we could summarise and state that the **paste is the weak link in concrete**. Hence, the lesser the quantity of the weak material, the stronger will be the concrete. This objective can be achieved by having less voids through the adoption of well graded aggregates. Thus you must have realised the need and importance of grading of aggregates in making of good and strong concrete.

a) **Research on Methods of Grading of Aggregates**

Several research workers have devoted their efforts in evolving methods to achieve good grading of aggregate at construction site. Fuller, Thompson, Talbort and Richart studied grading in relation to achieving higher strength, while Edward and Young proposed a method of proportioning based on the surface area to be wetted. Abrams introduced a parameter known as **Fineness Modulus** for arriving at satisfactory gradings. (For your information, Fineness modulus is an index of the coarseness or fineness of an aggregate sample.) But then different gradings can give same fineness modulus and hence this approach does not define the grading. Many other methods had been suggested but none of them is satisfactory. You may well ask then what should be done ? Well, at the construction site, a reliable and satisfactory grading can only be decided by trial and error, by accounting for characteristics of local materials with respect to size, shape, surface, texture, flakiness and elongation. A practical method which you can adopt is arrived at a grading by mixing aggregates of different size fractions in different percentages and choose the sample which gives maximum weight or minimum voids per unit volume. For this purpose, sieve analysis would be required to be done; and the same is now described.

b) **Sieve Analysis**

Sieve analysis is the operation of dividing a sample of aggregate into different size fractions, each of them consisting of particles of same size. Thus, it gives us the ability to determine the particle size distribution in an aggregate sample, which is known as **gradation.** If you plot the sieve size vs percentage of particles passing the sieve, we get the **grading curve**. The most common and convenient system employed for grading of aggregates is to use sieve openings of size which are continuously doubled e.g. 10 mm, 20 mm, 40 mm etc. You may wonder as to why this is done? Well, the major advantage is that adopting such a system and using a logarithmic scale, we get lines to represent successive sizes, at equal intervals.

i) **Coarse and Fine Aggregate Particle Size Distribution**

The aggregate used for making concrete normally have the particle size distribution as given in Table 2.6.

Table 2.6 : Distribution of C.A. and F.A.

Sl. No.	Coarse Aggregate (C.A.)	Fine Aggregate (F. A.)
1)	80 mm	4.75 mm
2)	40 mm	2.36 mm
3)	20 mm	600 micron
4)	10 mm	300 micron
5)	4.75 mm	150 micron

The aggregate size fraction from 80 mm to 4.75 mm are termed as coarse aggregate while 4.75 mm to 150 micron are termed as fine aggregate.

ii) **Sieving Process**

The grading pattern mentioned above is obtained by sieving a sample successively through all the sieves which are mounted one over the other in above order, with layer sieve on top. But then what should be the minimum weight of sample for sieve analysis? IS:2386 (part 1)-1963 has laid down the minimum weights as given in

Table 2.7 : Minimum Weight of Samples

Sl. No.	Maximum size present in substantial proportions (mm)	Minimum weight of sample to be taken for sieving (kg)
1)	63	50
2)	50	35
3)	40 or 31.5	15
4)	25	5
5)	20 or 16	2
6)	12.5	1
7)	10	0.5
8)	6.3	0.2
9)	4.75	0.2
10)	2.36	0.1

c) **Fineness Modulus**

We had referred to the term **Fineness Modulus** a little earlier under the heading **"Research on methods of grading of aggregates"**. Therein, we just mentioned that Fineness Modulus is an index of coarseness or fineness of the material.

Let us now try and understand it in more depth and see how it can be calculated for a given material.

Fineness Modulus is obtained by adding the cumulative percentages of aggregates retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The Table 2.8 below demonstrates, how it is worked out, based on the sieve analysis conducted on a sample of coarse and fine aggregate.

Table 2.8 : The Typical Example of the Sieve Analysis

IS Sieve Size	Coarse Aggregate			
	Weight retained (kg)	Cumulative weight retained (kg)	Cumulative percentage retained	Cumulative 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
4.75 mm	4	15	100	00
2.36 mm	–	–	100	00
1.18 mm	–	–	100	00
600 micron	–	–	100	00
300 micron	–	–	100	00
150 micron	–	–	100	00
Lower than 150 micron	–	–	–	00
Total	15 kg		713.3	
F.M. = 713.3 / 100 = 7.133				

Table 2.9 : The Typical Example of the Sieve Analysis

IS Sieve Size	Coarse Aggregate			
	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative percentage retained	Cumulative percentage passing
80 mm	–	–	–	–
40 mm	–	–	–	–
20 mm	–	–	–	–
10 mm	0	0	0	100
4.75 mm	10	10	2	98
2.36 mm	50	60	12	88
1.18 mm	50	110	22	78
600 micon	95	205	41	59
300 micron	175	380	76	24
150 micron	85	265	93	7
Lower than 150 micron	35	500	–	–
Total	500 gm.		246	
F.M. = 246 / 100 = 2.46				

An important point to note is that higher the Fineness Modulus (F.M.), for an aggregate, the coarser is the material. This is clear from the example tabulated above wherein we saw that the F.M. of coarse aggregate which was 7.133 is much higher than the F.M. of fine aggregate which was 2.46. You will notice that even within the fine aggregates like sand we sometimes designate or refer to different samples as coarse, medium and fine sand. In order to define this classification in a definitive manner you could use the Fineness Modulus as a general yardstick, as shown below for guidance :

Fine sand : Fineness Modulus range : 2.2 to 2.6

Medium sand : Fineness Modulus range : 2.6 to 2.9

Coarse sand : Fineness Modulus range : 2.9 to 3.2

A sand having F.M. value more than 3.2 is considered unsuitable for making concrete.

d) **Grading Requirements**

You have seen by now as to what is gradation, sieve analysis, fineness modulus and a grading curve, but we still have to ascertain whether or not a particular grading is suitable for concrete making. In nutshell, we have to determine the properties of a good grading curve.

It has been suggested that the main factors governing the good aggregate grading are:

i) The surface area of the aggregate (this determines the amount of water necessary to wet all the solids)

ii) The relative volume occupied by the aggregate

iii) The workability of the mix

iv) The tendency to segregate

Discussing the later points first, it would be seen that the requirements of workability and segregation tend to be somewhat opposed to each other. It is easier for the particles of different sizes to pack, smaller particles entering the voids between the larger ones; it is also easier for them to be shaken out of voids i.e. to segregate in dry state. However, for a good concrete it is essential that segregation is avoided.

For concrete mix to be workable, it should contain sufficient amount of material including cement which is smaller than 300 micron. If this is not so then the mix is harsh. Thus this is an important grading requirement.

As far as the relative volume occupied by the aggregate is concerned it shall be as large as possible as not only it leads to economy, but technically also by restricting the volume of paste, it produces desirable concrete.

Though the surface area of the aggregate is an important factor as it determines the amount of water necessary to wet all the sides, and in determining workability, but the exact role played by finer particles is not known (an increase in the specific surface of aggregate for a constant water/cement ratio has been found to lead to a lower strength of concrete). Thus over all, you can see that the grading of aggregates is a major factor in the workability of a concrete mix. The workability in turn regulates water/cement requirements, segregation and other properties in the hardened state.

e) **Practical Gradings**

One of the most commonly used practical grading curves are those of the Road Research Note no. 4 on the design of concrete mixes. They have prepared a set of type of grading curve for all-in-aggregate graded down from 20 mm to 40 mm. These are shown in Figures 2.1 and 2.2. Figures 2.3 and 2.4 show Grading Limits for Sand in Zones 1 to 4.

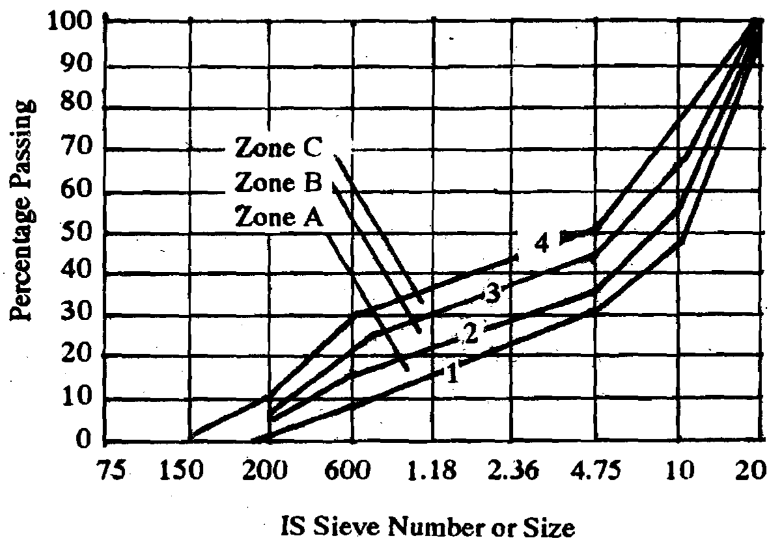

Figure 2.1: Type of Grading Curves for 20 mm Aggregates

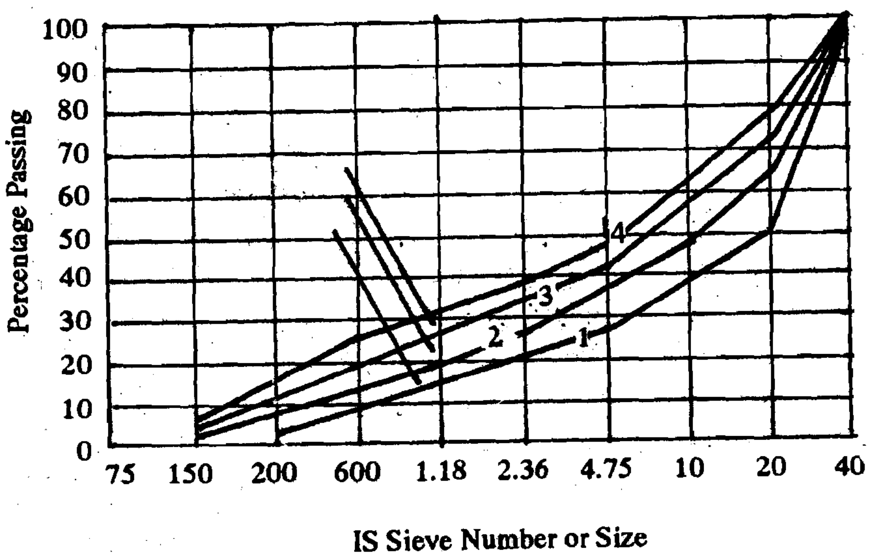

Figure 2.2 : Type of Grading Curve for 40 mm Aggregate

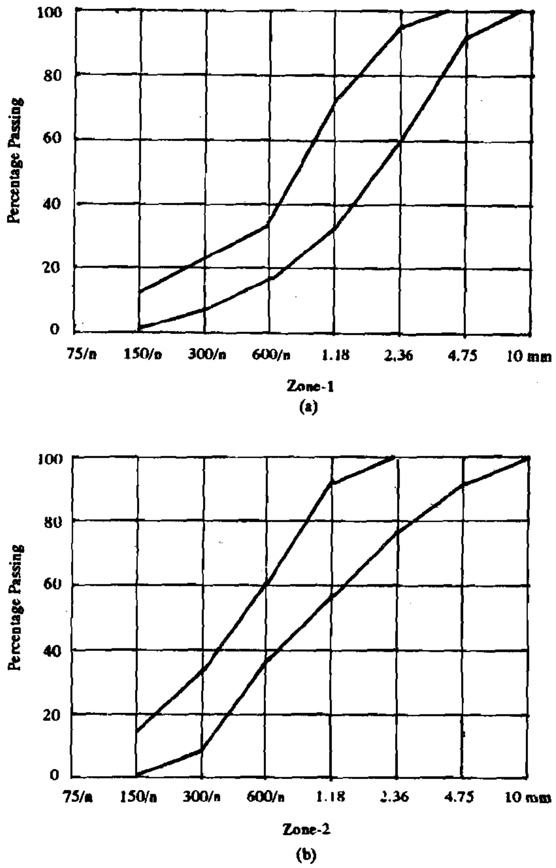

Figure 2.3: Grading Limits for Sand in Zones 1 & 2 of IS 383-1970

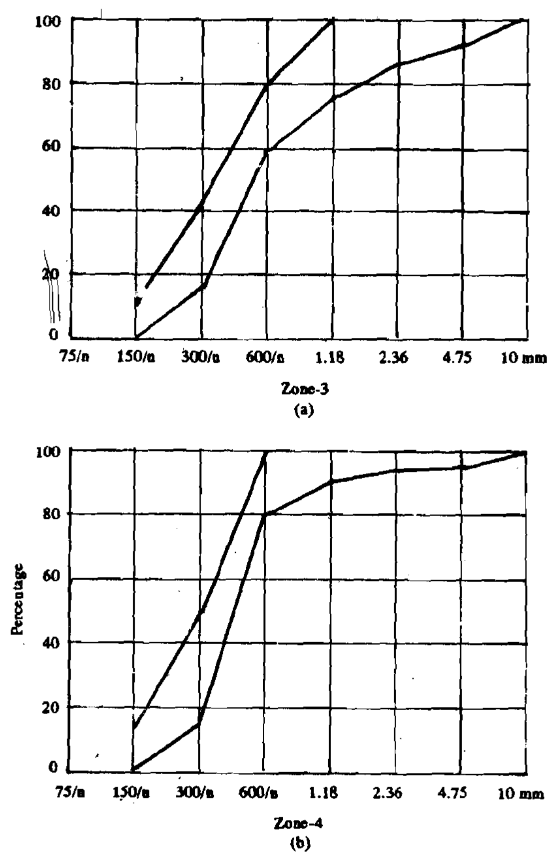

Figure 2.4 : Grading Limits for Sand in Zones 3 & 4 of IS 383-1970

Similar curves for aggregates with maximum size of 10 mm and downward have been prepared by Mcintosh and Erntroy and shown in Figure 2.6 and also you can see Grading curves for 80 mm Aggragates in Figure 2.5.

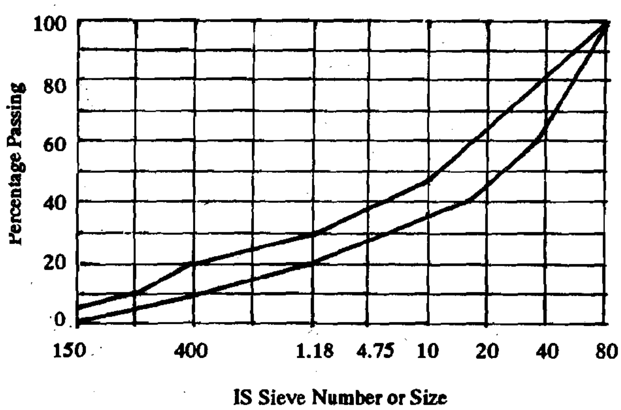

Figure 2.5 : Type of Grading Curves for 80 mm Aggregates

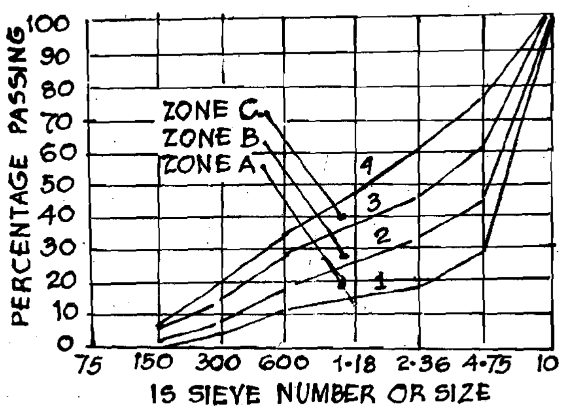

Figure 2.6: Mcintosh and Erntroy's Type of Grading Curves for upto 10 mm Aggregates

In Figures 2.1 and 2.2, it can be seen that there are four curves in each. A scanning of the y-axis i.e. percentage passing would reveal that the curve no.1 (lowest curve) is the coarseset grading while curve no. 4 (topmost curve) represents the finest grading. Between these four curves, lie three zone: A, B and C.

You will appreciate that the locally available aggregate may not conform to any one particular grading curve. Therefore, combination of different aggregates, intelligently and carefully would be required to obtain the same. It is for this reason that grading limits are laid down in various specifications rather than one single value for a particular sieve size.

For your information and easy reference, the following Tables 2.10 & 2.11 (A), 2.11 (B), 2.12, 2.13 give properties of some Indian Aggregates and give gradings limit properties of different aggregates as per IS : 383-1970.

Table 2.10 (A) : Physical Properties of Some of the Indian Aggregates

Sl. No.	Name of Place	Characteristics			
		Flakiness Index (%)	Elongation Index (%)	Specific Gravity	Water Absorption (%)
1)	Kirkee	16.8	20.8	2.84	1.20
2)	Uterlai (Rajasthan)	22.8 28.0	23.9 25.2	2.79 2.76	0.80 0.60
3)	Bhatinda	20.89	17.50	2.5	1.01
4)	Jammu	40.13 35.06	38.90 37.68	2.73 2.71	0.75 0.50
5)	Bhuj	25.2	14.2	2.90	0.90
6)	Nasik	27.8	31.3	2.67	0.75
7)	Ranchi	13.28 23.60	25.28 21.0	2.69 2.66	0.50 0.50
8)	Cochin	14.0 23.0	20.0 11.0	2.85 2.84	0.20 0.20
9)	Wellington	30.0 14.0	19.0 29.0	2.87 2.85	0.44 0.50
10)	Premnagar (Dehradun)	39.0 36.30	25.00 25.70	2.62 2.60	1.20 1.25
11)	Sulur Coimbatore	8.0	9.0	2.70	0.50
12)	Trivandrum	22.44 9.38	25.42 15.74	2.72 2.71	0.25 0.50
13)	Muzzafarpur	14.0	18.0	2.69	0.20
14)	Belgaum	20.20 31.80 15.70 24.00	38.80 29.20 38.40 29.30	2.94 2.98 3.00 3.00	0.65 0.47 1.31 1.00

Table 2.10 (B) : Typical Properties of Some of the Indian Aggregates

Sl. No.	Name of Place	Characteristics				Remarks Aggregate
		Crushing Value (%)	Impact Value (%)	Abrasion (%)	Soundness (mm)	(mm)
1)	Kirkee	16.97	18.65	18.54	4.2	20
2)	Uterlai (Rajasthan)	– 23.0	17.80 25.47	21.0 19.7	2.4 3.1	40 20
3)	Bhatinda	22.62	31.54	29.1	10.0	20
4)	Jammu	17.8 18.32	17.6 20.41	26.0 25.1	2.4 2.84	40 20
5)	Bhuj	18.80	13.25	11.2	10.0	20
6)	Nasik	24.83	–	21.00	4.00	40
7)	Ranchi	27.47 33.68	29.58 –	38.9 18.8	3.0 1.0	Unreactive 20 40
8)	Cochin	27.0 28.0	23.0 27.0	20.0 32.0	2.0 8.0	40 20
9)	Wellington	26.0	21.0	19.0	6.0	20
10)	Premnagar (Dehradun)	27.30 29.90	27.40 25.00	31.96 20.00	3.5 4.0	20 12.5
11)	Sulur Coimbatore	26.0	33.0	35.7	2.0	20
12)	Trivandrum	22.70 20.28	17.00 15.23	15.2 24.1	1.50 1.30	20 40
13)	Muzzafarpur	23.2	22.9	17.80	3.90	20
14)	Belgaum	20.80 22.30 21.80 12.40	17.20 14.80 10.15 13.10	8.90 10.10 10.55 9.95	0.85 0.87 0.66 0.63	40 40 20 20

Table 2.11 (A) : Grading Limits for Coarse Aggregates IS : 383-1970

IS Sieve Designation	Percentage passing for single-sized aggregate of nominal size (by weight)					
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm
80 mm	100	–	–	–	–	–
63 mm	85 - 100	100	–	–	–	–
40 mm	0 - 30	85 - 100	100	–	–	–

(Contd.)

20 mm	0 - 5	0 - 20	85 - 100	100	–	–
16 mm	–	–	–	85 - 100	100	–
12.5 mm	–	–	–	–	85 - 100	100
10 mm	–	0 - 5	0 - 20	0 - 30	0 - 45	85 - 100
4.75 mm	–	–	0 - 5	0 - 5	0 - 10	0 - 20
2.36 mm	–	–	–	–	–	0 - 5

Table 2.11(B): Grading Limits for Coarse Aggregates IS : 383-1970

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

Table 2.12 : Grading Limits for Fine Aggregates IS : 383-1970

IS Sieve Designation	Percentage passing by weight for			
	Grading Zone 1	Grading Zone 2	Grading Zone 3	Grading Zone 4
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 2.13 : Grading Limits of All-in-Aggregates

IS Sieve Designation	Percentage by weights passing for all-in-aggregate 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 - 35
600 micron	8 - 30	10 - 35
150 micron	0 - 6	0 - 6

Points to Note

i) The permissible limit on 150 micron IS sieve or crushed stone sands is increased by 20 percent.

ii) Where concrete of high strength and durability is required, fine aggregate conforming to any zone may be used, but the mix should be properly designed. For design of concrete mixes refer Unit 10 and 11.

iii) It is recommended that fine aggregate conforming to zone 4 should not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions.

SAQ 2

a) What is a good grading ?

b) What is **Fineness Modulus** ?

c) What are the main factors which govern a aggregate grading ?

d) Is there any restriction on use of fine aggregate conforming to Zone 4 ?

e) What are the grading limits for fine aggregates as per IS : 383 for Zone 2 ?

2.3 TESTING OF AGGREGATES

The tests for aggregates could be divided into two distinct categories as follows :

2.3.1 Tests for Physical Properties of Aggregates

i) **Test for Determination of Flakiness Index [IS : 2386 (Part 1) 1963]**

In this test 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 metal gauge. The flakiness index is taken as the total weight of material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.

ii) **Test for Determination of Elongation Index [IS : 2386 (Part 1) 1963]**

Here each fraction as above is gauged individually for length on the metal gauge. 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.

iii) **Test For Determination of Dry, Fine Silt and Fine Dust (Sedimentation Method) [IS : 2386 (Part 11) 1963]**

In this method in case of fine aggregate 300 gm of sample in air-dry condition passing 4.75 mm sieve is placed in a glass jar with 300 ml of diluted sodium oxalate solution. After swirling and rotating, it is transferred in a specified manner to a 1000 ml cylinder. A sample is drawn from this by a pipette and is dried at 100 °C to 110 °C and weighed.

The percentage of fine silt on dry or fine dust = $100/W_1\ (1000\ W_2/V - 0.8)$

where

W_1 = weight in gm of original sample

W_2 = weight in gm of dried sample

V = Volume in ml of the pipette

iv) **Test for Determination of Organic Impurities**

This test has been described very briefly under 2.2.10.

v) **Test for Determination of Specific Gravity**

This is a very simple test and specific gravity is found from the formula;

Specific gravity = $C/\ (B - A)$

where,

A = Weight in gm of saturated aggregate in water

B = Weight in gm of saturated surface dry aggregate in air

C = Weight in gm of oven dried aggregate in air

vi) **Test for Bulk Density and Voids**

This is a standard test in which aggregate is filled in a cylindrical measure 1/3 each time and tamped with 25 strokes.

$$\gamma = \text{Bulk Density} = \frac{(\text{net weight of aggregate in kg})}{\text{capacity of container in litres}} = \text{kg/litre}$$

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

where,

G_s = specific gravity of aggregate

γ = bulk density in kg/litre

2.3.2 Test for Mechanical Properties of Aggregates [IS:2386 (Part IV) 1963]

i) **Test for Determination of Aggregate Crushing Value (ACV)**

In this test about 6.5 kg of aggregates passing 12.5 mm and retained on 10 mm sieve is filled in a cylindrical measure, duly tamped and weighed (*A*). Now this aggregate is placed in the test apparatus and is loaded uniformly upto a total of 40 tonnes in 10 minutes. The aggregates are removed and sieved on 2.36 mm IS sieve and fraction passing is weighed (*B*).

$$\text{ACV} = \frac{B}{A} \times 100$$

The permissible A C V values are :

1) Aggregate for concrete other than wearing surface is not greater than 45.

2) Aggregate for concrete other than wearing surface is not greater than 45 but for runways, roads and air fields is not greater than 30.

ii) **Test for Determination of Ten Percent Fines Value**

The sample is prepared in the same manner as above. In this case load is applied at a uniform rate so as to cause in 10 minutes a total penetration of the plunger of :

15 mm for rounded or partially rounded aggregates (like uncrushed gravels)

20 mm for normal crushed aggregate

24 mm for honey combined aggregate (expanded sheles and slags)

The material is removed and sieved through 2.36 mm IS sieve and percentage passing is weighed. Two such tests are conducted.

$$\text{Load required for ten percent fines} = \frac{14 \times X}{Y + 4}$$

where,

X = load in tons causing 7.5 to 12.5 percent fines

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

iii) **Test for Determination of Aggregate Impact Value**

Aggregate passing 12.5 mm and retained on 10 mm sieve is dried and cooled. It is then filled, tamped and weighed in a cylindrical measure (*A*). It is then put in the apparatus and subjected to 15 blows of a standard hammer falling from height of 380 mm. The aggregate is sieved through 2.36 mm sieve and aggregate passing is weighed (*B*).

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

iv) **Test for Determination of Aggregate Abrasion Value**

Generally for this test the use of Los Angeles Abrasion Testing machine is prefered over the Daval Abrasion Testing Machine. The test sample is placed in the machine and rotated together with abrasive charge @ 20 to 30 rev/min for 500 revolutions. The aggregate is taken out and material coarser than 1.7 mm sieve is weighed known as final weight. The difference between original weight and final weight expressed as a percentage of original weight is the Abrasion value. It should not be more than 16 percent for concrete aggregates.

2.4 SUMMARY

We have seen that aggregates form an important constituent of concrete and occupy a relatively large volume. Therefore, a study of properties of aggregates is essential. This study helps us in distinguishing between different types of aggregate based on their source and size, shape and texture. A study of moisture content and bulking factor enable us to adjust the deleterious materials and detection of their presence and extent is essential as it can have negative effect on strength of concrete. This is true of both organic impurities as well as clay, silt etc. The capacity of the aggregate to withstand excessive changes in value due to physical conditions indicates its soundness. Alkali-aggregation reaction is very important in this regard.

Therefore, you will appreciate that reactivity of aggregate becomes a relevant aspect to be kept in mind.

We have also examined that due to different thermal coefficients of aggregate, paste and concrete, thermal incompatibility can arise resulting in severe stress in concrete. This thermal properties of aggregate is also relevant in regard to fire resistance of concrete. It is believed that grading of aggregate affects water requirements, workability and segregation tendencies in concrete which are relkated to strength. Therefore, it is essential to grade the available aggregate so as to satisfy the requirements of the IS in order to obtain dense, workable and strong concrete.

Indian Standards Institution has devised several tests to ascertain the suitability of aggregates for concrete making. These tests are meant both for physical and mechanical properties and ensure quality control.

Thus, on the whole we can sum up and say that aggregates form about 70 percent of the concrete and their properties affect considerably.

2.5 KEY WORDS

Matrix : Combination of concrete, water and fine aggregate; cement/paste.

Deleterious : Harmful.

Humus : Decayed biological matter.

Soundness : Ability of aggregate to withstand excessive changes in volume.

Gradation : Particle size distribution in sample.

Sieve analysis : Operation of subdividing a sample of aggregate into various size fractions, each consisting of particles of same size.

2.6 ANSWERS TO SAQs

SAQ 1

Check your answers with preceding text.

SAQ 2

Check your answers with preceding text.