

IS : 2386 (Part VIII) – 1963

(Reaffirmed 2002)

Edition 1.1

(1999-06)

Indian Standard

**METHODS OF TEST FOR AGGREGATES
FOR CONCRETE**

PART VIII PETROGRAPHIC EXAMINATION

(Incorporating Amendment No. 1)

UDC 691.322:552.12

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Price Group 5

Indian Standard

METHODS OF TEST FOR AGGREGATES
FOR CONCRETE

PART VIII PETROGRAPHIC EXAMINATION

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Indian Standard

METHODS OF TEST FOR AGGREGATES FOR CONCRETE

PART VIII PETROGRAPHIC EXAMINATION

0. FOREWORD

0.1 This Indian Standard (Part VIII) was adopted by the Indian Standards Institution on 26 October 1963, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Building Division Council.

0.2 One of the major contributing factors to the quality of concrete is the quality of aggregates used therein. The test methods given in this standard are intended to assist in assessing the quality of aggregates. In a given situation, for a particular aggregate, it may not be necessary to assess all the qualities and, therefore, it is necessary to determine beforehand the purpose for which a concrete is being used and the qualities of the aggregate which require to be assessed. Accordingly, the relevant test methods may be chosen from amongst the various tests covered in this standard. For the convenience of the users, the test methods are grouped into the following eight parts of Indian Standard Methods of Test for Aggregates for Concrete (IS : 2386-1963):

Part I Particle Size and Shape

Part II Estimation of Deleterious Materials and Organic Impurities

Part III Specific Gravity, Density, Voids, Absorption and Bulking

Part IV Mechanical Properties

Part V Soundness

Part VI Measuring Mortar Making Properties of Fine Aggregate

Part VII Alkali Aggregate Reactivity

Part VIII Petrographic Examination

0.3 The Sectional Committee responsible for the preparation of this standard has taken into consideration the views of concrete specialists, testing authorities, consumers and technologists and has related the standard to the practices followed in this country. Further, the need for international co-ordination among standards prevailing in different countries of the world has also been recognized. These considerations

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led the Sectional Committee to derive assistance from the published standards and publications of the following organizations:

American Society for Testing and Materials

United States Department of the Interior Bureau of Reclamation

0.4 Wherever a reference to any Indian Standard appears in these methods, it shall be taken as a reference to its latest version.

0.5 This edition 1.1 incorporates Amendment No. 1 (June 1999). Side bar indicates modification of the text as the result of incorporation of the amendment.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960 Rules for Rounding Off Numerical Values (*Revised*). The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

0.7 This standard is intended chiefly to cover the technical provisions relating to testing of aggregates for concrete, and it does not include all the necessary provisions of a contract.

1. SCOPE

1.1 This standard (Part VIII) covers two methods of petrographic examination of aggregates for concrete. Method I may be adopted for routine purposes and Method II for detailed investigations. Method II shall be treated as a reference method.

2. METHOD I

2.1 Object — This test involves visual inspection, and a segregation of the constituents of coarse and fine aggregates according to petrographic and chemical differences.

2.2 Apparatus

2.2.1 Screens conforming to the IS Sieve designations given below:

150 micron, 300 micron, 600 micron, 1.00 mm, 2.25 mm, 4.75 mm, 10 mm, 12.5 mm, 20 mm, 25 mm, 40 mm, 50 mm and 80 mm.

2.2.2 A balance having a capacity of 2 kg and sensitive to 0.1 g.

2.2.3 An anvil and hammer suitable for breaking pebbles. The anvil shall be set in a tray or otherwise arranged so as to keep loss of rock chips to a minimum.

2.2.4 Hand lens, stereoscopic microscope, petrographic microscope, and auxiliary equipment necessary for adequate petrographic examination and identification of rocks and minerals.

2.3 Procedure

2.3.1 Sufficient aggregate shall be roughly screened to provide at least the following quantities of the various sizes:

<i>Size of Aggregate</i>	<i>Weight</i>
	g
40 to 20 mm	4 000
20 to 10 mm	1 000
10 to 4.75 mm	200
4.75 mm to that retained on 2.36-mm IS Sieve	100
Passing through 2.36-mm IS Sieve and retained on 1.00 mm IS Sieve	50
Passing through 1.00-mm IS Sieve and retained on 600 micron IS Sieve	25
Passing through 600-micron IS Sieve and retained on 300 micron IS Sieve	25
Passing through 300-micron IS Sieve and retained on 150 micron IS Sieve	25
Passing through 150-micron IS Sieve to pan	10

2.3.2 Examination of the aggregate shall be performed by a qualified petrographer who is familiar with the problems of concrete. Each of the above size fractions shall be examined individually.

2.3.3 Each fraction shall be examined to establish whether the particles are coated with mineral substances (such as opal, calcium carbonate, or gypsum), silt or clay. Organic coatings may also occur. If such coatings are present, they shall be identified and evaluated by petrographic or chemical techniques. The potential physical and chemical effects of the coating on quality and durability of concrete shall be recorded. If coatings are present, the aggregate shall be washed, after preliminary examination, to remove the coating. The sample shall be dried in an oven at 105 to 110°C, observing the degree of agitation and extent to which the coating substances or soft particles are disintegrated and removed. The sample shall be further examined to determine particle shape and other pertinent properties.

2.3.4 The coarse aggregate fractions shall be examined particle by particle (each particle being broken on the anvil with hammer) and identified by a hand lens or microscope. The individual particles shall be segregated according to three criteria, that is (a) petrographic

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identity, (b) physical condition, and (c) anticipated chemical stability in concrete. Each category is classified by name (for example, granite, sandstone, limestone, and weathered basalt) and a designation of quality determined according to the following scale:

a) *Physical Quality*

- 1) Good aggregate particles which contribute to superior strength, durability, and abrasive resistance of concrete under any climatic condition.
- 2) Satisfactory aggregate particles which contribute to high or moderate strength, abrasive resistance, and durability of concrete under any climatic condition.
- 3) Fair aggregate particles which contribute to moderate strength, durability, and abrasive resistance under ideal conditions, but might contribute to physical breakdown of concrete under rigorous conditions.
- 4) Poor aggregate particles which contribute to low strength and poor durability of concrete under any climatic condition, and cause physical breakdown of concrete under rigorous climatic conditions.

b) *Chemical Quality*

- 1) Innocuous aggregate particles which do not participate in alkali-aggregate reactions harmful to concrete.
- 2) Deleterious aggregate particles which produce adverse effects on concrete through chemical reactions between particles and cement alkalis. Known reactive substances are the silica minerals, opal, chalcedony, tridymite, and cristobalite, zeolite, heulandite (and probably ptilolite), glassy to crypto-crystalline rhyolites, dacites and andesites and their tuffs, and certain phyllites. If significant proportions of deleterious particles are present in an aggregate, the use of low alkali cement or an effective combination of Portland cement and pozzolana shall be recommended.

2.3.4.1 After analysis is completed, the particles in each category shall be weighed (or counted) and their proportions shall be calculated as weight percentages of the whole sample.

2.3.5 Each fraction of fine aggregate shall be examined under a binocular microscope. Ordinarily, complete segregation of fine aggregate fractions shall not be required, but physically unsound or chemically deleterious particles shall be segregated and petrographically identified, and appropriate designation of quality shall be indicated. The fractions passing the 300-micron IS Sieve shall

be generally examined in immersion oils under the petrographic microscope to determine the presence and approximate quantity of any unsound or deleterious substances.

2.4 Reporting the Petrographic Examination

2.4.1 Following completion of his examination and analysis, the petrographer shall prepare a report summarising his observations and conclusions regarding the suitability of the aggregate under the anticipated conditions of service, and indicating any necessary qualifications as to its use, or the need for special tests to elucidate the significance of particular properties.

2.4.2 The petrographic analysis of commonly found aggregates is illustrated in Tables I and II which indicate for each constituent its petrographic identity, its proportion, its fundamental characteristics, and the petrographer's estimate of its physical and chemical quality.

3. METHOD II

3.1 Object — This recommended practice outlines procedures for the petrographic examination of samples representative of materials proposed for use as aggregates in concrete. The specific procedures employed in the petrographic examination of any sample will depend to a large extent on the purpose of the examination and the nature of the sample.

NOTE — Petrographic examinations are made for the following purposes:

- a) To determine the physical and chemical properties of the material that may be observed by petrographic methods and that have a bearing on the quality of the material for its intended use,
- b) To describe and classify the constituents of the sample, and
- c) To determine the relative amounts of the constituents of the sample, which is essential for proper evaluation of the sample when the constituents differ significantly in properties that have a bearing on the quality of the material for its intended use.

3.1.1 Identification of the constituents of a sample is usually a necessary step towards recognition of the properties that may be expected to influence the behaviour of the material in its intended use, but identification is not an end in itself. The value of any petrographic examination will depend to a large extent on the representativeness of the samples examined, the completeness and accuracy of the information provided to the petrographer concerning the source and proposed use of the material, and the petrographer's ability to correlate these data with the findings of the examination.

3.1.2 This method does not attempt to outline the techniques of petrographic work since it is assumed that the method will be used by

TABLE I ILLUSTRATIVE GENERAL PETROGRAPHIC ANALYSIS OF COARSE AGGREGATE

(Clause 2.4.2)

ROCK TYPES	PERCENT BY WEIGHT OF			DESCRIPTION OF ROCK TYPES	QUALITY	
	40 to 20 mm Size	20 to 10 mm Size	10 to 4.75 mm Size		Chemical	Physical
Granites	1.7	9.0	11.5	Slightly to moderately weathered, medium grained, hard	Innocuous	Satisfactory
Rhyolite porphyries	1.5	1.1	0.9	Slightly to moderately weathered, aphanitic, porphyritic, hard	Innocuous	Satisfactory
Andesite porphyries	29.5	17.2	10.5	Slightly to moderately weathered, aphanitic to fine grained, hard	Innocuous	Satisfactory
∞ Weathered andesite porphyries	11.9	10.6	99.1	Moderately weathered, fractured, firm to hard	Innocuous	Fair
Deeply weathered andesite porphyries	9.8	3.9	2.5	Deeply weathered, fractured, absorptive, firm to hard	Innocuous	Poor
Andesites	18.1	29.3	32.6	Slightly to moderately weathered, aphanitic to glassy, hard	Deleterious	Satisfactory
Basalts	21.9	21.8	20.5	Fresh to slightly weathered, aphanitic to glassy, good bonding characteristics	Innocuous	Good
Chalcedonic charts	2.0	3.1	5.4	Hard, massive, poor bonding characteristics	Deleterious	Fair
Quartzites	3.6	4.0	7.0	Hard, massive, fine grained	Innocuous	Satisfactory

**TABLE II ILLUSTRATIVE PETROGRAPHIC ANALYSIS OF
COARSE AGGREGATE FOR QUALITY**

(Clause 2.4.2)

	PERCENT BY WEIGHT		
	40 mm to 20 mm Size	20 mm to 10 mm Size	10 mm to 4.75 mm Size
<i>Chemical</i>			
Innocuous	79.9	67.6	62.0
Deleterious*	20.1	32.4	38.0
<i>Physical</i>			
Good	21.9	21.8	20.5
Satisfactory	54.4	60.6	62.5
Fair	13.9	13.7	14.5
Poor	9.8	3.9	2.5

*With cements high in alkalis.

qualified petrographers. It is intended to outline the extent to which such techniques should be used, the selection of properties that should be looked for, and the manner in which such techniques may best be employed in the examination of samples of aggregates for concrete. These objectives will have been attained if engineers responsible for the application of the results of petrographic examinations to the evaluation of aggregate materials for use in concrete construction have reasonable assurance that such results, wherever and whenever obtained, may confidently be compared.

NOTE — It is recommended that the rock and mineral names in IS : 383-1963 Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (*Revised*) should be used insofar as they are appropriate in reports prepared according to this method.

3.2 Apparatus and Supplies — The apparatus and supplies given in 3.2.1 and 3.2.2 comprise a recommended selection which will permit the use of all of the procedures described in this method. All specific items listed have been used in connection with the performance of petrographic examinations by the procedures described herein; it is not, however, intended to imply that other items cannot be substituted to serve similar functions. Whenever possible the selection of particular apparatus and supplies should be left to the judgement of the petrographer who is to perform the work so that the items obtained will be those with the use of which he has the greatest experience and familiarity. The minimum equipment regarded as essential to the making of petrographic examinations of aggregate samples are those

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items, or equivalent apparatus or supplies that will serve the same purpose, that are indicated by asterisks in 3.2.1 and 3.2.2.

3.2.1 Apparatus and Supplies for Preparation of Specimen

- a) *Rock-cutting saw preferably with 350 mm diamond blade.
- b) *Horizontal grinding wheel preferably 400 mm in diameter.
- c) Polishing wheel, preferably 200 mm to 300 mm in diameter.
- d) *Abrasives silicon carbide grit No. 150, 180, and 220; emery.
- e) Prospector's pick.
- f) *Microscope slides, clear, non-corrosive, 25 × 45 mm in size.
- g) *Canada balsam, neutral, in xylene.
- h) *Xylene.
- j) *Mounting medium, suitable for mounting rock slices for thin sections.
- k) *Laboratory oven.
- m) *Plate glass squares about 300 mm on an edge for thin-section grinding.
- n) *Jones riffle sampler with pans.
- p) *Micro cover glasses, noncorrosive, square, 12 to 18 mm, 25 mm, etc.
- q) Plattner mortar.

3.3.2 Apparatus and Supplies for Examination of Specimens

- a) *Polarizing microscope with mechanical stage; low, medium, highpower objectives, and objective centering devices; eyepieces of various powers; full- and quarter-wave compensators; quartz wedge.
- b) *Microscope lamps (preferably including a sodium arc lamp).
- c) *Stereoscopic microscope with objectives and eyepieces to give final magnifications from about 6X to about 60X.
- d) *Magnet, or an electromagnet.
- e) *Needle holder and points.
- f) Dropping bottle, 60-ml capacity.
- g) Forceps, smooth, straight-pointed.
- h) Petri culture dishes.
- j) *Lens paper.
- k) *Immersion media, $n = 1.410$ to $n = 1.785$ in steps of 0.005 (Note 1).

m) Counter

n) Photomicrographic camera and accessories (see Note 2).

NOTE 1 — It is necessary that facilities be available to the petrographer to check the index of refraction of the immersion media. If accurate identification of materials is to be attempted, as for example the differentiation of quartz and chalcedony or the differentiation of basic from intermediate volcanic glass, the indices of refraction of the media need to be known with precision. Media will not be stable for very long periods of time and are subject to considerable variation due to temperature change. In laboratories not provided with close temperature control, it is often necessary to recalibrate immersion media several times during the course of a single day when accurate identifications are required. The equipment needed for checking immersion media consists of an Abbe' Refractometer. The refractometer should be equipped with compensating prisms to read indices for sodium light from white light, or it should be used with a sodium arc lamp.

NOTE 2 — It is believed that a laboratory that undertakes any considerable amount of petrographic work should be provided with facilities to make photomicrographic records of such features as cannot adequately be described in words. Photomicrographs can be taken using standard microscope lamps for illumination; however, it is recommended that whenever possible a zirconium arc lamp be provided for this purpose.

3.3 Sampling — Samples for petrographic examination should be taken by or under the direct supervision of a geologist familiar with the requirements of aggregates for concrete and, in general, following the requirements of *IS : 2430- Methods of Sampling of Aggregate. The exact location from which the sample was taken, the geology of the site, and other pertinent data should be submitted with the sample. The amount of material actually studied in the petrographic examination will be determined by the nature of the examination to be made and the nature of the material to be examined, as described in **3.4**.

3.3.1 Undeveloped quarries should be sampled by means of cores drilled through the entire depth expected to be productive of sound material. Drilling of such cores should be in a direction that is essentially normal to the dominant structural feature of the rock. Massive material may be sampled by 55 mm diameter cores. Thinly bedded or complex material should be represented by cores not less than 100 mm in diameter. There should be an adequate number of cores to cover the limits of the deposit proposed for the work under consideration. The entire footage of the recovered core should be included in the sample and accurate data given as to elevations, depths, and core losses.

3.3.2 Operating quarries and operating sand and gravel deposits, in which stockpiles of the material produced are available, should be represented by not less than 45 kg or 300 pieces, whichever is larger, of each size of material to be examined. Samples from stockpiles should be composed of representative portions of larger samples collected with due consideration given to segregation in the piles.

*Since issued as IS : 2430-1969 Methods for sampling of aggregates for concrete.

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3.3.3 Exposed faces of nonproducing quarries, where stockpiles of processed material are not available, should be represented by not less than 2 kg from each distinctive stratum or bed, with no piece weighing less than 0.50 kg; or by drilled core as described in **3.3.1**.

3.3.4 Undeveloped sand and gravel deposits should be sampled by means of test pits dug to the anticipated depth of future economic production. Samples should consist of not less than the following quantities of material selected so as to be representative of the deposit.

<i>Sieve Size</i>	<i>Quantity</i>	
	kg	pieces
mm		
160 to 320	—	*
80 to 160	—	300*
40 to 80	180	—
20 to 40	90	—
4.75 to 20	45	—
Sand	22.5	—

3.4 Natural Gravel and Sand

3.4.1 *Selection of Samples for Examination* — Samples of gravel and natural sand for petrographic examination should be sieved according to **2** of Part I of this standard to provide samples of each sieve size. In the case of sands, an additional portion should then be sieved, without being washed, and tested according to **3** of Part I of this standard in order to provide a sample of the material passing the 75 micron IS Sieve. The results of the sieve analysis of each sample should be provided to the petrographer making the examination and used in calculating results of the petrographic examination. Each sieve fraction should be examined separately, starting with the largest size available. Rocks are more easily recognized in larger pieces; the breakdown of a heterogeneous type present in the larger sizes may have provided particles of several apparently different types in the smaller sizes. Some important and easily confused types may be recognizable using the stereoscopic microscope if they are first recognized and separated in the larger sizes, but may require examination using the petrographic microscope if they are first encountered in the smaller sizes.

3.4.1.1 The number of particles of each sieve fraction to be examined will be fixed by the required precision of determination of the less abundant constituents. Assuming that the field sampling and laboratory sampling procedures are accurate and reliable, the number

*Not less than one piece from each apparent type of rock.

of particles examined, identified, and counted in each sieve fraction will depend on the required accuracy of the estimate of constituents present in small quantities. The numbers given in this method are minimal. They are based on experience and on statistical considerations. It is believed that at least 300 particles of each sieve fraction should be identified and counted in order to obtain reliable results. Precise determinations of small quantities of an important constituent will require counts of larger numbers of particles.

3.4.2 Examination of Natural Gravel

3.4.2.1 The pebbles should be examined to establish whether exterior coatings are present. If they are, it should be determined whether the coatings consist of materials likely to be deleterious in concrete (opal, gypsum, easily soluble salts, organic matter). It should also be determined how firmly the coatings are bonded to the pebbles.

3.4.2.2 Rock types — The sieve fraction should be sorted into rock types by visual examination. If all or most of the groups present are types easily identifiable in hand specimen by examination of a natural or broken surface, and by scratch and acid tests, no further identification may be needed. Fine-grained rocks that cannot be identified microscopically or that may consist of or contain constituents known to be deleterious in concrete should be checked by examination with the stereoscopic microscope. If they cannot be identified by that means, they should be examined by means of the petrographic microscope. The amount of work done in identifying fine-grained rocks should be adapted to the information needed about the particular sample. Careful examination of one size of a sample, or study of information from previous examination of samples from the same source, will usually reveal the amount of additional detailed microscopic work required to obtain information adequate for the purpose.

3.4.2.3 Condition — The separated groups belonging to each rock type should be examined to determine whether a further separation by physical condition is necessary. If all of the particles of a rock type are in a comparable condition, that fact should be noted. More frequently, particles in several degrees of weathering will be found in a group. They should be sorted into categories based on condition and on the expectation of comparable behaviour in concrete. The types of categories intended are (a) fresh, dense, (b) moderately weathered, (c) very weathered; or (a) dense, (b) porous, (c) or porous and friable. It usually is not practicable to recognize more than three conditions per rock type, and one or two may be sufficient. An important constituent present in large quantities may sometimes require separation into four groups by condition. The conspicuous example is chert when it is the major constituent of a gravel sample. It may be present as dense,

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unfractured chert; as vuggy chert; as porous chert; and as dense but highly fractured chert. The determination of which of these four conditions characterizes a particle may be expected to have an important influence on prediction of the behaviour of the particle in concrete.

3.4.2.4 Record — Notes should be taken during the examination. Each rock type should be described; the relevant features may include the following:

- a) Particle shape;
- b) Particle surface;
- c) Grain size;
- d) Texture and structure, including observations of pore space, packing of grains, cementation of grain;
- e) Colour;
- f) Mineral composition;
- g) Significant heterogeneities;
- h) General physical condition of the rock type in the sample; and
- j) Presence of constituents known to cause deleterious chemical reaction in concrete.

Particle counts should be recorded so that tables can be made for inclusion in the report. When the examination has been completed, the notes should contain enough information to permit the preparation of tables and descriptions. Tables should be prepared showing the composition and condition of the samples by sieve fraction, and the weighted average composition, based on the gradation of the sample as received and on the distribution of constituents by sieve fraction. Descriptions of constituent groups should be prepared containing the relevant features among those enumerated as above.

3.4.3 Examination of Natural Sand

3.4.3.1 The procedure for the examination of natural sand is similar to that for the examination of gravel, with the modifications necessitated by the differences in particle size.

3.4.3.2 Sizes coarser than 600-micron IS Sieve — Each sieve fraction present, that is, coarser than the 600-micron IS Sieve should be reduced in the Jones riffle until a split or splits containing at least 300 particles are obtained. The reduced sample of each sieve fraction should be examined, and its constituents identified and counted using the stereoscopic microscope. It is convenient to spread out the sample in a flat-bottom glass dish, such as a petri dish and manipulate the grains with a forceps and dissecting needle. The identification of grains in the

coarser sand sizes is often easier when the grains are just submerged in water. The submergence lessens the reflection from the outer surfaces and may show diagnostic features that cannot be seen when the grains are dry. There are exceptions to this generalization. Where identification is difficult, the examination includes examination of the natural surface (dry and wet), examination of a broken surface (dry and wet), and scratch and acid tests. Only after all of these steps have been taken and the grain is still unidentified should the petrographer resort to the petrographic microscope. Grains that cannot be identified using the stereoscopic microscope, or that are suspected of consisting of or containing substances known to react deleteriously in concrete, should be set aside to be examined with the petrographic microscope. If the question of reaction with the minor alkalis of Portland cement is important in the examination of the sample, certain additions to the procedure are indicated. If the coarser sand sizes contain fine-grained, possibly glassy igneous rocks, several typical particles of each variety of such rocks should be selected for a more thorough examination. The petrographer should determine the presence or absence of glass by crushing typical grains and examining them in immersion media, using the petrographic microscope. In difficult or especially important cases, it may be necessary to break suspected grains and to make immersion mounts of part of the grain and thin section of another part. Where the sand contains chert and the potential reactivity of the chert is an important consideration, a number of chert particles from the fractions retained on the 600-micron IS Sieve should be set aside for determinations of the index of refraction.

3.4.3.3 *Sizes finer than 600 micron* — The sieve fractions finer than the 600-micron IS Sieve should each be reduced in a Jones riffle to about 4 or 5 g. The volume will usually be less than a level teaspoonful. In some gradations the fractions retained on the 150-micron and 75-micron IS Sieves may be present in such small amounts that reduction is unnecessary. These splits should be further reduced on a miniature Jones riffle or by coning and quartering with a spatula on a clean sheet of paper. A representative portion of each reduced split should be mounted in immersion oil on a clean glass slide and covered with a clean cover glass. No entirely satisfactory method of reducing a split to about 300 grains is known. The reduced split can be sampled by spreading it in a thin layer on glass or clean paper, dragging the end of a dissecting needle moistened in immersion oil through the sample, and transferring the grains that adhere to the needle to a drop of immersion oil on a clean slide. If this is done carefully, a fairly representative sample will be obtained. If the dissecting needle is made of magnetized steel, a concentration of magnetic minerals may result. It is usually necessary to make several mounts of the 300-micron and

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150-micron fractions to obtain at least 300 grains of each. The index of the immersion oil should be selected to make the identification of the important constituents as easy and as definite as possible. The use of an immersion oil with an index of or just below the lower index of quartz (1.544) is recommended. The slide should be mounted on a petrographic microscope equipped with a mechanical stage. Several traverses should be made, and each grain that passes under the cross hair should be identified and counted. Care should be taken to move the slide on the north-south adjustment between traverses so that no grain will be counted twice. Each sieve fraction passing the 600-micron and retained on the 75-micron IS Sieve should be examined in this way. Ordinarily, the material passing the 75-micron IS Sieve is mounted on a slide following the procedure described above, examined by means of the petrographic microscope, and its composition estimated. If an unusually large amount of this size is present, or if it contains constituents that may be expected to have an important effect on the suitability of the aggregate for the intended use, it should be counted.

3.5 Drilled Core, Ledge Rock, Crushed Stone and Crushed Sand

3.5.1 Examination of Drilled Core— Each core should be examined and a log prepared showing depth of core recovered, core loss and location; location and spacing of fractures and parting planes; lithologic type or types; alternation of types; physical condition and variations in condition; toughness, hardness, coherence; obvious porosity; grain size, texture, variations in grain size and texture; type or types of breakage; and presence of constituents capable of deleterious reaction in concrete. If the size of the core permits, the probability that the rock will make aggregate of the required maximum size should be considered. If the surface of the core being examined is wetted, it is usually easier to recognize significant features and changes in lithology. Most of the information usually required can be obtained by careful visual examination, scratch and acid tests, and hitting the core with a hammer. In the case of fine-grained rocks, it may be necessary to examine parts of the core, using the stereoscopic microscope, or to prepare thin sections of selected portions. Some considerations and procedures are more applicable to particular rock types than to others. Ordinarily, the layered rocks considered for concrete aggregate will be limestone, and occasionally metamorphic rocks, such as phyllite, gneiss, or schist. One of the most important questions arising in the examination of limestone is that of the presence, type, and distribution of argillaceous impurities. Limestones that contain intercalated thin beds of soft shale may make suitable sources of aggregate if the shale is so distributed

that it does not prevent manufacture of the required maximum size, and if the shale can be eliminated or reduced in processing. Where argillaceous impurities are present, it should be determined whether they actually consist of clay mineral or of other minerals in clay sizes. If they do consist of clay minerals, it should be established whether the clay minerals include members of the montmorillonite group (swelling clays). In the examination of fine-grained igneous rocks, particular attention should be directed to the nature of the ground-mass. This examination should include determination of the presence or absence of opal, chalcedony, natural glass, and clay minerals of the montmorillonite group; if any of these are found the amount should be estimated; if natural glass is found the type should be determined.

3.5.2 Examination of Ledge Rock — The procedure used in examination should be the same as for core samples to the extent that the spacing of samples and size of the individual pieces allow. If the sample consists of a relatively large quantity of broken stone produced by blasting, it is desirable to inspect the whole sample, estimate the relative abundance of rock types or varieties present, and sample each type before further processing. Subsequent procedure should be the same as given in **3.5.3**.

3.5.3 Examination of Crushed Stone — The procedure for examination of crushed stone should be similar to that for core, except that necessary quantitative data should be obtained by particle counts of the separated sieve fractions.

3.5.4 Examination of Crushed Sand — If no samples of the rock from which the sand was produced are available, the examination procedure should be similar to that for natural sand, with particular emphasis on the amount and extent of fracturing developed by the milling operations.

3.6 Calculations and Report

3.6.1 Calculations — The composition of each sieve fraction of a heterogeneous sample and the weighted average composition of the whole sample should be calculated as follows.

3.6.1.1 The composition of each sieve fraction shall be expressed by summing the total number of particles of that fraction counted, and calculating each constituent in each condition as a percentage of that total amount (as number of particles in percent, in each sieve fraction). It is convenient to calculate and record the percentages to tenths at this stage. An example of these calculations is given in the upper half of Table III.

3.6.1.2 The percentage by weight of the sieve fraction in the whole sample (individual percentages retained on consecutive sieves) shall be

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obtained from the gradation of the sample as determined by Part I of this standard.

3.6.1.3 By multiplying the percentage of the constituent in the sieve fraction determined as described in **3.6.1.1**, by the percentage of the sieve fraction in the whole sample, obtained as described in **3.6.1.2**, the percentage in the whole sample, of that constituent in that size shall be calculated (weighted percentage of constituents in sieve fraction, *see* Table III). It is convenient to calculate and record these percentages to tenths.

3.6.1.4 By adding the weighted percentages of each constituent in each sieve fraction, the weighted percentage of each constituent in the whole sample shall be obtained (*see* under weighted composition of sample in Table III).

3.6.1.5 A table shall be constructed to show the composition of each sieve fraction and the weighted composition of the whole sample. Values shall be reported to the nearest whole number. Constituents amounting to 0.5 percent or less of a sieve fraction or of the whole sample shall be reported as traces. Table IV is an example constructed from the data obtained in Table III. As a convention, the total in each sieve fraction and the total in the whole sample shall each be 100 percent without the traces. Difficulties in abiding by this convention can usually be avoided by grouping minor constituents of little engineering importance. It is preferable to tabulate constituents known to react deleteriously in concrete so that their distribution will be apparent from inspection of the table, even though the amount in the whole sample or in any fraction is very small.

3.6.2 Report— The report of the petrographic examination should consist of two principal parts, the summary report and the detailed report. The summary report customarily consists of two paragraphs which summarize, respectively, the essential data needed to identify the sample as to source and proposed use, and a brief description, including the essential data on composition and properties, of the material as revealed by the examination. The complete report records the test procedures employed, the data developed on the composition of the material, and a description of the nature and features of each important constituent of the sample, accompanied by such tables and photographs as may be required to adequately present the findings of the examination. Petrographic data in the summary should be expressed in terms likely to be intelligible to the engineer who must make the ultimate decision as to the suitability of a material for use as concrete aggregate.

3.6.2.1 The petrographic report should be a statement of the findings of the examination. When the sample has been found to possess

TABLE III CALCULATION OF RESULTS OF PARTICLE COUNTS*
(Clauses 3.6.1.1, 3.6.1.3, 3.6.1.4 and 3.6.1.5)

CONSTITUENTS†	COMPOSITION OF FRACTIONS RETAINED ON SIEVE							
	20 mm		12.5 mm		10 mm		4.75 mm	
	Number of Particles	Percent	Number of Particles	Percent	Number of Particles	Percent	Number of Particles	Percent
A ₁	250	50.0	200	40.0	150	30.0	50	10.0
A ₂	50	10.0	100	20.0	125	25.0	100	20.0
A ₃	10	2.0	50	10.0	75	15.0	100	20.0
B ₁	107	21.4	70	14.0	62	12.4	32	6.4
B ₂	76	15.2	53	10.6	19	3.8	87	17.4
B ₃	—	—	20	4.0	43	8.6	96	19.2
C ₁	5	1.0	5	1.0	20	4.0	20	4.0
C ₂	2	0.4	2	0.4	6	1.2	10	2.0
C ₃	—	—	—	—	—	—	5	1.0
Total	500	100	500	100	500	100	500	100
Individual percentage retained on sieve	17.4		32.6		29.5		20.5	
WEIGHTED PERCENTAGE OF CONSTITUENTS IN EACH SIEVE FRACTION				WEIGHTED COMPOSITION OF SAMPLE				
	20 mm	12.5 mm	10 mm	4.75 mm				
A ₁	8.7	13.0	8.9	2.1	32.7			
A ₂	1.7	6.5	7.4	4.1	19.7			
A ₃	0.4	3.3	4.4	4.1	12.2			
B ₁	3.7	4.6	3.7	1.3	13.3			
B ₂	2.6	3.5	1.1	3.6	10.8			
B ₃	—	1.3	2.5	3.9	7.7			
C ₁	0.2	0.3	1.2	0.8	2.5			
C ₂	0.1	0.1	0.3	0.4	0.9			
C ₃	—	—	—	0.2	0.2			
Total in sieve fraction	17.4	32.6	29.5	20.5				
Total in sample, condition 1					48.5			
Total in sample, condition 2					31.4			
Total in sample, condition 3					20.1			

*This table indicates a convenient method of setting up a work sheet for recording results and calculations. The results developed here are entered in the form indicated by Table IV. Table IV is included in the petrographic report, Table III is not.

†Letters (A, B, C) refer to the various constituents found, subscript numbers (1, 2, 3) refer to the various conditions in which each constituent has been found, such as relative degree of weathering.

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properties or constituents that are known to have specific unfavourable effects in concrete, those properties or constituents should be described qualitatively and, to the extent practicable, quantitatively. The unfavourable effects that may be expected to ensue in concrete should be mentioned also. When appropriate, it should be stated that a given sample was not found to contain any undesirable features. The report should not, however, contain a general statement of opinion by the petrographer concerning the quality of the material. The petrographer should avoid such general statements of opinion, since they are subjective and therefore not properly a part of a report of objective findings, and since they can properly be made only when data on different materials can be compared in connection with the requirements for a specific use.

TABLE IV COMPOSITION AND CONDITION OF AN AGGREGATE SAMPLE (TABLE CONSTRUCTED FROM CALCULATIONS SHOWN IN TABLE III)

(Clause 3.6.1.5)

AMOUNT, AS NUMBER OF PARTICLES IN PERCENT

	In Fractions Retained on Sieves Shown Below*				In Whole Sample†			Total
	20-mm	12.5-mm	10-mm	4.75-mm	Condition 1	Condition 2	Condition 3	
A	62	70	70	50	33	20	12	65
B	37	29	25	43	13	11	8	32
C	1	1	5	7	2	1	tr	3
Total	100	100	100	100	—	—	—	100
	Weighted average				48	—	—	—
	Weighted average				—	32	—	—
	Weighted average				—	—	20	—

*Based on count of 500 particles in each sieve fraction. (The number of particles of each sieve fraction counted should be shown in the report and this may conveniently be done as a footnote to the table.)

†Based on gradation of the sample as received and on the distribution of constituents by sieve fractions shown at the left above. (If the petrographic report forms part of a complete investigation of the sample, including a report of the gradation, the gradation need not be shown. If the petrographic report is to be submitted alone, the gradation of the sample should be included with it.)

3.7 Additional Test Method

3.7.1 *Object*

This test method describes procedure for determining undulatory extinction (UE) angle of coarse and fine aggregates and shall be conducted on aggregates containing generally more than 30 percent quartz. The undulatory extinction angle is the angle between the positions of extinction and its disappearance in the grain. It is a measure of the crystal lattices disturbance caused by geological stresses. Various researchers have used UE angle as indication of possible source for alkali reactivity of the rock.

3.7.2 *Procedure*

The undulatory extinction angle shall be determined in transmitted light (thin section) under a polarising microscope.

3.7.2.1 When the first extinction in the selected quartz grain showing the interference colour is visible, the position of graduated rotating stage of the polarising microscope shall be recorded.

3.7.2.2 Determine the second position by rotating the same grain with the rotating stage of the microscope through other extinction areas in the grains until the entire grain becomes bright coloured again except for some slightly grey shadows in the area covered **3.7.2.1**. Determine the angle between the two positions.

3.7.2.3 Repeat the measurements mentioned in **3.7.2.1** and **3.7.2.2** in the reverse direction also. This will improve the precision of the test, the difference between the two measurements, that is forward and reverse directions, should be small.

3.7.2.4 Average the values (that is difference between the two positions) obtained in the two directions for a particular grain. This shall be the characteristic UE angle for a given grain.

3.7.2.5 The angle characterising a thin section shall be obtained by averaging the values of all grains examined in the thin section.

3.7.2.6 The percentage of quartz grains showing undulatory extinction in the same section shall be determined by point-counting method.

NOTE — Some coarse aggregates may be of composite nature, that is, containing different rock types for example quartzite, granites, sandstone, etc. The undulatory extinction angle and the percentage of quartz grains showing UE shall be determined for each of the predominant constituents of the coarse aggregates.

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This Indian Standard has been developed by Technical Committee : BDC 2 and amended by CED 2

Amendments Issued Since Publication

Amend No.	Date of Issue
Amd. No. 1	June 1999

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