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Index of Aggregate Particle Shape and Texture of coarse aggregate as a parameter for concrete mix proportioning

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Abstract

Aggregates occupy bulk of the volume of concrete. Their size, grading, shape and surface texture have significant influence on the properties of concrete, both in fresh and hardened state. Specifications in various codes, on concrete mix proportioning, regarding size and grading of the aggregate are much clear than their counterparts regarding shape and surface texture, which is broadly classified into angular/crushed and rounded/uncrushed. The lack of quantitative definition of aggregate particle shape and surface texture often leads to inconsistent results, and requirement of number of trials for achieving desirable properties of concrete. Index of Aggregate Particle Shape and Texture (IAPST) as per ASTM D-3398-97, provides a quantitative measure of shape and surface texture of aggregate. The present investigation covers coarse aggregate with different IAPST. The data of 45 concrete mixes has been presented and the potential of IAPST of coarse aggregate as a parameter for concrete mix proportioning is discussed in the paper.

Keywords: Aggregate shape; Workability; Mix proportioning

1. Introduction

The aggregates not only make concrete economical by occupying more volume, but also impart volume stability and increase durability. The properties, such as size, grading, shape and surface texture, have marked influence on workability and strength of concrete. Aggregates having more angularity and rough surface texture contain more voids than the rounded aggregates with smooth surface texture and hence demand more water to produce workable concrete [1–3]. Secondly, the mechanical bond between the aggregate surface and cement paste, by virtue of interlocking, influences the strength of concrete [4]. This effect is more crucial in case of high strength concrete than normal strength concrete, particularly when the water–cement ratio is less than 0.40 [5].

The review of codes of practice on concrete mix proportioning indicates that the provisions regarding grading and size of aggregate are clearer than those on shape. The aggregates are broadly classified as angular/crushed and rounded/uncrushed, and accordingly separate values of water content, for desired workability, are specified in the code [6–8]. However, the shape and surface texture of the aggregate may vary from highly angular and rough to fully rounded and smooth, because it is the result of parameters, like type of parent rock, the forces to which it is subjected during and after its formation, and design and operation of crushing equipment. Hence, there is a need for proper quantification of these properties to further rationalize the process of concrete mix proportioning. Index of Aggregate Particle Shape and Texture (IAPST) as per ASTM D-3398-97, provides a quantitative measure for these properties. The paper presents the results of the experimental investigation to study the potential of IAPST of coarse aggregate as an important parameter in concrete mix proportioning.

2. Literature review

The importance of the measurement of aggregate shape was felt long back. The earlier attempts to measure numerically the shape of aggregate were based on observation and measurement of dimensions of individual particles. The

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ratios of intermediate to larger dimension and smaller to intermediate dimension were used for the classification of shape as oblate, prolate, triaxial and equiaxial. This concept was further modified and shape was classified into five classes as angular, subangular, subrounded, rounded and well rounded [9]. Flakiness and elongation indices, as suggested by various codes, are often used for the assessment of shape of aggregate particles [10–12]. However, these methods are not well appreciated as they give only a broad description of shape of aggregate and also involve lengthy and laborious process of handling individual particles. Attempts are also being made to bring the methodology to the 21st century by using image-processing techniques for the direct assessment of particle shape and texture with precision [13–15]. These methods are still in the stage of development.

In the indirect methods, the properties of aggregate in bulk that are influenced by their shape and surface texture are considered as a measure of shape. Such properties include bulk density, settling velocity, rate of flow of water through gravel, behavior of particles on inclined plane and the percentage voids. The methods based on percentage voids in the aggregate looked promising amongst other methods. Angularity number as suggested by Shergold [1] is a pioneering work in the evaluation of aggregate shape using the concept of percentage of voids. It is determined by subtracting the voids in the most rounded gravel from the voids present in the aggregate, when compacted in a specified manner. It is observed that the voids in the most rounded gravel are about 33%. Closer size fractions of aggregate are chosen for eliminating the effect of grading on voids. The aggregate from each size fraction is subjected to compaction in a standard mould by applying prescribed number of blows of a standard tamping rod. Weighted average of angularity number of various size fractions present in the aggregate is considered as angularity number of the aggregate. BIS and BS codes have adopted this method for the quantification of aggregate shape [10,11]. However, the method has several limitations. It gives contradictory results when regular-shaped bodies are tested. Furthermore, the heavy compaction applied may cause crushing as well as artificial changes in the surface texture of the aggregate and thereby affect the angularity number.

IAPST suggested by Huang [16] is based on the concept that the voids as well as the rate of change of voids in the single-sized aggregate, under standard compaction, depend upon its shape, angularity and surface texture. Subsequently, it is adopted as ASTM D-3398-97 [17] and is being used to study the influence of shape and texture of aggregates on the compaction and strength characteristics of asphalt concrete. However, its influence on the properties of Portland cement concrete remains to be investigated.

3. Determination of IAPST

The aggregates are to be sieved into various size fractions as shown in Columns 1 and 2 of Table 1. However, in the present investigation, they are sieved into closer size fractions by introducing a 16-mm sieve between 20 and 12.5 mm and a 6.3-mm sieve between 10 and 4.75 mm, for eliminating the effect of intersieve grading of aggregate. The aggregate samples from each size fraction are derived by the method of quartering. Bulk dry specific gravity of each size fraction of coarse aggregate is determined as per ASTM C 127-88 [18]. The mould and tamping rod to be used for each size fraction of aggregate are as per ASTM D3398-97 and reproduced in Table 1. The aggregate sample is compacted in three layers with 10 drops per layer of tamping rod. Each drop is applied from a height of 50 mm above the surface of aggregates. After the completion of tamping of the third layer, individual pieces of aggregate are added to make the surface level with the rim of the mould. The mould is then weighed and the weight of the aggregate sample (M_{10}) is determined to an accuracy of 1 g. The test is repeated twice and the average value of M_{10} is used for calculating

Table 1
Details of moulds and tamping rods as per ASTM D3398-97

Aggregate size (mm)		Details of mould					Details of tamping rod		
Passing	Retained	Type	Inside diameter (mm)	Inside height (mm)	Bottom thickness (mm)	Wall thickness (mm)	Diameter (mm)	Length (mm)	Mass (gm)
1	2	3	4	5	6	7	8	9	10
38.1	25.4	A	203.2	237	6.1	6.1	21.2	814	2204
25.4	19	B	152.4	177.8	6.1	6.1	15.9	610	930
19	12.7								
12.7	9.5	C	101.6	116.5	5.1	5.1	10.6	406.9	276
9.5	4.75								
4.75	2.36	D	76.2	88.9	4.1	4.1	7.9	306	116
2.36	1.18								
1.18	600 μm								
600 μm	300 μm	E	50.8	59.3	3.8	3.8	5.3	201.7	34
150 μm	75 μm								

Table 2
Properties of coarse aggregates and river sand used in the study

Aggregate designation	Type of aggregate	Voids (V_{10})	Voids (V_{50})	IAPST	Specific gravity	% Water absorption
1	2	3	4	5	6	7
A1	Crushed granite from plant 1	48.57	46.13	17.18	2.708	0.11
A2	Crushed granite from plant 1 with 6 h of attrition	46.31	44.15	14.85	2.708	0.11
A3	Crushed granite from Plant 2 with 10 h of attrition	45.04	42.87	13.58	2.745	0.10
A4	Gravel from Source 1	41.77	40.05	10.20	2.632	0.31
A5	Gravel from Source 2	38.98	37.51	7.34	2.646	0.11
FA	River sand	43.36	42.03	11.69	2.564	0.17

percentage voids (V_{10}). Similarly, percentage voids (V_{50}) is determined by applying 50 drops. The following equation is used to obtain IAPST of each size fraction: IAPST = $1.25 \times V_{10} - 0.25 \times V_{50} - 32$, where V_{10}=[1 − (M_{10}/sv)] × 100, V_{50}=[1 − (M_{50}/sv)] × 100, s is the bulk dry specific gravity of aggregate size fraction and v is the volume of mould. Weighted average of IAPST of individual size fractions is considered as IAPST of graded aggregate.

4. Research significance

Most of the standards on concrete mix proportioning have subjectively defined aggregates as angular and rounded. In the earlier attempts, it was shown that the shape and surface texture of aggregate influence workability and thereby water, cement and fine aggregate content. It also has an impact on the strength of concrete. In the absence of quantitative information with respect to the shape and surface texture, the mix proportioning has become more or less a trial-and-error process. Hence, there is a need to introduce shape and surface texture of aggregate as a parameter so as to reduce the trial-and-error procedure involved in concrete mix proportioning as envisaged in various codes.

5. Objective of research

IAPST of aggregate is being used to study the effect of shape and surface texture of aggregate on the compaction and strength characteristics of soil aggregate and asphalt concrete mixtures. In the present investigation, an attempt is made to identify the influence of IAPST of coarse aggregate on workability of Portland cement concrete.

6. Experimental program

The basic assumption made in most of the standards on concrete mix proportioning is that the compressive strength of workable concrete is, by and large, governed by the water–cement ratio. Another most convenient relationship applicable to normal concretes is that for a given type, shape, size and grading of aggregates, the water content determines its workability. Furthermore, it is observed that for a constant water–cement ratio and water content, workability depends upon the proportion of coarse and fine aggregates. Moreover, for a given material, there exists a unique combination of coarse and fine aggregates that yields maximum workability [19]. This implies that the volume of fine aggregate of a particular type and grading depends upon the grading, shape and surface texture of coarse aggregate. Thus, in the present investigation, IAPST of coarse aggregate, water content and volume fraction of fine aggregate (VFFA) in the total volume of aggregate are considered as the variables to study their influence on workability of concrete. Size and grading of coarse aggregate, source and grading of fine aggregate, type and grade of cement and free water–cement ratio of 0.40, by mass, are kept constant in the entire experimentation.

Crushed granite from two crushing plants and gravels from two sources are used as coarse aggregates. The crushed aggregate from Plants 1 and 2 are attritioned for 6 and 10 h, respectively, at a speed of 33 rpm, using Deval attrition machine, to obtain the coarse aggregates with intermediate values of IAPST. All the aggregates are washed, cleaned and dried. The coarse aggregates are sieved into closer size fractions of 25–20, 20–16, 16–12.5, 12.5–10, 10–6.3, 6.3–4.75 and 4.75–2.36 mm and the fine aggregates into 4.75–2.36 mm, 2.36–1.18 mm, 1.18 mm–600 μm, 600–300 μm and 300–150 μm and are stored separately. IAPST of aggregates is determined as per the procedure discussed in Section 3 and the results of V_{10}, V_{50} and IAPST are

Table 3
Grading of coarse and fine aggregate

Coarse aggregate		Fine aggregate	
Sieve size (mm)	Cumulative % passing	Sieve size (mm)	Cumulative % passing
1	2	3	4
25	100	10	100
20	97.5	4.75	100
16	80	2.36	87.5
12.5	60	1.18	72.5
10	40	600 μm	47
6.3	18	300 μm	19
4.75	05	150 μm	0
2.36	0	–	–

tabulated in Columns 3, 4 and 5 of Table 2. The properties, such as specific gravity on the basis of saturated surface dry condition and water absorption of coarse and fine aggregates, are determined as per ASTM C127-88 [18] and ASTM C128-88 [20], respectively, and are given in Columns 6 and 7 of Table 2. The grading of coarse aggregate, 20-mm nominal maximum size, and fine aggregate conforming to ASTM C33-99 [21] is used. Moreover, in the case of coarse aggregates, closer sieve sizes, as mentioned earlier, are used to maintain the intersieve grading uniform. The details of which are given in Table 3. Ordinary Portland cement with 28 days cube compressive strength of 54.2 MPa and tap water with a pH value of 8 is used.

7. Preparation of concrete and test on workability

The details of the mixes and variables considered in the experimentation are presented in Table 4. An air content of 2% was assumed for determining the proportions of the ingredients. All the material was weight batched. The weight of the aggregates and water was adjusted as per

Table 4
Concrete mixes and results of compaction factor test

Mix type	IAPST of coarse aggregate	Water content (kg/m^3)	VFFA in total aggregate	Compaction factor as per test	Optimum VFFA (Fig. 2a–e)	Maximum compaction factor (Fig. 2a–e)
1	2	3	4	5	6	7
A111	17.18	180	0.30	0.812	0.338	0.826
A112			0.35	0.824		
A113			0.40	0.788		
A121		190	0.30	0.877	0.327	0.885
A122			0.35	0.879		
A123			0.40	0.823		
A131		200	0.30	0.903	0.340	0.921
A132			0.35	0.920		
A133			0.40	0.880		
A211	14.85	170	0.25	0.806	0.299	0.830
A212			0.30	0.830		
A213			0.35	0.803		
A221		180	0.25	0.858	0.290	0.874
A222			0.30	0.873		
A223			0.35	0.838		
A231		190	0.25	0.879	0.315	0.914
A232			0.30	0.912		
A233			0.35	0.904		
A311	13.58	160	0.25	0.819	0.285	0.824
A312			0.30	0.823		
A313			0.35	0.807		
A321		180	0.25	0.876	0.284	0.889
A322			0.30	0.886		
A323			0.35	0.838		
A331		200	0.25	0.907	0.314	0.955
A332			0.30	0.953		
A333			0.35	0.940		
A411	10.20	150	0.20	0.803	0.246	0.828
A412			0.25	0.828		
A413			0.30	0.793		
A421		160	0.20	0.843	0.231	0.846
A422			0.25	0.845		
A423			0.30	0.830		
A431		180	0.20	0.910	0.244	0.941
A432			0.25	0.940		
A433			0.30	0.890		
A511	7.34	130	0.20	0.808	0.247	0.828
A512			0.25	0.828		
A513			0.30	0.803		
A521		160	0.20	0.920	0.250	0.935
A522			0.25	0.935		
A523			0.30	0.920		
A531		180	0.20	0.940	0.254	0.980
A532			0.25	0.980		
A533			0.30	0.950		

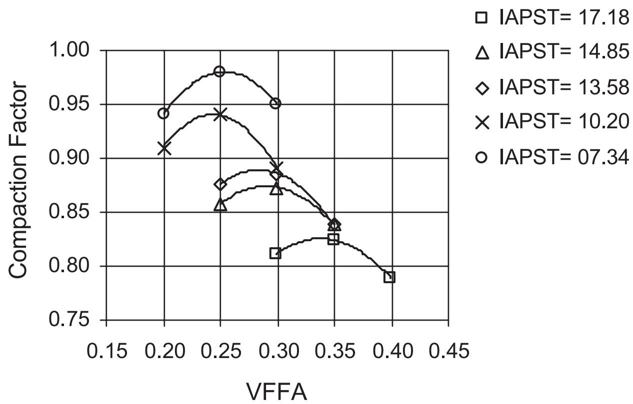

Fig. 1. Relation between IAPST, VFFA and compaction factor for the water content of 180 kg/m^3.

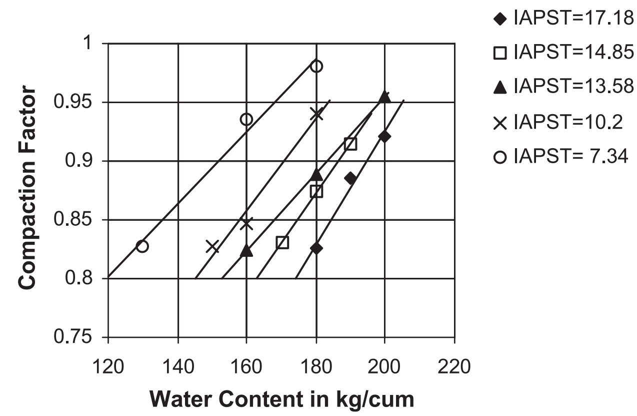

Fig. 3. Relation between water content and compaction factor for various IAPST.

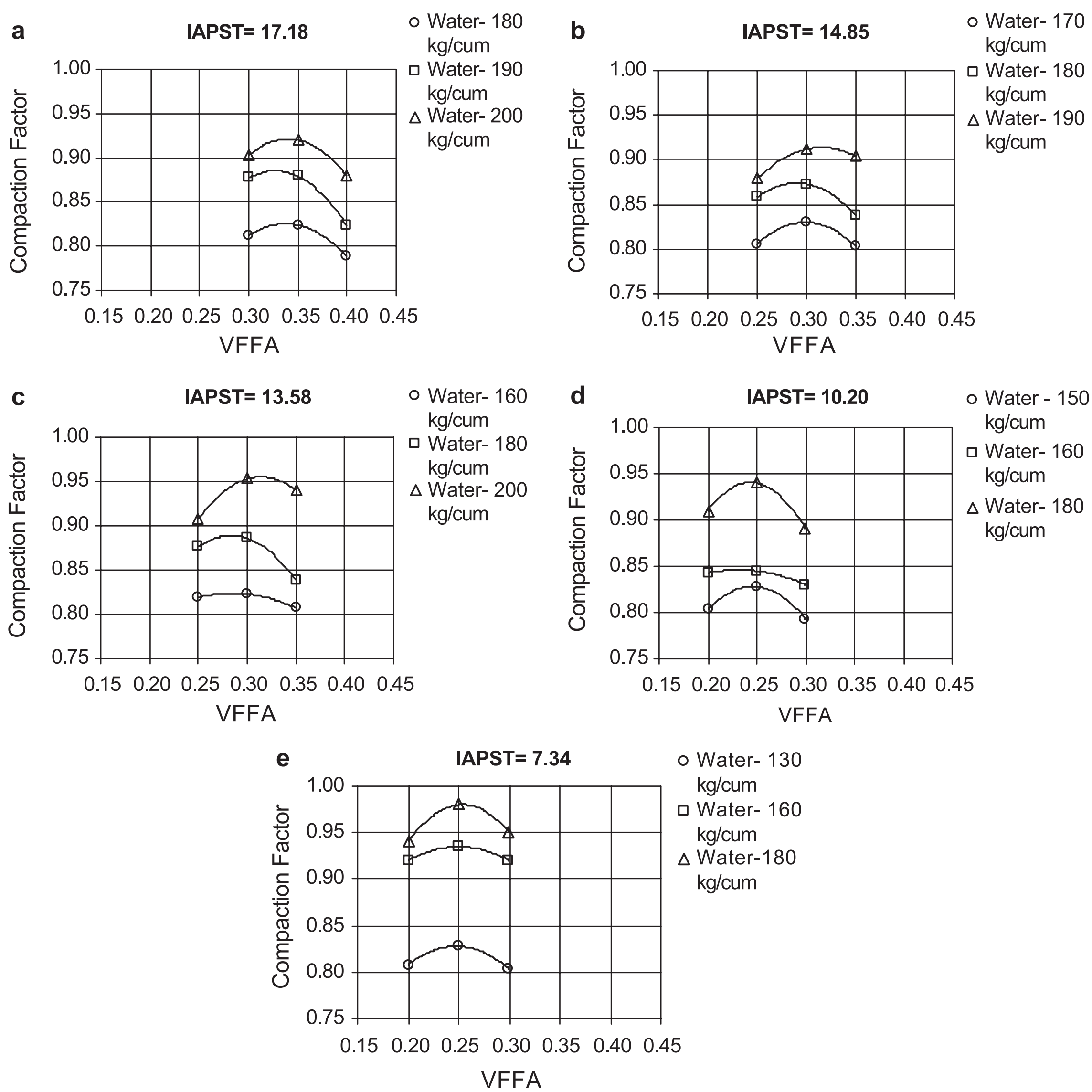

Fig. 2. Relation between IAPST, VFFA and compaction factor with variation in water content.

the water absorption and status of surface moisture of the aggregates. Mixing was carried out at a room temperature of 30 ± 2 °C in a laboratory electric mixer. Compaction factor test as per ACI 211.3-75 [22] was conducted to assess the workability of concrete. The test consists of measuring the degree of compaction, called compaction factor, as the ratio of density of concrete under standard compacting effort to the density of same concrete when fully compacted.

8. Results and discussions

The data of V_{10}, V_{50} and IAPST is presented in Table 2. It indicates that there is a reduction in V_{10}, V_{50} and IAPST as the aggregate shape and texture becomes more and more rounded and smooth. This is due to the fact that IAPST is indirectly a measurement of packing density of aggregate.

All being the same, for each of IAPST and water content, there are three VFFAs considered in the experimental work. Compaction factor of each mix is given in Column 5 of Table 4. An examination of these results show that for IAPST and water content, the compaction factor increased initially with the increase in VFFA and later decreased, indicating that there is an optimum VFFA for maximum compaction factor. The nature of variation is observed to be the same for all mixes with each IAPST. The trend of the variation is obtained by plotting the VFFA as abscissa and compaction factor as ordinate as shown in Fig. 1, typically, for mixes with water content of 180 kg/m^3. The equation of trend line as a second-degree curve is differentiated to obtain optimum VFFA for each IAPST. In general, the trend lines are one above the other and moved relatively closer to ordinate axis as the IAPST decreased, meaning, that as IAPST increases optimum, VFFA increases and compaction factor decreases. The relations between VFFA and compaction factor with different water contents for each IAPST are also given in Fig. 2a–e. From these relations optimum VFFA is obtained as stated before. Such values of optimum VFFA and maximum compaction factor are given in Columns 6 and 7, respectively, of Table 4.

With water content as abscissa and maximum compaction factor as ordinate, regression lines are obtained for each IAPST as shown in Fig. 3. It can be seen that for a particular compaction factor, the water content increases with an increase in IAPST. It also reveals that the difference in the water content for higher and lower IAPST goes on decreasing as the compaction factor increases. It may be due to the fact that the influence of aggregate properties on workability decreases with an increase in the richness of the mix [19].

With IAPST as abscissa and optimum VFFA as ordinate, the points are plotted for each water content. As there is a little variation in optimum VFFA for each IAPST and water content, a regression line is drawn for the combined data as shown in Fig. 4.

In the methods on concrete mix proportioning, the water content is specified with respect to extreme limits of shape of coarse aggregate. Figs. 3 and 4 facilitate the selection of water content and optimum VFFA, respectively, with respect to IAPST of coarse aggregate for achieving desired workability. Thus, IAPST of coarse aggregate is a useful parameter to further rationalise the existing process of concrete mix proportioning.

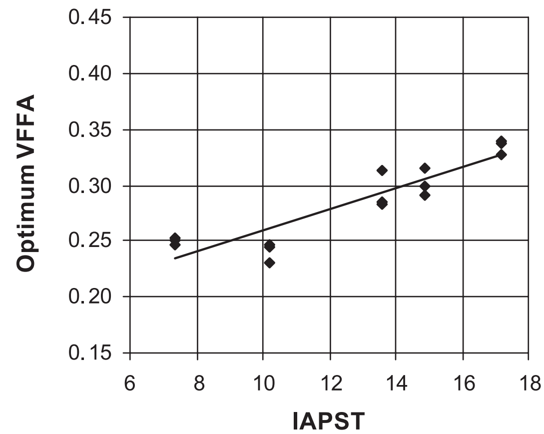

Fig. 4. Relation between IAPST and optimum VFFA.

9. Conclusions

Based on the results discussed above, the following conclusions can be drawn.

(1) For the same compaction factor and water–cement ratio, the water content increases as the IAPST of coarse aggregate increases.
(2) Optimum VFFA do not vary much with respect to the water content for a given IAPST and water–cement ratio.
(3) For a given type and grading of fine aggregate, optimum VFFA increases with the increase in IAPST of coarse aggregate.
(4) The relationship of IAPST of coarse aggregate with water content, VFFA and compaction factor indicates its importance as a useful parameter for further rationalizing the process of concrete mix proportioning.

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