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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 2, Issue 4, April 2017

Effect of Particle Packing of Aggregates on properties on High Performance Concrete (HPC)

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***Abstract*— In Civil Engineering, it is well known that the packing density of the particles in a concrete mix has great impact on the performance of concrete. High performance concrete (HPC) has become more and more popular in recent years. However, the various required performance attributes of HPC, including strength, workability and durability, often impose paradox requirements on the mix parameters to be adopted, thereby making the concrete mix design a very difficult task. This paper introduces the concept of packing density for increasing the performance of HPC. The concept is based on the belief that the performance of concrete mix can be optimized by maximizing the packing densities of the aggregate particles with manufactured sand (Type VSI) and fine particles. This paper involves the various mix proportions of aggregate particles with manufactured sand and study the behaviour of concrete and other parameters. Mix proportion includes the insertion of manufactured sand from 0% to 50% along with aggregates, thus to get the optimum packing density of the aggregate particles, the optimum packing density was obtained at proportion of 25% coarse aggregates (20mm downsize), 25% coarse aggregates (12.5mm downsize) and 50% manufactured sand. By using the optimum packing density combination in mix design of HPC and study the behaviour of concrete and its performance parameters. Using manufactured sand to fill the voids of coarser aggregates has increased the packing density thus by decreasing void ratio and making the structure dense and stiff. Thus increasing the packing density gives significant results on performance of HPC.**

Index Terms: **Alcofine-1203, Dry Loose Bulk Density Method (DLBD), High Performance Concrete (HPC), Packing Density, VSI (Vertical Shaft Impactor) Sand.**

I. INTRODUCTION

The grade of concrete is generally defined in terms of its characteristic compressive strength. Nowadays the demand for HPC is increasing, HPC that have not only high strength but also all round high performance in terms of other attributes such as workability, dimensional stability and durability. Because of the varying requirements of these performance attribute such as increase in strength often leads to decrease in workability and increases in both strength and workability leads to lower dimensional stability, HPC is much more difficult to produce[1], because of low water/cementitious materials ratio. So, dosages of chemical and mineral admixtures are to be added and mix optimization is needed in order to achieve all the desired properties, for this PCE (Polycarboxylate Ether) based admixture is used. In this paper, the concept of packing density is introduced. This concept is playing a more and more important role in modern concrete mix design because of realization that increasing of packing density by adjusting the grading of the whole range of solid particles, including the coarse aggregate, the fine aggregate and the cementitious materials, can improve the overall performance of the concrete mix. Thus the performance of HPC is directly dependent on the rock aggregate and fine materials used for concrete.

In HPC it is extremely necessary to ensure the use of fine and ultra-fine materials along with cement. The cementitious paste, which goes into voids between the aggregates, containing various sizes and shapes of particles in suspension plays an important role in properties of fresh concrete. Further, from the literature, we can say that the nature of particle packing has a significant influence on the properties of HPC. To optimize the particle packing density of concrete, the particles should be selected to fill up the voids between large particles with smaller particles and so on, in order to obtain a dense and stiff particle structure. For increasing the packing density well graded and angular aggregates should be used.

Today there are many types of crushing equipment's (e.g. Cone Crusher, Jaw Crusher, VSI, etc.) are available that imparts different properties and shape to the materials. Crusher crushes the rubble and converts rubble into coarse and fine aggregates. Following are the stages of manufacturing of aggregates-

Aggregates production technology includes two main stages. The first stage is extracting rubble. The second stage is processing the rubble into aggregates (via crushing and screening).

The crushing process is done into three stages:

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ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

- Primary crushing stage, (Jaw crusher)
- Secondary crushing stage, (Cone Crusher)
- Tertiary crushing stage. (VSI)

Stage 1- In this stage, the rubble is loaded into charging hopper of the feeder, the feeder steadily feeds the rubble into primary crusher (i.e. Jaw Crusher). The crusher crushes the rubble stone into average sized pieces.

Stage 2- The rubble that has been crushed into average-sized pieces is fed by the belt conveyer into the secondary crusher (i.e. Cone Crusher). These average size pieces are now crushed into smaller pieces. These rock pieces are passed through screening so as to eliminate the clay content. But the rock pieces are more flaky and elongated coming out from this stage, so the rock pieces are further proceed to VSI (Vertical Shaft Impactor)

Stage 3- In this stage the rock pieces are feed through VSI hopper, the rock pieces are coming out from this crusher are more angular(Cubical). From this crusher we can get the required rock pieces of well graded by screening of aggregates.

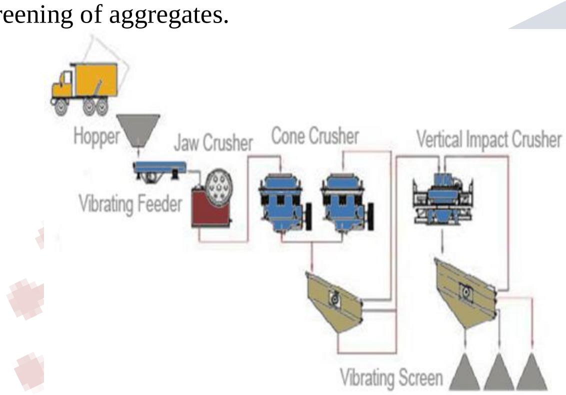

Figure 1 Manufacturing of Aggregates (Source: Google.com/images)

In Mumbai suburbs (e.g Thane, Navi Mumbai, Kalyan, etc.) most of the local builders used the second stage aggregates (which are flaky and elongated) just to save the cost of project. But by using these aggregates it makes the concrete structure weak or undesired quality. Using aggregates of this quality decrease the life of structure and indirectly leads to maintenance cost. Renowned builders in Mumbai used the VSI (Stage-3) aggregates and sand (this process cost an extra 100 Rs/Ton approximately). Using these aggregates enhanced the packing density of aggregates due to its shape and strength properties. The interlocking between the aggregates is done properly to great extent compare to other, thus making the concrete structure dense and stiff, which directly increases the performance and life of structure and indirectly cut the cost of building maintenance to great extent. VSI aggregates and sand are more angular in shape, thus interlocking or contact between the aggregates and sand is more.

II. PACKING DENSITY

It is well known that the packing density of the particles in a concrete mix has great impact on the performance of concrete[2]. Aggregate packing directly affects the way of aggregate particles forming a structure to transmit and distribute loads[3]. The packing density of particles, defined mass of aggregates required to fill the container of a unit volume. As we know concrete is made largely of aggregate particles, its properties are greatly influenced by packing density of aggregates. Hence, by studying the packing density of the aggregates can help to improve understanding of the behavior of concrete.

Packing density optimization has importance in modern concrete technology. For example, for the same cement content higher packing density reduce the cement paste needed to fill voids of aggregates and increase the amount of excess paste and lead to a higher workability. Alternatively, at the same workability, increase in packing density of the aggregate would restrict the use of cement consumption, cost of production of the concrete. A higher packing density of the concrete mix decreases the use of water to improve the strength of the concrete without compromising the workability. Therefore, packing density has great importance, especially for production of high-performance concrete (HPC). However, there is so far no generally accepted method of packing density measurement. For aggregates, although there are codified test methods for measuring the packing density under dry condition, the measured packing density under dry condition is sensitive to the amount of compaction applied and they do not include the possible effects of water and chemical admixture added. Therefore, the dry packing methods are not applicable to cementitious materials. Therefore, Dry packing method for aggregates mix proportions is used to find out the packing density.

III. PACKING OF AGGREGATES

Packing of aggregates is nothing but the bulk density. Bulk density of aggregates is the mass of aggregates required to fill the container of a unit volume after aggregates are batched based on volume. For finding density there is codified method (IS 2386 Part-III)

It depends on the packing of aggregate i.e. either loosely packed aggregates or well dense compacted aggregates. In case, if the specific gravity of material is known, then it depends on the shape and size of particles. It is because, if all the particles are of same size than packing can be done up to a very limited extent. If the addition of smaller particles is possible within the voids of larger particles than these smaller particles enhance the bulk density of the packed material. Shape of the particles also influence very widely, because closeness of particles depends on the shape of aggregates.

For finding packing density of aggregate there are two methods i.e.

- Dry Packing Method
- Wet Packing

A) Dry Packing Method

Dry packing method is done by filling the container with dried aggregates until it overflows from the container (DLBD bucket). Now level the top surface of container by rolling a rod on it (Uncompacted), or by filling the container in three layers and tamped each layer with a 16mm diameter rounded nosed rod (Compacted). After filling in three layers now leveled the top surface and evaluate compacted packing density. After that, weight the aggregate mass that is inside the container and divide it by the volume of container. This will give you the packing density of the aggregates.

B) Wet Packing Method

This method is not in IS code or any other country code. This wet packing method is developed by Researcher Albert K.H. Kwan (Department of Civil Engineering) The University of Hong Kong, Hong Kong.

In wet packing method, the predetermined amount of blended aggregate or solid portion of a concrete mix is mixed with water at various water/solid (W/S) ratio by volume to determine the voids ratio and solid concentration of each resulting mixture. From the bulk volume of the mixture, which is the same as the volume of a container, and the solid volume of the mixture in the container, which can be determined from the W/S ratio and the weight of the mixture, the voids ratio and solid concentration can be determined as, Plotting the voids ratio and solid concentration against the W/S ratio, the minimum voids ratio and maximum solid concentration , which is taken as the wet packing density of the solid particles, can be determined.[2]

IV. PACKING DENSITY (METHODOLOGY)

The first part is to find the optimum density of aggregate. The proposed mix proportion of aggregate mix i.e. Sand (VSI type), 10mm and 20mm aggregates are as follows:-

TABLE 1: Proposed Mix Proportions in percentages.

Sr. No.	Sand (Type VSI)	10 mm Aggregates	20 mm Aggregates	Density (Kg/Lit)
1	50	25	25	1.977
2	50	10	40	2.03
3	50	40	10	1.947
4	50	20	30	1.945
5	50	30	20	1.948
6	45	10	45	1.927
7	45	45	10	1.973
8	45	20	35	1.984
9	45	35	20	2.002
10	45	30	25	1.935
11	45	25	30	1.971
12	45	40	15	1.951
13	45	15	40	1.968
14	40	60	0	1.845
15	40	0	60	1.909
16	40	30	30	1.87
17	40	20	40	1.872
18	40	40	20	1.85
19	40	45	15	1.919
20	40	15	45	1.962
21	40	10	50	1.873
22	40	50	10	1.785
23	30	70	0	1.761
24	30	0	70	1.809
25	30	35	35	1.774
26	30	40	30	1.803
27	30	30	40	1.806
28	30	45	25	1.748
29	30	25	45	1.786
30	30	20	50	1.898
31	30	50	20	1.848
32	20	40	40	1.846
33	20	30	50	1.79
34	20	50	30	1.817
35	20	20	60	1.873
36	20	60	20	1.84
37	20	65	15	1.768
38	20	15	65	1.842

39	20	70	10	1.81
40	20	10	70	1.864
41	20	35	45	1.844
42	20	45	35	1.877
43	10	80	10	1.721
44	10	10	80	1.751
45	10	45	45	1.722
46	10	40	50	1.733
47	10	50	40	1.739
48	10	60	30	1.734
49	10	30	60	1.745
50	10	20	70	1.748
51	10	70	20	1.708
52	10	35	55	1.756
53	10	55	35	1.726
54	10	25	65	1.739
55	10	65	25	1.733
56	0	50	50	1.709
57	0	40	60	1.693
58	0	60	40	1.677

The optimum packing density will be found out by IS code 2386(Part-III) method. The packing density is to be found out by Dry Loose Bulk Density (DLBD) method. Following is the procedure to find out packing density. For density measurement author had taken saturated and surface dry aggregates.

1. Prepare the batch mix of 7 kg for each trial.
2. By taking each mix proportion, mix the aggregates thoroughly according to the mix proportion.
3. Measure the volume of the cylindrical mould and record the volume "V" in litre. (For density measurement 3 litres DLBD bucket was used)
4. Fill the cylindrical measure to overflowing by means of a shovel or scoop, the aggregate being discharged from a height not exceeding 5 cm above the top of the measure
5. Level the top surface of the aggregate in the cylindrical mould measure, with a straightedge or tamping bar.
6. Determine the weight of the aggregate in the mould and record the weight "W" in kg.
7. Calculate density by using the equation,

Packing Density = W/V

Where,
W = Weight of loose aggregate in cylindrical metal measure, kg
V = Volume of cylindrical metal measure, litre.
After finding out the packing densities of all the mix proportions, tests on aggregates are carried out.

V. TESTS AND MATERIALS USED

Testing on Aggregates

Before doing the mix design, author have conducted some tests on aggregates and sand to know the quality, particle shape and size, absorption and moisture content, specific gravity and silt content, which will further require in mix design. Following tests are carried out on aggregates

- Flakiness Index
- Elongation Index
- Silt Content
- Absorption
- Specific Gravity

(IS Code 2386: Part I & III)

Following are the results of the above test on aggregates-

1. Flakiness Index = 2.04%
2. Elongation Index = 15.5%
3. Silt Content = 6.5%
4. Absorption-

TABLE 2: Absorption of aggregates

Materials	Absorption
Sand	3.39%
10 mm Aggregates	1.44%
20 mm Aggregates	1.12%

5. Specific Gravity-

TABLE 3: Specific Gravity of aggregates

Materials	Specific Gravity
Sand	2.64
10 mm Aggregates	2.76
20 mm Aggregates	2.75

Materials Used

- Cement – Ambuja Powercem (OPC-53)
- Flyash – Ashtech
- Alcofine – Alcofine-1203
- Sand – VSI Type
- Coarse Aggregates – VSI Type
- Admixture – Chryso (Water Reducing Superplasticizer)

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ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

VI. MIX DESIGN (M60 GRADE)

For mix design the top five (higher bulk densities) densities and bottom five (lowest bulk densities) densities (which is marked red for top and yellow for bottom densities) are taken. Now three mix proportion from top five are selected and from bottom the two lower densities are selected (In bottom five densities among all, three mix proportion are with 0% sand so it has been neglected and remaining two are chosen with 10% sand so as to compare it with top densities).

Now after selecting the densities the next step is to design high performance concrete of M60 grade using the mix proportion of aggregate according to their densities.

Mix design steps are carried out and finally got the mix design quantities after applying the absorption correction to the aggregate (that will increase the free water content).

Following are the mix design of M60 grade of the five trials-

TABLE 4: Mix Design of selected trials (M60 grade)

Mix Design (M60 Grade)	**Trial-1**	**Trial-2**	**Trial-3**	**Trial-4**	**Trial-5**
Cement	425 kg	425 kg	425 kg	425 kg	425 kg
Flyash	125 kg	125 kg	125 kg	125 kg	125 kg
Alcofine	25 kg	25 kg	25 kg	25 kg	25 kg
Crushed Sand	770 kg (45%)	770 kg (45%)	866 kg (50%)	173.1 kg (10%)	173.1 kg (10%)
Coarse Aggregate-I	611 kg (35%)	350 kg (20%)	433 kg (25%)	1211.7 kg (70%)	1384.8 kg (80%)
Coarse Aggregate-II	350 kg (20%)	611 kg (35%)	433 kg (25%)	346.2 kg (20%)	173.1 kg (10%)
Water	189.4 kg	189.4 kg	189.4 kg	189.4 kg	189.4 kg
Admixture	2.58 kg (0.45%)	2.875 kg (0.5%)	2.58 kg (0.45%)	2.01 kg (0.35%)	1.73 kg (0.3%)

Note- The admixture dosage was altered to achieve the target flow of 600 to 650 mm and desired workability.

VII. TEST METHOD

Now, after the design mix tests had been performed on fresh concrete and hardened concrete. For the fresh concrete, workability was measured. For that slump test was done for Initial flow, 30 minutes, 60 minutes, 90 minutes, 120 minutes and 150 minutes. The results of slump flow test are as follows-

Workability:

According to IS-1199 (1959) slump test were carried out.

TABLE 5: Slump flow results of Trials

Flow	**Trial-1 (mm)**	**Trial-2 (mm)**	**Trial-3 (mm)**	**Trial-4 (mm)**	**Trial-5 (mm)**
Initial Flow	650	640	645	410	530
30 min	410	440	600	40	170
60 min	310	350	540		
90 min	270	290	470		
120 min	40	110	200		
150 min			170		

Figure-2 shows graph showing the slump flow at Initial, 30 minutes, 60 minutes, 90 minutes, 120 minutes, 150 minutes of respective trials. From the table it can be seen that the slump of Trial-4 and Trial-5 drops down as they both are the worst conditions taken to compare with the other trials. So after 30 minutes the slump of Trial-4 and Trial-5 instantaneously drops down due to lack of presence of fine materials i.e. sand.

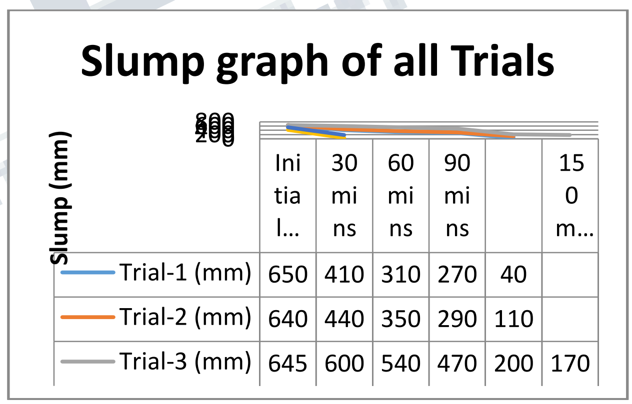

FIGURE 2: Slump graph of Trials

For the Trial-4 and Trial-5, problem arises to achieve the target flow because due to less sand available to form a cohesive concrete. Increase in admixture dosage greater than 0.35% will segregate the concrete. Thus to avoid segregation, limit the admixture dosage upto 0.35% just to achieve the cohesiveness.

Compression Test

As per IS 516 (1959) the concrete are tested for compression in hardened state for 3 days, 7 days and 28

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

days. Following are the compression test results in tabular form-

TABLE 6: Compression test results of Trials

Trials	3 days (MPa)	7 days (MPa)	28 days (MPa)
Trial-1	34.84	46.59	61.73
Trial-2	42.2	46.05	63.77
Trial-3	40.2	44.52	63.35
Trial-4	33.81	52.36	65.58
Trial-5	39.62	50.83	63.54

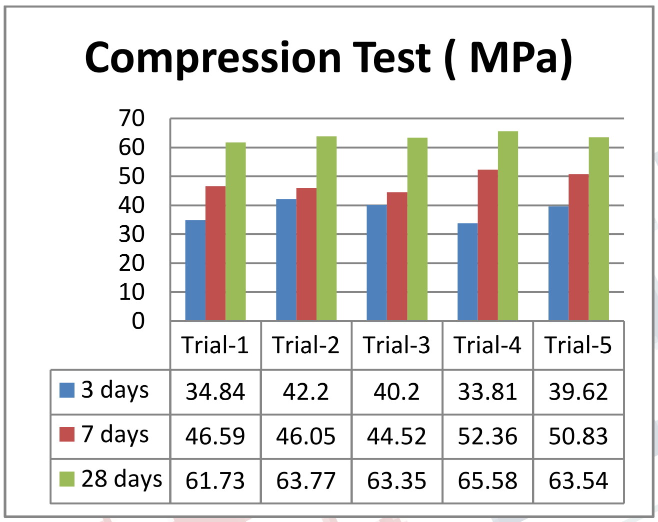

FIGURE 3: Compression test graph of Trials

RCPT (Rapid Chloride Penetration Test)

As per ASTM C1202 "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration", test have been carried out for concrete trials and got the following results for the trials-

TABLE 7: Slump flow results of Trials

Trials	RCPT test results (Coulombs)
Trial-1	2018
Trial-2	1676
Trial-3	1661
Trial-4	2128
Trial-5	2161

Note- This test method does not measure concrete permeability. It measures concrete resistivity. Resistance is calculated as volts divided by current.

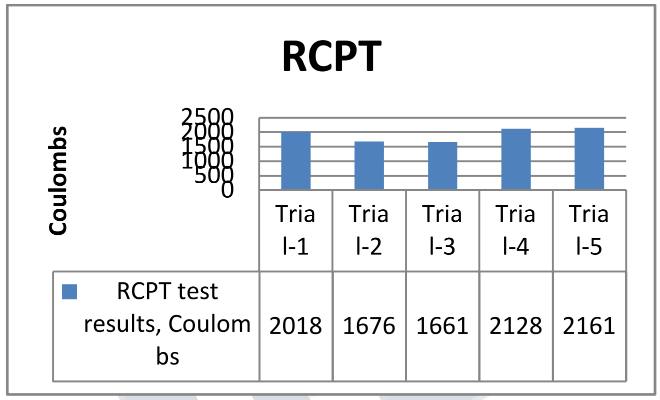

FIGURE 4: RCPT graph of Trials

TABLE 8: RCPT ratings (per ASTM C1202)

Charge Passed (coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

The following is a partial list of factors that can affect the test results:

- Cement factor
- Air content
- Water/Cement ratio
- Curing of the test sample
- Aggregate source or type

Above table shows the rating of RCPT in terms of coulombs. From the figure-4, conclude that Trial-2 and Trial-3 is in to low criteria (less chloride penetration). This is due to the aggregate used in concrete which influence the RCPT rating, and less void available for penetration.

VIII. CONCLUSION

From the results tabulated above it can be concluded that Trial-3 i.e. 50% Sand, 25% 10 mm aggregate, 25% 20mm aggregate was found to be optimum. As per workability concern the Trial-3 was found to be best as it is workable upto 120 minutes as compared to remaining trials. Compression test results at the end of 28 days didn't show much variation in all trials. For Trial-4 and Trial-5 it has shown slight more compressive strength compared to others, because of having more coarse aggregate inside it. As per RCPT Trial-2 and Trial-3 was found to be more resistive than others, but from workability concern we will choose Trial-3. As water permeability concern it can be concluded that the Trial-4 and Trial-5 will show more water permeability than the remaining trials, because of less packing in the concrete (voids are more) thus Trial-4 and Trial-5 will permit more water into the concrete than other trials. From the above results Trial-3 was found more optimum concluding the results of workability, compressive strength and RCPT. Thus sand and fine materials play an important role reducing the voids and improving the strength of concrete by increasing the packing density. As we are using water reducing admixture the percentage of coarse aggregate shall be limited, not more than 35% (single size aggregates) thus to avoid segregation. From the mix design table it can be concluded that as percentage of coarser aggregate was increased, percentage dosage of admixture was decreased. In order to achieve mix of good workability, water was kept constant and admixture was playing factor.

REFERENCES

[1] Henry H.C, Wong, Albert K.H. Kwan, "Packing Density: A Key Concept for Mix Design of High Performance Concrete", Proceedings of the Materials Science and Technology in Engineering Conference, HKIE Materials Division, Hong Kong, pp. (1-15), May 2005.

[2] Leo Gu Li, Albert K.H. Kwan, "Wet packing Method for Blended Aggrergate and Concrete Mix", Civil Engineering and Urban Planning, pp.(827-833), 2012. (ASCE)

[3] Shihui Shen, Huanan, "Characterize packing of aggregate particles for paving materials: Particle size impact", Construction and Building Materials 25, pp.(1362-1368), 2011.

[4] A.K.H. Kwan, P.L. Ng, Huen, "Effects of fines content on packing density of fine aggregate in concrete", Construction and Building Materials 61, pp.(270-277), April 2014.

[5] L.G. Li, A.K.H. Kwan, "Packing density of concrete mix under dry and wet conditions", Powder Technology 253, pp.(514-521), December 2013.

[6] Leo G. Li, Albert K.H. Kwan, "Effects of superplasticizer type on packing density, water film thickness and flowability of cementitious paste", Construction and Building Materials 86, pp.(113-119), April 2015.

[7] Lin Shen, Hamed Bahrami Jovein, Shihui Shen and Mo Li, "Effects of Aggregate Properties and Concrete Rheology on Stability Robustness of Self-Consolidating Concrete", Journal of Materials in Civil Engineering, Vol. 27, No.-5, pp.(1-10), May 2015. (ASCE)

[8] IS: 2386 (Part I)-1963. Methods of test for aggregates for concrete. Bureau of Indian Standards, New Delhi.

[9] IS: 2386 (Part-III)-1963. Methods of test for aggregates for concrete. Bureau of Indian Standards, New Delhi.

[10] IS: 456-2000. Plain and Reinforced Concrete. Bureau of Indian Standards, New Delhi.

[11] IS: 10262-2009. Concrete Mix Proportioning-Guidelines. Bureau of Indian Standards, New Delhi.

[12] IS 9103-1999. Concrete Admixtures- Specification. Bureau of Indian Standards, New Delhi.

[13] IS: 1199-1959. Methods of Sampling and Analysis of Concrete. Bureau of Indian Standards, New Delhi.

[14] IS: 516 – 1959. Methods of tests for Strength of Concrete. Bureau of Indian Standards, New Delhi.

[15] ASTM C1202, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.

