An Experimental Study on Self-compacting Concrete by Packing Density Method

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Abstract In the 21st century concrete had reached a big milestone, invention of self compacting concrete (SCC), compaction of concrete was done by its own weight. SCC is a heterogeneous material; hence some problems are there to obtain the proportion of SCC. Some researchers have developed the design procedures to get the proportions of SCC, however very few studies found in establishment of relationship between water binder ratio (w/b) and compressive strength of concrete. Hence, more research has to be done on relationship between w/b ratio and compressive strength with different combination of materials with help of available mix design. From all the available design methods of SCC, Packing density method will give aggregate proportions appropriately and paste content also determined appropriately. In this study, experimental work was carried on to develop a relationship between the compressive strength of concrete to w/b ratio using Packing density method. In First stage, packing density of aggregate was conducted for mixture of 20mm of aggregate with 10mm aggregate, River sand and Crushed sand individually. After that, packing density was determined for mixture 20mm aggregate, 10mm aggregate and crushed sand. Mix design was carried out based on packing density Method with w/b ratios 0.38, 0.40, 0.42. Fresh Properties of Self-compacting concrete was determined by Slump flow, L-box, V-funnel with different dosage of Super Plasticizer (SP) and compressive Strength was determined. Effect of w/b ratio and S.P dosage on compressive strength was studied through Graphs. Finally a relationship between the w/b ratios to Compressive strength of concrete was developed through linear Regression analysis in MS Excel sheet.

Keywords: Packing density; fresh properties; compressive strength, linear regression

1. Introduction

In concrete industry, Self-compacting concrete (SCC) is one of innovative invention. Self-compacting concrete means which flow without any external vibration and satisfying properties like flow ability, passing ability, filling ability and segregation to resistance. In recent times, the usage of SCC has been increasing rapidly and enhances the construction productivity. The fundamental principle to produce SCC is lower the coarse aggregate content, increase the powder content. However the problems due to heat of hydration will be reduced by incorporation of mineral admixture [1,2]. Apart from all these, SCC is a sustainable concrete [3].

The packing density is the ratio of volume of solids to the total bulk volume. This method is primarily fixing the optimum proportion of aggregates, and then paste quantity was determined to fill
the voids. This method was introduced by the “Feet”, in 1892[4-8]. The void content will plays a crucial role while determining strength of concrete. More voids will leads to less strength & poor quality of concrete. Therefore by good packing of aggregates will decrease the voids and increase the strength [9].

Even though many researchers are making SCC with different design methods, still investigations are going on to develop a correlation among different parameters of concrete for different combination of materials was incorporated. In the 1990’s Okamura and Ozawa have proposed a mix proportioning system for SCC by keeping the coarse aggregate and fine aggregate contents were constant and altering the w/p ratio and super plasticizer dosage. Later, JRMCA was proposed a “Standardized mix design method” of SCC to overcome the omkura’s mix design. In 2001, Nan su proposed and a simple mix design for SCC [10, 11]. However, Particle Packing theory is also one of the most essential concepts, most of researchers focused on design the mix proportions of SCC. In packing density method, quantity of aggregate will increase and cement content will reduce without altering the strength, when compared to conventional method. Mriramachand et al. was suggested Compressible packing model was the best model to optimize the aggregate packing density for SCC[12].

Objectives of research:

- To determine the optimum quantity of Coarse aggregate and fine aggregate by packing density method
- To determine the dosage of super plasticizer for Self-compacting concrete with (water/binder) w/b ratios 0.38, 0.40 and 0.42
- To determine the compressive strength of SCC for w/b ratios 0.38, 0.40 and 0.42
- To determine the quality of concrete for w/b ratios 0.38, 0.40 and 0.42 by UPV
- To develop a relationship between the w/b ratios verses compressive strength of concrete

2. Materials Used

In this study, Ordinary Portland cement, river sand, crushed sand, 20mm down aggregate, 10mm down aggregate, super plasticizer Adva 960 was utilized and their physical properties are given in Table 1 and 2.

| Property of cement       | Test result |
|-------------------------|-------------|
| Normal Consistency      | 32          |
| Fineness                | 6           |
| Initial Setting time    | 45 min      |
| Final setting time      | 600 min     |
| Compressive Strength @ 28-days | 53 MPa    |
| Specific Gravity        | 3.12        |

| Aggregate type          | Fineness modulus | Specific Gravity |
|-------------------------|------------------|------------------|
| River Sand              | 2.67             | 2.45             |
| Crushed Sand            | 2.54             | 2.60             |
| 20 mm down aggregate    | 7.5              | 2.8              |
| 10 mm down aggregate    | 2.66             | 5.6              |

- Super Plasticizer: A PCE based Super plasticizer was used for SCC and its Specific Gravity 1.108.
- Ground granulated Blast Furnace Slag (GGBS): GGBS was taken from JSW Cements pvt.ltd and Specific gravity was 2.8
- No Viscosity Modifier admixtures (VMA) were used in the SCC preparation.

3. Methodology

In the present research work, the influence of w/b ratio on properties of self-compacting concrete at different admixture dosage by using Packing Density Method. In the First Phase, Packing density of aggregate was determined by blending of 20mm coarse aggregate with 10mm coarse aggregate alone, with river sand alone and with crushed sand alone in different proportions. Based on results of above mentioned combinations, further, packing density was determined with the blend of 20mm coarse aggregate, 10mm coarse aggregate and crushed sand. Graphs were drawn between packing density verses percentage of fraction blended and optimum proportions of aggregate were determined. In Second Phase, Mix compositions were carried out by using packing density method. In binder content, 70% of OPC and 30% of GGBS were taken. Three w/b ratios (0.38, 0.40, and 0.42) are taken. All the mix compositions of SCC are given Table 3. The fresh properties of SCC were determined at 0.5%, 0.55%, 0.60% dosage of super plasticizer for 3 w/b ratios by Slump-flow test, V-funnel test, L-box test, J-ring test. The test results were verified with the European Federation for Specialist Construction Chemicals and Concrete Systems guidelines (EFNARC Guidelines). For each w/b ratio, at all S.P dosages, where SCC was achieved considered as the Optimum dosage of SCC for that w/b. Concrete cube specimens (150mmx150mmx150mm) were prepared and compressive strength was measured for 3-days, 7-days, 28-days as per IS 14858:2000 in Compression Testing Machine. The Ultra sonic pulse velocity test was also performed to assess the Quality of concrete IS: 13311 (Part-II):1992. Further, Correlation study was done between w/b ratio and compressive strength of concrete by linear regression analysis. The w/b ratio values and compressive strength values were inserted in MS Excel sheets and graph was drawn. From regression analysis, one relationship between w/b ratio and compressive strength of concrete was achieved.

4. Results and Discussion

4.1 Packing Density test:

The packing density of aggregate mixture is defined as the solid volume in a unit total volume. Packing density was calculated based on Narasimha raj et.al [4].

\[
\text{Packing density} = \frac{\text{Bulk density} \times \text{weight of fraction}}{\text{Specific Gravity}}
\]

Table 3 gives all the details of packing density of aggregates and Figure 1 shows a graphical representation of Packing Density of aggregates. Table 4 gives details of packing density of mixed aggregates (20mm aggregate sample, 10mm aggregate sample and crushed sand) and in Figure 2 graphical representation is shown.

| % fraction | 10mm mm aggregate (Kg/m³) | river sand (Kg/m³) | crushed sand (Kg/m³) |
|------------|--------------------------|-------------------|---------------------|
| 0          | 523.7                    | 514.6             | 364.9               |
| 10         | 562.0                    | 634.8             | 384.5               |
| 20         | 569.7                    | 675.7             | 430.8               |
| 30         | 576.8                    | 675.5             | 435.6               |
| 40         | 584.0                    | 690.4             | 452.3               |
| 50         | 597.3                    | 698.2             | 470.0               |
| 60         | 582.7                    | 681.1             | 462.9               |
From bulk density test of 20 mm and 10 mm aggregate, maximum bulk density, minimum void content and optimum packing density was obtained at 50:50 proportions. From bulk density test of 20 mm and river sand, maximum bulk density, minimum void content and optimum packing density was obtained at 50:50 proportions. From bulk density test 20 mm aggregate and crushed sand, maximum bulk density, minimum void content and optimum packing density was obtained at 50:50 proportions.

Table 4: Bulk density and packing density of mixed aggregates

| S. No | proportion of 20 mm aggregate | proportion of 10 mm aggregate | proportion of crushed sand | Weight of both 20 mm + 10 mm and Crushed Sand | Bulk Density | Packing Density | void content |
|-------|-------------------------------|-------------------------------|----------------------------|-----------------------------------------------|--------------|----------------|-------------|
| 1     | 45                            | 45                            | 10                         | 35.52                                         | 1745.33      | 628.31         | 371.69      |
| 2     | 40                            | 40                            | 20                         | 37.03                                         | 1846.00      | 669.60         | 330.40      |
| 3     | 35                            | 35                            | 30                         | 37.58                                         | 1882.67      | 688.05         | 311.95      |
| 4     | 30                            | 30                            | 40                         | 37.62                                         | 1885.33      | 694.18         | 305.82      |
| 5     | 25                            | 25                            | 50                         | 37.47                                         | 1875.33      | 695.63         | 304.37      |
| 6     | 20                            | 20                            | 60                         | 37.4                                         | 1870.67      | 699.02         | 300.98      |
| 7     | 15                            | 15                            | 70                         | 36.47                                         | 1808.67      | 680.80         | 319.20      |
| 8     | 10                            | 10                            | 80                         | 36.01                                         | 1778.00      | 674.12         | 325.88      |
| 9     | 5                             | 5                             | 90                         | 35.6                                          | 1750.67      | 668.54         | 331.46      |
4.2 Trail Mixes composition details
All trail mixes were designed by packing density method by considering w/b ratios 0.38, 0.40, 0.42 at super plasticizer dosage (S.P) of 0.5%, 0.55%, and 0.6%. Details of all trail mixes composition is given in Table 5.

Table 5: Details of trail mixes composition

| Mix No | Cement (Kg/m³) | GGBS (Kg/m³) | F.A (Kg/m³) | C.A (20mm) (Kg/m³) | C.A (10mm) (Kg/m³) | Water (Kg/m³) | S.P dosage content |
|--------|----------------|---------------|-------------|--------------------|--------------------|---------------|-------------------|
| TM1    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 190           | 0.5%              |
| TM2    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 190           | 0.5%              |
| TM3    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 190           | 0.6%              |
| TM4    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 200           | 0.5%              |
| TM5    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 200           | 0.6%              |
| TM6    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 200           | 0.6%              |
| TM7    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 210           | 0.5%              |
| TM8    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 210           | 0.55%             |
| TM9    | 350            | 150           | 1030.74     | 343.58             | 343.58             | 210           | 0.6%              |

4.3 Fresh Properties of Self-compacting Concrete:
The fresh properties of SCC were conducted and verified as per European Federation for Specialist Construction Chemicals and Concrete Systems guidelines. In order to assess the fresh properties of SCC, the slump flow test, L-box test, J-ring test and V-funnel test was conducted. The test results data is shown in Table 6. TM1 -TM3 were prepared with w/b=0.38, TM4-TM6 were made with w/b=0.40 and TM7-TM9 were made with w/b=0.38.

Table 6: Fresh concrete properties test results of all mixes

| Mix no | w/b ratio | SP dosage content | Slump flow (mm) | V funnel (sec) | L box | J ring (mm) |
|--------|-----------|-------------------|-----------------|---------------|-------|-------------|
| Range  |           |                   | 650mm -800mm    | 8-12sec       | 0.8-1 | 0-10        |
| TM1    | 0.5%      |                   | 500             | 28            | 0.5   | 5           |
| TM2    | 0.38      | 0.55%             | 550             | 13            | 0.4   | 3           |
| TM3    | 0.6%      | 0.6%              | 660             | 12            | 0.8   | 1           |
| TM4    | 0.40      | 0.5%              | 600             | 46            | 2     | 1.5         |
| TM5    | 0.55%     | 0.5%              | 680             | 18            | 1     | 1           |
From the Fresh Properties test on Self-compacting concrete, for all three w/b ratios, the SCC properties are satisfied at S.P dosage 0.6%. However, at S.P dosage 0.55% was also given satisfactory results for w/b ratio=0.40 and w/b ratio=0.42. This is due to slightly higher water than w/b ratio = 0.38. The slump flow, V-funnel, L-box, J-ring values was increasing with w/b ratio. All mixes were given a satisfactory results in J-ring test. With 0.5% of S.P dosage, for all 3 w/b ratio mixes shown unsatisfactory results. With 0.55% of S.P dosage, only w/b ratio=0.38 mix shown unsatisfactory values in L-box and V-funnel test. As the water content increases, the SCC was formed at lesser S.P dosage. It is observed that, less than the 0.5% of S.P dosage flow characteristics was not form and more than 0.6% of S.P dosage leads to bleeding and segregation. Hence the optimum dosage of S.P to obtain SCC was taken at 0.6%.

4.4 Compressive Strength test

The Compressive Strength test results of 3-days, 7-days and 28-days was shown in Table 7. The strength variations of all 3 w/b ratios were shown separately. Figure 3, Figure 4 and Figure 5 will give the compressive strength details of w/b ratio =0.38, 0.40 and 0.42 for all S.P dosage.

| w/b ratio | S.P dosage | 3 days (MPa) | 7 days (MPa) | 28 days (MPa) |
|-----------|------------|--------------|--------------|---------------|
| 0.38      | 0.5%       | 18.62        | 44.815       | 56.45         |
|           | 0.55%      | 24.5         | 37.00        | 61.6          |
|           | 0.6%       | 24.4         | 45.38        | 74.03         |
|           | 0.5%       | 21.50        | 51.46        | 65.16         |
| 0.40      | 0.55%      | 22.9         | 52.91        | 69.40         |
|           | 0.6%       | 23.1         | 49.45        | 70.00         |
|           | 0.5%       | 20.4         | 41.24        | 64.74         |
| 0.42      | 0.55%      | 19.95        | 36.8         | 60.48         |
|           | 0.6%       | 21.74        | 41.95        | 65.9          |

Figure 3: Compressive Strength of concrete graph of w/b = 0.42
From the Figure 3, the strength values of w/b=0.38 were increased as increasing S.P dosage. For 3-
days strength was achieved in the range of 18 MPa to 24 MPa, for 7-days strength was achieved in the
range of 32.2 MPa to 45.38 M Pa and for 28 days strength was achieved in range of 56 MPa to 74
MPa. The increasing in percentage of strength of 28-days with 0.6% of S.P dosage was up to 23.7%.

![Figure 4: Compressive Strength of concrete graph of w/b = 0.40](image1)

From the Figure 4, the strength values of w/b=0.40 were increased marginally. For 3-days strength
was achieved in the range of 22 M Pa to 23 MPa, for 7-days strength was achieved in the range of 49-
50 MPa and for 28 days strength was achieved in range of 66 MPa to 70 MPa. The increasing in
percentage of strength of 28-days with 0.6% of S.P dosage was up to 7.42%.

![Figure 5: Compressive Strength of concrete graph of w/b = 0.42](image2)

From the Figure 5, the strength values of w/b=0.42 increased marginally. For 3-days strength
was achieved in the range of 19 M Pa to 21 M Pa, for 7-days strength was achieved in the range of 36-42
MPa and for 28 days strength was achieved in range of 62 M pa to 66 M pa. The increasing in
percentage of strength of 28-days with 0.6% of S.P dosage was up to 9%.

The increasing percentage of strength of 28-days with 0.6% of S.P dosage of w/b =0.38 is much
higher than the w/b ratio=0.40, 0.42. For w/b ratio = 0.38, at lesser S.P dosages, doesn’t exhibit the
SCC characteristics, hence internal compaction was not done properly. Consequently, reduction in
strength was high. For w/b ratio = 0.40 and 0.42, even at lesser S.P dosages, the flow characteristics were not met required value, still mix shown good characteristics up to some degree. Therefore, the increasing in percentage of strength of 28-days was less. For all w/b ratios, high strength concrete was achieved this is due to high binder (500 Kg/m$^3$) content.

4.5 Ultra sonic Pulse Velocity Test:

Table 8: Ultra Sonic Pulse Velocity of SCC

| Trail mix no w/b ratio | 3 days (km/s) | 7 days (km/s) | 28 days (km/s) |
|------------------------|--------------|--------------|---------------|
| TM1 0.38              | 4.132        | 4.273        | 4.232         |
| TM2 0.38              | 4.35         | 4.208        | 4.049         |
| TM3 0.38              | 4.308        | 4.518        | 4.686         |
| TM4 0.40              | 4.549        | 4.658        | 4.532         |
| TM5 0.40              | 4.43         | 4.587        | 4.587         |
| TM6 0.42              | 4.747        | 4.744        | 4.759         |
| TM7 0.42              | 4.532        | 4.87         | 4.823         |
| TM8 0.42              | 4.521        | 4.658        | 4.505         |
| TM9 0.42              | 4.565        | 4.808        | 4.886         |

![Ultra Sonic Pulse Velocity test](image)

Figure 6: Ultra Sonic Pulse Velocity of Concrete test results

The Table 7 gives the details of Ultra sonic Pulse Velocity (UPV) test for all mixes of 3-days, 7-days, and 28-days. Figure 8 gives bar chat representation of UPV test results of all mixes. From the ultra sonic pulse velocity test results, the pulse velocity of mixes with w/b ratio = 0.38, for 3-days, 7-days, 28-days, it reaches from 4.1 km/s to 4.6 km/s. It is observed that, the samples which satisfy the SCC characteristics were shown good quality of concrete others shown less quality because of not forming Self-compact concrete. Only with S.P dosage 0.6% is given excellent quality of concrete. With w/b ratio = 0.40, all mixes shown above pulse velocity above 4.5 km/s. With w/b ratio = 0.42, all mixes shown above pulse velocity above 4.5 km/s. The quality of concrete samples of w/b ratio= 0.38 was shown less, because of less water content and internal compaction errors.
4.6 Correlation between w/b ratios versus compressive strength of Concrete:

In this correlation Study of w/b ratio versus compressive strength of concrete was developed for the mixes which weresatisfied the fresh properties of SCC, were taken into consideration. In Table 9, w/b ratio and corresponding strength values are shown. In Figure 7, a graph was drawn between w/b ratios and compressive strengths in MS-Excel sheets. By performing regression analysis a relationship was developed.

Table 9: w/b ratios and Compressive strength

| w/b ratio | Compressive strength (MPa) |
|-----------|---------------------------|
| 0.38      | 74                        |
| 0.4       | 70                        |
| 0.42      | 65                        |

From Figure 7, the relation betweenw/b ratio and compressive strength was linear and equation is \( y = -225x + 159.6 \). Muhammad Wihardi Tjaronge et.al were also developed an equation between w/c versus Compressive strength, \( y = -200x + 135.6 \) [14]. Both equations and graphs are having similar profile.

5. Conclusions

1. From the Packing Density method, the final proportion of aggregates arrived with mixture of 20mm aggregate, 10 mm aggregate and crushed sand is 20:20:60 receptively.
2. From experimental investigation, as the w/b ratio increases the flow characteristics was increased and among all w/b ratios, the optimum dosage of S.P was found at 0.6% of weight of cement.
3. From compression test results, it is observed that, mixes of three w/b ratios achieved high strength concrete and as the w/b ratio increases the compressive strength was decreased.
4. For all three w/b ratios, the excellent quality of concrete was shown at 0.6% of S.P dosage.

5. The equation $y = -203.2x + 151.2$ can be used to determine the compressive strength, for 500 kg/m$^3$ binder content with 30% of GGBS replacement and with 60:40 Fine aggregate to Coarse aggregate.

6. The research work can be useful in general construction of building where High strength SCC is required.

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