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A STUDY ON THE INFLUENCE OF GRADE OF CONCRETE ON BOND STRENGTH OF SELF COMPACTING CONCRETE

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Abstract: ***Decrease in the porosity of concrete enhances the performance in fresh and hardened states. This method works more easily in case of Self Compacting Concrete (SCC) which basically utilizes more fines than normal concrete. The question now arises how to effectively modify this pore structure. The answer to this can be a right combination of the different sizes of the granular skeleton (aggregate) to optimize in such a way to yield concrete with good strength and durability. The increased use of finer material in SCC mixes by increasing the use of various mineral admixtures or more finer aggregates itself as a replacement for coarse aggregate or as addition is being followed. One way of arriving the optimum sizes and proportions of coarse/fine aggregate for preparing a dense concrete is the Compressible Packing Model (CPM) concept. So far Nansu method of mix design is popular, but there are certain limitations in this method. Investigations for establishing a rational mix-design method and self-compactability testing methods have been carried out from the viewpoint of making self-compacting concrete a standard concrete.***

In the present work three grades M20, M40 and M60 SCC mixes were developed using Compressible Packing Model concept to arrive at the proportions of aggregate. To qualify the Self-Compacting Concrete mixes thus developed, Slump flow, J-Ring, V-funnel, L-flow tests were conducted and the fresh properties obtained are checked against the specifications given in EFNARC Specifications. Compressive strength tests were conducted to know the strength properties of the mixes. From that mix proportions fifty four pullout tests were carried out in order to investigate the bond behavior between SCC and steel bars with M20, M40, and M60 grade of concrete with and without steel fibers. A steel bar of diameter 16mm, with three embedded lengths i.e., 100mm, 150mm and 300mm were considered as parameters in this work. Pullout tests were carried out on the casted cylindrical specimens to determine bond strengths. The tests results were analyzed from a statistical point of view, evaluating the variability of the response. The results shows that bond stress was increased with an increased grade of self compacting concrete and also bond stress was increased by the addition of steel fibers for all grades of SCC and corresponding slip decreases for same diameter of bar with constant embedment length.

Keywords: Reinforcing bars, cement, aggregates, and water, chemical admixturs, mineral admixtures

I. INTRODUCTION

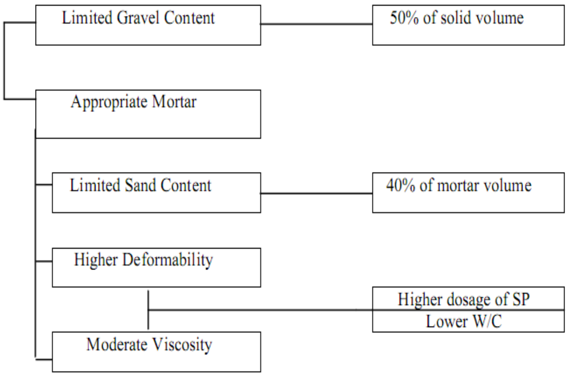
Self compacting concrete (SCC) represents one of the most significant advances in concrete technology for decades. In recent years, self-compacting concrete (SCC) has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness. Self compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self-weight with little or no vibration effort, and which is at the same time, cohesive enough to be handled without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of heavily reinforced structural members. Development of self-compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. Self compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances. The concept of self-compacting concrete was proposed in 1986 by Professor Hajime Okamura [1], but the prototype was first developed in 1988 in Japan, by Professor Ozawa [2] at the University of Tokyo. Self-compacting concrete was developed at that time to improve the durability of concrete structures. Since then, various investigations have been carried out and SCC has been used in practical structures in Japan, mainly by large construction companies. Investigations for establishing a rational mix-design method and Self Compactability testing methods have been carried out from the viewpoint of making it a standard concrete. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the compaction. With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions. Usually, these concretes have higher workability, superior mechanical properties and greater resistance to chemical attack as compared to traditional concrete.

Mechanism for achieving SCC

The method for achieving self-compacting concrete involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when concrete flows through the confined zones of reinforcing bars. Okamura [1] and Ozawa [2] have employed the following methods to achieve self-compactability (Fig. 1.1 & 1.2)

(1) Limited aggregate content.
(2) Low water-powder ratio
(3) Use of super plasticizer

The frequency of collision and contact between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. Research has found that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal is effective in avoiding this kind of blockage.. Theoretical analysis of seepage is done using the concept of flownet. Theoretical and practical results are compared. Highly Viscous paste is also required to avoid the blockage of coarse aggregate when concrete flows through obstacles. When concrete is deformed, the paste with a high viscosity also prevents localized increase in internal stress due to the approach of coarse aggregate particles. High deformability can be achieved only by the employment of a super plasticizer, keeping the water-powder ratio to a very low value.Fig.1.2 Mechanism for achieving self-compactability since the development of the prototype of self-compacting concrete in 1988, the use of self compacting concrete in actual structures has gradually increased. The main reasons for the employment of self-compacting concrete can be:



II. LITERATURE REVIEW

Numerous mix proportioning methods have been proposed for SCC. This chapter summarizes some mixture proportioning methods described in the literature. The methods vary widely in overall approach, in the range of materials and performance characteristics considered, and in the level of complexity. SCC mixture proportions depend, in large part, on the application. Requirements for hardened properties, filling ability, segregation resistance, and especially passing ability may vary widely by application. These factors must be considered prior to starting the mixture proportioning process. All mixture proportioning methods must ensure adequate yield stress and plastic viscosity of the concrete. According to Yahia et al. (1999), a low yield stress is important for filling ability while high mortar plastic viscosity is needed for placement in highly congested sections and for mixtures with high coarse aggregate contents. High deformability can be achieved by limiting the coarse aggregate volume while segregation resistance can be achieved by controlling the mortar theology through reducing the w/cm, increasing the powder content, or adding VMA. S. VenkateswaraRao, M.V. SeshagiriRao, P. Rathish Kumar [19] developed standard and high strength Self Compacting Concrete (SCC) with different sizes of aggregate based on Nansu’s mix design procedure. The results indicated that Self Compacting Concrete can be developed with all sizes of graded aggregate satisfying the SCC characteristics. The mechanical properties viz., compressive strength, flexural strength and split tensile strengths were studied at the end of 3, 7 and 28 days for standard and high strength SCC with different sizes of aggregate. It was noted that with 10mm size aggregate and 52% flyash in total powder the mechanical properties were superior in standard SCC, while 16 mm size aggregate with a 31% flyash in total powder improved the properties of high strength SCC. Dr. R. Sri Ravindrarajah, F. Farrokhzadi and A. Lahoud In their research discussed about Flowing concrete (FC) and Self-Compacting concrete (SCC). However, it was emphasized that flowing concrete need not to have the self-compacting capability. FC can also produced by having excess amount of water in the mix without any superplasticiser. Such a mix is prone to high bleeding and segregation. This paper discusses the results of an experimental investigation into the properties of flowing concrete and self-compacting concrete mixes having varying dosage of high-performance super plasticer. The properties investigated are workability, bleeding capacity, segregation potential, compressive and tensile strengths, and drying shrinkage. Flowing concrete had 465 kg/m3 of cement whereas the self- compacting concrete consisted of 350 and 135 kg/m3 of cement and fly ash, respectively. The workability was assessed using slump flow and box-differential height tests. The bleeding capacity for the flowing concrete was higher than that for the self-compacting concrete. The strength of both concrete types was found to increase when vibration was employed at the time of moulding of test specimens and the effect of vibration in strength was significant at later ages. Drying shrinkage was influenced by the mix compositions and super plasticiser dosage. Andr´eLecomte [2] analyses the measurements of packing densities realized for grains of different nature and size. The measurements were obtained using several methods. The aim is to propose a method for “soft “grains that suffer abrasion when packed in a cylindrical container and subjected less than 10 kPa compression to vibration, which is the conventional approach. Less demanding methods are proposed that involve horizontal, vertical or combined accelerations without additional stress. The packing index does not suffice, however, as in the standard test to characterize these approaches. The results are in most cases governed by the size of the grains and the diameter of the container. Models were then calibrated and validated to calculate, from experimental parameters, the packing index that must be associated to every measure. Miao Liu [3]discussed the use of higher volume fly ash and ground glass in SCC, thus widening the types of additions available for SCC, saving landfill and reduces CO2 emissions by the use of less cement. The results show that for constant filling ability of the SCC, replacement of cement with fly ash or ground glass requires an increase in water/powder ratio and a reduction in super plasticiser dosage. Both additions degraded the passing ability, consistence retention and hardened properties but not to a prohibitive extent. SCC with up 80% cement replaced by fly ash or glass volume ratio of 6.4% is possible and the material properties of SCC are similar to those of vibrated concrete. Also the UCL method of mix design was extended to higher coarse aggregate contents and different additions. Martin hunger [11] the work covers a very broad field, actually different but none the less closely related topics, which are all connected by the idea of an improved sustainability of the construction material concrete; the far most abundantly produced man-made material. The initial focus on the new development of a mix design concept for SCC quickly created a self-perpetuating dynamic. In this way a profound analysis of some concrete technology related issues could be connected to the solution of practical problems. During the course of the development of the new mix design, a packing based approach, it turned out that the developed new concrete types showed a number of benefits, such as improved density, more efficient use of the cementitious materials, and an optimized way of using available (local) raw materials. These observations called for a more thorough study of the applicability of alternative aggregates, such as mineral waste materials from the natural stone processing industry. Since the greatest share of these industrial wastes are powder or slurry, the focus was on the application of mineral waste powders in concrete. In order to assess the advantage of these mixes compared to commonly designed SCCs, the introduction of suitable life-cycle analysis tools was necessary.

Introduction of Experimental study

The experimental program was designed to study the comparison of bond behavior and bond strengths of M20, M40, and M60 grade of SCC with and without steel fibers. The program consisted of casting and testing a total number of 54 cylinders of size 150mm diameter and 300mm height with 16 mm Φ Tor steel bars and 9 cubes of 150x150x150 mm size, were casted in 3 batches. Of these 54 cylinders 18 cylinders for M20, and 18 cylinders for M40 grade of self compacting specimens and 18 cylinders of M60 grade of self compacting specimens, and their corresponding 9 cubes for compressive strength . The specimens were cast with the steel rebar in perfect vertical position with help of fasteners at the top end of mould in order to avoid secondary stresses in the bar. The steel bars were rust free and perfectly straight. For each concrete batch, the cube compressive strength was determined on three 150 x 150 x150 mm3 Cubes. The mix proportion for M20, M40, and M60 grade of Self compacting concrete was designed by using CPM model. The fly ash was incorporated in the above mix proportion by replacing 39.58% for M20, 26.82% for M40 and 19.38% for M60 respectively. This optimum content of fly ash was obtained by casting trail mixes and from previous studies. Water reducing admixtures are added into mixes on requirement, till the desired fresh properties are exhibited by them. The details of the specimen's cast are shown in Table Figures and tables:

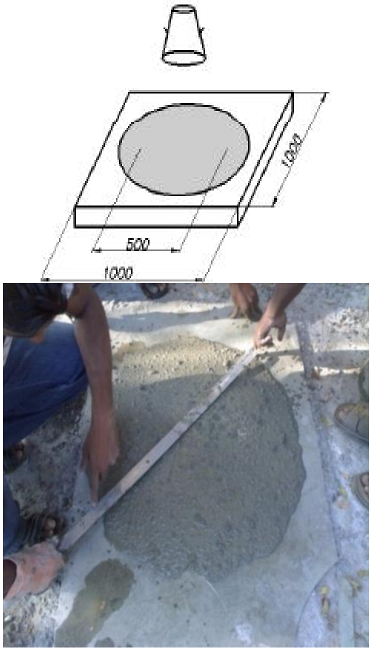


Fig.1.Abrams Slump flow Equipment

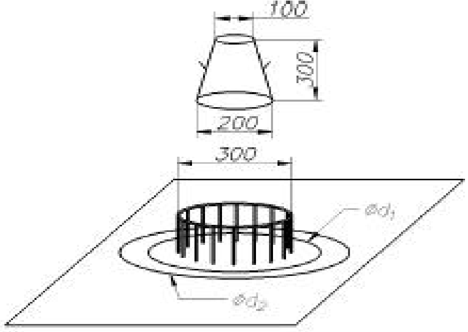


Fig.2. J-Ring equipment

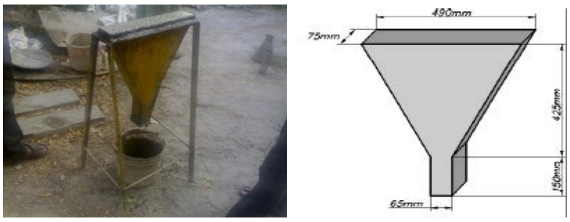


Fig.3. V-Funnel equipment

III. MIX DESIGN

To produce SCC, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. As a part of mix design aggregate proportions are calculated using compressible packing model. Cement quantity and fly ash content are obtained from previous literature and these are modified according to EFNARC specifications to get fresh, hardened properties and economical mixes.

STEP 1: Calculation of Coarse aggregate and Fine aggregate

The packing factor (PF) of aggregate is defined as the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. Clearly, PF affects the content of aggregates in SCC. A higher PF value would imply a greater amount of coarse and fine aggregates used, thus, decreasing the content of binders in SCC. Consequently, its flow ability, self-compacting ability and compressive strength will be reduced. On the other hand, a low PF value would mean increased dry shrinkage of concrete. As a result, more binders are required, thus, raising the cost of materials. In addition, excess binders used would also affect the workability and durability of SCC. Therefore, it is important to select the optimal PF value in the mix design method so as to meet the requirements for SCC properties, and at the same time taking economic feasibility into consideration. The content of fine and coarse aggregates can be calculated as follows.

$$W_g = PF * W_{gl} * (1 - \frac{s}{a})$$

$$W_s = PF * W_{sl} * (\frac{s}{a})$$

Where,

W_g= Content of coarse aggregates in SCC (kg/m^3);
W_s= Content of fine aggregates in SCC (kg/m^3);
W_{gl}=Unit volume mass of loosely piled saturated surface-dry coarse aggregate in air (kg/m^3);
W_{sl}=Unit volume mass of loosely piled saturated surface-dry fine aggregates in air (kg/m^3);
PF = Packing factor;
(s/a) = volume ratio of fine aggregates to total aggregates

Obtaining aggregate proportion using CPM

In practice, the measurement of φ (REAL PACKING DENSITY), is done by pouring a dry sample of mass Ms in a cylinder of cross section *S* and height h. The corresponding packing index is $K = 4.1$

The calculation of φ is as follows:

Total volume *V* of the packing:

$$V = S * h$$

Real volume *v* of the aggregate:

$$v = \frac{Ms}{BRD}$$

(BRD = Bulk Relative Density)

$$\Phi = \frac{v}{V} = \frac{Ms}{S * h * BRD}$$

The virtual packing density of a single component mixture is denoted β_i

$$\beta_m = (1 + \frac{1}{K})\varphi$$

K = compaction index which depends on method of compaction
= 4.1 for pouring

Container wall effect

The above measured packing density β_m is a confined packing density, since it is altered by the wall effect, called q, induced by the walls of the cylinder.

In the case of a mono-sized aggregate of size *d*, the virtual density β_m, must be corrected to obtain the non-confined virtual packing density, according to the relation:

$\beta_i = q\beta_m$

$$q = \frac{1}{1 - (1 - K_w)(1 - \frac{d_i}{d_c})^2 (1 - \frac{d_i}{h})}$$

Where,

K_w is a coefficient linked with the form of the grains, equal to 0.88 for rounded grains and 0.73 for crushed grains.

d_i = diameter of the aggregate
d_c = diameter of the cylindrical container
h = height of the container

Loosening Effect

The loosening effect describes an effect whereby the introduction of small particles forces apart larger particles. The theoretical basis for this was a curve fit of an analysis of several researchers data over the course of more than 50 years.

$$\boldsymbol{a_{ij} = (1 - \left(1 - \frac{d_j}{d_i}\right)^{1.02})^{0.5}}$$

Where,

The value d_i represents is the average particle diameter.
$d_i = (d_{max}.d_{min})^{0.5}$
d_{max} = diameter of the largest particle in the group.
d_{min} = diameter of the smallest particle in the group.

Wall effect due to particles

The wall effect describes an effect whereby larger particles cause interstitials in the mixture which are too small to be filled by other particle classes. The theoretical basis for this was a curve fit of an analysis of several researchers' data over the course of more than 50 years.

$$b_{ij} = 1 - (1 - \frac{d_i}{d_j})^{1.50}$$

Virtual Packing Density

The overall virtual packing density Υ_i for a mixture of any number of particle size classes with independent beta values is defined by the following equation where the value y_i represents the volume fraction of the 'i'th size class when each of the i size classes to be mixed are measured in beakers before combination.

$$\Upsilon_i = \frac{\boldsymbol{\beta_i}}{\boldsymbol{1 - \sum_{j=1}^{i-1}\left(1 - \beta_i + b_{ij}\left(1 - \frac{1}{\beta_j}\right)\right) y_j - \sum_{j=i+1}^{n}\left(1 - \frac{a_{ij}\beta_i}{\beta_j}\right) y_j}\ ]}$$

In the table shown in the appendix show the proportions with the least virtual packing density. We chose these proportions for calculating the packing factor and there by coarse aggregate and fine aggregate. The proportion corresponding to least virtual packing density is taken for determining the packing factor. Corresponding packing factors and the mix proportions are shown in the following table 3.6 and calculations are shown in the appendix.

STEP 2: Calculation of powder Content

To secure good flow ability and segregation resistance, the content of binders (powder) should not be too low. However, too much cement used will increase the drying shrinkage of SCC. EFNARC has given guidelines for calculating powder content and from the previous studies. We fixed the cement content and fly ash content is decided by minimum powder content according to EFNARC specification (the total powder content to be maintained in SCC is 450-600 kg/m3 as per EFFNARC Specifications.)

STEP 3: Determining the mixing water content

Although factors such as content of fine and coarse aggregates, material proportions, and curing age can affect the compressive strength of SCC, the ratio of water to binders by weight (w/b) is the most prominent determinant of compressive. Water content is obtained through trial mixes.

STEP 4: Determining SP dosage.

Adding an adequate dosage of SP can improve the flow ability, self-compacting ability and segregation resistance of fresh SCC for meeting the design requirements. Optimum dosage of Conplast SP430 should be determined with trial mixes. As per the manufactures, a dosage range of 0.5 - 2.0 litres per 100 kg of mixes cementitious material is normally recommended.

STEP 5: Trial mixes and tests on SCC

Trial mixes can be carried out using the contents of materials calculated as above. Then, quality control tests for SCC should be performed to ensure that fresh and strength properties described in the chapter are satisfied.

In the event that satisfactory performance cannot be obtained, then adjustments should be made until all properties of SCC are satisfied. For example, when the fresh SCC shows poor flowability, the PF value is reduced to increase the binder volume and to improve the workability. Depending on the apparent problem, the following courses of action might be appropriate:

1) Using additional filler.
2) Modifying the proportions of the sand or the coarse aggregate.
3) Using a viscosity modifying agent, if not already included in the mix.
4) Adjusting the dosage of the superplasticizer and/or the viscosity modifying agent.
5) Adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

Sample calculation of the proposed method is given in APPENDIX.

IV. RESULTS & DISCUSSIONS

Compressive Strength:

The cube specimens were tested on compression testing machine of capacity 3000 KN .The bearing surface of the machine was wiped off clean and any loose other sand or other material removed from the surface of the specimen .The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cubes as casted that is, not top and bottom. The axis of the specimen was carefully aligned at the center of the loading frame. The load applied was increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The maximum load applied on the specimen was recorded. The details of a cube specimen under test is shown in Fig 3.7

Fig.1. Details of cube testing under TOTM

Bond Strength:

The cylindrical specimens cast were arranged in the universal tensile test machine (UTM) of 100 tonne capacity. The initial arrival at amount of bond length to be used in the specimens for each grade has been calculated using the following formula as per IS: 456.

$L_d = \Phi$ x fst/4 τbd

Where Φ = nominal diameter of the bar.

fst= allowable tensile stress in the steel bar .

τbd = Design bond stress .

The values of Design bond stress have been taken from IS: 456 for each corresponding grade of concrete mix. And the allowable tensile stress value has been taken as the 60% of average designated yield stress of the bar.

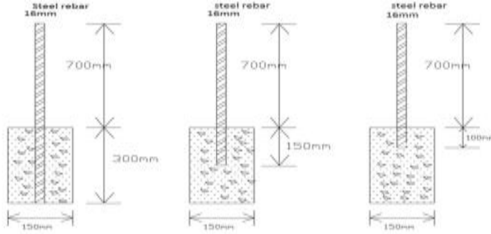


Figure.2. Details of bar profile and embedded length into the specimen

The arrangement of the test setup has been shown in fig 3.9. An idea of load transfer mechanism has been given in the fig 3.10.The cylinder with rebar in its vertical position has been inserted carefully through the gap with grips loosened in the bottom adjustable platen. And the inserted bar was tightened at the top grips to hold the specimen firmly. A 20 mm thick iron plate with 20 mm wide slit was arranged over the specimen to avoid it from penetrating into the large opening provided above it for accommodating grips as the pullout load increases in the lower adjustable platen .The adjustable platen was lift up and down to set the specimen exactly in position for testing . An extensometer meter with gauge length of 50mm and 0.002 mm precision was arranged at the middle of the rod in the open portion to measure the elongation of the bar with load. A dial gauge with 0.01 mm precision has been set at the top of the main arm as shown in the (fig 3.9) to read total movement including extension and slip in the bar and specimen respectively.

Test setup in long view

Fig.4. Details of the test setup for pull-out test.

A protecting tin was arranged under the specimen to avoid sudden fall after failure. Extensometer and Dial gauge readings have been taken for every load increment with an interval of 0.4 Tonne. The detailed drawing of test setup with sectional view of the specimen fixing has shown below in (fig 3.11). Under different loading levels, the relative displacement between the steel rebar and the concrete, that is the slippage value at the free end of the rebar, can be computed by the displacement difference between the two dial gauges. With application of load on the specimen the static mechanical energy (load) will be transferred to the specimen through the bar. In this process some amount of energy will be absorbed by the bar itself resulting in the elongation of the bar. The reading obtained from the dial gauge at the top arm of the UTM is the combined effect of elongation of free bar and as well as the slip produced in the specimen. The extensometer arranged to the bar will take the effect of elongation till the specimen ultimately fails in slip which is initiated by formation of micro cracks on the surface of specimen at top end and leading to giant fracture.

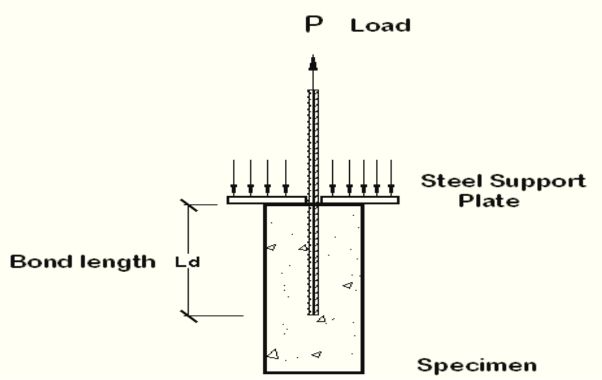


Fig.3. Development of load transfer mechanism on the specimen

The total movement of the setup can be assumed as Δa and elongation of bar taken as Δe from which slip in the specimen for a given embedded length of the bar is given by Therefore Δs = Δa- Δe.

Where Δe = Total elongation of bar measured over a fixed gauge length.

= Extensometer constant * extensometer reading / gauge length.

=0.002* a*(projected length- grip length)/g = (0.002* a/50)* 600.

Δa = Total movement of the frame = Dial gauge reading *dial constant. =0.01* C (C= dial 2 reading)

, the experimental investigations here conducted on M20, M40 & M60 grades of SCC with and without steel fiber and the bond behavior have been analyzed. In the present work the idea is to study the bond behaviour of self compacting concrete for M20, M40 & M60 for various parameters like effect of fiber and different embedded lengths. The results of 54 cylindrical specimens with 16 mm Φ deformed bar embedded in them for Bond studies and 9 cubes for compressive strength have been presented below.

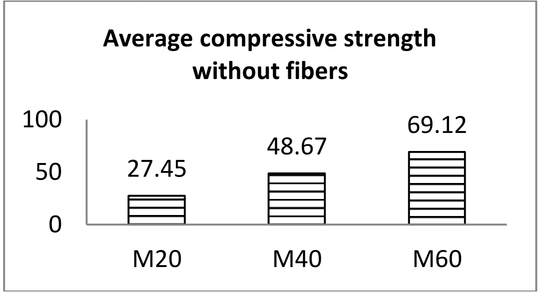


Fig.5 Average compressive strength without steel fibers

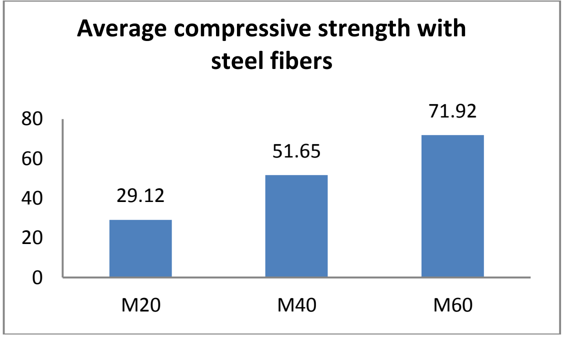


Fig.6. Average compressive strength with steel fibers

V. CONCLUSION

A detailed experimental programme was taken up to understand the influence of grade of concrete on the bond aspect of self compacting concrete. Based on the study the following conclusions can be drawn.

- There is a marginal increase in the compressive strength of steel fibers based concrete as compared to no fiber concrete.
- There is an increase in ultimate bond stress with increase in grade of self compacting concrete at same embedment length.
- There is an increase in ultimate bond stress value with increase in grade of self compacting concrete with steel fibers.

- In case of steel fibers concrete the increase in ultimate bond stress is significant for all embedment length. This can be attributed to the mode of cracking behavior between the bar and concrete.
- When compared between self compacting concrete with and without steel fibers the ultimate bond stress increased for steel fibers for same grade of concrete. This is true for M40 and M60 grade of SCC.
- There is a decrease in ultimate slip value with increase in grade of self compacting concrete at same embedment length.
- There is a decrease in ultimate slip value with increase in grade of self compacting concrete with steel fibers.
- When compared between self compacting concrete with and without steel fibers the ultimate slip value increased for steel fibers for same grade of concrete. This is true for M20, M40 and M60 grade of SCC.
- There is an increase in fracture energy with increase in embedment length and addition of fibers the grade of concrete increases. However the energy is more in case of steel fiber based SCC. The reason can be because of very clearly by establishing strain hardening portion.

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