MECHANICAL PROPERTIES OF M25 GRADE CONCRETE OF SLEF COMPACTING CONCRETE

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Abstract - *Cast in-situ concrete is the most frequently used material worldwide in the multi-storey residential buildings. Conventional concrete (CC) casting relies on compaction to ensure adequate strength and durability. Inadequate compaction affects the quality and durability of concrete structures. Self- compacting concrete (SCC) was first developed in Japan in 1986 as a quality assurance concept to address the issues like long production times, unhealthy work environment in the cast in-situ concrete technology. The excellent user-friendly self-flowing characteristics of SCC are of great attraction today in traditional construction industry also. But it is not yet utilized in house buildings to large extent with the conception that the use of higher fines and chemical admixtures in SCC leads to more material cost and higher strengths than the required for CC and also higher paste volume and lower coarse aggregate content cause higher drying shrinkage of SCC. .*

In the mix design of SCC, the relative proportions of key components are generally considered by volume rather than by mass. On the basis of these proportions, a simple tool has been designed for the SCC mix design. As mortar is an integral part of SCC design, this study also investigated the use of mini slump cone test along with the graduated glass plate to obtain the optimization of superplasticiser (SP) and viscosity modifying agent (VMA) in self compacting mortar (SCM). To make use of the SCC for normal buildings and to have adequate bond between aggregates and reinforcement in concrete structures, crushed granite stones of size 20 mm and 10 mm were blended in this study.

In this study, three mixes 28_60:40A, 28_60:40B and 28_60:40 were prepared with different paste contents 36.0%, 37.7% and 38.8% respectively in order to evaluate the SCC fresh properties and the desired strength. All the mixes had a coarse aggregate content of 28% with 60:40 (20 mm and 10 mm) blending by percentage weight of total coarse aggregate and 0.36 w/cm (by weight). It is evidently revealed that for a given coarse aggregate content and its blending, the decrease in fines content decreases the paste content and hence decreases the performance of SCC. From the results, it is concluded that for the given coarse aggregate content of 28% with the coarse aggregate blending 60:40 (20 mm and 10 mm), the fines content of 495 kg/m^3 can be considered as moderate fines and the paste content of 38.8% can be considered as an adequate paste content for a given w/cm (0.36).

From the compressive strength results, it is concluded that only the SCC mix 28_60:40 has attained a compressive strength of 32 MPa which was equivalent to M 25 grade of CC. The mix proportion of 28_60:40 can be adopted for the design of M 25 grade of SCC. This investigation further studied the hardened mechanical properties of M 25 grade of SCC and CC at different curing periods. The hardened properties that were determined are compressive strength after 7, 28, 56 and 112 days of curing and modulus of elasticity, splitting tensile strength, flexural strength and bond strength of concrete after 28, 56 and 112 days of curing. Results shown that fly ash blended SCC mixes have attained enhanced mechanical properties at later ages as compared to that of CC.

***Key Words*:** fly ash, ground granulated blast furnace slag, geopolymer concrete, mill rejected coal.

1.1 INTRODUCTION

Self-compacting concrete (SCC) is considerably a new concrete technology that was developed within the last two decades. Okamura in Japan first proposed the necessity of SCC in 1986 to cater for the reduction in skilled workers and to increase concrete durability by increasing the workability of concrete (Ozawa *et al*., 1989). According to ACI 237R-07 (2007), self-compacting concrete (SCC) is highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation. Ozawa and Maekawa produced the first prototype of SCC at the university of Tokyo in 1988 (Ozawa *et al*., 1989; RILEM TC 174 SCC, 2000).

Recommendations on the design and applications of SCC in construction have now been developed by many professional societies, including the American Concrete Institute (ACI), the American Society for Testing and Materials (ASTM), Center for Advanced Cement-Based Materials (ACBM), Precast Consulting Services (PCI) etc., but the most available standard is published by EFNARC (European Federation of National Trade Associations) which is the European federation dedicated to special construction chemicals and concrete systems (EFNARC, 2002).

The workability of SCC can be characterized by the three fresh properties (EFNARC, 2002): filling ability, passing ability and segregation resistance. Filling ability is the ability of SCC to flow under its own weight and to completely fill the formwork. Passing ability is the ability of SCC to flow through restricted spaces without blocking. Segregation resistance is the ability of SCC to remain uniform and cohesive during and after transporting and placing. Additional properties, such as robustness and consistence retention, are also important in applications of SCC. Robustness refers to the ability of SCC to retain its fresh property when the quality and quantity of constituent materials and the environmental conditions change. Consistence retention refers to the period of duration of the fresh properties. Just like the conventional concrete (CC), there is not a single test method to measure the above mentioned workability parameters. Therefore, EFNARC (2002) proposed list of test methods to determine the workability properties of SCC. Among these slump flow, J-ring, V-funnel, L-box, and U-box are the most widely accepted and used tests.

1.2 Advantages of SCC:

SCC offers many advantages for the precast, pre-stressed and cast-in-situ construction:

- Low noise-level in the plants and construction sites
- Eliminated problems associated with vibration
- Reduced labo cost
- Improved quality and durability
- Faster construction and resulting cost savings
- Higher strength
- Improved consolidation around reinforcement and bond with reinforcement
- Improved pumpability
- Improved better surface finishing

1.3 Disadvantages of SCC

SCC requires higher powder and chemical admixture (SP and VMA) contents than CC and so the material cost is higher (The Concrete Society and BRE, 2005). It was reported that in most cases, the cost increase ranged from 20% to 60% compared to similar grade CC (Nehdi *et al*., 2004; Ozawa, 2001). Such a high premium has somehow limited SCC application to general construction. However, in very large structures, increased material cost by using SCC was outweighed by savings in labor costs and construction time (Billberg, 1999).The increased content of powder and admixture also leads to higher sensitivity (i.e. reduced robustness) of SCC to material variation than that of CC; thus greater care with quality control is required (Walraven, 1998)

1.4 Properties of Self-Compacting Concrete

SCC is generally classified as one of the three types, powder, VMA or combined type, depending on the method of providing viscosity (EFNARC, 2006).

- Powder-type SCC is said to have low water-powder ratio (W/P) and high powder content. Due to higher powder (fines) content, powder-type SCC mixes are sensitive to changes in constituent materials. Due to the low W/P ratio, such concretes are expected to have a high strength and shrinkage than the required. The interactions of superplasticizers and powders should be carefully monitored.
- VMA-type SCC is said to have a high viscosity modifying agent (VMA), which is added for increasing the plastic viscosity. In this type of SCC, powder content is less because viscosity is controlled by VMA. The compatibility between superplasticizers and VMA should be carefully monitored.
- Combined-type SCC is developed in order to improve the robustness of the SCC. In this type of SCC, the VMA dosage is less than that of VMA-type SCC and the powder (fines) content is less than that of powder-type SCC. Viscosity is provided by the VMA along with powder. This type of SCC was reported to have high filling ability, high segregation resistance and improved robustness (Khayat and Guizani, 1997). The compatibility between superplasticisers, VMA and powders should be carefully monitored.

1.5. MIXING PROCEDURE

It is to be noted that the environmental conditions affect the SCC fresh properties and temperature should be maintained at 20±2°C during mixing. At a high temperature, the SCC will have less consistency due to the enhanced hydration of the cement (Aarre and Domone, 2004). In general, the mixing time of SCC is longer than that of CC to ensure adequate mixing of constituent materials (Chopin *et al*., 2004; Emborg, 2000). Pedersen and Smelpass (2003) preferred a SCC mixing time of exceeding 5 minutes. Peterson (1998) suggested a longer mixing procedure of 6 minutes in total beginning with a dry processing with all materials except water.

Superplasticiser (SP) is one of the important constituent materials in making successful SCC. Efficiency of SP mainly depends on the method of addition of SP during mixing (Takada *et al*., 1998b; Aiad, 2003).

There are two methods of adding SP to the mix viz. direct (simultaneous) addition and delayed addition (Takada *et al*., 1998b; Aiad, 2003). In the direct addition, the SP is mixed in all the mixing water and then mixed with other materials. It resulted direct contact of SP with the fresh cement and caused more adsorption of SP with cement and there by resulting availability of less amount of free SP (Takada *et al*., 1998b). Whereas, in the delayed addition, all constituent materials except the SP are mixed with part of the total mixing water and then remaining mixing water was added with SP several minutes after starting mixing. During this delayed addition, less amount of SP adsorbed with cement and thereby more amount of free SP is available to improve SCC fresh properties. It is concluded that lower the amount of admixtures adsorbed by cement, higher is the filling ability (Aiad, 2003; Uchikawa *et al*., 1995).

All constituent materials (powder and aggregates) except SP were mixed with 80% of total mixing water and superplasticiser was mixed with the remaining 20% of total water 1 minute after the start of mixing (Jin, 2002; Liu, 2010). It was found that the optimum addition time of SP was 1–2 min after adding water which produced a mixture with higher flowability and better consistence retention (Jin, 2002; Liu, 2010). Schwartzentruber *et al*., (2006) concluded that these two different methods tend to give different values of spread and flow time.

Viscosity modifying agent (VMA) is also one of the important constituent materials in making successful SCC with adequate viscosity. As similar to SP, the efficiency of VMA is also affected by the mixing procedure. It has been found that the order of addition, the mixing conditions and the compatibility between VMA and the SP affect the SCC performance (Jin, 2002, Liu 2010).

Jin (2002) revealed that delayed addition of VMA after the addition of SP after 1 minute of starting the mix leads to provide adequate viscosity of SCC. Liu (2010) also studied the delayed addition of VMA was found to perform better in SCC. For the delayed addition, after a minute of mixing with 70% of the mix water, 15% mixing water along with the superplasticiser was added, and then the VMA dissolved with the remaining 15% of the mix water was introduced after a further minute (Liu, 2010).

1.6. Objectives:

- To make a concrete without using cement (i.e. Geopolymer concrete).
- To study the different strength properties of geo-polymer concrete with percentage replacement of MRCA.
- To develop a mixture proportioning process to manufacture fly ash (ASTM Class F) and GGBS based geopolymer concrete incorporating MRCA as coarse aggregate with different replacement levels from 0% to 40% at ambient room temperature curing.
- To identify and study the effect of prominent parameters that affects the properties of fly ash and GGBS based geopolymer concrete incorporating MRCA as coarse aggregate with different replacement levels from 0% to 40% at ambient room temperature curing.

2. TEST METHODS ON SSC

Table 2.1 List of test methods for workability properties of SCC

	Method	Property
1	Slump flow	Filling ability
2	T_{50cm} slump flow	Filling ability
3	J-ring	Passing ability
4	V-funnel	Filling ability
5	V-funnel at 5 minutes T_{5min}	Segregation resistance

6	L-box/ U-box	Passing ability
7	GTM screen stability test	Segregation resistance
8	Orimet	Filling ability

2.1. Slump flow test

Slump flow test measures horizontal deformations. It is used to examine the horizontal flow of SCC in the absence of obstructions. Slump flow value is the mean diameter of the concrete flowing over a plate after a slump cone is lifted. Higher the slump flow value, higher is the deformation capacity of the SCC. It can also be used to indicate segregation resistance of SCC.

The test apparatus, shown in Fig. 2.1, consists of the normal slump cone used for conventional concrete, 100×200×300 mm, and a base plate. The dimensions of the base plate are 1000×1000 mm and graduated with a circle marking the central location for the slump cone and a further concentric circle of 50 cm diameter. At the same test the T_{50cm} slump flow time is measured when the concrete reaches a spread of 50 cm diameter. T_{50cm}, the time from lifting to the concrete reaching a 50 cm diameter, is popularly used to indicate the deformation rate. The higher the T_{50cm} value, the lower is the deformation rate of the concrete.

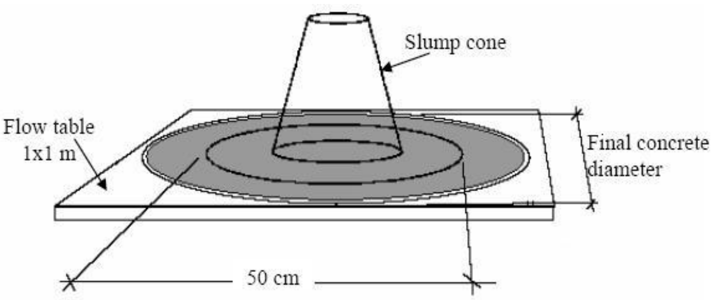

Fig. 2.1 Slump flow test

Segregation can be visually examined by observing the SCC flow and the edge of the spread after flow stops. The presence of a halo of paste or unevenly distributed coarse aggregate is considered as an indication of segregation. Higher the slump flow and lower the T_{50cm} time, higher is the flowing ability of concrete to fill the formwork under its own weight. It is the most commonly used test to assess the SCC filling ability. The acceptable range of slump flow is 650-800 mm and T_{50cm} time is 2-5 seconds (EFNARC, 2002).

2.2 V-funnel test:

The V-funnel test is used to measure the time for the concrete to flow out of the V-funnel under its own weight. This test is used to examine the plastic velocity and segregation resistance of concrete. Long V-funnel time indicates low deformation capacity or blockage of the flow due to high inter-particle friction. This test is used to determine the filling ability of the concrete with nominal maximum size (NMZ) of 20 mm. Fig. 2.2 shows the test apparatus for V-funnel test. The flow time is the time between opening of the trap door and when the light is seen through the V-funnel. After this, the funnel can be refilled with concrete and left for 5 minutes to settle and then the trap door is opened to allow the concrete to flow out under gravity.

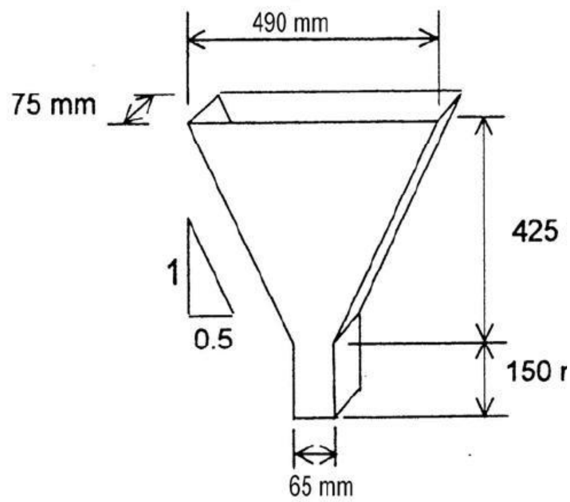

Fig. 2.2 V-funnel test

The V-funnel flow time at T_{5min}, which is the time between opening of the trap door and when the light is seen through the funnel, is also measured. This flow time T_{5min} indicates the segregation resistance (EFNARC, 2002). The acceptable range of V-funnel flow time is 6-12 seconds and flow time at T_{5min} is V-funnel flow time plus 3 seconds (EFNARC, 2002).

2.3 L-box test:

The L-box test is used to examine the passing ability of SCC in a confined area. The L-box test assesses the filling ability and passing ability of SCC (Petersson *et al*., 1996) Blocking and segregation can easily be detected visually in this test.

The test apparatus, as shown in Fig. 2.3, consists of a rectangular box section in L-shape with vertical and horizontal sections and a movable gate is placed in front of vertical reinforcing steel bars.

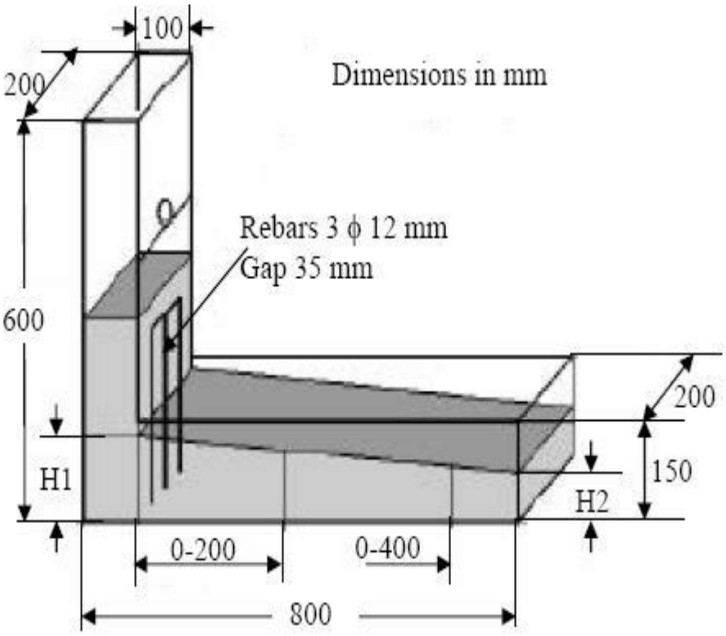

Fig. 2.3 L-box test

Concrete is filled in the vertical section of L-box without any compaction, left for 1 minute and then the gate is lifted up to let the concrete to flow into the horizontal section. When the concrete flow stopped, the height of the concrete at the end of the horizontal section (H2) and vertical section (H1) is measured. The value of H2/H1 represents the blocking ratio as shown in Fig. 2.5. The acceptable range of blocking ratio is 0.8-1.0 for good passing ability of SCC (EFNARC, 2002).

2.4 U-box test:

U-box test was developed by the Technology Research Center of the Taisei Corporation in Japan (Hayakawa *et al*., 1993) and used to measure both filling and passing ability of SCC. Fig. 2.6 shows the test apparatus which consists of two compartments separated by a middle wall. An opening with a movable gate is fitted between the two compartments. Reinforcing steel bars with nominal diameters of 13 mm are installed at the gate with center-to-center spacing of 50 mm.

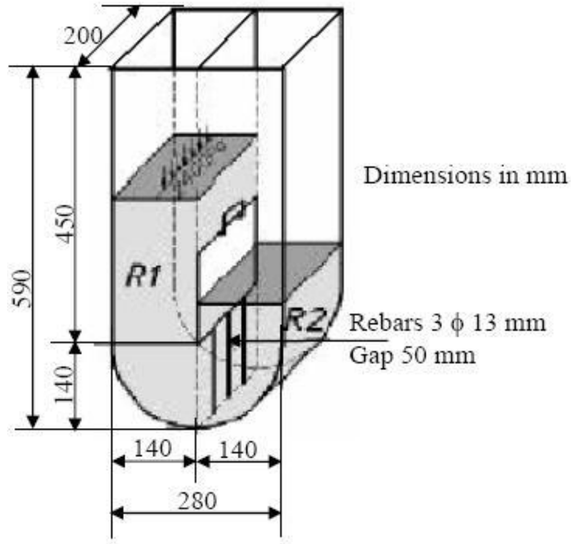

Fig. 2.6 U-box test

It creates a clear spacing of 35 mm between the steel bars. The left hand compartment is filled with about 20 liter of concrete without any compaction and left it for 1 minute and then the gate is lifted to let the concrete to flow upwards in the other compartment. The height of concrete in each compartment is measured after the concrete flow stopped (h_1, h_2) as shown in the above Fig. 2.6. The filling height is calculated as $h_1 - h_2$. The acceptable range of filling hei4ht value is 0- 30 mm for SCC (EFNARC, 2002).

4. MATERIALS

Constituent materials used to make SCC can have a significant influence on the fresh and hardened characteristics of the SCC. The following sections discuss constituent materials used for manufacturing SCC. Chemical and physical properties of the constituent materials are presented in this section.

4.1 Cement

Ordinary Portland Cement 53 grade (Dalmia) was used corresponding to IS 12269 (1987). The chemical properties of the cement as obtained by the manufacturer are presented in the Table 4.1.

Table 4.1. Chemical composition of cement

Particulars	Test result	Requirement as per IS:12269-1987
Chemical Composition		

% Silica(SiO_2)	19.79	
% Alumina(Al_2O_3)	5.67	
% Iron Oxide(Fe_2O_3)	4.68	
% Lime(CaO)	61.81	
% Magnesia(MgO)	0.84	Not more Than 6.0%
% Sulphuric Anhydride (SO_3)	2.48	Max. 3.0% when $C_3A>5.0$ Max. 2.5% when $C_3A<5.0$
% Chloride content	0.003	Max. 0.1%
Lime Saturation Factor CaO-$0.7SO_3/2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3$	0.92	0.80 to 1.02
Ratio of Alumina/Iron Oxide	1.21	Min. 0.66

4.2 Coarse aggregate

Crushed granite stones of size 20 mm and 10 mm are used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm and 10mm as per IS 2386 (Part III, 1963) are 2.6 and 0.3% respectively. The gradation of the coarse aggregate was determined by sieve analysis as per IS 383 (1970) . The grading curves of the coarse aggregates as per IS 383 (1970).

4.3 Fine aggregate

Natural river sand is used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS 2386 (Part III, 1963) are 2.6 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS 383 (1970) and presented in the Table 3.8. The grading curve of the fine aggregate as per IS 383 (1970) . Fineness modulus of sand is 2.26.

4.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided.

5. SCC MIX DESIGN

5.1 Selection of SCC mix proportions

SCC can be made from any of the constituents that are generally used for structural concrete. In designing the SCC mix, it is most useful to consider the relative proportions of the key components by volume rather than by mass (EFNARC, 2002). The following key proportions for the mixes listed below (Okamura and Ozawa, 1995; EFNARC, 2002; Khayat, 1998; Domone 2006b):

1. Air content (by volume)
2. Coarse aggregate content (by volume)
3. Paste content (by volume)
4. Binder (cementitious) content (by weight)
5. Replacement of mineral admixture by percentage binder weight
6. Water/ binder ratio (by weight)
7. Volume of fine aggregate/ volume of mortar
8. SP dosage by percentage cementitious (binder) weight

VMA dosage by percentage cementitious (binder) weight

5.2 Design of SCC mix design tool

The following material properties for the SCC mix design tool are .Specific gravity of cement, fly ash, coarse aggregate and fine aggregate.

1. Percentage of water absorption of coarse and fine aggregates.
2. Percentage of moisture content in coarse and fine aggregates.
3. Dry-rodded unit weight (DRUW) of coarse aggregate for the particular coarse aggregate blending.
4. Percentage of dry material in SP and VMA.

5.3 Detailed steps for SCC mix design tool

The detailed steps for mix design are described as follows:

1. Assume air content by percentage of concrete volume.
2. Input the coarse aggregate blending by percentage weight of total coarse aggregate.
3. Input the percentage of coarse aggregate in DRUW to calculate the coarse aggregate volume in the concrete volume.
4. Adjust the percentage of fine aggregate volume in mortar volume.
5. Obtain the required paste volume.

6. Adopt suitable water/ binder ratio by weight.
7. Input the percentage replacement of fly ash by weight of cementitious material.
8. Input the dosage of SP and VMA (if required) by percentage weight of binder.
9. Adjust the binder (cementitious material) content by weight to obtain the required paste.

6.0 CONCLUSIONS

- Self compacting concrete mix design tool is developed based on the key proportions of the constituents (EFNARC, 2002). This tool is very simple and user friendly for the self compacting concrete mix design.
- This tool can be used for the SCC mix with or without blended cement and coarse aggregate with or without coarse aggregate blending. This tool can also be enhanced for multi blended cements with more additives.
- This tool is also useful for Self compacting mortar design. It displays all necessary data for SCC mix design and also displays constituent materials for SCC or SCM for the required volume.

Optimization of SP and VMA in self compacting mortar

- Mini slump cone and graduated glass plate is the best choice for SCM tests to evaluate the mortar spread and its viscosity (T_{20}) respectively in order to get the optimization of SP and VMA in SCM. T_{20} is the best alternative for mini V-Funnel test for determining the viscosity of the spread.
- Polycarboxylate ether based SP (Sika Viscocrete 10R) and Polycarboxylate ether based VMA (Sika Stabilizer 4R) showed better performance in SCM in view of good mortar spread, adequate viscosity (T_{20}) and consistence retention.
- VMA dosage doesn't affect the saturation point of SP dosage.
- For mortars with the same cementitious proportions, the dosage of SP expressed in terms of percentage weight of cementitious, holds the same value even with the variation of w/cm.
- For mortars with the same cementitious proportions, the dosage of SP expressed in terms of percentage weight of cementitious, holds the same value even with the variation of percentage of sand in mortar.
- The increase of sand in mortar decreases the spread and increases the viscosity (T_{20}).

Mechanical properties of M 25 grade of SCC

- In the development of M 25 grade of SCC, for the given coarse aggregate content of 28% with the coarse aggregate blending 60:40 (20 mm and 10 mm), the fines content of 495 kg/m^3 can be considered as moderate (low) fines and the paste content of 38.8% can be considered as an adequate paste content for a given w/cm (0.36).
- For a given w/cm and replacement level of class F fly ash, the reduction in the binder content decreases the cement content, fly ash content and paste content and hence decreases the strength and performance of SCC.
- The designed M 25 grade of fly ash blended SCC mix 28_60:40 was performing enhanced mechanical properties at later ages as compared to that M 25 grade of CC and hence, it can be recommended for low rise building constructions.

6.1 Future work

Based on the investigation of this project, the development and mechanical properties of M 25 grade of SCC have been studied and the SCC mix 28_60:40 has been identified.

The future work includes:

- Durability studies on M 25 grade of SCC. They are water absorption, rapid chloride permeability at different curing periods and drying shrinkage at different drying periods.

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