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Research Paper

EXPERIMENTAL INVESTIGATION ON DURABILITY PROPERTIES OF M60 GRADE SELF-COMPACTING CONCRETE BY PARTIAL REPLACEMENT WITH CEMENT BY GGBS, LIME POWDER AND METAKAOLIN

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ABSTRACT: Today the concrete decomposes very easily due to environment as pollution. Once concrete decomposed the percolation of water takes place. Due to this inner reinforcement will corrode easily. Major failure of all reinforcement structure due to corrosion of reinforce. In this view, project studies the Durability properties of Self-Compacting Concrete with partial replacement of cement by different admixtures at various percentage with GGBS, Lime powder and Metakaolin. Five mixes were prepared by replacing 25% of cement with different percentages of GGBS, Lime Powder and Metakaolin. W/C ratio is maintained constant as 0.34 and superplasticizer dosage is fixed as 1% by weight of cement content. To fulfil the EFNARC guidelines for workability, filling ability and passing ability were found by Slump test, V-Funnel, L-Box and J-Ring before filling moulds. The compressive strength of harden SCC cubes also measured after specific period of curing i.e. 28 and 60 days. The workability test results showed that better performance when cement was replaced by GGBS alone as increasing percentage of LP & MK slightly reduced the workability properties due to densification of mixes. Meanwhile the compressive strength indicates an increase with increasing % of GGBS with LP & MK. The grade of concrete studied in this investigation was M60 and designed by means of Nansu method according to EFNARC guidelines for SCC. In the investigation of durability properties, were carried over concrete in Acidic environment with HCl and H2SO4. Meanwhile Sulphate attack test with MgSO4 and Na2SO4. Sorptivity and Water absorption also carried out as a part of investigation.

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I. INTRODUCTION

Now a Days there is a growth in urbanization tends to rapid growth in construction activity such as high-rise buildings, hallow shafts, express high ways and massive constructions structures. For achieving such projects with the appropriate requirements such as accomplishing the project with in constraint time at economical budgeting. Therefore, construction industry looks forward for amenable and fastest techniques here comes into picture the Self compacting concrete (SCC) which is compacted by its own weight and fill formwork especially in congested place like beam-column joint and spread into every corner of farm works. In other words, definition of SCC is the fresh concrete which flow by its own weight and spread over formwork without any vibrators. Self-compacting concrete (SCC) is non-segregating concrete that can spread into all places, fill the formwork and encapsulate the reinforcement without any need of vibration. By this concrete speedy construction is possible with nice finishing's. Usually this concrete is used where there is hard to apply vibrators for compaction. There are three main

properties of Self Compacting Concrete are Filling ability, Passing ability and most importantly Resistance to Segregation. To check these properties for SCC few tests are conducted on fresh concrete such that,

- Slump test, T50 cm slump test and V-funnel test are of Filling ability test
- L-box, U-box, J-ring are of Passing ability test
- V-funnel at T5 min is for Segregation resistance test

It is a sensitive mix, which is strongly dependent on the homogenous mix of concrete with its constituents. The use of mineral admixtures not only improves the hardened properties but also durability properties of the concrete.

SCC is the most viable option forsite conditions with constrained access and locations of congested reinforcements. In simple terms SCC could be an engineered material such that out of many problems need of skilled labor, compaction of concrete in massive distribution of reinforced bars, passing ability to rid of honeycombs in column beam joints, high workability, enhanced resistance to chemical attacks and mechanical stress, lower permeability, non-segregation nature, durability of concrete etc. had solved by SCC with efficiency. Durability isgeneral analysis of the service life and the performance of concrete in all aggressive environments. But to obtain such qualities in SCC, comprises with Cement, FA, CA, Admixtures, and new constituents like copper slag, industrial by products, Metakaolin, and Water, super plasticizer. Current Studies in SCC, which are being conducted in many countries, can be divided into following categories;

- Use of rheometers to obtain data about flow behavior of cement paste and concrete,
- Mixture proportioning methods in SCC,
- Characterization of SCC using laboratory test methods,
- Durability and Hardened properties of SCC and their comparison with normalconcrete, and
- Construction issues related to SCC

Materials opting in production of SCC should be suitable to concrete mix, and shouldn't be harmful such that shouldn't be detriment of quality it may cause corrosion of steel.

Design principles of Self Compacting Concretes

According to EFNARC guidelines for SCC, mix design is designed by adopting Nansu method. While designing mix design for SCC it is particular that the constituents of concrete is calculated by volume bases rather than mass.

- Water/powder ratio by volume of 0.80 to 1.10.
- Total powder content - 160 to 240 litres (400-600 kg) per cubic meter.
- CA content normally 28 to 35 percentage by volume of the mix.
- Water / cement ratio is selected based on requirements in EN 206. Typically, water content does not exceed 200 litre/m3.
- The sand content balances the volume of the other constituents.

II. REVIEW OF LITERATURE

Rizwan A khan (2015) states that the self-compacting concrete mix which containing 20% fly ash and 10% Metakaolin shows best results in compressive strength with durable properties. Using metakaolin in concrete performs high durability comparatively to lime-powder based concrete.

Biswadeep Bharali (2015) explained that the presence of fly ash in SCC improves workability of fresh concrete and addition of GGBS requires high dosage of superplasticizer to obtain acceptable workability. Therefore, in the combined replacement of FA and GGBS cement shows increase in strength by increase in percentage of replacement. He conveyed using fly ash improves workability meanwhile

GGBS improves compressive strength.

M Jagadeesh (2017) concluded the replacing cement with fly ash reduce the strength of SCC mix when compared with GGBS. Moreover, conventional SCC mix with the combined replacement of FA and GGBS withstands all the strengths and obtained optimum results.

S Srihari et al (2015) described the addition of Metakaolin to concrete decreases the workability. However, that can be improve by increasing super plasticizer and change in w/b ratio. He said that replacement of cement by Metakaolin forms (C-S-H) gel which improves the compressive strength and makes concrete stronger by blocking existing pores in harden concrete.

B H V Pai (2014) describes that to achieve acceptable workability requirement of SCC should adopt the mineral admixtures as powder content in concrete mix and states that presences of GGBS improves best results in compressive strength, split tensile strength and flexural strength. The low strength of SF based SCC mix is possible due to the high amount of SF (50.19%).

S A Kristiawan et al (2016) explained that the degradation of SCC due to sulfuric acid attack as measured by compressive strength loss and diameter change can be reduced with a higher inclusion of fly ash to replace partially cement. The extent of the reduced degradation is more pronounced at a later age. The effect of fly ash content to modify sscresistance against sulfuric acid could be explained by the combination of lower cement content, pozzolanic reaction and refinement of interparticle spaces.

Udit A Chavda et al (2018) concludes the strength of Self Compacting can be increase by use of admixture like fly ash, silica fume. In result it was found that for achieving maximum strength of SCC only 15% fly ash is required if it is added more than 15% then the strength gradually started reducing in both compressive and tensile.

Imad R. Mustafa (2017) reviews on recent research works upon SCC there are number of studies encounter upon partial replacement with cement by additives and concludes, usage of fly ash improves workability on fresh concrete but reducing hardened properties of SCC. And in future, this will lead to a more active promotion of research to establish the optimal mix design method for SCC.

K. Sathish Raja et al (2016) concludes that the industrial waste products can be effectively used as a replacement material in self compacting concrete. It is also understood that different products exhibit different properties at the fresh and hardened state. It is also clearly evident that the durability characteristics of the concrete are significantly improved with the partial replacement of materials.

P. Kannan et al (2015) states that the increase in fine material increases the stability of self-compacting concrete. And partial replacement of cement and fine aggregate with finer aggregate with finer material exhibits self-compacting concrete with low segregation potential.

Parth Rasalia et al (2018) explains that cement is mainly utilized in construction while its drawback to environmental pollution due to emission of CO2 in manufacturing of cement. Therefore, he investigated partial replacement of cement by metakaolin at different proportions and copper slag as fine aggregate at various proportions and concludes that the increase of metakaolin more than 10% reduces strength. And addition of copper slag more than 40% decreases compressive strength.

III. OBJECTIVE OF THE STUDY

From the research data there are many papers, projects which concludes that SCC is rapid growing concrete for future activities in construction industry. Therefore, in practical point of view developing such concrete in economic considerations with sufficient durable and strength quality in it is the main objective. Thereafter to decline in cost analysis,

waste materials of industry which is not harmful for Human's utilization is suggested to use in application of construction activities. Lime powder, Metakaolin two major mineral admixtures deals in this project while GGBS acts as a pozzolana material in cement content.

IV. EXPERIMENTAL INVESTIGATION

In this investigation studies the Durability properties of Self Compacting Concrete of M60 grade when cement content was partially replaced with GGBS, Lime powder and Metakaolin. Here, at various percentage content of mineral admixtures maintaining 25% of cement content replacement five mixes are studied as shown in table 1. Whereas Mix M1 perform as conventional concrete for comparison between mixes with 25% GGBS and75% cement content in it.

A. Mix design

Mix design method used in this project is Nansu method, one of the benefits among SCC could withdraw mix design of concrete by any standard Mix Design methodology. Trial and error method applied to obtain final mix proportions in mix design. In this project at 9th trail test the final mix design is obtained with 25% pozzolana content is allowed for acceptable workability. While using Nansu method in mix design it is particular that to check weather that fulfill EFNARC guidelines for SCC. Not only Nansu method, for concrete like SCC it should withstand the acceptable criteria in guidelines. In this investigation M60 grade concrete with proportions 1(cement) :1.751(FA) :1.395(CA). And total five different mixes were prepared with partial replacement of cement by different proportions of admixtures as shown in table 1. Among them M1 acts as the conventional concrete. Specimen used in this were 45 cubes of 100 mm side and After curing of age 28 days.

Table.1 Mix Proportions of different mixes

Mix	Proportions	Cement (Kg/m^3)	Pozzalona			FA (Kg/m^3)	CA (Kg/m^3)
			GGBS (Kg/m^3)	*LP (Kg/m^3)*	*MK (Kg/m^3)*		
M1	75%C+25%GGBS	436	145.5	0	0	1019	812
M2	75%C+15%GGBS+10%LP	436	87.3	58.2	0	1019	812
M3	75%C+15%GGBS+10% MK	436	87.3	0	58.2	1019	812
M4	75%C+10%GGBS+15%LP	436	58.2	87.3	0	1019	812
M5	75%C+10%GGBS+15% MK	436	58.2	0	87.3	1019	812

B. Mixing

Mixing can be defined as the phase of concrete where the cement paste aid to bind the coarse aggregate and fine aggregate with homogenous proportion of constituents. The equipment utilized for mixing is pan mixing, maximum quantity of concrete can be produced in that equipment is 75-90 kg/m^3. While mixing procedure it should be sure that the batch must be less than the limit of pan mixing such that divide batching into two or more parts. By assuming 15% of wastage in every parts of batch.

C. Fresh properties of SCC

According to EFNARC guide lines for SCC the fresh concrete is classified to SCC until and unless it fulfills the three properties i.e. Filling ability, Passing ability and resistance

against towards segregation. Therefore, EFNARC guidelines provided few tests to confirm the classification i.e. SCC. Those tests are as follows

Slump test: Usually Marsh slump test is known and well-practiced in testing workability of concrete, dimensions of slump, types of slumps, decides the characteristic of concrete. But here in SCC, the slump test is done differently with same equipment following fig shows it. The marsh cone is reversed in case of SCC to quantify the flowing ability of concrete and tabulated the spreading of concrete on plane. Hence characteristic of concrete is confirmed if the results achieved acceptable workability.

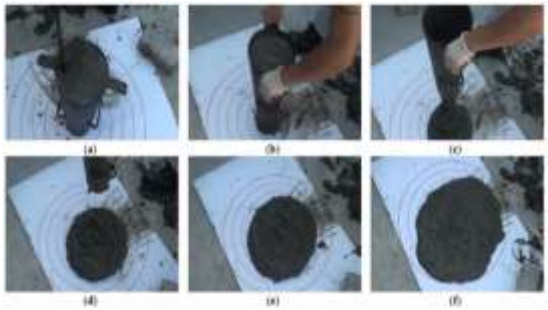


Fig.1 Slump Test

L-Box, V-Funnel, J-Ring: According EFNARC guideline for SCC, the tests are conducted. Before conducting test, it is particular that grease/oil is applied to the internal core of equipment's such that to avoid concrete sticks inside the equipment. As shown in Figure 2 (a), (b), (c). The test results are shown in the table 2.



Fig. 2 Tests on fresh concrete

D. Curing

Curing of concrete is a beginning phase of hardened concrete by that concrete is protected against loss of moisture for required hydration. Curing helps in reducing thermal and plastic cracks, which can severely impact durability of structures. Generally, a concrete gain target mean strength by 28 days of curing period, few minerals admixtures may react with concrete constituents such that tests are considered at 60 days, 90 days and 110 days in research works. In this investigation curing considered for testing hardened properties is 28 days and 60 days.

E. Harden Properties of concrete

To determine the Durability properties of hardened concrete subjected to following tests,

Compression Test: In simple terms, the resistance ability of cubes is determined by subjected to load with gradual increasing upon specimen and noted the failure point of concrete at 28 days of curing. The top phase of cube is placed towards front side while testing, and before passing to test the cubes are thoroughly cleaned. Procedure for compression test is placing specimen in machine facing top phase towards front, later applying load with gradual increasing and note down reading as shown in Fig.3

Compressive Strength = Ultimate Load / cross sectional area of standard cube



Fig.3 Compression Test

Acid Attack and Sulphate Attack: The procedure for testing acid attack and sulphate attack is similar but test solution is acid in acid attack, whereas sulphate in sulphate attack. After curing period of concrete cubes are removed from water and cleaned with soft and warm cloth to avoid dust settled on surfaces of cubes. So that cubes are weighed and readings are tabulated, later on diluting the acid / sulphate to 5%

concentration by molarity calculation. Now the specimens are dipped inside the solvents such that every surface are subjected to acid/ sulphate. Throughout the curing period in acid/ sulphate it is particular that to maintain the solution concentrated. By every 15 days the solutions should change to maintain the concentration of the acid/ sulphate. After removal of specimens from solutions the cubes are as show in Fig.4 whereas specimens in (a) and (b) are subjected to acidic environment, (c), (d) and (e) represents sulphate attack resistant cubes.

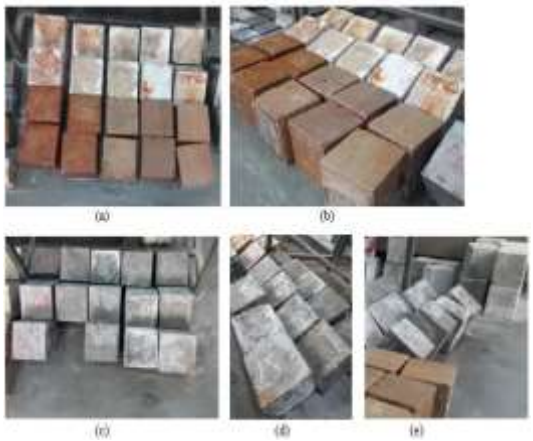


Fig.4 Acid attack and Sulphate attack specimens

Sorptivity: The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used of the test fluid. The cubes after casting were immersed in the water for 28 days curing. After that cubes weighed dry and processed test with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating. This test technique is utilized to decide the pace of ingestion (sorptivity) of water by pressure driven bond concrete by estimating the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. This test conducted as per code ASTM C1585-13. The quantity of water absorbed in time intervals 15,30,60,120,240,360,1440,2880 and 4320 in minutes was measured by weighting the specimen on a top pan balance weighting upto 0.1 mg.

Sorptivity of concrete = $I/T^{1/2}$ ($mm/min^{0.5}$)

Where, I =ΔW/Ad

ΔW = Change in weight in grams, A = Area of cross-section on Test conducted in mm^2d = Density of water (0.001 $gram/mm^3$), T = duration in min

Water Absorption: Water absorption is measured by measuring the increase in mass as a percentage of dry mass. As per investigation results of surface water absorption (sorptivity) and internal water absorption shows that surface water absorption is higher than internal water absorption for all the specimens. This is due to the rapid loss of water at the cover concrete during curing. The 100mm cubes after casting were immersed in water for 28 days curing. These specimens were then oven dried for 24 hours at the temperature110°C until the mass became constant and again weighed. This weight was noted as the dry weight (W1) of the cube. After that cubes are immersed in water at regular time intervals of 15,30,60,90,180,480,1440 and 2880 in minutes. Then this weight was noted as the wet weight (W2) of the cubes.

% water absorption = [(W2– W1) / W1] x 100

Where, W1 = Oven dry weight of cubes in grams

W2 = wet weight of cubes in grams.

F. Special Details & Material calculations

In the investigation of Durability properties of SCC, overall from all mixes 150mm cubes are 150 and 100mm cubes are 60, at ages 28 and 60 days. These all are summarized based on sharing of all five mixes M1, M2, M3, M4 and M5 respectively.

G. Casting

Casting is a segment, from one of the procedures in formation of cubes with fresh

concrete. Before pouring fresh concrete into moulds it should be assured that the cubes edges inside are applied with grease/ oil to avoid honey comb in the bottom of cubes.

H. De-molding

In general, SCC takes 24 - 48 hours to achieve hardened strata after casting cube. While de-molding the cubes proper care should be taken to avoid damage for cubes, because for durability test procedure the edges must need good finishing as shown in Fig 5. After that cubes are kept for curing in water bodies for 28days and 60days, later on processed to testing.



Fig.5 Specimens of all mixes

V. RESULTS AND DISCUSSIONS

Thus, the concrete here is Self-Compacting Concrete need to conduct test on both fresh and harden concrete. Therefore, to achieve acceptable workability of concrete it should fulfil the passing ability, filling ability and resistance against segregation. These tests are conducted as per EFNARC guidelines for SCC.

A. Fresh Properties

After various trial and error tests the final mix proportions fixed as per mix design the proportion of mixes as shown in table 2.

Table.2 Test results on Fresh concrete

Property	M1	M2	M3	M4	M5
V-funnel (sec)	10	11	12.5	14	16
J- ring (mm)	4	4	6	5	7
L-box (ratio)	0.9	0.86	0.81	0.75	0.7
Slump (mm)	650	630	615	590	570

B. Harden properties

Durability of concrete is generally performed for acid attack, sulphate attack, permeability, sorptivity, water absorption, alkali aggregates reaction, drying shrinkage, abrasion resistance, impact resistance, rapid chloride ion penetration and corrosion. But in this investigation test conducted on hardened concrete are as follow.

- ✓ Acid Attack with HCl and H_2SO_4
- ✓ Sulphate Attack with $MgSO_4$ and Na_2SO_4
- ✓ Sorptivity with Water as test fluid
- ✓ Water Absorption

Off-course for comparing Compressive test is done, in two phases before subjected to durability tests and after tests with individual samples of same mixes. Mix M1 treat as conventional concrete in the investigation with 25% GGBS as pozzolana material in cement content. The compressive test results of all mixes are shown in table 3.

Table. 3 Test result for Compression Test at 28 days

Mix	Proportions	Compression test (28 days)			Average (MPa)
		1	*2*	*3*	
M1	75%C+25%GGBS	72.88	71.92	72.5	72.43
M2	75%C+15%GGBS+10%LP	84.2	83.6	83.4	83.73
M3	75%C+15%GGBS+10%MK	63.5	63.9	62	63.13
M4	75%C+10%GGBS+15%LP	71.6	72.8	72.2	72.20
M5	75%C+10%GGBS+15%MK	47.6	47.1	46.4	47.03

C. Acid attach test

H_2SO_4: Specimens subjected to Acid environment at ages 28 days and 60 days, Mix M1 treated as conventional concrete for comparing to other mixes.

HCl: Specimens subjected to Acid environment at ages 28 days and 60 days, Mix M1 treated as conventional concrete for comparing to other mixes.

D. Sulphate attack

MgSO4: Specimens subjected to Sulphate attack at ages 28 days and 60 days, Mix M1 treated as conventional concrete for comparing to other mixes.

Na2SO4: Specimens subjected to Sulphate attack at ages 28 days and 60 days, Mix M1 treated as conventional concrete for comparing to other mixes.

E. Sorptivity

Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t). Usually mixes which having lowest Sorptivity value is preferable, in durability point of view because the capillary suction height depends on pores left in concrete. In other words, lowest permeability height performs best durability property therefore permeability depends on capillary suction of water penetration height of specimen. Therefore 0.0167, 0.0834, 0.1188,0.2782 and 0.031 are sorptivity values for the mixes M1, M2, M3, M4 and M5 respectively.

F. Cost Analysis

Even the durability properties of concrete are fair being uneconomical in making concrete, then thus concrete is not suggestable in construction activities. The following table 4 shows the cost per kilo gram analysis for preparation of $1m^3$ concrete. Off course by adopting few techniques in project management the cost of construction can be reduced, however on an average the preparation of $1m^3$ concrete is tabulated.

Table 4 Materials and their cost per Kg

Materials	Cement	GGBS	Lime Powder	Metakaolin	Fine Aggregate	Coarse Aggregate
Cost per kg (Rs)	7	3	5	13	1	1

Table 5 Comparison of Cost in Mixes per $1m^3$

Mixes	Cost per $1m^3$ (Rs)	Cost variation (%)
M1	5552.1	-
M2	5668.2	2.09
M3	6110.82	10.06
M4	5726.7	3.14
M5	6390.18	15.09

From the analysis the cost of mix M2 is showing economic among all mixes with acceptable workability and durability properties. Metakaolin based concrete neither economic nor durable while compared to mix M1. Lime-powder based concrete performed durable with economical.

VI. Conclusions

1. The investigation results show that compressive strength is increased about 15.5 % in mix M2 i.e. 10% LP and 15% GGBS. This is due to densification of structure.
2. As increasing the lime powder percentage, the compressive strength decreases as observed in mix M4.
3. The test results show that the percentage loss in weight in acidic environment with H_2SO_4 is low for M2 mix when compared to M1 at 28 days.
4. The test results show that the percentage loss in strength in acidic environment with H_2SO_4 is low for M2 mix when compared to M1 even at 60 days.
5. The test results show that the percentage loss in weight in acidic environment with HCl is low for M4 mix when compared to M1 at 28 days.
6. The percentage loss in strength in acidic environment with HCl is high for M2 mix with permissible loss of compressive strength and it is slightly less while compared to mix M1 at 60 days.
7. In case of sulphate attack with $MgSO_4$ the percentage loss in weight is low for M3 mix when compared to M1 at 28 days.
8. But the test results show that percentage loss of strength is moderate in mix M2 while compared to M1 at 60 days. This is due to filling of voids in structure by means of $MgSO_4$ alkali reactions with concrete constituents.
9. The test results show that sulphate attack with Na_2SO_4 is low for M2 mix when compared to M1 at 28 days.
10. But the test results show that percentage loss of strength is low in mix M3 while compared to M1 at 60 days. This is due to filling of voids in structure by means of Na_2SO_4 alkali

reactions with concrete constituents.

11. Sorptivity data states that except mix M4 all other mixes are permissible limit only
12. From the water absorption test results point of view mixes M1 and M4 are showing better results comparatively with other mixes.

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