Development of Mix Proportions for Different Grades of Met Kaolin Based Self-Compacting Concrete

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Abstract: Concrete is the most widely used construction material because of its mould ability into any required structural form and shape due to its fluid behavior at early ages. Thorough compaction, using vibration, is normally essential for achieving workability, the required strength and durability of concrete. Inadequate compaction of concrete results in large number of voids, affecting strength and long term durability of structures. Self-Compacting Concrete (SCC) provides a solution to these problems. As the name signifies, it is able to compact itself without any additional vibration. However, wide spread applications of SCC have been restricted due to lack of standard mix design procedure and testing methods. It is gaining wide acceptability because no vibration is needed and noise pollution is eliminated. The construction process is safer and more productive.

This study presents the performance of M40 grade SCC by using Ordinary Portland cement, fine aggregate from Krishna river sand sieved through 600µm, 10-12.5 mm crushed gravel, mineral admixtures like Metakaolin (MK), Fly ash (FA), Ground granulated blast furnace slag (GGBS)and chemical admixture named Master Glenium Sky 8234 used as a superplasticiser. MK is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. The performance of MK in SCC is not well documented, particularly over a wide range of grades. In particular, the effects of MK as a high surface area mineral addition on the workability as well as mechanical properties of SCC need to be fully recognized. So, the present study is an effort to characterize the fresh and hardened properties of SCC containing MK. The another supplementary cementitious material used in this study was Fly ash (FA) which can be obtained as finely divided residue that results from the combustion of ground or powdered coal and is transported by flue gases from the combustion zone to the particle removal system. Slag is a non-metallic product consisting essentially of glass containing silicates and aluminates of lime and other bases, as in the case of blast furnace slag, which is developed simultaneously with iron in blast furnace or electric pig iron furnace. Granulated slag is obtained by further processing the molten slag by rapidly chilling or quenching it with water or steam and air. Master Glenium Sky 8234 is an admixture of a new generation based on modified poly carboxylic ether. It is free from chloride and is compatible with all types of cements.

This experimental study demonstrates that MK, FA, GGBS can be successfully used as an admixture in the preparation of SCC. In order to prepare suitable mix proportion for M 40 grade for MK, FA, GGBS based SCC, investigations were undertaken replacing cement with 0%, 10%, 15%, 20%, 25% and 30% of MK, FA, GGBS and with adjusted dosage of super plasticizer (Master Glenium Sky 8234). As per the European guidelines for Self-compacting concrete, slump flow test, V-funnel test and L-box test have been carried out on fresh properties of MK, FA, GGBS based SCC. The compressive strength, split tensile strength and flexural strength of the specimens have been analyzed for 7-days and 28 days curing. And finally optimized mix proportions have been recommended for M40 grade of MK, FA, and GGBS based SCC. The fresh concrete test results revealed that by substituting different percentages of MK, FA, and GGBS in SCC satisfactory workability properties can be achieved, even though no viscosity modifying agent was needed.

The test results for acceptance characteristics of self-compacting concrete such as slump flow test; V-funnel test and L-Box test were satisfactory as per EFNARC for developed mix proportions of M40 grade SCC mix. Further, compressive strength, tensile strength and flexural strength at the age of 7 and 28 days were also determined and 10% to 15% replacement of MK, 20 to 25 % replacement of FA, and 30 to 35 % of GGBS can be regarded as a suitable replacements and optimized mix proportions have been recommended for M40 grade of MK, FA, GGBS based SCC from this experimental study.

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1.1 General

Self-Compacting Concrete was first developed in 1986 in Japan to achieve durable concrete structures since then, various investigations have been carried out and mainly large construction companies have been used this type of concrete in practical structures in Japan. Concrete that requires little vibration or compaction has been used in Europe since the early 1970's but self-compacting concrete was not developed until the late 1980's in Japan.

Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction.

1.2 Development of Self-Compacting Concrete

For several year beginning in 1983, the problem of the durability of concrete structure was a major topic of interest in Japan. The creation of durable concrete structures requires adequate compaction by skilled workers. The design of modern reinforced structures becomes more and more advance, the designed shapes of structure are becoming increasingly complicated and heavy reinforcing is no longer unusual. Furthermore the gradual reduction in the number of skilled workers in Japan’s construction industry has lead to a similar reduction in the quality of construction work one solution for the achievement of durable concrete independent of the quality of construction work in the employment of SCC, which can be compacted into every corner of a form work, purely by means of its own weight without need for vibration compaction. The necessity of this type of concrete was proposed by Okamura in 1986. Studies to develop SCC, including a fundamental study on the workability of concrete, have been carried out by “Ozawa and Maekawa” at the university of Tokyo.

1.3 Benefits and Advantages of SCC

Modern, presently day self-compacting concrete (SCC) can be classified as an advanced construction material. The SCC as the name suggests, does not require to be vibrated to achieve full compaction. This offer many benefits and advantages over conventional concrete.

1. Improved quality of construction and reduction of onsite repairs.
2. Faster construction times
3. Low overall cost
4. Facilitation and introduction of automatic concrete construction
5. Improvement of health and safety is also achieved through elimination of handling of vibrates
6. Substantial reduction of environmental noise loading on and around a site.
7. Possibilities for utilization of “dusts”, which are currently waste products demanding with no practical application and which are costly to dispose of.
8. Better surface finishes
9. Easier placing
10. Thinner concrete sections.
11. Greater freedom in design
12. Improved durability and reliability of concrete sections
13. Ease of placement results in cost savings through reduced equipment and labor requirement.
14. SCC makes the level of durability and reliability of the structure independent from the existing co-site conditions related to the quality of labor, casting and compacting systems available.
15. The high resistance to external segregation and the mixtures self-compacting ability allow the elimination of micro-defects, air bubbles and honeycombs responsible for penalizing mechanical performance and structural durability.

2.1 Mix Design

M-40 Concrete Mix Design		
As per IS 10262-2009		
A.1.	**Stipulations for Proportioning**	
1	Grade Designation	M40
2	Type of Cement	OPC 53 grade confirming to IS-12269-1987
3	Maximum Nominal Aggregate Size	12.5 mm
4	Workability	Zero Slump
5	Exposure Condition	Normal
6	Type of Aggregate	Crushed Angular Aggregate
7	Mineral Admixtures	Metakaolin, Fly ash, GGBS
8	Qty. of Mineral Admixture used	5%,10%,15%,20%,30%,35%,40% by wt. of cement

9	Chemical Admixture Type	Superplasticiser (Master Glenium SKY 8234)
10	Dosage of Chemical Admixture	0.8 to 1.3 % by wt of cement i.e., 8 to 13 ml per one kg of cementicious material.
11	Target Mean Strength	48.25N/mm^2

In this study, three series of concrete mixes were developed. These series of concrete mixes were prepared with the water-cement ratio of **0.38** and the targeted compressive strength of **40MPa** at 28 days. The Mix proportion finally adopted is **1:1.6:1.6** for grade **M40**.

2.2 Slump Flow Test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete. The T_{50} time is a secondary indication of filling ability. A lower time indicates greater flow ability.

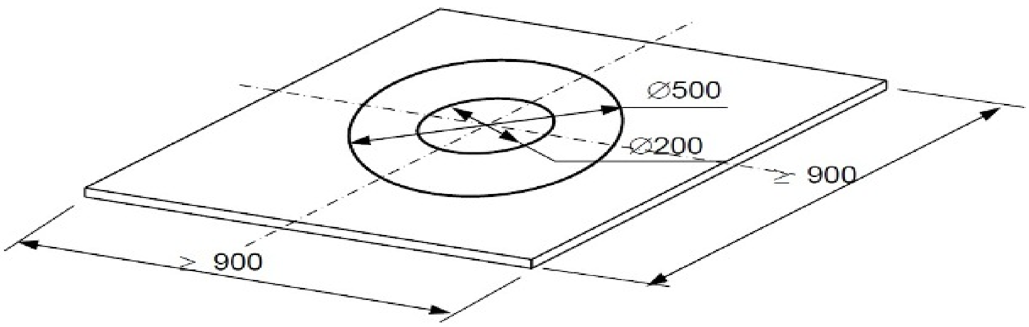

Figure 2.1. Slump flow apparatus dimensions

2.3 V-Funnel Test

This test was developed in Japan and used by Ozawa. The equipment consists of a v-shaped funnel, shown in figure. The described v-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20mm.The V-funnel is filled with about 12lt.of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow will increase significantly. Though the test is designed to measure the filling ability, the result is affected by concrete properties other than flow.

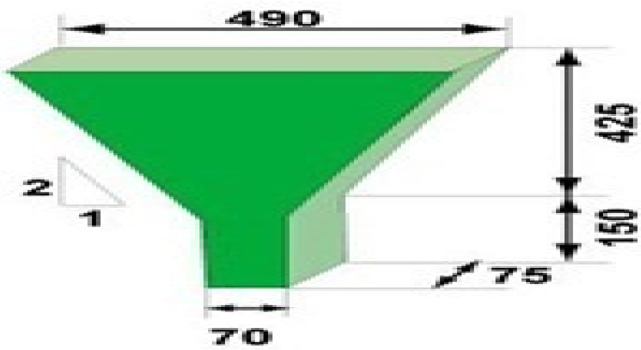

Figure 2.2. V-funnel Dimensions

2.4 L-Box Test

Peterson has described the test, based on a Japanese design for underwater concrete. The test assesses the flow of the concrete and also the extent to which it is subject to blocking by reinforcement.

The apparatus consists of rectangular-section box in the shape of an ‘L’ with a vertical and horizontal section, separated by a movable gate, in front of which vertical lengths of reinforcement bat are fitted. The vertical section is fitted with concrete and the gate lifted to let the concrete flow into horizontal section. The bars can principally be set at any spacing to improve a more or less serve test of the passing ability of the concrete. When the flow has stopped, the height of concrete at the end of the horizontal section is expressed as a proportion of that remaining in the in the vertical section (H2/H1 in the diagram). It indicates the slope of the concrete when at rest. This is an indication passing ability or the degree to which the passage of concrete through the bars is restricted.

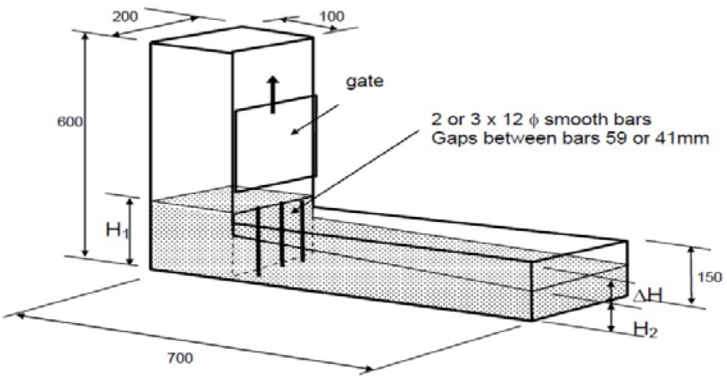

Figure 2.3. L-Box Dimensions

2.5 Accelerated curing test

Objective

Normally, the strength of concrete is found out after 7 days and 28 days. For some construction activities, it may be too late and need to know the strength earlier.

Reference Standards

IS:9013-1978-Method of making, curing and determining compressive strength of accelerated cured concrete test specimen.

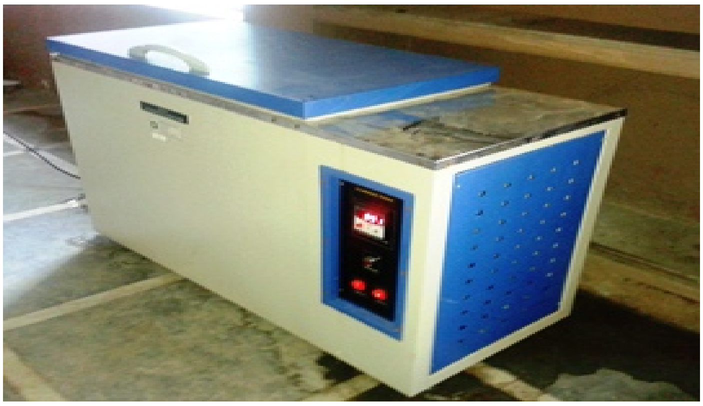

Figure 2.4. Accelerated Curing Tank

3. Results

3.1 Mix 1

- ✓ The mix proportion of mix 1 was shown below.

Cement	:	fine aggregate	:	coarse aggregate	:	water
1	:	1.6	:	1.6	:	0.34
500 kg/m^3	:	800 kg/m^3	:	800 kg/m^3	:	170 kg/m^3
0% Metakaolin; 1 % of super plasticizer (Master Glenium SKY 8234)						

- ✓ The mix 1 workability details was shown in table 3.1

Table 3.1. Workability Details of mix 1

S.No	Workability Tests	Values	Results
1	Slump Test (mm)	600	Pass
2	T_{50cm} Slump (sec)	2	Pass
3	V-Funnel (sec)	No viscosity	Fail
4	V-Funnel after 5mins	-	-
5	L- Box (h_2/h_1)	-	-

3.2 Replacement with Fly ash

Mix 1:

- ✓ The mix proportion of mix 1 was shown below.

Cement	:	fine aggregate	:	coarse aggregate	:	water
1	:	1.6	:	1.6	:	0.38
500 kg/m^3	:	800 kg/m^3	:	800 kg/m^3	:	190 kg/m^3
10% Fly ash; 1.3 % of super plasticizer (Master Glenium SKY 8234)						

- ✓ The Mix 1 workability details was shown in table 3.2.

Table 3.2. Workability Details of Mix 1

S.No	Workability Tests	Values	Results
1	Slump Test (mm)	680	Pass
2	T_{50cm} Slump (sec)	4	Pass
3	V-Funnel (sec)	8.5	Pass
4	V-Funnel after 5mins	13.25	Pass
5	L- Box (h_2/h_1)	0.93	Pass

3.3 Replacement with GGBS

Mix 1:

- ✓ The mix proportion of mix 1 was shown below.

Cement	:	fine aggregate	:	coarse aggregate	:	water
1	:	1.6	:	1.6	:	0.38
500 kg/m^3	:	800 kg/m^3	:	800 kg/m^3	:	190 kg/m^3
10% GGBS; 1.3 % of super plasticizer (Master Glenium SKY 8234)						

✓ The mix 1 workability details was shown in table 3.3.

Table 3.3. Workability Details of Trial mix 1

S.No	Workability Tests	Values	Results
1	Slump Test (mm)	680	Pass
2	T_{50cm} Slump (sec)	3	Pass
3	V-Funnel (sec)	8.7	Pass
4	V-Funnel after 5mins	13.8	Pass
5	L- Box (h_2/h_1)	0.933	Pass

3.4 Compressive Strength Result for Different Admixture Proportions

Table 3.4. Test results of Compressive strength test for different admixture proportions

Replacement level (%)	Compressive Strength (Mpa)	
Metakaolin (%)	7 days	28 days
0	34.33	46.6
10	38.1	48.4
15	39.21	52.5
20	35.43	42.0
25	31.2	37.1
30	28.74	29.6

3.5 Split Tensile and Flexural Strength test results for different admixture proportions

Table 3.5. Test results of Split Tensile and Flexural Strength test for different admixture proportions

Replacement level (%)	Split Tensile Strength (Mpa)		Flexural Strength (Mpa)	
Metakaolin (%)	7 days	28 days	7 days	28 days
0	3.0	4.80	5.2	7.7
10	4.2	6.30	7.9	9.21
15	4.6	6.83	8.5	9.94
20	3.9	4.6	6.9	8.5
25	3.7	4.9	5.4	7.32
30	3.5	4.5	5.1	6.81

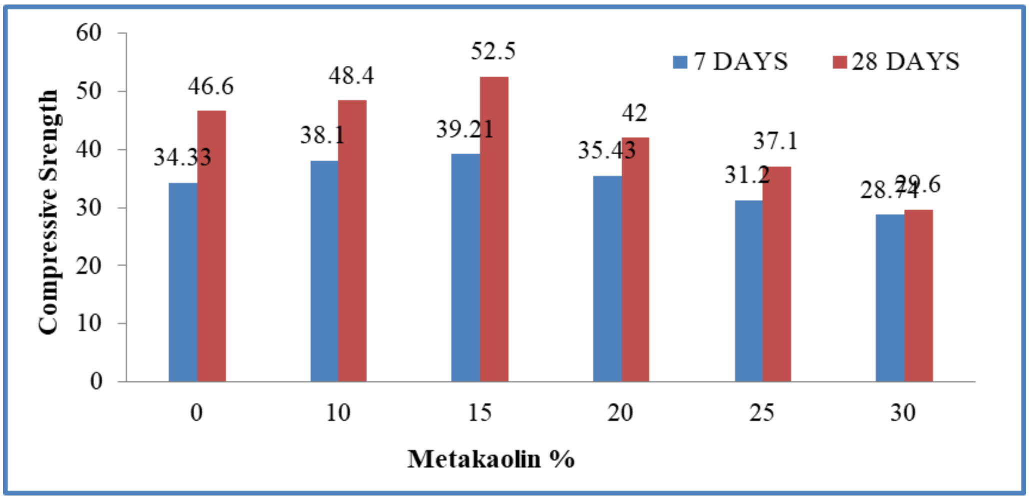

Figure 3.1.Graph showing Compression Strength at various proportions of Metakaolin

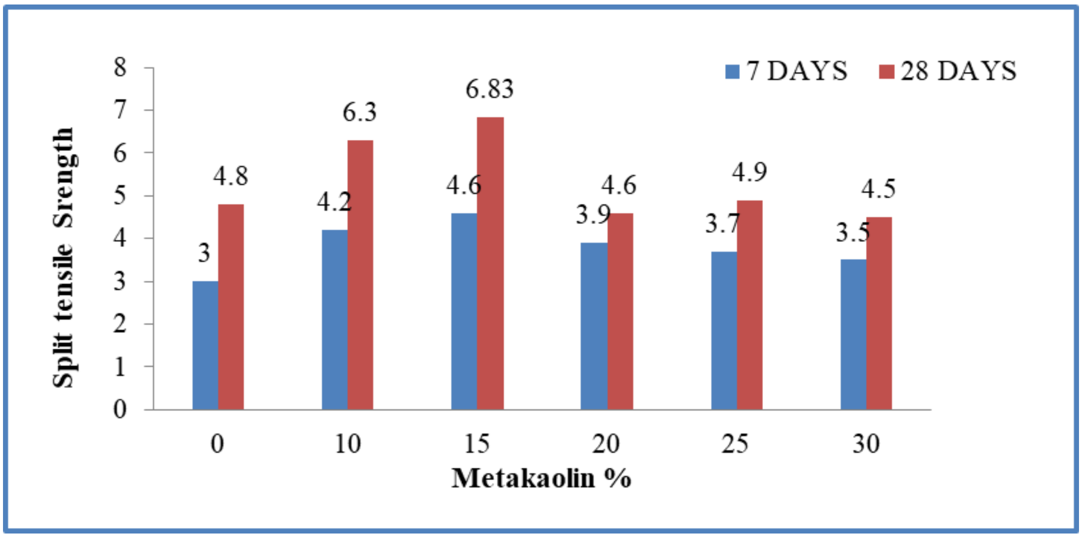

Figure 3.1(a). Graph showing Split tensile Strength at various proportions of Metakaolin %

3.6 Hardened Properties for GGBS Replacement

Table 3.6. Test results of Compressive strength test for different admixture proportions

Replacement level (%)	Compressive Strength (Mpa)	
GGBS (%)	7 days	28 days
0	34.33	46.6
10	35.61	47.48
15	35.92	47.9
20	36.21	48.28
25	37.17	49.57
30	39.165	52.22
35	43.995	58.66
40	33.6	44.8

Table 3.7. Test results of Split Tensile and Flexural Strength test for different admixture proportions

Replacement level (%)	Split Tensile Strength(Mpa)		Flexural Strength(Mpa)	
GGBS (%)	7 days	28 days	7 days	28 days
0	3	4.8	5.2	7.7
10	3.3	4.89	4.2	4.94
15	3.6	4.9	4.24	5.1
20	3.69	4.43	3.8	5.23
25	4.3	4.93	4.1	5.34
30	4.48	5.16	4.16	5.67
35	4.74	5.63	5.2	6.2
40	3.78	4.46	3.95	4.6

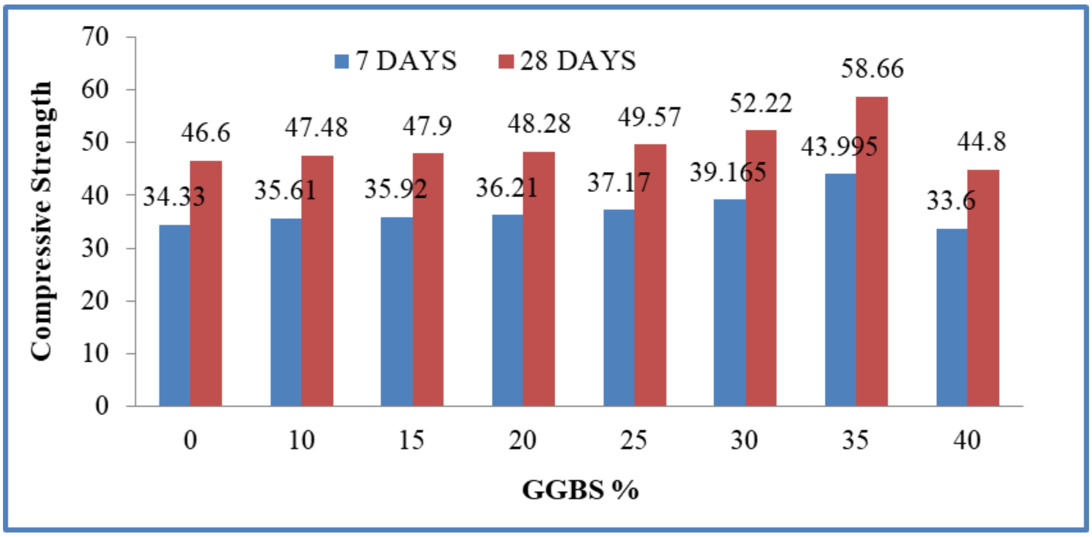

Figure 3.2. Graph showing Compression Strength at various proportions of GGBS %

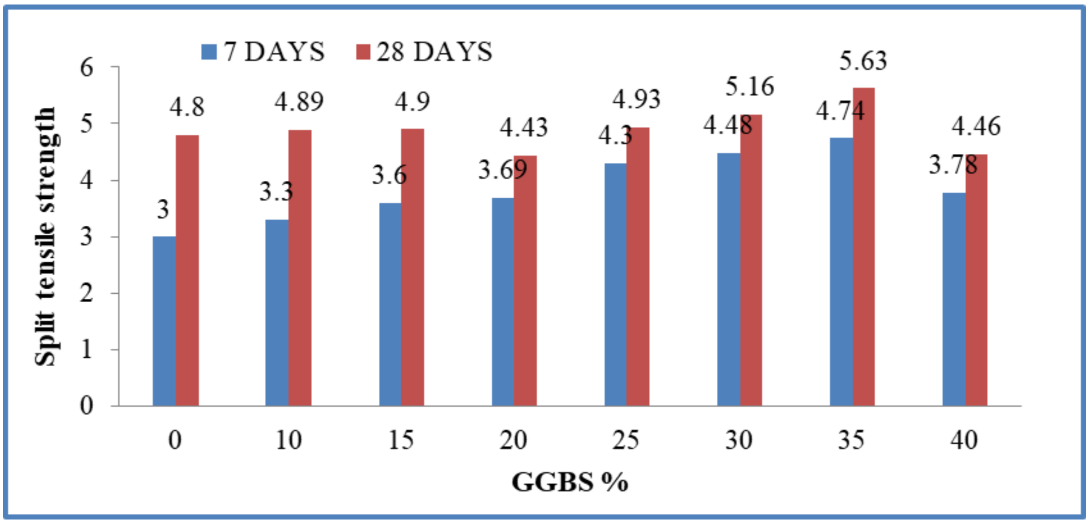

Figure 3.2(a). Graph showing Split tensile Strength at various proportions of GGBS %

4. Conclusions

This study was carried out to evaluate the fresh and hardened properties of SCC containing MK, GGBS, FA for developing M40 grade of SCC. The following conclusions can be drawn:

1. SCC containing MK, GGBS, FA with slump flow values between 660 and 750 mm can be produced by adjusting the high range water reducer dosage. SCC with this range of slump flow can practically be used in many applications.
2. SCC with MK, GGBS, FA can be produced with proper workability without using viscosity modifying agent.
3. With 0% replacement of ad mixture with cement, firstly attained M40 SCC mix. Then MK, GGBS, FA was partially replaced at 10%, 15%, 20%, 25% and 30% by weight of cement, it seems that 10% to 15% replacement of MK, 20-25% of fly ash and 30-35 % of GGBS can be regarded as a suitable replacement and have been recommended M40 grades of MK based SCC mix which provides good workability and achieved desired strength grade.
4. Splitting tensile strength and flexural strength followed the same pattern as compressive strength for different desired grades of SCC. The split tensile strength and flexural strength values were low and almost same as conventional normal concrete.

5. The powder content was chosen as indicated in guidelines of EFNARC for producing different grades of SCC.
6. After choosing the results GGBS is the best replacement for M40 grade SCC. Metakaolin and fly ash as follows respectively.

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