Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 01

February 2016, P.P.146-150

Fresh and Hardened Properties of Glass Fiber Reinforced Self Compacting Concrete with Fly ash and Metakaolin Combination

JITHIN DAVID[1] AND VASUDEV R[2]
Department of Civil Engineering, Toc H Institute of Science and Technology, Arakkunnam,, Kerala, India
Email: *jithindavid007@gmail.com, vasu.vasudev@gmail.com*

Abstract: Self compacting concrete (SCC) is one of the emerging technique in concrete technology, which is developed as a solution for areas where placement and compaction of concrete is difficult. One of the salient features of SCC is the usage of higher amount of powder content which is achieved by the usage of mineral admixtures. The glass fiber addition in SCC is a mean to control the early shrinkage cracking in SCC due to higher powder content and also it improves the flexural strength and tensile strength of concrete. The present study aims at a comparison of fresh and hardened properties of SCC with 0.025%, 0.05% & 0.075% (by volume of mix) addition of glass fiber. A combination of the Fly ash (30% replacement of cement) and Metakaolin (at 10% replacement of cement) used as mineral admixtures. The workability of SCC mixture is analyzed by carrying out Slump Flow Test, L Box Test and V Funnel Test. The compressive strength & split tensile strength value of SCC mix was found to improve with increase in rate of addition of the glass fiber and the maximum improvement is observed for mix having 0.075% of glass fiber.

Keywords: *Self Compacting Concrete, Glass Fiber, Metakaolin, Compressive Strength, Fresh Properties*

1. Introduction

Self-compacting concrete (SCC) is a high flow concrete which can consolidate by its self-weight. The concept of SCC was developed in Japan in 1980s on the grounds of several quality related issues of ordinary concrete such as defective workmanship, poor durability, lack of finishing etc. The use of SCC enhances the productivity of the concrete work by reducing the time for placing, consolidating and finishing of the concrete. The application of SCC is most essential in location where the steel reinforcement is too much closely spaced such as heavily reinforced slabs, beam column joints etc and also in the areas where compaction using equipments is not possible. The addition of mineral admixtures such as fly ash or metakaolin which are finer than the cement particles makes the concrete more dense and impermeable and hence the durability is improved. The self-compacting property of a mix is obtained by means of several modifications over the ordinary concrete mix. The major characteristics of SCC mix include lower proportion of coarse aggregates, high volume of powder (cementitious materials), usage of special type of super plasticizers etc. The mineral admixtures are added to SCC in order to increase the total powder content in the mix so as to enhance the stability of mix and thus by prevent chances of segregation. The polycarboxylate-ether based super plasticizers are used to enhance the flow of the mix without increase in water content. A viscosity modifying agent (VMA) can be also added to mix to get required stability of mix at lower powder content.

The presence of higher amount of powder content in the SCC mix make it prone to early age shrinkage cracking and the addition of glass fiber is an effective method to control this. The glass fiber possess a higher modulus value in comparison with the cement matrix. When it mixed with wet concrete and it quickly dispersed in to concrete mix without forming any lumps. Also it helps to control bleeding in the SCC at fresh state .The fresh properties of the SCC does not significantly affected due to a lower addition rate of glass fiber .The glass fiber is superior to polypropylene fiber, since it is having greater tensile strength and higher modulus.

Mineral admixtures are added in to the concrete as a partial replacement of cement to enhance the strength and durability characteristics of the mix. Metakaolin is a pozzolanic material, manufactured by heating kaolinite clay at a temperature of 650°C to 900°C. Since the material is finer than cement, it is having a larger surface area and thus it rapidly reacts with water. This reaction results in formation of C-S-H gel which reduces porosity in concrete and thereby increases compressive strength. At a higher replacement level (above 10%) metakaolin tends to reduce workability of the mix. It also reduces the alkalinity of the mix and thereby lessens the environment for alkali silica reaction when glass fibers are added to concrete. Fly ash is used as an economical replacement of cement in SCC mix. Fly ash particles are finer than cement and spherical in shape which helps to increase the flowability of SCC. The early age compressive strength is found to reduce due to addition of fly ash. A combination of fly ash and metakaolin can compensate for the drawbacks of each of the materials when they mix to SCC individually. Fly ash in the above combination prevents the workability reduction due to addition of metakaolin. Whereas the metakaolin contributes to the early age compressive strength. Also metakaolin improves the early setting of the mix which may get extended due to addition of fly ash.

1.1. Literature Review

The inclusion of glass fiber and metakaolin in to the SCC mix make it more durable as well as various strength parameters such as flexural strength, split tensile strength etc are also improved. Okamura et al. (2003) [6] proposed the basic guidelines for preparing a self-compacting concrete. The modifications for the mix proportion was made with (1) Limited aggregate content (2) Low water-powder ratio (3) Use of superplasticizer. Also the various workability tests on fresh SCC mix detailed, such as the Slump Flow test, L-Box test, V-Funnel test, U-Box test etc. Madandoust et al. (2012) [9] carried out analysis to identify fresh and hardened properties of SCC mixed with metakaolin, having a cement replacement level from 0-20% and with different water binder ratios of 0.32,0.38 & 0.45.The early age (14 Days) compressive strength was found to increase about 27% due to addition of metakaolin. A higher proportion of metakaolin (20% replacement) affects the the flow characteristics of the mix. The optimum replacement level of 10% was found to be suitable to attain maximum improvement in compressive strength. Marikunte et al. (1997) [10] analyzed hot water durability of composite material containing cement only, 25% cement replacement with metakaolin & 25% cement replacement with silica fume. The glass fiber enhances the tensile and flexural properties of the mix. Also the metakaolin composite with glass fiber was more durable than other two composite as it shows only minor loss in flexural and tensile strength, modulus of elasticity and toughness with aging. Kavitha et al. (2015) [7] studies the micro level properties of SCC with metakaolin and identifies that the crack width of SCC was significantly decreased due to pozzolanic action of metakaolin. This may be attribute to the reduction in Ca:Si ratio on C-S-H gel by action of metakaolin. Apart from these metakaolin was found to increase the formation of C-S-H gel formation and there by filling the capillary pores and reduces the permeability of concrete. Siddique (2010) [8] analyzed the properties of SCC mix with fly ash.The optimum replacement level of fly ash for maximum compressive strength and split tensile strength was found to be 20%. The compressive strength values tend to reduce up on increase in addition rate on above rate. The maximum reduction in carbonation depth and an increase in chloride penetration resistance were observed for a replacement level of 25%. Guneyisi et al. (2010) [4] investigates compressive strength and drying shrinkage properties of self-compacting concrete with binary and ternary blends of cement, metakaolin and fly ash. On a binary blend with cement, fly ash shows a reduction in compressive strength whereas metakaolin shows an improvement in strength. However in the case of a ternary blend of metakaolin and fly ash the negative effect of metakaolin in slump flow was compensated by fly ash and the early age strength reduction due to fly ash was compensated by metakaolin. Guneyisi et al. (2008) [3] find out that the addition of fly ash may extend the setting time of SCC, which is found to reduce in a ternary blend with fly ash and metakaolin. The addition of metakaolin makes the mix more viscous and hence the use of viscosity modifier (VMA) can be avoided. Barluenga et al. (2007) [2] evaluated the cracking control ability of glass fiber, identifies that a lower addition rate of glass fiber does not significantly affect the workability. The maximum cracking control is observed in case of glass fiber addition of 600 g/m^3. The SCC is found to have higher amount shrinkage in comparison with ordinary concrete and also it depends upon the type of mineral filler used in the mix. Ahmet et al. (2015*)* [1] carried out comparative analysis of concrete with glass fiber and basalt fiber, identifies that the flexural strength and split tensile strength tends to reduce beyond a addition rate of 0.50%. Also at a higher addition rate of 1% the fracture energy increased more than 50%. Suresh (2008) [11] compares the stress strain characteristics of SCC and glass fiber reinforced SCC. The tensile strength and split tensile strength was found to improve due to addition of glass fiber. The value of elastic modulus of SCC was less than ordinary concrete, but for glass fiber reinforced SCC an improvement of 14.2% over the ordinary concrete. Also the ductility and energy absorption capacity was found to improve due to addition of glass fiber.

Based on the studies of Kavitha et al.[7] the optimum replacement level for metakaolin was found to be 10%. Siddique [8] suggests a replacement level of fly ash as 25%, for improving the durability characteristics. The manufacturer specified dosage of glass fiber is 600g/m^3 of concrete for ensuring maximum crack resistance. In the present study the glass fiber of varying proportions from 0.025% to 0.075 % is mixed to observe the variations in compressive strength values due to addition of glass fiber. The replacement of metakaolin is 10% which is the optimum value.The replacement level of fly ash in the mix is 30% so as to ensure the adequate workability characteristics for the mix having metakaolin a glass fiber.

2. Experimental Investigation

The SCC mix with varying percentage of glass fiber (0.025% to 0.075%) was considered along with a control mix during the analysis. Each mix combination was subjected to various tests of workability to ensure the self-compacting behavior. The hardened properties of each mix were also analyzed to make sure the results satisfying the mix design strength requirements.

2.1. Materials Used

The cement used is of OPC grade 53 conforming to IS: 12269-1987. High Reactive Metakaolin (HRM) used is having a specific gravity of 2.6. Fly ash collected from Mettur Thermal Power Plant, Tamil Nadu, India, having a specific gravity of 2.2. Coarse aggregate used is locally available crushed granite stone with 12mm maximum size aggregate, having a specific gravity of 2.78. Manufactured sand (M-Sand) conforming to Zone II of IS 383-1970 having a specific gravity of 2.77 is used as fine aggregate. Polycarboxylate ether (PCE) based super plasticizer having specific gravity of 1.085 is used to achieve required flow of the mix. Due to addition of metakaolin the mix becomes more viscous and so the use of viscosity modifying agent is avoided. Glass fiber used is of alkali resistant (AR) Cem-FIL type having length 12mm and 14 micron diameter. The glass fiber is of high dispersion type with a specific gravity of 2.68.

2.2. Mix Proportioning

Mix design of SCC is carried out based on the guidelines of EFNARC [5]. In the initial step a mix design based on IS 10262-2009[12] was prepared for M30 mix, with 10 mm maximum size of aggregate and fine aggregate of Zone II. Initially water to binder ratio (W/B Ratio) of 0.40 was selected. This mix design was modified so as to meet all the requirements as per EFNARC guidelines. Based on trials it has been observed that at a higher proportion of glass fiber (0.05% & 0.075% by volume of mix) the slump flow values of the mix was lesser than the EFNARC specified range(650mm-800mm). Hence the water to binder ratio increased to 0.425 to obtain required workability. Table 1 shows the mix design details of the control mix.

***Table 1:** Mix Design: Control Mix*

Sl. No.	Material	Weight (kg/m^3)
1	Cement	350
2	Metakaolin	0
3	Fly ash	150
4	Glass Fiber	0
5	Fine Aggregate	905.27
6	Coarse Aggregate	806.20
7	Water	212.50
8	Admixture	3.75

Table 2 briefs the details of different SCC mix with combinations of Cement (CEM), Metakaolin (MK), Fly ash (FLA) and Glass Fiber (GF).

***Table2:** Mix Combinations of SCC*

Mix No.	CEM (kg/m^3)	MK (kg/m^3)	FLA (kg/m^3)	GF (%)	Admixture Dosage
CM	350	0	150	0	0.75
M1G1	300	50	150	0.025	0.95
M1G2	300	50	150	0.05	1.00
M1G3	300	50	150	0.075	1.05

2.3. Tests on Fresh Concrete

The fresh mix of SCC was subjected to various tests for workability as per EFNARC guidelines [5]. Slump flow test, T_{50} cm time test and V-Funnel test were conducted to assess the flowability of the mix. L-Box test was conducted to check the passing ability of the mix. The mix was also inspected for any segregation during the mixing process.

2.4. Tests on Hardened Concrete

As the part of analysis the 7 days and 28 days compressive strength values of each combination of the SCC mix were investigated. The early age strength characteristics of each mix combination were found out from 7 days compressive strength. This is essential to identify the variations in early age compressive strength due to addition of fly ash only (Control Mix) in the mix and also to find out the improvements while a combination of fly ash and metakaolin was used. The variations in compressive strength due to increase in addition rate of glass fiber was analyzed based on the 28 days compressive strength results. Concrete cube specimen of size 150 x 150 x 150 mm was casted, cured and tested under standard conditions as per relevant IS specifications. The compressive strength value was calculated as the average of 3 cube specimens.

3. Results and Discussion

The fresh and hardened properties of each mix combinations were analyzed and the details are given below

3.1. Fresh Concrete Properties

***Table 3:** Fresh Properties of SCC*

Mix Designation	Slump Flow (mm)	T_{50} (S)	L-Box Ratio	V Funnel (S)
CM	680	3.12	0.84	12.8
M1G1	680	4.65	0.81	11.54
M1G2	660	4.88	0.8	11.78
M1G3	650	4.95	0.8	12.01

The fresh concrete properties are analyzed as per the guidelines of EFNARC. The addition of metakaolin the makes the mix more viscous, and hence the use of viscosity modifying admixtures is not required in this case. The workability characteristics of the mix, especially the slump flow found to be improved significantly when the fly ash replacement level was increased from 25% to 30%. The finer size and spherical shape of the fly ash imparts lubricating effect on the mix, which contributes to the workability improvement. However the addition of glass fiber to this mix makes it more viscous and it results in reduction in slump flow below the EFNARC specified limit of 650mm. In order to improve the flow characteristics the water binder ratio was increased to 0.425 from the initially adopted value of 0.40. The fresh properties of each mix combination are analyzed at this water binder ratio and with varying percentages of admixture dosages and the results are explained in Table 3.

The slump flow values of different mix combination ranges between 650 to 680mm. The slump flow values found to reduce with the incremental addition of glass fiber from 0% to 0.075% and correspondingly the super plasticizer dosage needed to be increased from 0.75% to 1.05%. The reason for this reduction in workability can be related to the surface area of glass fiber, which also gets coated with mortar along with coarse aggregates. The T_{50} cm time of different mix combination found to be between 3.12 to 4.95 sec. The T_{50} cm time is the indication of the viscosity of the mix, which is found to increase due to addition of metakaolin as well as glass fiber. The L-box blocking ratio for all mixes ranges from 0.8 to 0.84. The addition of glass fiber in this case found to affect the passing ability of the SCC due to the increase in viscosity of the mix. The V-funnel time of different mix combinations found to be in between 11.54 to 12.8 sec. The V funnel time of control mix found to exceed the EFNARC specified range of 12 seconds. The segregation observed in the control mix makes it mix non homogeneous and thus causes the delayed flow time in the V funnel. Apart from this for the other mixes, the V funnel values found to increase with increase in glass fiber addition. The glass fiber at a higher addition rate (0.05% & 0.075%) found to control the segregation as observed in the case of SCC mix without glass fiber (Control Mix).

3.2. Properties of Hardened Concrete

As the part of analysis on hardened properties of SCC, such as compressive strength as well as split tensile strength were carried out.

Table 4: *Compressive Strength values of SCC*

Sl No.	Mix Proportion	7 Days Compressive Strength (MPa)	28 Days Compressive Strength (MPa)
1	CM	26.25	38.36
2	M1G1	40.05	42.68
3	M1G2	41.5	44.05
4	M1G3	42.3	46.23

The compressive strength values of each mix combinations were tested on 7 day & 28 day curing period and results are detailed in Table 4. The 7 day compressive strength value obtained for the control mix was 26.25 MPa, which was found to increase to a maximum of 42.3 MPa when metakaolin was added. This indicates influence of metakaolin in early age compressive strength development. This increase is attributed to the larger surface area of metakaolin, due to which it accelerates the hydration process. The maximum improvement for 28 day compressive strength was observed in case of mix M1G3 which shows an increase of 20.5% over the control concrete. The pozzolanic reaction of metakaolin due to which it forms more C-S-H gel, causes reduction in pores and increase in strength development of concrete at 28 days curing period. The impact on compressive strength due to the incremental addition of glass fiber (by 0.025%) is less significant in comparison with metakaolin. The maximum improvement in this regard observed in case of mix M1G3 over mix M1G2, which shows an increase of 5% in 28 days curing.

The split tensile strength values of all mix combinations are analyzed for a curing period of 28 days and test results summarized in Table 5. The split tensile strength values shows an increasing trend with increase in addition rate of the glass fiber in the mix. The maximum observed strength gain was 29.74% for mix M1G3 (containing 0.075% glass fiber) over the control mix. The reduction in the growth of micro cracks in concrete due to the addition of glass fiber causes improvement in the split tensile strength of concrete. The metakaolin also contributes for the improvement in split tensile strength, since it refine the pore structure of concrete due to its filling effect and pozzolanic reactions.

Table 5: *Split Tensile Strength values of SCC*

Sl No.	Mix Proportion	28 Days Split Tensile Strength (MPa)
1	CM	3.53
2	M1G1	3.94
3	M1G2	4.32
4	M1G3	4.58

4. Conclusions

The analysis on fresh and hardened properties of glass fiber reinforced self-compacting concrete with fly ash and metakaolin blend was carried out and the following conclusions can be drawn.

The combination of metakaolin and glass fiber found to affect the fresh properties of SCC, since it increases the viscosity of the mix and thereby reducing the flow of the mix. The fresh properties of SCC found to improve when the fly ash percentage was increased from 25% to 30%. Thus fly ash in the mix increases the powder content in SCC as well as reduces the super plasticizer requirement. The addition of glass fiber at higher proportion (0.05% & 0.075%) found to reduce bleeding in the mix and thus improves stability of the mix. The slump flow values of different SCC mix ranges between 650-680mm, the T_{50} cm time was between 3.12 to 4.95 sec, V funnel time's ranges between 11.54 to 12.8 sec and the L box blocking ratio values varies between 0.8 to 0.84.

The addition of metakaolin in the mix significantly improves the early age compressive strength from 26.25 MPa to 42.3 MPa and thereby compensating for slow strength gaining effect of fly ash as observed in the case of control mix. The 28 days compressive strength tests reveal that the addition of 10% of metakaolin can increase the compressive strength of SCC by 20.5% over the control concrete. The incremental addition of glass fibers (by 0.025%) found to increase the compressive strength of concrete, and the maximum improvement observed was 5%.

The split tensile strength values of different mix combinations ranges between 3.53 MPa to 4.58 MPa. The incremental addition of glass fiber significantly improves the split tensile strength values of concrete and the maximum observed improvement was 29.74% for mix having 0.075% of glass fiber. The addition of metakaolin also contributes for increase in split tensile strength.

From the comparison of fresh and hardened properties of different mixes, it has been observed that the glass fiber reinforced SCC shows superior strength characteristics over the control concrete. The increase in glass fiber addition reduces the flow properties of the mix and also it increases the super plasticizer demand. The optimum combination from the compared combination while considering the strength characteristics can be the mix M1G3; having 10% replacement level of metakaolin and 0.075% glass fiber addition. The workability of this particular mix was comparatively lesser than the other mixes, but it can be improved by increasing the super plasticizer dosage.

5. Scope for Further Study

The analysis on durability characteristics of the mix combinations can also be an area for investigation.

6. Acknowledgements

The authors express sincere gratitude to R.M.C Ready-mix Ltd., Cochin, Kerala for the kind support and guidance. And also extends thanks to the EICL Trivandrum for the allocation of High Reactive Metakaolin (H.R.M) for the work.

References

[1] Ahmet B. Kizilkanat, Nihat Kabay, Veysel Akyiincil, Swaptik Chowdhury, Abdullah H, " Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study", *Construction and Building Materials*, Vol. 100, PP. 218-224, 2015.

[2] Barluenga G, F. Hernández-Olivares, **"**Cracking control of concretes modified with short AR-glass fibers at early age. Experimental results on standard concrete and SCC", *Cement and Concrete Research*, Vol. 37, PP. 1624–1638, 2007.

[3] Erhan Guneyisi, Mehmet Gesoglu, " Properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and metakaolin", *RILEM Journal of Materials and Structures,* Vol. 41, PP. 1519–1531, 2008.

[4] Erhan Guneyisi, Mehmet Gesoglu, Erdogan Ozbay, "Strength and drying shrinkage properties of self-compacting concretes incorporating multi-system blended mineral admixtures", *Construction and Building Materials*, Vol. 24, PP. 1878–1887, 2010.

[5] EFNARC, 2005. The European Guidelines for Self-compacting Concrete Specification, Production and Use (May)

[6] Hajime Okamura, Masahiro Ouchi "Self-Compacting Concrete" *Journal of Advanced Concrete technology*, Vol. 1, PP. 5-15, 2003.

[7] Kavitha O R, Shanthi V M, Prince Arulraj, Sivakumar P, "Fresh, micro- and macrolevel studies of metakaolin blended self-compacting concrete", *Applied Clay Science,* Vol. 114, PP. 370–374, 2015.

[8] Rafat Siddique, "Properties of self-compacting concrete containing class F fly ash", *Materials and Design,* Vol. 32, PP. 1501–1507, 1997.

[9] Rahmat Madandoust, S. Yasin Mousavi, "Fresh and hardened properties of self-compacting concrete containing metakaolin", *Construction and Building Materials,* Vol. 35, PP.752–760, 2012.

[10] Shashidhara Marikunte, Corina Aldea, and Surendra P. Shah,"Durability of Glass Fiber Reinforced Cement Composites" *Advanced Cement Based Materials,* Vol.5, PP. 100-108, 1997.

[11] Suresh Babu T, " Mechanical Properties And Stress- Strain Behavior Of Self compacting Concrete With And Without Glass Fibers", *Asian journal of civil engineering (building and housing)*,Vol. 9, PP. 457-472, 2008.

[12] *IS: 383-1970. Specification for coarse and fine aggregates from natural sources for concrete. New Delhi (India): Bureau of Indian Standards.*

[13] *IS: 456-2000.Plain and Reinforced Concrete - Code of Practice New Delhi (India): Bureau of Indian Standards.*

[14] *IS: 3812-1 -2003. Specification for Pulverized Fuel Ash, Part 1.For use as pozzolana in cement, cement mortar and concrete*

[15] *IS: 10262-2009.Concrete Mix Proportioning-Guidelines. New Delhi (India): Bureau of Indian Standards.*