Investigation on Performance of Fly Ash Based Self Compacting Concrete with Metakaolin and Quarry Dust

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Abstract Self-compacting concrete is a fresh concrete that flows under its own weight and does not require external vibration to undergo compaction. It is used in the construction where, it is hard to use vibrators for consolidation of concrete. The acute shortage and high price of river sand led to the enormous usage of M sand in construction. Use of quarry dust as a fine aggregate is a good alternative to M sand and a better remedy to the disposal of quarry dust. Quarry dust is a by-product from the crushing process during quarrying activities. Large scale of cement production causes the discharge of high amount of carbon dioxide resulting in global warming. This can be reduced by the use of metakaolin, as a partial replacement for cement contributing to higher workability, long term strength and to make concrete more economically available. In this study an attempt is made to study on the M40 equivalent fly ash based self-compacting concrete is partially replacing cement with metakaolin by 10, 15 and 20% of weight of cement and the fine aggregate is partially replacing with quarry dust by 20, 25, 30 and 35% of weight of fine aggregate and in order to evaluate the strength parameters, they are compared with M40 equivalent fly ash based self-compacting concrete.

Keywords Self-compacting concrete · Metakaolin · Quarry dust

1 Introduction

Self-compacting concrete (SCC) is a concrete which can be placed and compacted under its self weight without vibration effort. It has high workability that it can flow under its own weight [1]. SCC mixes usually contain superplasticizer, high content of fines and/or viscosity modifying additive (VMA). The use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation [2]. Self-compacting concrete is a recent development in the construction industry. The utilization of SCC started growing

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rapidly, EFNARC, making use of broad practical experience of all members of Europe federation with SCC, has drawn up specification and guidelines to provide a frame work for design and use of high quality SCC during 2001 [3].

Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time such as Metakaolin (MK). It possesses a high reactivity with calcium hydroxide having the ability to accelerate cement hydration. Metakaolin reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel [4, 5]. The scarcity of good quality natural river sand due to depletion of resources and restriction due to environmental consideration has made concrete manufactures to look for suitable alternative fine aggregate. One such alternative is Quarry Dust (QD), it is generally considered as a waste material after the extraction and processing of rocks can be used as a replacement for fine aggregate [6–8]. The experimental program is designed to investigate the strength of fly ash based self-compacting concrete by replacement of cement with metakaolin at 10, 15 and 20% by weight of cement and replacement of fine aggregate with quarry dust at 20, 25, 30 and 35% by weight of fine aggregate. The slump flow test, T50 test and J ring test were conducted for all mixes to know the fresh property of self-compacting concrete. Compressive strength, Flexural strength and Split tensile strength test was conducted at 7 and 28 days and the values are compared with the values of fly ash based self-compacting concrete.

2 Objectives

The main objective of this investigation is:

- To establish M40 equivalent Fly ash based Self-Compacting Concrete based on strength parameters.
- To evaluate the optimum percentage of Metakaolin in Fly Ash based SCC, the metakaolin is partially replaced at 10, 15 and 20% of weight of cement.
- To evaluate the optimum percentage of Quarry Dust with optimum percentage of Metakaolin in Fly Ash based SCC, the quarry dust is partially replaced at 20, 25, 30 and 35% of weight of FA.
- To analyse the fresh and hardened properties of Fly Ash based SCC with optimum percentage of Metakaolin and Quarry Dust.

3 Materials and Properties

The different material tests used in this investigation and test results of the materials are illustrated in Table 1.

The sieve analysis was done for the gradation of aggregate. From that study the fine aggregate and quarry dust are in zone 2, these can be used for the concrete works. The water absorption is also conducted for coarse aggregate (not greater than 2%)

Table 1 Material properties

Materials	Tests	Test results	Reference code
Cement	Fineness	5%	IS 4031-1988 Part-IV (Reaffirmed 2009)
	Consistency	32%	IS 4031-1988 Part-XI (Reaffirmed 2009)
	Initial setting time	45 min	IS 4031-1988 Part-V (Reaffirmed 2009)
	Specific gravity	3.15	IS 4031-1988 Part-IV (Reaffirmed 2009)
Fine aggregate	Specific gravity	2.68	IS 2386-1963 Part-III (Reaffirmed 2016)
	Water absorption	2.24%	IS 2386-1963 Part III (Reaffirmed 2016)
Coarse aggregate	Specific gravity	2.72	IS 2386-1963 Part-III (Reaffirmed 2016)
	Water absorption	0.354%	IS 2386-1963 Part III (Reaffirmed 2016)
Quarry dust	Specific gravity	2.57	
Fly ash	Specific gravity	2.3	
Metakaolin	Specific gravity	2.6	

and fine aggregate (between 0.3 and 2.5%) and the results are in specified limits, shown in Table 1. Based on these material properties the mix design is carried out.

3.1 Mix Design

The mix designs were carried out for concrete grade 40 MPa based on European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC) guidelines [9] and IS 10262: 2009 [10] (Table 2).

Table 2 Mix design of specimen with varying percentage of fly ash, metakaolin and quarry dust

Notation	Cement (kg/m^3)	Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	QD (kg/m^3)	MK (kg/m^3)	SP (l/m^3)	Water (l/m^3)
F30 (CM)	413	177	848	765	0	0	3.54	200
F30MK10	354	177	848	765	0	59	3.54	200
F30MK15	324.5	177	848	765	0	88.5	3.54	200
F30MK20	295	177	848	765	0	118	3.54	200
F30MK15QD20	324.5	177	679	765	169	88.5	3.54	200
F30MK15QD25	324.5	177	636	765	212	88.5	3.54	200
F30MK15QD30	324.5	177	594	765	254	88.5	3.54	200
F30MK15QD35	324.5	177	551	765	297	88.5	3.54	200

Table 3 Workability results

Mixes	Slump flow (mm)	J-ring (mm)	Passing ability (mm)	T50 slump flow (s)	Remarks (as per ASTM 1621/C 1621 M)
F30 (CM)	681	672	9	2.5	No visible blocking since passing ability values are between 0–25 mm
F30MK10	670	662	8	3	
F30MK15	690	681	9	2.5	
F30MK20	675	667	8	2.8	
F30MK15QD20	715	706	9	2.5	
F30MK15QD25	705	695	10	2.6	
F30MK15QD30	690	682	8	2.9	
F30MK15QD35	674	665	9	3.5	

4 Results and Discussions

4.1 Fresh Properties

The main characteristics of Self-Compacting Concrete are the properties in the fresh state. Several test methods have been developed in attempts to characterize the properties of Self-Compacting Concrete. In this study three properties are used to evaluate the fresh properties of Self-Compacting Concrete, shown in Table 3. F30 represents the SCC containing fly at 30%. F30MK10, F30MK15 and F30MK20 represents the SCC containing MK at 10%, 15% and 20% respectively. F30MK15QD20, F30MK15QD25, F30MK15QD30 and F30MK15QD35 represents the SCC containing QD at 20%, 25%, 30% and 35% respectively. Fresh property tests are done and the fresh properties of SCC satisfies the requirements of EFNARC guidelines.

4.2 Hardened Properties

The properties of hardened SCC were measured in terms of Compressive Strength, Split Tensile Strength test and Flexural Strength Test confirming to IS 516: 1959.

Compressive strength test was conducted on 150 mm × 150 mm × 150 mm concrete cubes as per IS 516: 1959 (reaffirmed 2018) in digital compression testing machine. Compressive strength test was conducted after 7 days and 28 days of curing. The compressive strength of fly ash based self-compacting concrete cubes by varying the percentage of metakaolin and quarry dust is given in Table 4 and Fig. 1. After 28 days of curing the SCC with 15% metakaolin gives the maximum compressive strength, the value is 57.8 N/mm^2 at 28 days. This mix gives 17.4% increase in

Table 4 Compressive strength of self-compacting concrete with different mix

Notation	Compressive strength (N/mm^2)	
	7 days	28 days
F30 (CM)	**36.45**	**49.23**
F30MK10	44.8	57.1
F30MK15	**45.21**	**57.8**
F30MK20	44.01	56.2
F30MK15QD20	35.8	48.2
F30MK15QD25	**37.8**	**50.3**
F30MK15QD30	39.2	52.31
F30MK15QD35	35.9	48.5

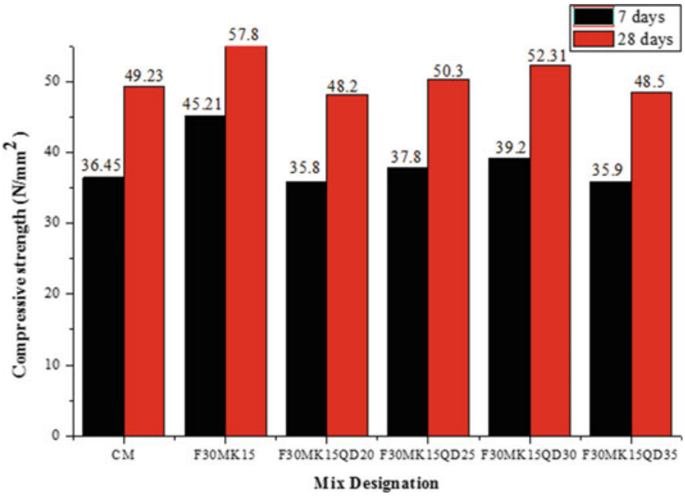

Fig. 1 Variation of compressive strength with optimum percentage of fly ash, metakaolin and varying percentage of quarry dust

strength at 28 days when correlated to control mix. The reasons for improve the compressive strength of SCC is metakaolin reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel and it enhance strength parameters. The compressive strength for 25% QD is 50.3 N/mm^2. This mix gives 14.91% decrease in strength when compared to F30MK15 and 2.17% increase in strength at 28 days when correlated to control mix. The reasons of the improvement in strength is the higher amount of finer particles in the quarry dust act like fillers by filling the voids between cement paste and aggregate and thus increases the strength.

Split tensile strength test was conducted as per IS: 5816: 1999 (reaffirmed 2018) in digital compression test in machine. Split tensile strength test was conducted after 7 and 28 days of curing. The effects of metakaolin in fly ash based self-compacting

Table 5 Split tensile strength of fly ash based self-compacting concrete with varying percentage of metakaolin

Notation	Split tensile strength (N/mm^2)	
	7 days	28 days
CM	**2.8**	**3.9**
F30MK10	3.3	4.2
F30MK15	**3.6**	**4.4**
F30MK20	3.1	4.1
F30MK15QD20	2.9	4
F30MK15QD25	**3.1**	**4.1**
F30MK15QD30	3.3	4.2
F30MK15QD35	2.8	3.9

concrete on the tensile strength are shown in Table 5. The tensile strength value of SCC increases with increase in percentage of cement replacement with metakaolin upto a percentage of 15%. The split tensile strength gain maximum at 15% replacement of cement with metakaolin. The effects of metakaolin and quarry dust in fly ash based self-compacting concrete on the tensile strength are shown in Table 5 and Fig. 2. The split tensile strength is obtained as 4.1 N/mm^2 for 25% replacement.

This mix gives 7.31% decrease in strength when compared to F30MK15 and 5.12% increase in strength at 28 days when correlated to control mix.

Flexural strength test was conducted as per IS 516: 1959 (Reaffirmed 2018) in Universal testing machine. Flexural strength test was conducted after 28 days of curing. The effects of metakaolin in fly ash based self-compacting concrete on the flexural strength are shown in Table 6. The maximum flexural strength is 6.2 N/mm^2 for 15% replacement of metakaolin. The effects of metakaolin and quarry dust in fly

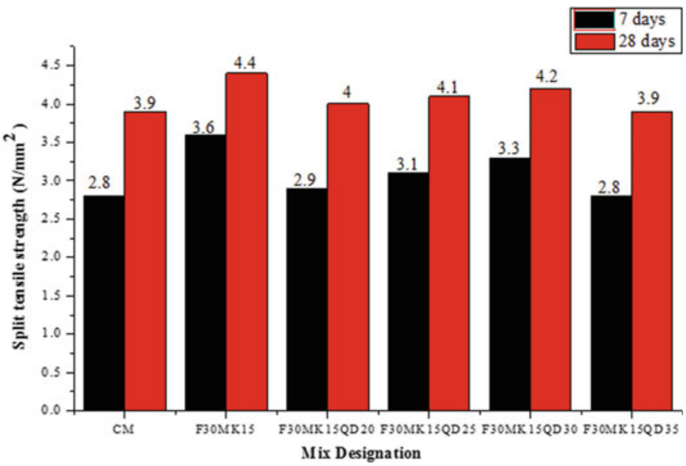

Fig. 2 Split tensile strength of fly ash based self-compacting concrete with optimum percentage of metakaolin and varying percentage of quarry dust

Table 6 Flexural strength of fly ash based self-compacting concrete with varying percentage of metakaolin

Notation	Flexural strength (N/mm^2)
	28 days
CM	**5.4**
F30MK10	5.9
F30MK15	**6.2**
F30MK20	5.5
F30MK15QD20	5.5
F30MK15QD25	**5.7**
F30MK15QD30	5.9
F30MK15QD35	5.3

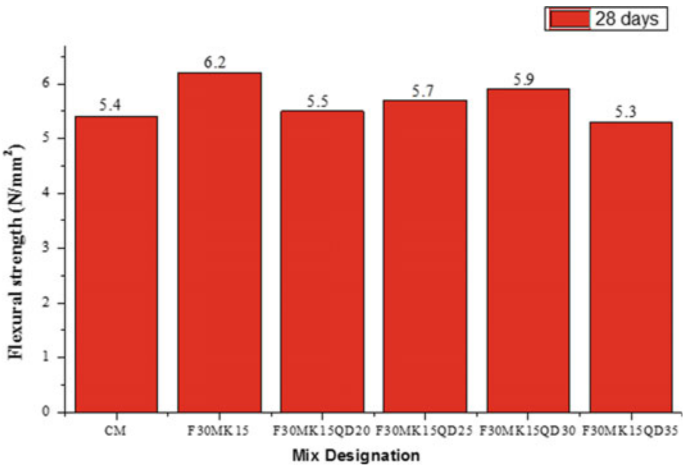

Fig. 3 Flexural strength of fly ash based self-compacting concrete with optimum percentage of metakaolin and varying percentage of quarry dust

ash based self-compacting concrete on the flexural strength are shown in Table 6 and Fig. 3. The flexural strength is 5.7 N/mm^2 for 25% replacement of fine aggregate by quarry dust. This mix gives 8.77% decrease in strength compared with F30MK15 and 5.5% increase in strength at 28 days when correlated to control mix.

5 Conclusions

Based on the experimental investigation, the following conclusions were drawn.

- Mix proportion of SCC is derived with various test conforming to the requirements of Self compacting concrete conforming to the acceptance criteria of SCC and

EFNARC guidelines. Fresh property tests of all the mixes are done and the fresh properties of SCC satisfies the requirements of EFNARC guidelines.

- The control mix can be adopted as F30 based on strength parameters.
- In fly ash based SCC with 15% MK compared with control mix, the compressive strength increased about 17.4% (49.23–57.8 N/mm^2), split tensile strength increased about 12.82% (3.9–4.4 N/mm^2) and the flexural strength is increased about 14.1% (5.4–6.2 N/mm^2) at 28 days.
- Also the fresh properties of SCC with 15% MK satisfies the requirements of EFNARC guidelines.
- The optimum amount of metakaolin was obtained as 15% in terms of compressive strength, split tensile strength and flexural strength. Beyond the optimum replacement level, the strength was reduced, but greater than the control mix.
- The reasons for improve the strength parameters of SCC is metakaolin reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel and it enhance strength parameters.
- In fly ash based SCC with 15% MK and 25% QD is compared with F30MK15, the compressive strength decreased about 14.91% (57.8–50.3 N/mm^2), split tensile strength decreased about 7.31% (4.4–4.1 N/mm^2) and the flexural strength is decreased about 8.77% (6.2–5.7 N/mm^2) at 28 days.
- In fly ash based SCC with 15% MK and 25% QD is compared with control mix, the compressive strength increased about 2.17% (49.23–50.3 N/mm^2), split tensile strength increased about 5.12% (3.9–4.1 N/mm^2) and the flexural strength is increased about 5.5% (5.4–5.7 N/mm^2) at 28 days.
- The optimum amount of quarry dust was obtained as 25% and these values are less than the optimum percentage of metakaolin mix, but greater than control mix.
- The main reason of the improvement in strength parameters is the higher amount of finer particles in the concrete mix, these finer particles of quarry dust act like fillers by filling the voids between cement paste and aggregate and thus strengthen the concrete specimen.
- The use of quarry dust as a replacement for fine aggregate is environmentally helpful and it reduce the construction cost. So the quarry dust is an alternative material for replacing fine aggregate for manufacturing of concrete.
- So it can be concluded that, the fly ash based self-compacting concrete with 15% replacement of metakaolin in cement and 25% replacement of quarry dust in fine aggregate shows greater strength and workability than the control mix. It can be effectively used where compaction is very difficult due to the presence of heavy reinforcements like beams, columns and for structural members with typical architectural requirements.

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