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Experimental Investigation of Strength and Durability Properties of Self-healing Concrete using Silica Fume and Metakaolin as Mineral Admixtures

Mohammad Noorul Husen Khan

Department of Civil Engineering Dr MGR Educational and Research Institute University
Maduravoyal, Chennai Tamilnadu, India
E-mail: noorulhusen.nep@gmail.com

Abstract—*Self-healing phenomenon in cementitious materials has been noticed and been studying for a long time. One of the strategies employed for the self-healing of cementitious material is using mineral admixtures like silica fume. This research outlines the method of preparation, testing procedure and salient results on self-healing and also the eco-friendly concrete that is manufactured using the waste products of coal industries. The effects of self-healing on normal concrete by adding small amounts of silica fume to concrete is studied. For this purpose, silica fume is added to concrete at percent of 12.5% and cement is replaced by metakaolin by 0%, 5%, 10% & 15% been prepared having a constant water-cementitious material ratio of 0.45. M30 mix design is being done as per the Indian Standard Code IS: 10262-1982. A uniaxial compression load was applied to generate micro cracks in concrete where cube specimens were pre-loaded up to 70% and 90% of the ultimate compressive load determined at 28 days. Later, the extent of damage was determined as percentage loss in mechanical properties (as determined by setting time, compatibility, bond strength, compressive strength) and percentage increase in permeation properties (Sulphate attack, chloride ingress, carbonation). After pre-loading, concrete specimens are stored in water for a month, the mechanical and permeation properties are monitored every two weeks and increase or decrease in strength and durability properties are studied.*

Keywords*: Cementitious; self – healing; uniaxial; pre – loading;*

1. INTRODUCTION

The deterioration of concrete structures before the end of service life can be prevented by means of using self-healing concrete. From the construction of foundation to bridge structures, concrete is the main component for construction. Traditional concrete when subjected to tensile load, it exhibits cracking. A healing agent that works when bacteria embedded in the concrete convert nutrients into limestone has been under development.

This project is to study the self-healing potential of plastics, polymer composites, asphalt and metals as well as concrete.

The first self-healing concrete products (successful research results permitting) are expected to hit the market in two years' time and are expected to increase the lifespan of many Civil Engineering structures.

2. WHY THE NEED?

Concrete is the most important building material. Major problem in concrete is cracking. Cracking cause the water to seep and degrade concrete as well as steel.

As we know, concrete is good in compression and weak in tension, we opt for steel as a reinforcement in concrete structures.

But structures under water are vulnerable to steel corrosion. In order to heal the cracks before the steel reinforcement gets corroded, we can go for self-healing concrete.

3. METHODOLOGY

This research aims to discuss the effects of self-healing of concrete by adding any mineral admixtures like metakaolin and silica fume. The effects of self-healing on normal concrete incorporating the mineral admixtures when subjected to continuous water exposure will be studied. For this purpose, normal concrete with different mineral admixture replacement ratios will be prepared having a constant water-cementitious material ratio of 0.45. A uniaxial compression load was applied to generate microcracks in concrete where cube specimens were pre-loaded up to 70% and 90% of the ultimate compressive load determined at 28 days.

Later, the extent of damage will be determined as percentage of loss in mechanical properties (as determined by compressive strength and split tensile tests) and percentage of increase in permeation properties (water permeability and sorptivity index test). After pre-loading, concrete specimens will be stored in water for a month and the mechanical and permeation properties be monitored every two weeks.

4. EXPERIMENTAL STUDY

Fig. 1a: Silica fume

Fig. 1b Metakaolin

Use of silica fume (Figure 1 a) and Metakaolin (Figure 1 b) in concrete reduces the effect of alkali silica reaction in concrete. Use of mineral admixtures like silica fume and metakaolin offers good resistance to chloride attack. It consequently reduces the corrosion of steel reinforcement. It also protects the concrete structures from sulphate attack and ingress of other harmful chemicals.

Highly durable concrete can be achieved by adopting a dense concrete matrix. Dense concrete matrix typically means a very compact microstructure which increases the strength properties as well as decreasing the permeability thereby providing good resistance to transport of corrosive materials to the steel reinforcement. Use of well graded particles in concrete mix conceptually produces a dense matrix which is in turn affected by the use of mineral additives such as silica fume, or by the use of low water-to-cement ratios. In order to produce a highly durable self-healing concrete, cubes have been prepared by adding silica fume in percentage of 12.5% as a binder in addition to adding cement to concrete. Also cubes are prepared by replacing 5%, 10% and 15% of cement with metakaolin. Silica fume was added in percentage of 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%. It has been experimentally found that 12.5% gave the maximum strength and it was the optimum percentage to be added as a self-healing agent. A conventional mixture without any admixture is cast for comparing the strength and durability properties of silica fume and metakaolin concretes. Microcracks are produced in the concrete specimens by applying 70% and 90% of ultimate compressive strength after 28 days curing. The preloaded concrete specimens are tested for compressive strength and split tensile tests at 7 and 28 days and sorptivity index tests after 28 days. The physical properties of the cement, fine aggregates and coarse aggregates are determined by means of conducting standard tests. M30 grade concrete was used for testing.

5. TEST RESULTS

The physical properties of silica fume have been found out and the results are given in table 1.

Table 1: Physical Properties Of Silica Fume

Physical Parameters	Silica fume
Particle size (typical)	< 1 µ m
Bulk density (as-produced)	130 to 430 kg/m^3
(slurry)	1320 to 1440 kg/m^3
(densified)	480 to 720 kg/m^3
Specific gravity	2.2
Surface area (BET)	13,000 to 30,000 m^2/kg

The presence of any type of very small particles will improve concrete properties. This effect is termed either “particle packing” or “micro filling”.

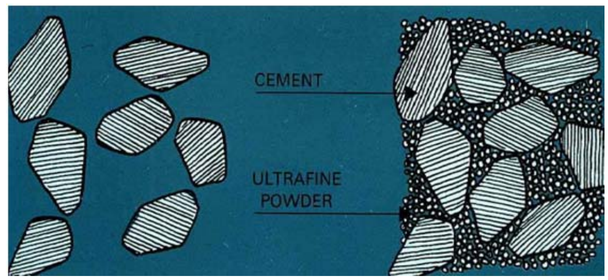


Fig. 2: Particle packing effect

Silica fume is simply a very effective pozzolanic material which plays a vital role in producing calcium hydroxide which helps in healing the cracks.

The physical properties of the cement, fine aggregate and coarse aggregate used in concrete mix were determined by means of conducting standard tests like consistency, setting time, water absorption, specific gravity and density and the results are given in table 3.

In order to determine the mechanical properties of conventional concrete and the concrete made with silica fume, compressive strength, split tensile strength and flexural strength tests were conducted and the results are given below in table 4.

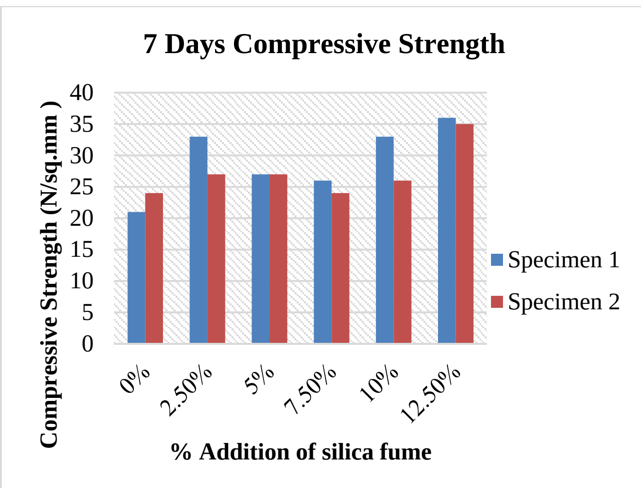
Table 3: Test Results on Cement, Fine Aggregates and Coarse Aggregates

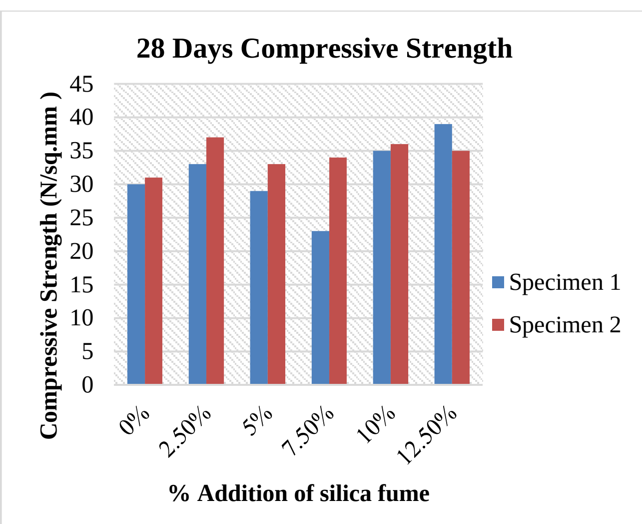
CEMENT	
Specific gravity	3.15
Fineness of cement by dry sieving	1%
FINE AGGREGATE	
Fineness modulus	3.416
D_{10}	0.25 mm
D_{30}	0.42 mm
Uniformity coefficient	3.28
Coefficient of curvature	0.86
Percentage of coarse sand	46.2%
Percentage of medium sand	45.8%
Percentage of fine sand	1.0%
Specific gravity	2.575
Bulk density in loose state	1550 kg/m^3

Bulk density in rodded state	1674.2 kg/m^3
COARSE AGGREGATE	
Fineness modulus	3.169
Bulk density in loose state	1680.22 kg/m^3
Bulk density in rodded state	1823.20 kg/m^3
Specific gravity	2.833
Water absorption	0.41%

TABLE 4 COMPRESSIVE STRENGTH RESULTS IN N/MM^2

Specimen no	Days	Percentage of Silica fume					
		0%	**2.5%**	**5%**	**7.5%**	**10%**	**12.5%**
1	7	21	33	27	26	33	36
2		24	27	27	24	26	35
1	28	30	33	29	23	35	39
2		31	37	33	34	36	37

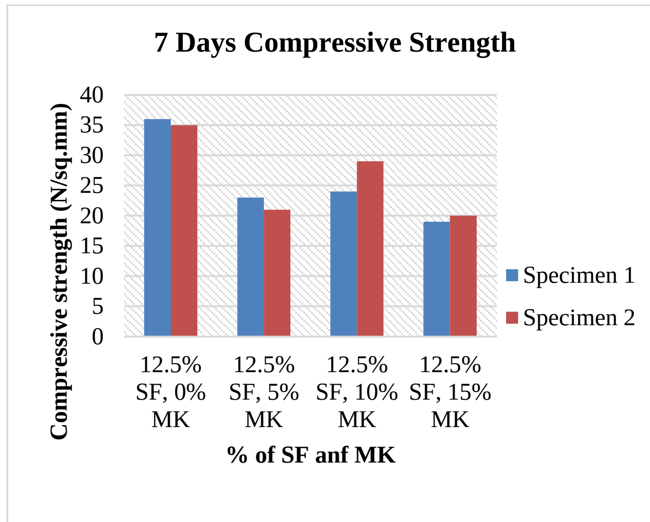


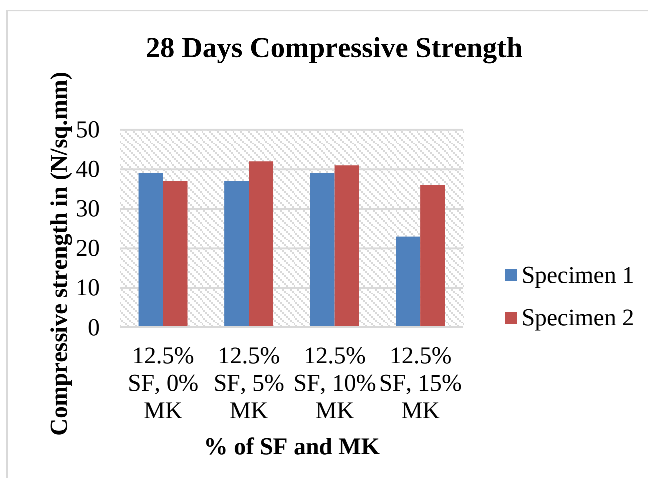


After finding the optimum percentage (12.5%) of silica fume which gave the maximum strength, metakaolin is used as a partial replacement of cement in the percentage of 5%, 10% and 15% and compressive strength results are shown in table 5.

Table 5: Compressive Strength Results In N/Mm^2

Specimen no	Days	Percentage of Silica fume	Percentage of metakaolin			
			0%	**5%**	**10%**	**15%**
1	7	12.5%	36	23	24	19
2			35	21	29	20
1	28		39	37	39	23
2			37	42	41	36



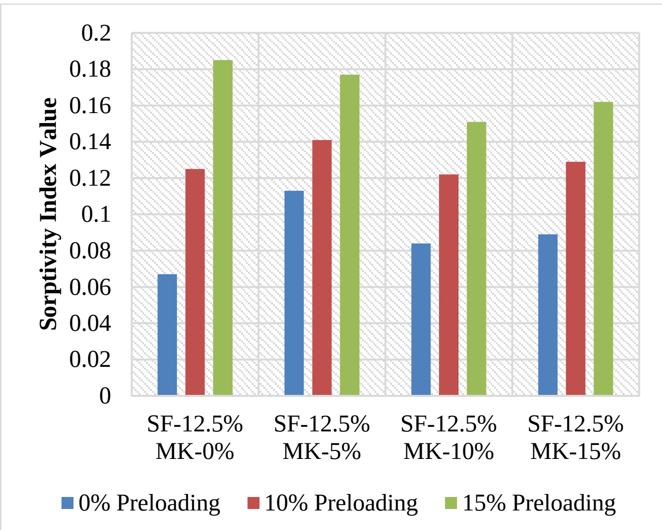


The durability of the concrete mixes using metakaolin and Silica fume as admixtures have been determined using Sorptivity test and the healing effect was studied through Sorptivity Index values. The sorptivity test has been studied under continuous water exposure.

Sorptivity test results using Silica fume and metakaolin as mineral admixture is given in table. 6.

Table 6: Sorptivity Test Results Using Silica Fume and Metakaolin as Mineral Admixture

Mineral Admixtures		Pre – Loading		
Metakaolin (%)	**Silica Fume (%)**	**0%**	**70%**	**90%**
0	12.5	0.067	0.125	0.185
5		0.113	0.141	0.177
10		0.084	0.122	0.151
15		0.089	0.129	0.162



6. CONCLUSION

In this research work, Silica fume concrete was tested for compressive strength for ultimate loading. It was found that the mix has given maximum strength at 12.5% addition of silica fume and 10% replacement of metakaolin. The concrete had good workability and the hardened concrete had good durability. As the study describes the presence of very minute silica and metakaolin particles available in the microstructure of concrete, these observations are attributed to the self-healing of the pre-existing cracks, mainly by hydration of anhydrous particles (Silica fume and MK) on the crack surfaces.

When 12.5% of silica fume is added to total weight of cement, the strength increases twice the target mean strength, the compression increases and hence there is increase in tensile strength thereby ductility increases and the cracks are reduced.

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