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An Experimental Study on Flyash as Self Healing Material

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Abstract

Self healing concrete is the need of the hour in the current scenario. Deterioration is inevitable although innovations are streaming in the field of concrete technology. Admixtures come handy in economy point of view for achieving self-healing in concrete structures so as to reduce the cracks in the earlier stage itself. In this research work, Fly Ash (FA) is used as an admixture for achieving self-healing in concrete. Different proportions are tested and the optimum replacement of fly ash is found out experimentally as 25%. Strength tests like compression, split tensile, flexure, ultrasonic pulse velocity tests are carried out to assess the mechanical properties of the concrete specimens. The specimens are cured for 28 days, preloaded for 80% of ultimate compressive strength and again kept under continuous water exposure for another 28 days so as to facilitate self-healing process. The tests exclusive for determining the self-healing process of concrete are sorptivity, water absorption, beam crack width and depth determination. FESEM and EDAX analysis are done for obtaining the crystal structure and mineral composition of the healed specimens. The test results indicated that fly ash proved to be a good self-healing agent without compromising on strength parameters.

Keywords: Deterioration, Self – healing, Admixture, Preloaded

INTRODUCTION

Durability of concrete is associated with dense concrete matrix, is conceptually a very compact microstructure and lower permeability which can be achieved by adopting well graded particle size distribution, use of mineral additives like fly ash and silica fume or by the use of low water to cement ratio. Cracks formed in the structures can be prevented at the earlier stage itself by controlling the factors causing deterioration, thereby following the self-healing technique naturally. Self-healing is attributed by the formation of calcium carbonate due to exposure to atmospheric moisture. Age of concrete also plays a major role in self-healing mechanism – longer the age of concrete, higher will be the calcium carbonate precipitation (Ferrara et al., 2014).

Some researchers have already suggested adopting low water binder ratios in the mix design, thereby facilitating the availability of more unhydrated particles for autogenous healing to take place. Though the use of admixtures like fly ash and blast furnace slag decreases the strength of concrete, their use as a self-healing material is highly appreciable. Research has shown that fly ash can be replaced upto 85% and in general, can be said, higher the replacement percentage of slag and fly ash, higher will be the self-healing capacity.

LITERATURE STUDY

Tittelboom etal (2012) have studied the effect of blast furnace slag and fly ash on crack healing ability of concrete structures. The reason for self-healing is that slag and fly ash reacts slowly to for hydration products and due to the excess time taken for hydration reaction, forming a dense matrix. Microscopic analysis indicated that crack widths below 200μm closed completely due to CaCO3 formation.

Edvardsen (1999) has given some recommendations after investigating the self-healing behaviour of structures, subjected to water exposure. The results showed that the cracks healed at a faster rate at earlier stages. As well as active cracks showed good healing response compared to dormant ones. The microstructure analysis showed the formation of CaCO3 crystals.

Sangadji and Schlangen (2012) proposed a new self-healing technique, similar to the concept of bone morphology, making use of a prefabricated cylindrical porous concrete core, placed internally in the concrete beam. Once the formation of cracks is detected by sensors, a healing agent is infused in the gap between the beam and the cylindrical concrete core. The proposed method is suitable to adopt when the cracks are inaccessible and when it is too dangerous for a manual repair to adopt.

Sahmaran etal (2008) have discussed the self-healing effect on self-consolidating concrete using fly ash as mineral additive. The fly ash replacement ratio adopted in this research is 35% and 55% with a constant water binder ratio of 0.35. Micro cracks are generated by preloading the specimens by 70% and 90% of ultimate compressive strength. The extent of damage and the efficiency of self-healing was determined by compressive strength, UPVT, rapid chloride permeability and sorptivity tests. The microstructure analysis of the healed slices indicated the formation of CSH gel as the healing product.

Min etal (2011) have reviewed that the process of self-healing is a combination of combined physical and chemical processes. The use of hollow fibres, microencapsulation techniques, expansive agents, mineral admixtures, bacteria and shape memory alloys come handy whenever we need self-healing effect to take place in a structure.

Kamran etal (1998) have described the application of a liquid metal to preserve the stress induced micro cracks in concrete caused due to external loading. SEM analysis showed that unloaded specimens had interfacial transition zone, which is a collection of interconnected pores. These interconnected pores connect with each other to form cracks when external load is applied which is preserved for later studies by pouring the molten metal which is an efficient, cost effective and reliable method.

METHODOLOGY

To study the self-healing behavior, cubes have been prepared by replacing fly ash in percentage of 5%, 10%, 15%, 20%, 25% and 30% and for reference, a conventional M30 concrete cube is cast without adding fly ash. Micro-cracks are produced in the concrete specimens by applying 70% of ultimate compressive strength after 28 days curing. The preloaded concrete specimens are tested for compressive strength, tensile strength, flexural strength and ultrasonic pulse velocity tests at 7 and 28 days to assess the mechanical properties of conventional concrete as well as fly ash replaced concrete. Durability properties are assessed by means of Rapid Chloride Penetration Test (RCPT), Sorptivity index, Water absorption test, Flexural test + Ultrasonic Pulse Velocity Test (UPVT). Crack width and depth measurement in done in flexure beams. SEM and EDAX analysis is carried out to ascertain whether self-healing has taken place due to the addition of fly ash.

TEST RESULTS

The physical properties of raw materials used in the experimental study are given in table 1.

Table I. Details of Raw Materials Used

Raw Material	Type / Source	Specific Gravity	Total Absorption
Cement	Zuari OPC 53Grade	3.15	NA
Fly Ash	Ennore	2.20	NA
Coarse Aggregate	20mm graded – Walajabad	2.70	0.40
	12.5mm/10mm graded – Walajabad	2.70	0.54
Fine Aggregate	M.Sand from VSI Crusher– Walajabad	2.65	1.35
Admixture	Varaplast SP123 – Akarsh Specialities	1.20	---
Water	Suitable for Construction Purpose	1.00	---

The mix design adopted was M30 and the density is kept constant. The details of mix desi

Table 2. Mix Designs Adopted

Material	OPC + FA design
OPC	270
Fly Ash	90
20mm	597
12.5mm	469
MS	856
Water	170
SP123 L	3.1
TOTAL	2452

7 and 28 days compressive strength results are given in table 3.

Table 3. Compressive Strength Test Results

Days	Fly ash replacement percentage (%)						
	0	5	10	15	20	25	30
7	30	28	26	26	26	30	23
28	57	47	47	46	43	56	42

The compressive strength results for different fly ash replacement percentages are shown graphically in figure 1.

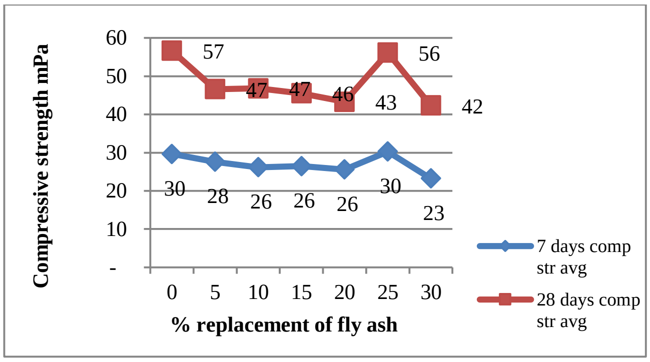

Figure 1. Compressive Strength Test

28 days split tensile strength results are given in table 4.

Table 4. Split Tensile Strength Test Results

Specimen	% replacement of fly ash						
	0	5	10	15	20	25	30
Specimen 1	2.776	2.64	2.57	2.43	2.07	2.67	1.75
Specimen 2	2.845	2.31	3.59	2.93	3.33	3.56	2.46

The split tensile strength results are shown graphically in figure 2.

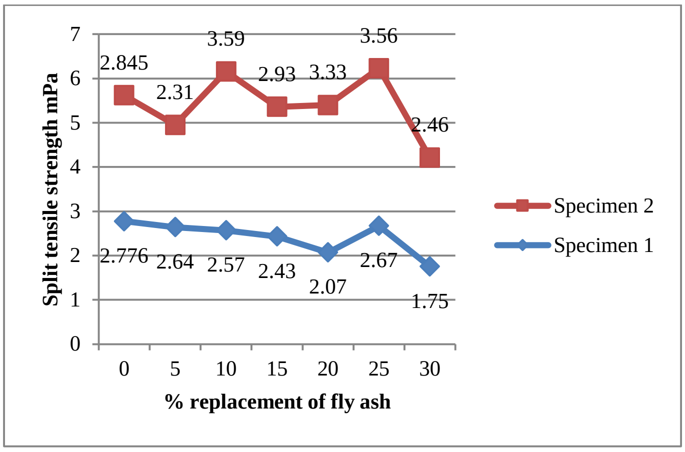

Figure 2. Split Tensile Test

28 days flexural strength results are given in table 5.

Table 5. Flexural Strength Test Results

% replacement of fly ash						
0	**5**	**10**	**15**	**20**	**25**	**30**
2.93	3.61	4.48	4.12	3.61	5.05	4.46

The flexural strength results are shown graphically in figure 3.

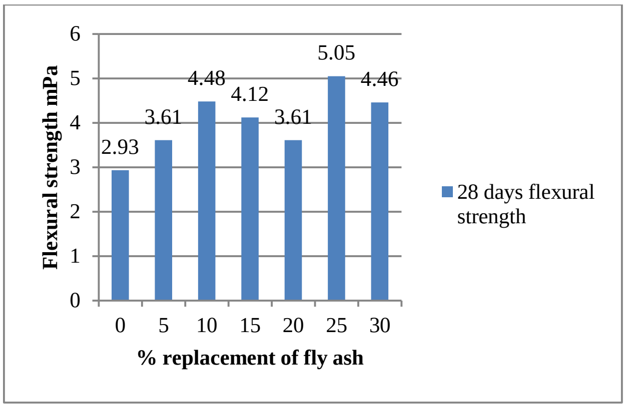

Figure 3. Flexural Strength Test

Ultrasonic pulse velocity test was conducted initially after 28 days curing. Then micro-cracks are induced by applying 70% of ultimate compressive load and UPV test is carried out. Then the specimens are kept undisturbed in water for another 28 days for self-healing effect to take place and UPV test is conducted again to confirm whether self-healing has taken place or not. The UPV test results at different ages are given in table 6.

Table 6. Ultrasonic Pulse Velocity Test Results

Test	**Initial (28 days)**	**70% preloading (28 days)**	**After healing (56 days)**
UPV	5	4.6	5.2
	5.3	5.1	5.4
	5.2	4.7	4.9
Average	5.17	4.80	5.17

The average Ultrasonic pulse velocity test results at different ages are indicated in figure 4.

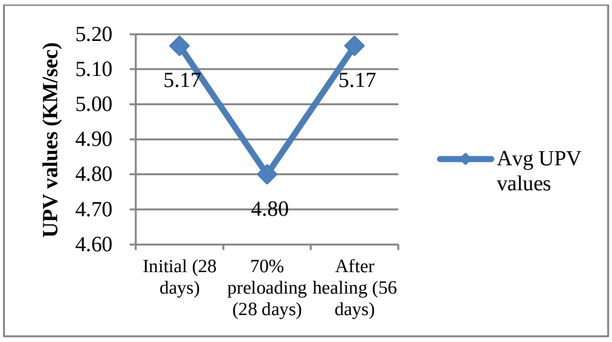

Figure 4. Ultrasonic Pulse Velocity Test

The compressive strength test is carried once again to ascertain the healing effect due to the addition of fly ash at 56 days. Compressive strength results after healing are given in table 7.

Table 7. Compressive Strength Test Results After Healing

Test	**Initial (28 days)**	**70% preloading (28 days)**	**After healing (56 days)**
Compressive strength	56.6	48.8	55.2
	52.7	53.3	56.4
	55.6	53.5	57.2
Average	55	52	56

Compressive strength results after healing is indicated graphically in figure 5.

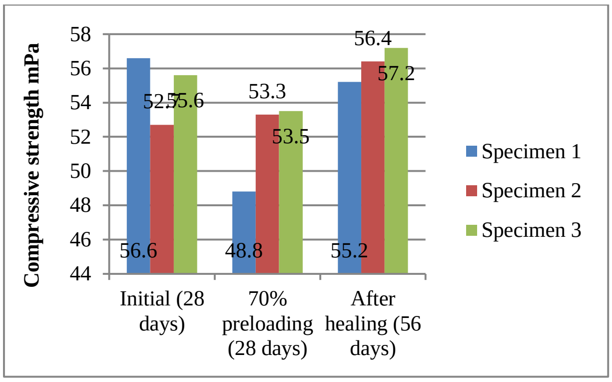

Figure 5. Compressive Strength Test Results after Healing

Sorptivity test is an approximate indicator of self-healing effect in concrete. The sorptivity test results for 70% and 90% preloading rate are given in table 8.

Table 8. Sorptivity Test Results

Fly Ash replacement %	Preloading rate %		
	0	70	90
0	0.116	0.134	0.173
5	0.074	0.118	0.141
10	0.085	0.135	0.153
15	0.132	0.162	0.198
20	0.127	0.151	0.171
25	0.124	0.141	0.185
30	0.115	0.116	0.136

The sorptivity test results for different fly ash replacement ratios are shown graphically in figure 6.

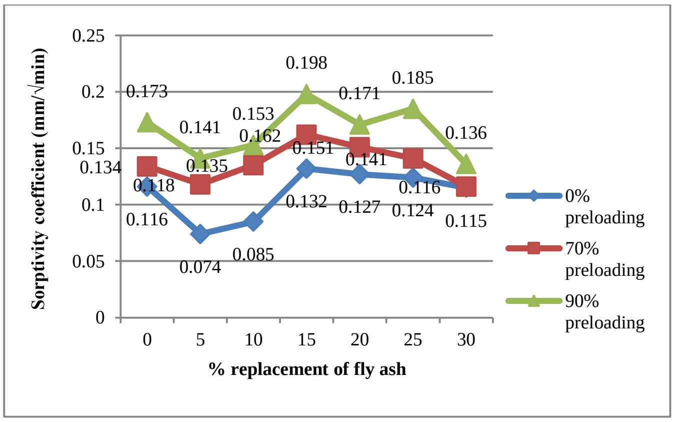

Figure 6. Sorptivity Test

Rapid Chloride Permeability test is carried out to find the chloride ion diffusion in concrete. Denser the concrete, the chloride ion penetration is less. RCPT is carried out after 28 and 56 days curing. The specimens are preloaded 80% for inducing cracks and kept in water for another 28 days. Then again the test is done for examining the formation of self-healing products which would have sealed the cracks and made a denser concrete. The RCPT results are given in table 9 and given graphically in figure 7.

Table 9. RCPT Values

Initial (28 days)	Initial (56 days)	80% preloading (28 days)	After healing (56 days)
1184	784	1249	873

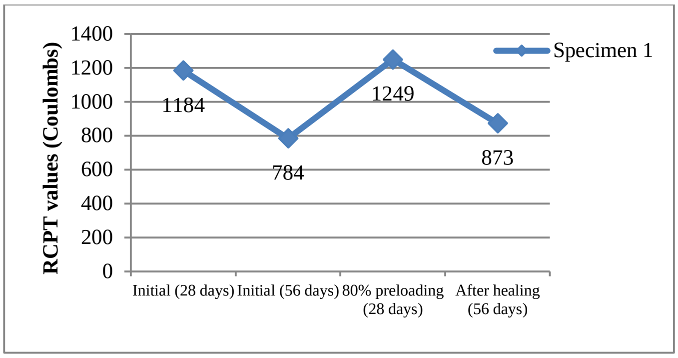

Figure 7. RCPT Values

Water absorption test is conducted on cube specimens of size 100 mm after 28 days of curing as per ASTM C 642-81. The specimens were dried out in a hot air oven at a temperature of 105°C. The dried specimens were cooled at room temperature, weighed accurately and noted as dry weight. Then the specimens were immersed in water. The immersed specimens were taken out at regular intervals of time, surface dried using a clean cloth and weighed. This process was continued till the weights became constant (fully saturated). The difference between the measured water saturated mass and oven dried mass expressed as a percentage of oven dry mass gives the saturated water absorption. The water absorption test values are given in table 10 and indicated in figure 8.

Table 10. Water Absorption Test Results

Initial (28 days)	80% preloading (28 days)	After healing (56 days)
4.6	4.9	4.3

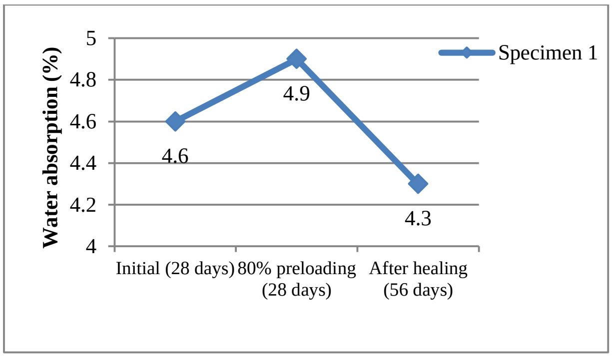

Figure 8. Water Absorption Values

Cracks are induced in flexure beams and the crack width is measured by means of microscope initially and after healing. There was a considerable reduction in crack width when fly ash is used as mineral admixture. The reduction in crack width after 56 days is given in table 11.

Table 11. Reduction in Crack Width

Specimen		Initial (28 days)	After healing (56 days)
Specimen 1	Average	0.098	0.083
Specimen 2		0.090	0.087

The crack width reduction for fly ash as mineral admixture is indicated graphically in figure 9.

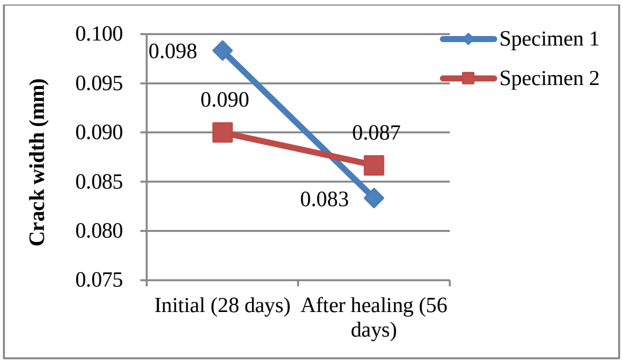

Figure 9. Reduction in Crack Width

Crack depth is measured by means of Ultrasonic Pulse Velocity test initially and after healing. There was a considerable reduction in depth of the crack when fly ash is used as mineral admixture. The reduction in depth of the crack after 56 days is given in table 12.

Table 12. Reduction in Depth of the Crack

Specimen		Initial (28 days)	After healing (56 days)
Specimen 1	Average	0.048	0.03
Specimen 2		0.047	0.012

The crack depth reduction for fly ash as mineral admixture is indicated graphically in figure 10.

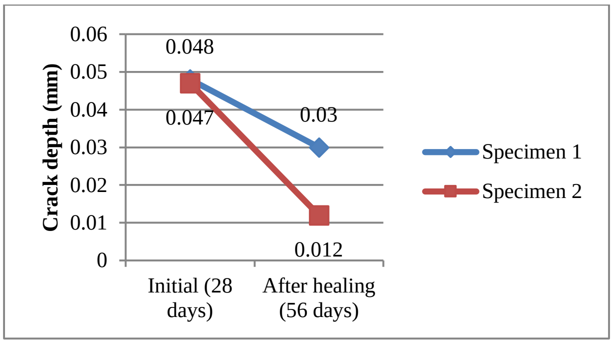

Figure 10. Reduction in Depth of the Crack

FESEM analysis is done for determining the crystal structure of the specimen in the point where cracks are induced. EDAX was carried out to ascertain the composition of the healing products. The healing effect was observed at the cracks which is evident from the formation of fibrous mass whose composition indicated the presence of elements like Ca, Si and O. The FESEM analysis image is shown in figure 11.

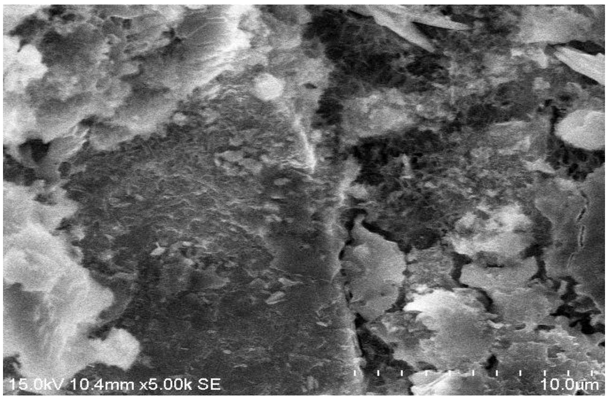

Figure 11. Fesem Image Of Fly Ash Based Specimen

The composition of the healed product is given by EDAX method which is indicated in figure 12 and the percentage of each element present is given in table 13.

Table 13. Composition of Elements from EDAX Analysis

Element	Weight%	Atomic%
O K*	60.68	77.15
Si K	13.38	9.69
Ca K	25.94	13.17
* represents the electron shell from which it has been transmitted		
Total	100.00	

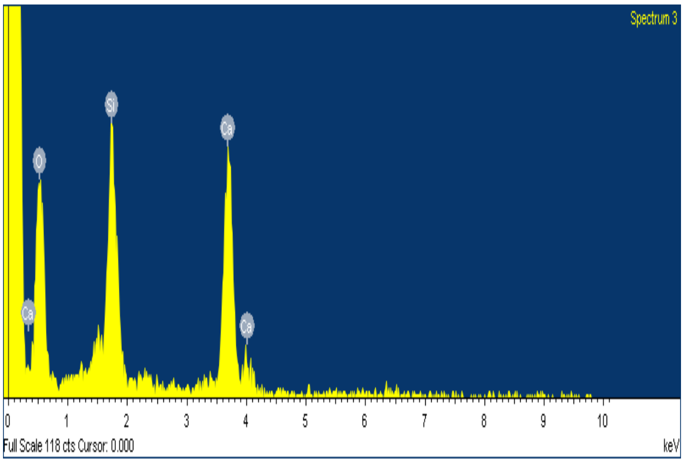

Figure 12. EDAX Image Showing Elemental Composition of the Healed Product

CONCLUSION

In this research work, fly ash had been replaced 25% for cement and tested for strength and durability properties.

1. It has been experimentally found out that the fly ash added concrete before inducing cracks produced compressive strength, split tensile strength and flexural strength values of 56 mPa, 3.1 mPa and 5 mPa respectively after 28 days curing.
2. After inducing micro-cracks, the compressive strength value decreased to 52 mPa and the regain in compressive strength was 56 mPa when the specimens are immersed in water again for another 28 days.
3. The compressive strength test was facilitated by UPV test having an initial value of 5.17 km/s for un-cracked specimen, decreased to 4.8 km/s during 70% preloading and again gave the original value of 5.17 after healing.
4. Sorptivity test results showed significant decrease in value for 30% fly ash replacement.
5. RCPT produced a value of 1184 coulombs initially, increased to 1249 at 80% preloading and showed a significant decrease of 873 coulombs after healing from which it can be clearly stated that healing has taken place and packing effect has been occurred.
6. Water absorption test results before and after healing are 4.6% and 4.3% respectively so as to conclude that decrease in water absorption values projected that healing has been done by fly ash.
7. Beam crack width reduced from an initial value of 0.094 mm to 0.085 mm and crack depth too decreased from 0.048 mm to 0.021 mm measured using microscope and ultra-sonic pulse velocity test respectively. The decrease in values clearly indicated that internally self-healing has been effected by the reaction between cement and fly ash.
8. FESEM image showed some white growths in the cracked region. EDAX results indicated the presence of 60.68% oxygen, 13.38% silica and 25.94% calcium.
9. The healed product formed is concluded as CSH from Ca/Si ratio of 1.93. The healed product is Cal-Sil having a chemical composition of Ca2SiO4 (or) 2Ca2SiO4. Cal-Sil acted as a sealant for cracks (Haoliang and Guang, 2011).

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