BEHAVIOR OF INTERNALLY CURED SELF COMPACTING CONCRETE WITH FLY ASH UNDER AMBIENT CURING CONDITIONS

J. SHANMUGA PRIYA*, K. CHINNARAJU ,V.JAGANATHAN[3]
, Division of structural Engineering, Anna University, Chennai- Tamilnadu, India.

This research studies self compacting concrete mixes with 0, 30, 40 and 50% fly ash as replacement which are internally cured with super absorbent polymer and lightweight expanded clay aggregates against Self Compacting Concrete which are conventionally cured by submerging in water for a specific period. The optimum dose of the Internal curing agent was determined based on the chemical shrinkage of cement paste and it was presoaked in the mixing water and incorporated at the time of mixing. Fresh properties like slump cone, V funnel and L box tests were made and the effect of fly ash and internal curing agent was reported. Properties like compressive strength and durability factors such as rate of water absorption and resistance to chloride penetration were studied. Also the relationship between compressive strength and chloride penetration was established. It was found that the addition of fly ash seems to be beneficial for self curing concrete specimens up to 40% in terms of strength and durability. Concrete internally cured with super absorbent polymer showed better performance when compared with concrete cured with clay aggregates.

Keywords: *internal curing, self compacting concrete, durability, superabsorbent polymer, light weight expanded clay aggregate, fly ash, curing*

1. Introduction

Self-compacting concrete (SCC) is a sort of special concrete, which combines all alone with no external compaction. This property is accomplished by increasing the powder content, adding viscosity modifiers or a blend of both. A well designed self-compacting concrete fills the structures even in exceptionally blocked zones. Co

nsequently it is important to acquire an ideal blend of SCC whose fresh properties are superior to ordinary cement concrete. Beneficial cementitious materials like Fly Ash, GGBS, Silica Fume, Rice Husk Ash, and so on, are commonly added to increase the powder content of SCC. Fly ash is delivered from coal in thermal power plants where coal is pounded and blown with air into ignition chamber. The lighter debris stays suspended in the flue gas and is eliminated by electrostatic precipitators. It is a pozzalanic material which is in a finely divided structure and on contact with water responds with calcium hydroxide to create cementitious compounds [1]. Fly ash mostly acts as filler in the concrete at early ages, yet prompts significant quality at later ages. This offers sense to the fact that the effectiveness of fly ash increments with age. Babu and Rao studied about the efficiency of fly ash in concrete. The authors made an extensive study on the efficiency of pulverized fuel ash in concrete over a wide range of percentage replacements (15-75%). They depicted the relation between compressive strength of concrete and water cementitious material ratio for normal and fly ash replaced concretes. Lower replacement levels (up to 20%) show higher compressive strengths than control concrete [2-4].

Internal curing is done by providing additional water for curing to the concrete by means of internal reservoirs of water inside the concrete. Internal curing is generally done to increase the hydration and decrease the self desiccation in mixtures with low water-cement ratio.[5]. The quantum of water required for internal curing is calculated using the chemical shrinkage of paste, absorption capacity of the curing material and expected degree of hydration [6]. Studies on cement paste blended with fly ash shows a decrease in the chemical shrinkage [7,8]. Though many materials are under research to be used as internal curing materials, the two most common materials are superabsorbent polymers and lightweight aggregate. [9,10].

Super absorbent polymers (SAP) can be used for different concrete applications such as shrinkage reduction, rheology modification, frost resistance, etc., [11]. Super absorbent polymers are materials which are capable of absorbing enormous quantity of water (5 to 500 times of its own weight) and release it to the surroundings at low relative humidity. The mechanism of absorption of fluids by super absorbent polymers is based on the principle of osmosis. Chemically stable covalently cross linked polymer acrylamides can be used in concrete applications. The suitability of super absorbent polymers to be used in concrete is decided upon its absorption capacity. Absorption capacity of super absorbent polymers can be found out using tea bag test. [12,13]. The dosage and method of incorporating internal curing water has significant effect on the workability. When the polymer was made to pre absorb the curing water, the slump value increases whereas the dry addition

---

*Autor corespondent/*Corresponding author*,
E-mail:priyasudhakar06@gmail.com

decreased the workability of concrete. The addition of SAP has no influence on the compressive strength at early ages and at later ages the compressive strength of concrete increases continuously. Also the particle size has a strong influence on the compressive strength gain [14, 15]. The effect of curing conditions also plays a major role in increasing the hydration and compressive strength. Curing of concrete by sealing performed better in all the cases in terms of compressive strength, chloride permeability and water absorption [16]. The water required for internal curing can be obtained by equating the water demand of the paste to the water supplied by the internal reservoirs on assumption that no water is lost to the surrounding due to evaporation [17] The factors on which the water demand depends are the quantity of cementitious material used, chemical shrinkage of the hydrating paste and absorption capacity of the curing material [18]. Internal curing concept is applied to concrete mixtures which have a water- cement ratio less than 0.42. Lopez et.al investigated the effect of internal curing to traditional concrete having w/c greater than 0.42 and found that the internal curing when applied even under poor curing conditions would increase the degree of hydration, compressive strength and reduce the chloride permeability [19]. The effect of SAP on chloride permeability was significant for water–cement ratio of 0.33 but was minor for lower water cement ratios. The effect of micro fillers could improve the durability of internally cured concrete [20]. It was also reported that shrinkage in internally cured fly ash blended mortars was lesser when compared with the mortars with Ordinary Portland Cement. [21,22].

Though light weight expanded clay aggregates are very much suitable for internal curing, their suitability for producing Self Compacting Concrete is limited. Bogas et al (2012) produced self compacting lightweight concrete with expanded clay aggregate and studied the behavior. Fly ash was used as a mineral admixture. Since there is a great difference in density between lightweight aggregates and the mortar, Self Compacting Light weight Concrete had more segregation when compared to that of SCC. Also it was found that, there is a sudden drop in the self compactibility for higher volumes of aggregate. Hence for higher volumes of lightweight aggregate the production of Self Compacting Concrete is not feasible [23]. Artificial expanded clay aggregates are produced from burning out of gases from clay. This leads to a structure of dense shell and a porous core which is more suitable for internal curing. [9]

2.Materials

Ordinary Portland cement of grade 53 conforming to the requirements of IS 269 – 2015 [24] was used whose specific gravity and specific surface area were 3.15 and 300m^2/kg respectively. Class F Fly ash conforming to IS 3812 [25] obtained from Ennore thermal power station, Tamilnadu, India was used whose specific gravity was 2.2. Commercially available poly carboxylic ether based super plasticizer (AURAMIX 400) with a specific gravity of 1.09 and solid content not less than 30% was used as a chemical admixture. Natural river sand of specific gravity 2.5 and fineness modulus 2.36 was used. Light weight expanded clay aggregates which were manufactured by burning clay at 1100°C. The size fraction used for this study is 0-2mm which is effective in internal curing whose absorption capacity is 18% of the total volume. The aggregate grading belongs to zone II of IS 2386 [26]. The particle size distribution of the fine aggregates as well as the clay aggregates are given in Fig1. Crushed granite was used as coarse aggregate whose nominal size is 12.5 mm and specific gravity 2.8. Acrylic sodium salt polymer (SAP) was also used as internal curing material. The absorption capacity of the polymer was found using tea bag method and was found to be 125g/g in tap water.

3.Mix Design

The mix design was based on efficiency factor of fly ash. Concrete mixes with 0, 30, 40 and 50% replacement of fly ash based on the efficiency

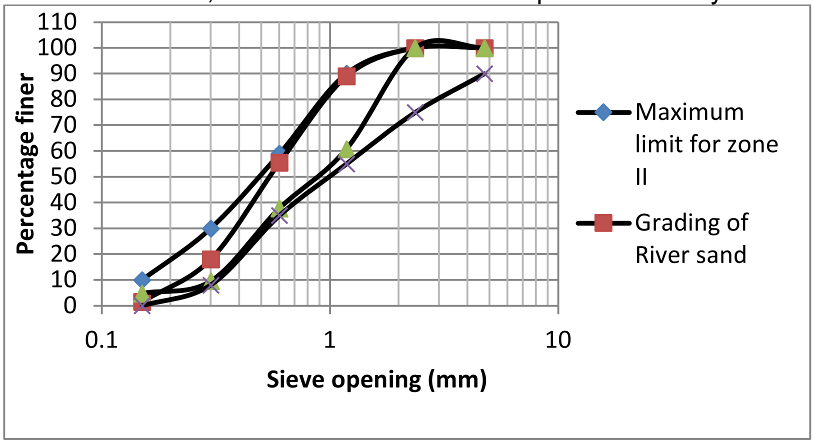

Fig. 1 - Particle size distribution of fine aggregates and expanded clay aggregate

Table 1

Mix proportions of Self Compacting Concrete

Mix Designation	Cement (kg/m^3)	Fly Ash (kg/m^3)	Total Water (l/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Internal curing agent dosage (kg/m3)		Super Plasticizer Dosage
						SAP	LECA	
0 scc	500	-	195	867.99	800	-	-	1%
30 scc	350	150	194.26	801.82	800	-	-	1%
40 scc	300	200	189.96	795.44	800	-	-	1%
50 scc	250	250	175.79	813.75	800	-	-	1%
0 SAP	500	-	195	867.99	800	0.22	-	1%
30 SAP	350	150	210.47	801.82	800	0.18	-	1%
40 SAP	300	200	199.09	795.44	800	0.13	-	1%
50 SAP	250	250	181.33	813.75	800	0.09	-	1%
0 LECA	500	-	195	714.94	800	-	153	1%
30 LECA	350	150	210.47	667.33	800	-	135	1%
40 LECA	300	200	199.09	719.74	800	-	76	1%
50 LECA	250	250	181.33	767.71	800	-	46	1%

factor as mentioned by Dinakar [27].The coarse aggregate content was taken as 800 kg/m^3 for all the mixes and the fine aggregate content was adjusted to satisfy the total volume of aggregates according to the guidelines specified by EFNARC [28]. The total cementitious material content was kept constant as 500 kg/m^3 and the fly ash replacements were made accordingly to each mix. The water content was determined based on the requirements of paste content and the minimum water content required to satisfy the paste content requirement was adopted. The superplasticizer dosage was constantly adopted as 1% of the cementitious material content by weight in order to determine the effectiveness of curing agents in terms of workability.The water/binder ratio varied for every composition because of the change in percentage of fly ash for every mix. To determine the exact water demand of the mixes, superplasticizer dosage was kept constant and the water/binder ratio was determined based on trial and errors and was fixed at the minimum water content required by every mix to satisfy the workability criteria. Hence the water/binder ratio varied for every mix. The mix proportions of concrete specimens conventionally cured with water and those of internal curing are given in Table 1.The dosages of internal curing agents were determined on the chemical shrinkage of the paste. Based on the absorption capacity of the curing material, chemical shrinkage of paste and the expected degree of hydration, the volume of internal curing was determined according to [29] and the volume of internal curing material was taken.

4.Concrete Casting and Curing

Concrete mixtures with and without internal curing was cast separately as per the mix proportioning mentioned elsewhere. The first set of mix consisted of four different batches of self compacting concrete wit 0, 30, 40 and 50 % fly ash replacement without any internal curing agent. Each batch had three samples of 150 mm×150 mm cubes. The second set of mix consisted of four batches of self curingself compacting concrete with superabsorbent polymer as internal curing agent with the same fly ash percentages. The superabsorbent polymer was presoaked in the mixing water 24 hours before the commencement of mixing. At the time of mixing, the excess water was decanted from the presoaked gel and was used for mixing. The presoaked gel was added to the mixture lastly after a uniform mix was achieved and the drum was rotated for one more minute. The third set of mix used lightweight expanded clay aggregate which was presoaked a day before mixing. Since the light weight fine aggregates had some floaters floating on the soaked water surface, they were discarded by filtering before mixing. Hence the saturated weight of the aggregates was determined and the determined quantity of soaked aggregates was measured and added at the time of mixing. Each batch had 3 samples of 150mm×150 mm cubes which were used for ambient curing.

The concrete casting procedure is as follows. It was ensured that all the materials brought for mixing were in air dried condition. The cement was thoroughly mixed with hands before mixing for homogeneity. The contents were proportioned according to the mix design and weighed accurately. All the dry ingredients were emptied into a laboratory batch mixer and water was added along with the superplasticizer after a few rotations for uniform mixing of the ingredients. The mixing period was around 5 minutes till uniformity in the mixture was observed.

The curing procedure involved for the first set of concrete mixtures was conventional curing by immersion in water. The samples were removed from the moulds after a day or two depending upon the fly ash content of the mix and were marked with suitable identifications and were immersed in water till the period of testing. The second and third set of concrete mixes had internal curing agents hence they were not submerged in water for curing. In both these sets, three samples for each batch were kept in laboratory conditions without any covering or sealing where moisture loss through evaporation was allowed. The temperature and relative humidity of the laboratory was 27±5°C and 62±3% respectively.

4.1.Fresh properties

Self Compacting Concrete has superior fresh properties which makes it easier to handle than the conventional concrete. The workability properties include filling ability, passing ability and segregation resistance for Self Compacting Concrete. Various test procedures for determining these properties are mentioned in the EFNARC guidelines. The effect of fly ash replacement and the internal curing agents were studied. These tests also served as the qualifying criteria for SCC.

4.2.Compressive strength

Compression testing machine with 200 Ton capacity was used for testing. Bearing plates were equipped in the testing machine for uniform distribution of the loads applied. Test was made at the ages of 7, 28, 56, 90 and 180 days after casting. The average of three values was taken as the representative of each batch.The cubes were placed in the testing machine in such a manner that, the load was applied opposite to the cast surfaces. The load was applied continuously and gradually increased at the rate of 140 kg/cm^2/minute. The maximum load applied to the specimen was recorded and the pattern of crack formed was also observed. The compressive strength was then calculated by dividing the maximum load applied to the specimen by the cross sectional area of the specimen [30]. The average of three values was taken as the representative of each batch.

4.3.Sorptivity

Sorptivity indicates the rate of water absorption through capillary action by the concrete specimen. The specimens were conditioned prior to testing. The specimens were 100mm diameter cylindrical disc specimens with length 50 mm which were cut from molded cylinders. Two representative specimens one from the interior core and one from the surface were taken and the average value of their absorption was reported to avoid data scattering. The specimens were conditioned prior to testing. The specimens were placed in a desiccator with potassium bromide solution for 72 hours to maintain a temperature 50°C and RH of 80%, after which they were placed in plastic containers for 15 days before testing. The initial mass of the discs was noted and all the sides were coated with epoxy except the side which is exposed to water. The specimens were placed on a support in a pan containing water and it was ensured that only the bottom surface was in contact with water. The mass of the discs were recorded at regular intervals after wiping off excess moisture as mentioned in ASTM C 1585[31].

4.3.Rapid Chloride Penetration Test

This test determines the resistance of concrete to penetration of chloride ions. The specimens are of 100mm diameter cylindrical discs with 50mm length which were cut out of molded cylinders. The specimens were preconditioned before testing the resistance to chloride ions. Three representative specimens for each mix were taken and the average value was reported. The specimens were placed in a vacuum desiccator and were vacuum pumped at a pressure 50 mm for 3 hours after which water is allowed into the container to fill all the voids in the concrete specimen to be saturated with water. After allowing water, the vacuum pump is allowed to run for another 1 hour. After conditioning the specimens were taken out, wiped off and was placed in the test cell set up where the negative terminal of the cell was connected to 3% sodium chloride solution and the positive terminal of the cell was connected to 0.3% sodium hydroxide solution. The electrical connections were made and the charge passed was noted for every 30 minutes for 6 hours. The calculations are done according to ASTM C 1202-12[32].

5.Results and Discussions

5.1.Fresh properties

Inclusion of fly ash in Self Compacting Concrete helps in improving the workability. This study also evaluated the effect of addition of presoaked internal curing agents such as super absorbent Polymer and Light weight expanded clay aggregates. The effect of fly ash and the type of curing on slump, T_{50} time and V funnel time are shown in Fig 2(a), 2(b) and 2(c) respectively.

The results show that the flowability of concrete increases with increase in percentage of fly as replacement. It is also inferred that addition of internal curing material increases the flowability. Internally cured concrete with SAP has higher flowability than the reference concrete and concrete with LECA. This is because, since SAP was added in the form of presoaked gel, the friction gets reduced between the molecules and spreads more evenly, whereas LECA in the form

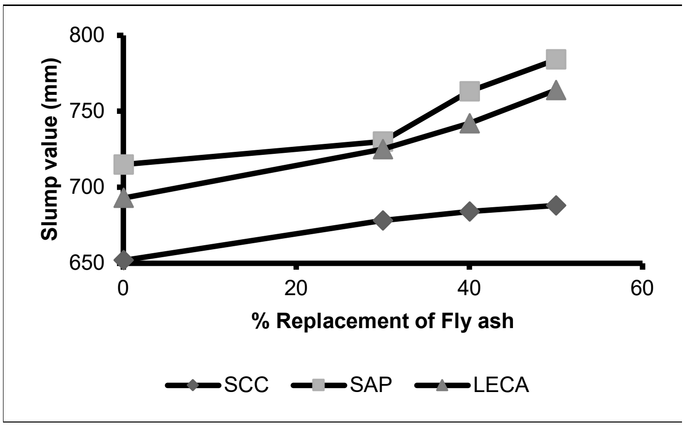

Fig. 2 - (a) Effect of fly ash on slump value.

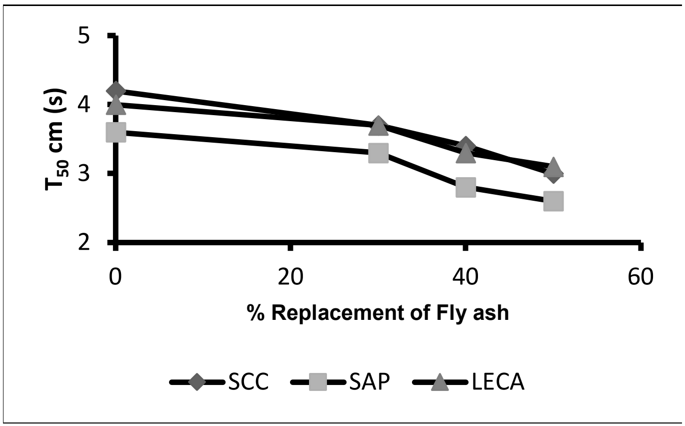

Fig. 2 - (b) Effect of fly ash on T_{50} cm time.

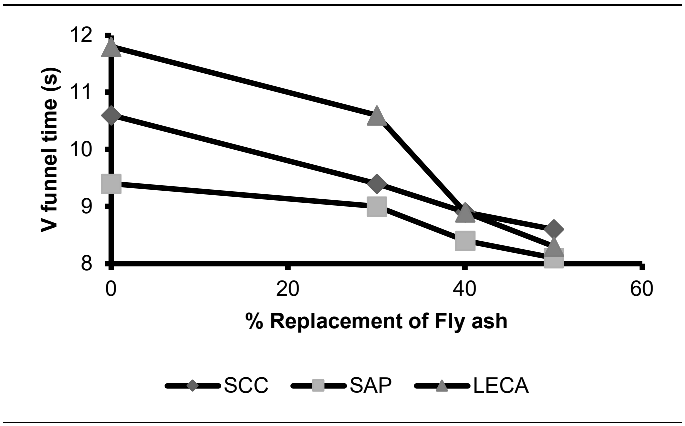

Fig. 2 - (c) Effect of fly ash on V Funnel time.

of spheres showed lesser flowability though it performed better than that of conventional concrete without any curing agent.

The $T_{50\,cm}$ time is an indication of flowability of concrete. Lesser the time taken to flow, greater is the flowability. The results show that, internally cured concrete with SAP has better flowability and the concrete with LECA and the reference concretehave shown almost similar results. This shows that incorporating SAP in the form of presoaked gel increases the flowability of concrete.

The V funnel time indicates the flow time of the concrete. Since the concrete flows under gravity this test indirectly measures the segregation of concrete. The test results show that concrete with SAP takes very less time to flow, hence greater flowabilty, whereas the concrete with LECA has taken much longer to flow than the reference concrete without internal curing. However, when the fly ash replacement percentage increased beyond 30%, the flow time was reduced and was better than the conventional concrete.

5.2.Compressive strength

The results of compressive strength at 7, 28, 56, 90 and 180 days for conventionally cured specimens, internally cured with SAP and LECA are shown in Fig 3(a), 3(b) and 3(c) respectively. The results reveal that, though the addition of fly ash decreases the strength of concrete, the percentage rate of strength gain is better when compared to concrete without fly ash. When SAP was added in the form of presoaked gel, the compressive strength of concrete without fly ash gradually decreased from 28 to 180 days. It is necessary to mention here that, the concrete samples were cured under ambient laboratory conditions for determining the efficacy of the Internal curing agents. When there was 0% fly ash in the concrete the internal relative humidity of concrete increased due to increased heat of hydration and hence, the SAP could not act as an internal reservoir and released the stored water as free water for evaporation even before complete hydration could take place.For concrete without fly ash, and conventional water curing the rate of strength gain from 28 days to 180 days is 25% whereas concrete with 30% fly ash has gained 44% at 180 days. But beyond this, the rate of strength gain gradually decreased to 28% and 21%. When the concrete is cured with superabsorbent polymer, for concrete with 0% fly ash there was decrease in strength, whereas the rate of strength gain was 31% when for 30% fly ash replacement. Beyond this percentage though there was decrease in the strength gain, it was better than conventionally cured concrete. A similar pattern was observed for LECA samples but the loss of strength was lesser because of the water retention capacity of the clay aggregates were better. When concrete was internally cured with lightweight expanded clayaggregate, again there was a fall in the strength at 180 days when no fly ash was added. But at 30% fly ash replacement the strength gain was 38% and beyond this there was a steep fall in the strength gain. This may be attributed to the week interfacial zone between the porous light weight aggregate and the dense matrix.

5.3.Sorptivity

The sorptivity results are given in Fig 4. This test is done at 28 days and 180 days for all the concrete specimens. This test is intended to determine the susceptibility of concrete to absorb

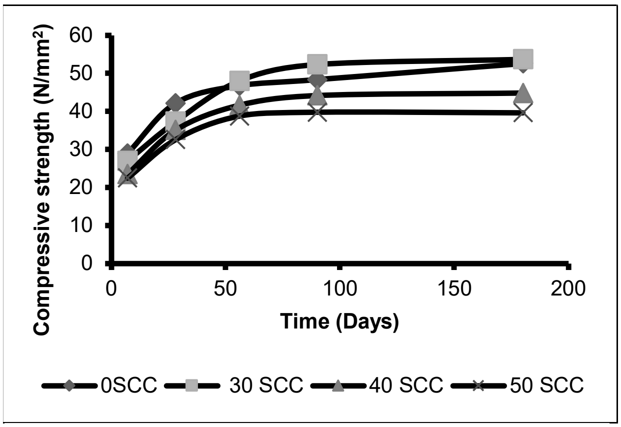

Fig. 3 - (a) Compressive strength development of conventionally cured SCC.

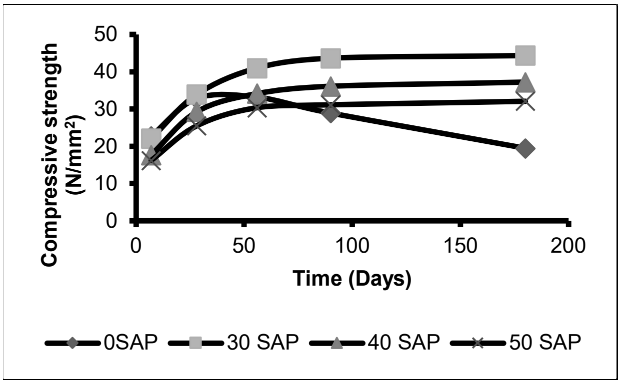

Fig. 3 - (b) Compressive strength development of internally cured SCC with SAP.

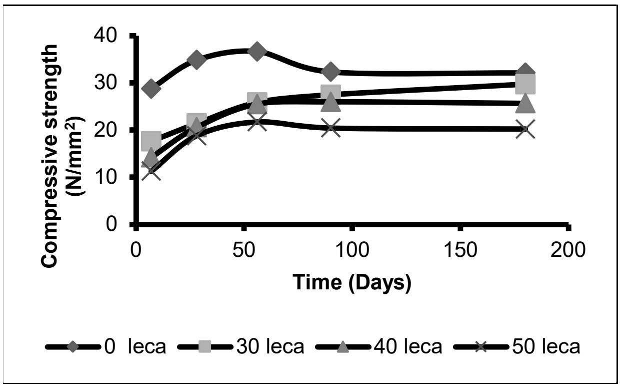

Fig. 3 - (c) Compressive strength development of internally cured SCC with LECA.

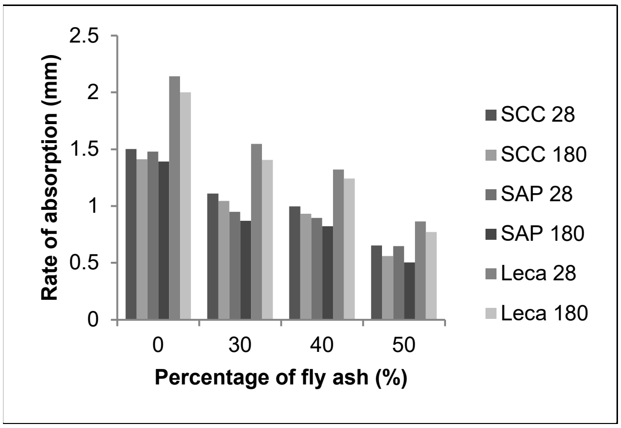

Fig. 4 - Effect of fly ash on rate of water absorption.

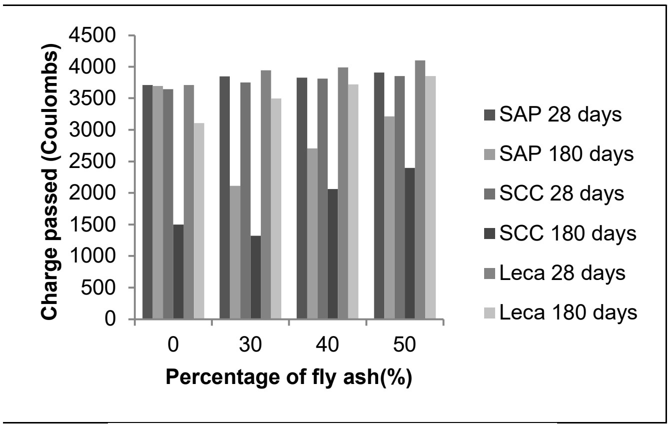

Fig. 5 - Effect of Fly ash on Chloride resistance.

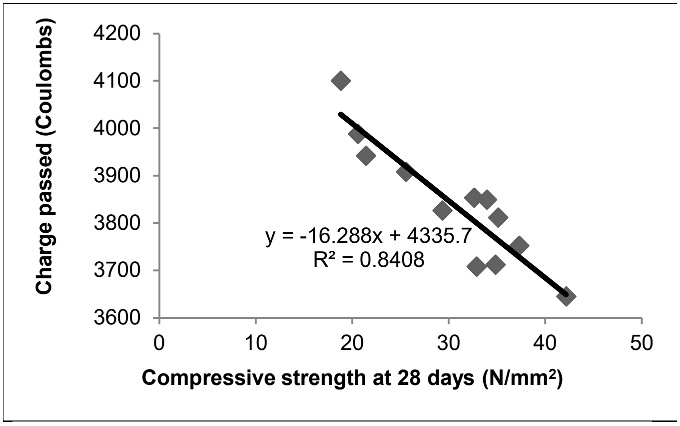

Fig. 6 - (a) Relationship between compressive strength and chloride resistance at 28 days.

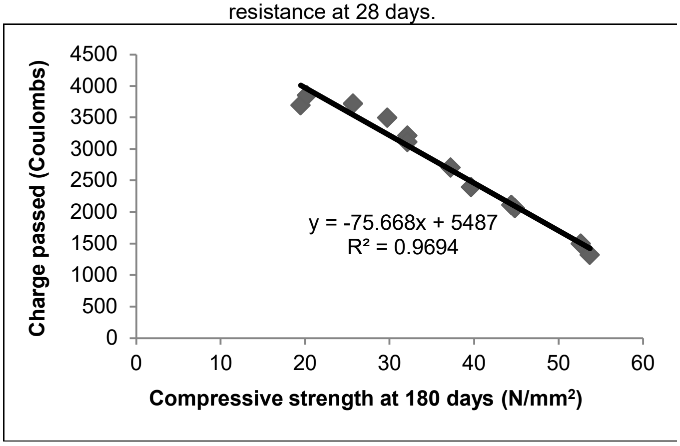

Fig. 6 - (b) Relationship between compressive strength and chloride resistance at 180 days.

water. The presence of supplementary cementitious material and curing age pays a major role in the sorptivity of concrete.

The inclusion of fly ash has reduced the sorptivity values invariably in all curing conditions indicating the dense matrix because of higher paste content. The effect of internal curing agents on the sorptivity is found beneficial at 180 days. The sorptivity values of concrete cured with SAP is lesser than the reference concrete at 180 days, whereas the values remain little higher at 28 days. This indicates that concrete containing fly ash has been cured properly even in the absence of external curing when SAP was used. However, the sorptivity of concrete internally cured with

LECA remained higher because of the network of pores which lead to the capillary action of water.

5.4.Rapid Chloride Penetration Test

This test is made to evaluate the resistance of concrete specimen to chloride penetration. When cured properly the resistance to chloride penetration of concrete increases with time. The chloride penetration values of all the specimens are given in Figure 5. Lesser the charge passed higher is its resistance to chloride penetration.

The resistance to chloride of internally cured concrete specimens was comparatively lesser than the conventionally cured concrete. The effect of fly ash is very much appreciable at 180 days. SAP cured concrete with 30% fly ash had higher resistance at 180 days and beyond that there was less resistance. Similarly concrete with LECA also showed better resistance at lower fly ash percentage. This trend indicates a strong correlation of chloride resistance to compressive strength of concrete. The relationship between compressive strength and chloride resistance at 28 and 180 days is given in Figure 6(a) and 6(b) respectively.

6.Conclusions

The chemical shrinkage of paste decreases with the increase in percentage of fly ash. Hence the internal curing water requirement is reduced with increase in fly ash percentage. Fly ash can be effectively used in self compacting concrete to increase the workability of concrete. Fly ash helps in improving the degree of hydration of concrete which in turn improves the rate of strength gain up to 40% replacement.

The workability of concrete mixes with internal curing agents is also better than their reference counterparts. This may be due to the additional water added as internal curing water. This water is converted into gel form when the superabsorbent polymer is presoaked hence acts as a viscosity modifying agent to improve the workability of concrete. On the other hand a slight segregation is seen in mixes with lightweight expanded clay aggregates. Hence preparation of self compacting concrete with lightweight expanded clay aggregate with more than 25% of the aggregate volume is not feasible.

Since the quantity of superplasticizer was kept constant, the variations in the strength and workability are highly dependent on the water content of each mix. The percentage of fly ash replacement levels varied for each mix and the mix with 50% fly ash had the lowest water demand. This is attributed to the fact that, the spherical shape of the fly ash particles increases the particle packing density thereby reducing water demand. Hence the water content and the fly ash percentage are highly dependent on each other. Though water content is reduced when fly ash percentage was high, it did not affect the workability of the concrete. When compressive strength was concerned, the control mix with highest water content showed the maximum compressive strength at 28 days. Reduction of water/binder ratio in the subsequent mixes by incorporating fly ash did not increase their strength. Similar pattern was observed for concrete mixes with SAP and LECA. Hence this proves that fly ash incorporation reduced the strength of concrete in spite of water content reduction.Replacement of fly ash is beneficial in improving the rate of strength gain even under adverse curing conditions when internal curing agents are added in the presoaked form.

Internally cured concrete specimens with 0% fly ash showed a gradual decrease in strength indicating that, the degree of hydration is incomplete. When fly ash is added, the internally reserved water held up in the curing agents is used effectively even when the concrete is allowed to dry. However the rate of strength gain is found maximum at 30 to 40% and beyond this, there is a steep decrease.

When LECA is used as internal curing agent, the rate of strength gain is higher only at 30% fly ash replacement and reduced beyond that. This is due to the fact that there is a difference in the density of the matrix and the density of the light weight aggregates. This may also be the reason for the segregation of the mixes beyond 30% of fly ash replacement.

Fly ash decreased the sorptivity of all the mixes regardless of the type of curing. Also, internally cured mixes had lesser sorptivity at 180 days which is an indication of denser matrix and thus reduced capillary action. But concrete specimens having LECA as internal curing agent, showed higher sorptivity values. Another considerable fact was that when the discs were selected for sorptivity testing, the core discs had lesser sorptivity values than the surface discs in all the cases. This shows that the internal curing water was not distributed effectively for hydration to take place.

The chloride resistance pattern of the concrete specimens showed a similar trend to that of compressive strength. This indicates that compressive strength and resistance to chloride has strong correlation. Also the chloride resistance increased with increase in percentage of fly ash. And the resistance was better with time for all the mixes.

REFERENCES

[1] Gang, Xianming, Characteristics and applications of fly ash as a sustainable construction material: A state-of-the-art review, Resources Conservation and Recycling, 2018, **136**(10), 10-16.

[2] KG Babu, GS Rao, Efficiency of fly ash in concrete with age, Cement Concrete Research, (1996), **26**(3), pp 465–474.

[3] KGBabu, GS Rao, Early strength behaviour of fly ash concretes, Cement Concrete Research, 1994, **24** (2), 277–284.

[4] KGBabu, GS Rao, Efficiency of fly ash in concrete, Cement Concrete Composites, 1993, **15**(4), 223–229.

[5] W.Weiss& L Montanari, Guide Specification for Internally Curing Concrete. In National Concrete, Pavement Technology Center, 2017, **5**. https://doi.org/10.1016/S1673-8527 (08)60032-6

[6] D Bentz & Weiss, Internal Curing: A 2010 State-of-the-Art Review,NISTIR 7765, 2011..

[7] ASTM C 1608-07, Standard Test method for chemical shrinkage of cement Pastes, (2007) ASTM International,

[8] S Sarkar, A Halder, S Bishnoi, Shrinkage In Concretes Containing Fly Ash, Innovations in Concrete Construction, (2013) UKIERI Concrete Congress.

[9] O. M. Jensen &P.Lura, Chapter 5 - Materials and Methods for Internal Curing , RILEM TC 196-ICC: Stae-of-the-Art Report, 2007, 45–55.

[10] G. R Sensale& A. F. Goncalves, Effects of Fine LWA and SAP as Internal Water Curing Agents . International Journal of Concrete Structures and Materials, 2014, **8**(3), 229–238. https://doi.org/10.1007/s40069-014-0076-1

[11] V Mechtcherine, & H. W. Reinhardt, Application of Super Absorbent Polymers (SAP) in Concrete Construction: State-of-the-Art Report Prepared by Technical Committee 225-SAP, 2012, (January), 1–164. https://doi.org/10.1007/978-94-007-2733-5

[12] V Mechtcherine., D Snoeck., C Schröfl, N De Belie, Klemm, K Ichimiya, V.Falikman, Testing superabsorbent polymer (SAP) sorption properties prior to implementation in concrete: results of a RILEM Round-Robin Test. , Materials and Structures/Materiaux et Constructions, 2018, **51**(1). https://doi.org/10.1617/s11527-018-1149-4

[13] C Schröfl. D Snoeck,& , V Mechtcherine. A review of characterisation methods for superabsorbent polymer (SAP) samples to be used in cement-based construction materials: report of the RILEM TC 260-RSC, Materials and Structures/Materiaux et Constructions, 2017, **50**(4). https://doi.org/10.1617/s11527-017-1060-4

[14] J. Olawuyi& W. P.Boshoff, Influence of Superabsorbent Polymers (SAP) on Fresh and Early-age Properties of High-performance Concrete, 10th ACI/RILEM International Conference - ICCM2017, (Ic), 1–12.

[15] J Dang, J Zhao & Z. Du. Effect of superabsorbent polymer on the properties of concrete. Polymers, **9**(12), 1–17. https://doi.org/10.3390/polym9120672

[16] Al-Hubboubi, T Al-Attar, H Al-Badry, S Abood, R Mohammed., & B Haddhood Performance of super-absorbent polymer as an internal curing agent for self-compacting concrete MATEC Web of Conferences, 2018, **162**(5), 3–7. https://doi.org/10.1051/matecconf/201816202023

[17] T Manzur, S Iffat, & M. A Noor, Efficiency of sodium polyacrylate to improve durability of concrete under adverse curing condition. Advances in Materials Science and Engineering, 2015, vol 2015, https://doi.org/10.1155/2015/685785

[18]PHenkensiefken, P Briatka., D Bentz T Nantung, & J Weiss Plastic Shrinkage Cracking in Internally Cured Mixtures ,Concrete International, 2010, **32**(2), 49–54.

[19] G Espinoza-Hijazin& M Lopez. Extending internal curing to concrete mixtures with W/C higher than 0.42. Construction and Building Materials, 2011. **25**(3), 1236–1242. https://doi.org/10.1016/j.conbuildmat.2010.09.031

[20] S Zhutovsky& K. Kovler Durability Aspects of Internally Cured High Performance Concrete, International RILEM Conference on Use of Superabsorbent Polymers and Other New Additives in Concrete, (2010). (August), 305–314.

[21] D.P. Bentz, Internal curing of high-performance blended cement mortars, ACI Materials Journal, 2010, **104**(4), 408–414.

[22] S Altoubat, T. Junaid, M. Leblouba& D. Badran Effectiveness of fly ash on the restrained shrinkage cracking resistance of self-compacting concrete ,Cement and Concrete Composites, , 2017, **79**, 9–20. https://doi.org/10.1016/j.cemconcomp.2017.01.010

[23] J. Bogas, A.Gomes& Pereira Self-compacting lightweight concrete produced with expanded clay aggregate,Construction and Building Materials, 2012, **35**, 1013–1022. https://doi.org/10.1016/j.conbuildmat.2012.04.111

[24] IS 269:2015 Ordinary Portland Cement – Specifications, 2015, Bureau of Indian Standards, New Delhi, India.

[25] IS 3812 (Part 1) Pulverized fuel ash-specification, Part 1, for use as pozzolana in cement, cement mortar and concrete (third revision), 2013, Bureau of Indian Standards (BIS), New Delhi, India.

[26] IS 2386 – 3 Methods of tests for aggregate of concrete, 1963, Bureau of Indian Standards (BIS), New Delhi, India.

[27] P Dinakar, Design of self-compacting concrete with fly ash. Magazine of Concrete Research, 2012, **64**(5), 401–409. https://doi.org/10.1680/macr.10.00167

[28] EFNARC, "The European Guidelines for Self- Compacting Concrete Specification, Production and Use", 2005.

[29] D. Bentz., P. Lura & J. Roberts Mixture Proportioning for Internal Curing (2005), Concrete International. Vol 27. Pp 35-40.

[30] IS 516:1959 Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India.

[31] ASTM C 1585 – 04, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes

[32] Standard Test Method for Electrical Indication of Concrete’s Ability to ResistChloride (2012). (C), 1–8. https://doi.org/10.1520/C1202-12.2s

****