INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 3)
Available online at: www.ijariit.com

Experimental study on the influence of internal curing on concrete properties using pre-soaked lightweight aggregates and Super Absorbent Polymer

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ABSTRACT

ACI defines Internal Curing (IC) as a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water. The introduction of SAP as a new additive for the production of concrete materials presents a number of new possibilities in respect of water control, i.e., the purposeful water absorption and/or water release in either fresh or hardened concrete. Proper curing of concrete structures is important to ensure they meet their intended performance and durability requirements. In conventional construction, this is achieved through external curing, applied after mixing, placing and finishing. Internal Curing (IC) is a very promising technique that can provide additional moisture in concrete for more effective hydration of the cement and reduced self-desiccation. Internal curing implies the introduction of a curing agent into concrete that will provide this additional moisture. Concrete expands and contracts because of change in temperature, freezing and thawing cycle and environmental conditions. During early age hardening of concrete exhibits few cracks due to its chemical nature. The main reason for crack development in paste fraction is the loss of water due to chemical reaction and environment. The crack development due to aggregate was mainly on its chemical composition and physical properties. The crack due to plastic shrinkage could be reduced by adopting an internal curing method. This internal curing agent supply absorbed water to concrete to minimize the crack effect due to plastic shrinkage. Internal curing does not replace conventional surface curing but works with it to make concrete more robust. Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world. In this study, M25 Concrete was used to cast cubes beams and cylinders with the mix design of 1:1.78:2.92 replacing sand with presoaked vermiculite and in other mix replacing cement with SAP. The results of 28 days compressive strength, flexural strength and split tensile strength indicates a higher strength with usage of 0.35% SAP and 5% vermiculite as internal curing agents.

Keywords— *SAP, Vermiculite, Internal curing, compressive strength, shrinkage*

1. INTRODUCTION

Concrete expands and contracts because of change in temperature, freezing and thawing cycle and environmental conditions. During early age hardening of concrete exhibits few cracks due to its chemical nature. The main reason for crack development in paste fraction is the loss of water due to chemical reaction and environment. The crack development due to aggregate was mainly on its chemical composition and physical properties. There are many reasons for the crack development in concrete like cracks due to plastic shrinkage, drying shrinkage and settlement cracks. Shrinkage is a loss of excess water from the concrete leads to a reduction in its volume and gets hardening. The most common crack formation in concrete was mainly due to plastic shrinkage. The crack due to plastic shrinkage could be reduced by adopting an internal curing method. This internal curing agent supply absorbed water to concrete to minimize the crack effect due to plastic shrinkage. Internal curing does not replace conventional surface curing but works with it to make concrete more robust. Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world. ACI defines Internal Curing (IC) as a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water. The even distribution of additional water sources within the concrete will lead to greater uniformity of moisture throughout the thickness of the section and thus reduced internal stresses due to differential drying. While drying shrinkage may not be completely prevented in the long term, delaying it will allow the mixture to gain strength and be better able to resist the associated stresses. Once concrete sets, hydration creates partially-filled pores in the cement paste which causes stress that results in shrinkage. IC provides readily available additional water throughout the concrete so hydration can continue while more of the pores in the cement paste remain saturated. This reduces shrinkage, cracking, early age curling/warping, increases strength and lowers the permeability of the concrete.

The durability, strength and high performance during the life cycle of the concrete structure generally depends on the curing of concrete and it is crucial from the initial setting hours. Therefore, an effective curing method is required in order to increase the hydration of cementitious material and minimize the cracking problems due to drying shrinkage. When the mixing water is in contact with the cementitious materials, the hydration starts. During hydration some part of the mixing water becomes chemically bonded to the hydration products, some other adsorbed at the surface of the hydration products, and the rest remains in solution at the capillary pores formed during hydration. Cementitious materials get the water from the capillary pores to promote hydration, which generates surface tensions that result in volumetric reductions known as autogenous shrinkage. In case the free autogenous shrinkage of a concrete structure is not prevented, internal tensile stresses can be introduced at early ages, which can exceed the tensile strength of the concrete. As a result, premature cracks can be created, making the concrete more vulnerable to the ingress of potentially aggressive species and thus severely reducing the durability of the concrete. So that the autogenous shrinkage of hardening concrete becomes the core area of various research projects. One of the most conventional and well known applied curing methods is external water curing to mitigate the autogenous shrinkage of small size concrete elements. However, once the capillary pores de-percolate, it will be more difficult to provide adequate external water curing. Therefore, internal water curing by means of pre-soaked or saturated light weight aggregate and Super Absorbent Polymer (SAP) is considered as the most effective method for reducing autogenous shrinkage. An internal water reservoir is created into the fresh concrete through the inclusion of internal curing agent into the concrete. Once the initial free water has been consumed, the water absorbed by the light weight aggregate/SAP will be gradually released to maximize the heat of hydration.

1.1 Introduction of internal curing of concrete

The American Concrete Institute in 2010 defined internal curing as "supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation". Within the first decade of the 21st century, this technology has been intentionally incorporated into concrete mixtures at the proportioning stage, using a variety of materials including pre-wetted lightweight aggregates, pre-wetted crushed returned concrete fines, superabsorbent polymers, and pre-wetted wood fibers. The ongoing exploration of extensions of the internal curing concept that employ the internal reservoirs to contain materials other than water is reviewed. Finally, the critical issue of sustainability is addressed. To reduce shrinkage cracking, a method named as internal curing is developed. In this method, internal curing agents by means of LWA added to balance the reduction of water content. Hence LWA plays a major role in internal curing. And at the same time fabrication of heavy structure needs high strength concrete to hold the structure without failure. ACI defines Internal Curing (IC) as a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water. The even distribution of additional water sources within the concrete will lead to greater uniformity of moisture throughout the thickness of the section and thus reduced internal stresses due to differential drying. While drying shrinkage may not be completely prevented in the long term, delaying it will allow the mixture to gain strength and be better able to resist the associated stresses. Once concrete sets, hydration creates partially-filled pores in the cement paste which causes stress that results in shrinkage. IC provides readily available additional water throughout the concrete so hydration can continue while more of the pores in the cement paste remain saturated. This reduces shrinkage, cracking, early age curling/warping, increases strength and lowers the permeability of the concrete.

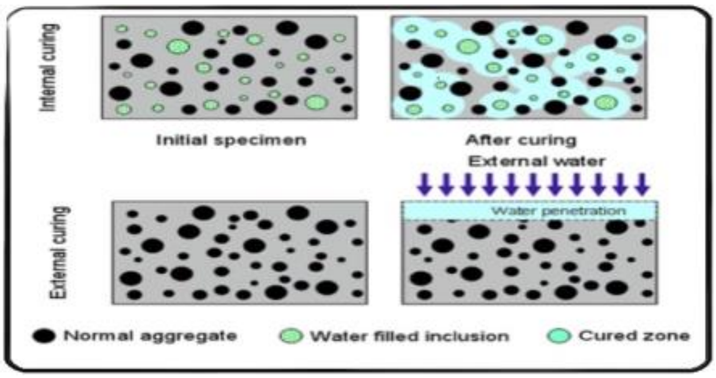

Fig. 1: Internal curing of concrete

The process of curing involves maintaining satisfactory moisture content and temperature after the concrete is placed in order to hydrate the cement particles and produce the desired hardened concrete properties. Proper curing can improve strength, durability, abrasion resistance etc. Curing either supplies additional moisture from the original mixing water or minimizes moisture loss from the concrete. Water may be bonded directly on the concrete to prevent evaporation of water from the fresh concrete. Internal curing grew out of the need for more durable structural concrete that is resistant to shrinkage cracking. Internal curing decreases the risk of cracking by providing additional water to a concrete mixture for the purpose of prolonged cement hydration without affecting the w/c ratio. Internal curing can be provided by highly absorptive materials that will readily desorb water for cement hydration. Materials that may be used for internal curing include LWA, Superabsorbent Polymer (SAP), perlite, and wood pulp. Internal curing does not replace conventional surface curing but works with it to make concrete more robust. Internal curing also helps compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world.

Field knowledge revealed the truth of high strength concrete which needs not to be high-performance concrete and vice versa. Improvement in compressive strength, bond strength and abrasion resistance can be achieved on adding silica fume with Portland cement concrete. The main idea of using lightweight aggregate was to build the structure with less weight and high insulation. On applying heat to vermiculite leads to the expansion and such expanded vermiculate was refer as expanded vermiculite. This expanded vermiculite was used as a spray in building plasters to provide advance coverage, fire conflict, adhesion and opposition to chipping, cracking and shrinkage.

2. INTRODUCTION OF VERMICULITE AND SAP

2.1 Vermiculite

Fig. 2: Vermiculite

Vermicular is an Italian word for a worm from which it has consequent its name as vermiculite. Some establishment quotes the Latin word vermicular from which the name vermiculite might be implemented. Vermiculite is a hydrous phyllosilicate mineral group and is micaceous in the environment. Vermiculite is formed by weathering or hydrothermal alteration of biotite or phlogopite. Exfoliated vermiculite is obtainable in five different grades, which are based upon weight rather than particle size. It undergoes significant expansion when heated. Vermiculite is chosen to replace fine aggregates in concrete because of its specific properties such as it is lighter in weight, improved workability, improved fire resistance, improved resistance to cracking and shrinkage and mainly inert chemical nature. Vermiculites take for concrete preparation which passes through 2.36mm sieve size.

2.2 Super absorbed polymer

Fig. 3: Super absorbed polymer

The introduction of SAP as a new additive for the production of concrete materials presents a number of new possibilities in respect of water control, i.e., the purposeful water absorption and/or water release in either fresh or hardened concrete. Proper curing of concrete structures is important to ensure they meet their intended performance and durability requirements. In conventional construction, this is achieved through external curing, applied after mixing, placing and finishing. Internal Curing (IC) is a very promising technique that can provide additional moisture in concrete for more effective hydration of the cement and reduced self-desiccation. Internal curing implies the introduction of a curing agent into concrete that will provide this additional moisture. Superabsorbent polymer (also called slush powder) can absorb and retain extremely large amounts of a liquid relative to their own mass. Water-absorbing polymers, which are classified as hydrogels when cross-linked absorb aqueous solutions through hydrogen bonding with water molecules. An SAP's ability to absorb water depends on the ionic concentration of the aqueous solution. In deionized and distilled water, an SAP may absorb 300 times its weight (from 30 to 60 times its own volume) and can become up to 99.9% liquid, but when put into a 0.9% saline solution, the absorbency drops to approximately 50 times its weigh The presence of valence cations in the solution impedes the polymer's ability to bond with the water molecule. The total absorbency and swelling capacity are controlled by the type and degree of cross-linkers used to make the gel. Low-density cross-linked SAPs generally have a higher absorbent capacity and swell to a larger degree. These types of SAPs also have a softer and stickier gel formation. High cross-link density polymers exhibit lower absorbent capacity and swell, but the gel strength is firmer and can maintain particle shape even under modest pressure. The largest use of SAPs is found in personal disposable hygiene products, such as baby diapers.

Adult diapers and sanitary napkins SAP was discontinued from use in tampons due to 1980s concern over a link with toxic shock syndrome SAP is also used for blocking water penetration in underground power or communications cable, horticultural water retention agents, control of spill and waste aqueous fluid, and artificial snow for motion picture and stage production. The first commercial use was in 1978 for use in feminine napkins in Japan and disposable bed liners for nursing home patients in the USA.

3. EARLIER STUDIES

George C. Hoff gave the consultancy report on "The Use of Lightweight Fines for the Internal Curing of Concrete. (2002). The benefits of using lightweight aggregates in concrete to help reduce cracking in slabs and bridge decks have been intuitively known for decades by the lightweight aggregate industry but the reasons as to why this occurred were not extensively examined and the benefits were not widely promoted. It was believed, and correctly so, that the lower modulus of the LWA and the improved transition zone around the LWA particles due to their generally vesicular surface, helped reduce stress concentrations between the paste and the aggregate and those reductions subsequently reduced the amount of early-age cracking in the concrete.

Dale P. Bentz studied Internal Curing and Microstructure of High-Performance Mortars. (2010) while typically used to reduce early-age autogenous shrinkage and cracking, internal curing will also strongly influence the microstructure that is produced in cement-based materials. In this paper, the microstructure of a set of three different blended cement high-performance mortars produced with and without internal curing will be compared. For these mortars with the ratio of a water-to-cementitious material of 0.3 by mass, internal curing has been provided by the addition of pre-wetted lightweight fine aggregates. Their microstructures have been examined after 120 days of sealed curing using scanning electron microscopy of polished surfaces in the back-scattered electron imaging mode. Clear distinctions between the microstructures produced with and without internal curing are noted, including differences in the unreacted cementitious content, the porosity, and the microstructure of the interfacial transition zones between sand grains (normal and lightweight) and the hydrated cement paste.

4. EXPERIMENTAL PROGRAM

4.1 Materials used

- **Fine aggregate:** The fine aggregate used in this investigation is clean river sand passing through 4.75 mm sieve and conforming to grading zone II. The fine aggregates were tested as per Indian standard specifications IS 383-1970.
- **Coarse aggregate:** Locally available coarse aggregates having the maximum size of 10 to 20mm was used in this present work.
- **Cement:** The cement used in this study is 53 grade OPC manufactured by Chettinad cement.
- **Water:** The potable water available in the college premises.
- **Super absorbent polymer:** The superabsorbent polymers constituting of Sodium Polyacrylate in the form of round beads are used. They are labelled as non-toxic and eco-friendly.
- **Vermiculite:** Vermiculite is chosen to replace fine aggregates in concrete because of its specific properties such as it is lighter in weight, improved workability, improved fire resistance, improved resistance to cracking and shrinkage and mainly inert chemical nature. Vermiculites took for concrete preparation which passes through 2.36mm sieve size.
- **Casting of specimens:** The Concrete cube specimens (150 ×150 × 150 mm size), Beam specimens (100 x 100 x 750 mm) & Cylinder specimens (150mm dia) were casted by replacing sand with 5%, 10%, 15% pre-soaked light weight aggregate like vermiculite and other mix by replacing cement with 0.2%, 0.35%, & 0.5% super absorbent polymer.

5. RESULTS

5.1 Compressive Strength Test (SAP)

Table 1: Compressive strength results for SAP (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	16.87	22.29	22.96	19.63
14	23.15	27.91	30.52	26.87
28	26.51	32.26	34.30	30.21

5.2 Flexural Strength Test (SAP)

Table 2: Flexural strength results for SAP (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	3.53	3.87	4.49	4.03
14	4.84	6.04	6.09	5.49
28	5.44	6.95	7.09	6.22

5.3 Split Tensile Test (SAP)

Table 3: Split tensile strength results for SAP (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	1.83	2.04	2.30	2.22
14	2.80	2.80	3.15	2.92
28	2.83	3.20	3.54	3.10

5.4 Compressive Strength Test (Vermiculite)

Table 4: Compressive strength results (Vermiculite) (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	16.87	23.39	22.75	20.71
14	23.15	31.21	27.72	26.84
28	26.51	34.45	31.60	30.15

5.5 Flexural Strength Test (Vermiculite)

Table 5: Flexural strength results (Vermiculite) (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	3.53	4.46	3.61	4.18
14	4.84	6.10	6.03	5.55
28	5.44	7.03	6.70	6.14

5.6 Split Tensile Test (Vermiculite)

Table 6: Split tensile strength test results (Vermiculite) (N/mm2)

Days	Conventional M25	0.2% SAP	0.35% SAP	0.5% SAP
7	1.83	2.39	2.05	2.29
14	2.80	3.28	2.97	3.13
28	2.83	3.59	3.44	3.21

5.7 Graphical Representation

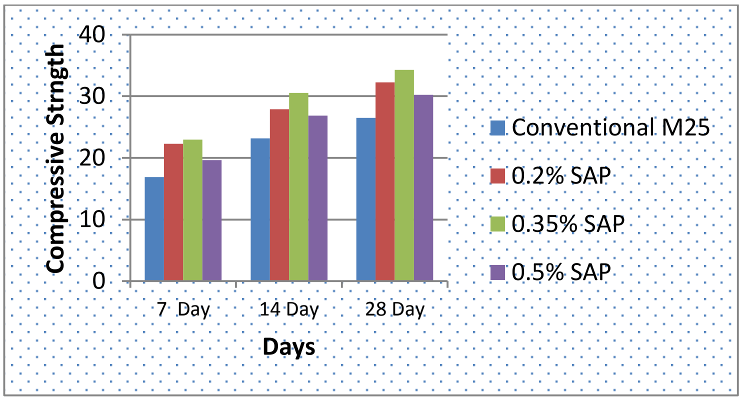

Fig. 4: Compressive strength results for SAP (N/mm2)

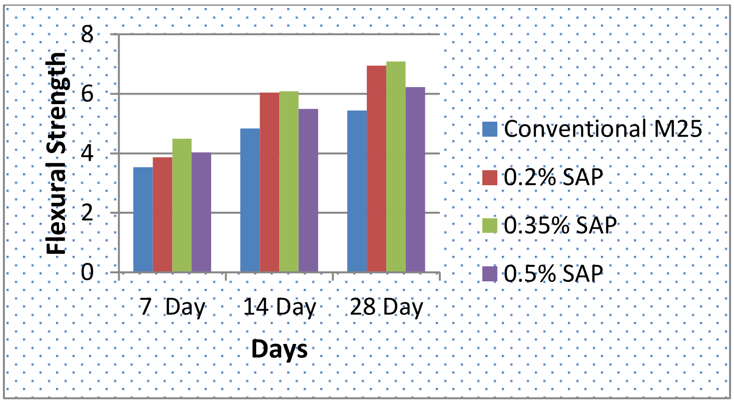

Fig. 5: Flexural strength results for SAP (N/mm2)

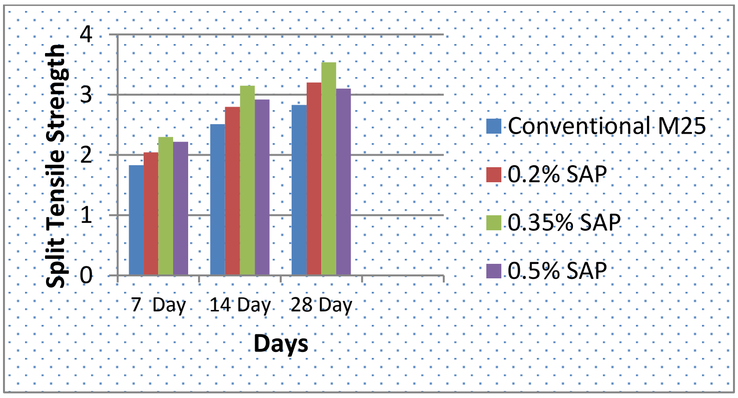

Fig. 6: Split tensile strength results for SAP (N/mm2)

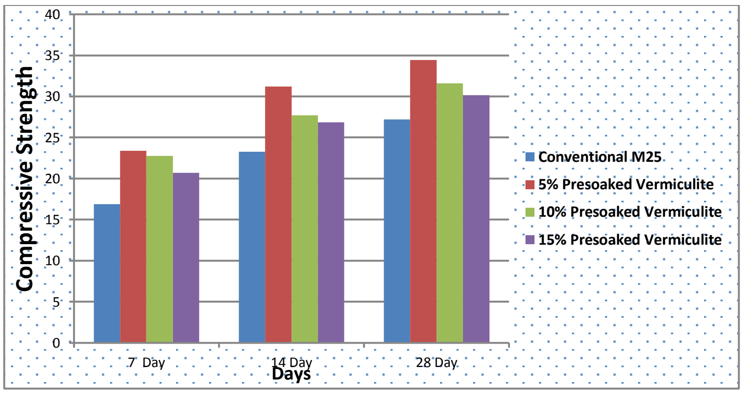

Fig. 7: Compressive strength results for vermiculite (N/mm2)

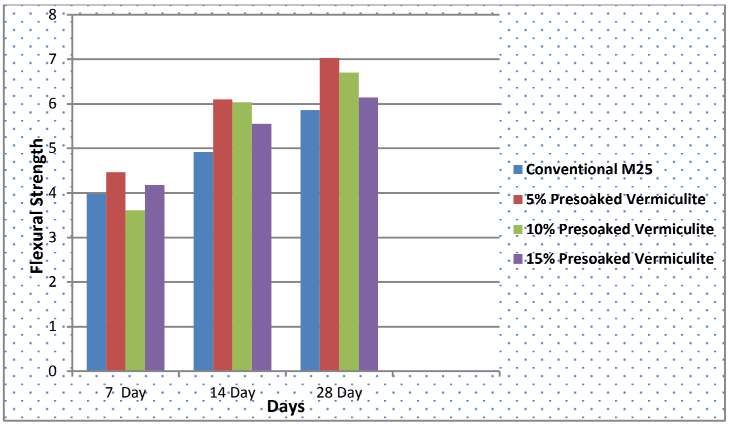

Fig. 8: Flexural strength results for vermiculite (N/mm2)

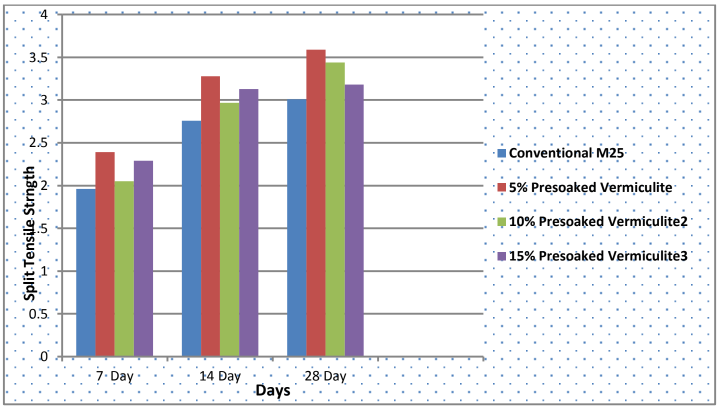

Fig. 9: Split tensile strength results for vermiculite (N/mm2)

6. CONCLUSIONS

From experimental work and testing of specimen following conclusions have been concluded:

(a) After28-day concrete attaining highest compressive strength when 0.35% of super absorbed polymer is added and increase compressive strength up to 29% and also using 5% of vermiculite added the compressive strength of concrete increase up to 30% as compared to conventional concrete.

(b) After 28 days concrete attaining highest Split Tensile strength when 0.35% of super absorbed polymer is added and increase Split Tensile strength up to 25% and also using 5% of vermiculite added the Split Tensile strength of concrete increase up to 26.85% as compared to conventional concrete.

(c) After 28-day concrete attaining highest Flexural strength when 0.35% of super absorbed polymer is added and increase Flexural strength up to 27.75% and also using 5% of vermiculite added the Flexural strength of concrete increase up to 29% as compared to conventional concrete.

(d) For the given interval of SAP the compressive strength, split tensile strength and flexural strength of concrete at 28 days increases from 14% to 29%, 15% to 30%, & 9% to 25% respectively as compared to conventional concrete, maximum at 0.35% dosage of SAP.

(e) For the given interval of presoaked Vermiculite the compressive strength, split tensile strength and flexural strength of concrete at 28 days increases from 13.7% to 29%, 12.86% to 29%, & 13.4% to 26% respectively as compared to conventional concrete, maximum at 5% replacement of presoaked vermiculite.

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