Use of Super Absorbent Polymers (SAP) for Autogenous Curing of Road Pavement

Abhijit Temkar[1], Atul Pujari[2]

[1]*Student, Dept. of Civil Engineering, Sinhgad Institute of Technology and Science, Pune, Maharashtra, India.*
[2]*Professor, Dept. of Civil Engineering, K J College of Engineering & Management Research, Pune, Maharashtra, India.*

Abstract - *During the hydration process, the conventional concrete with a low w/c ratio experiences a considerable amount of autogenous shrinkage deformation, which leads to early-age cracks and these premature cracks severely reduce the durability of concrete. External water curing is one of the most conventional and well-known applied curing methods to avoid the autogenous shrinkage however once the capillary pores de-percolate, it will be more difficult to provide adequate external water for curing. Internal curing has found to be the best strategy for reducing early age chemical shrinkage because it releases absorbed water gradually and maximises the hydration process. The primary goal of this research is to see how internal curing compares to typical curing in conventional concrete. Internal curing was achieved by super absorbent polymer (SAP) and the experimental parameter was a percentage of SAP substitution to regular sand. Experimental results revealed that internal curing water provided by the SAP, effectively reduce the early-age chemical shrinkage and significantly increase the compressive strength of concrete. The addition of SAP to cement pastes and concretes significantly reduced autogenous shrinkage. However, the complete mitigation of autogenous shrinkage was not always possible even when the extra amount of SAP was incorporated into the mixtures. It was also shown that incorporating SAP over 45 percent resulted in a decrease in compressive strength gain. The use of SAP can be easily incorporated in the construction of road pavement. The use of super absorbent will reduce the amount of maintenance required for curing after the construction and also increase the strength of the pavement.*

***Key Words*: SAP- Super Absorbent polymer, de-percolate, compressive strength, Chemical shrinkage, autogenous shrinkage.**

1.INTRODUCTION

In the last few decades advances in concrete technology have given rise to the use of new additives which mix with the concrete to enhance the properties of concrete. Internal curing is one of the greatest advancement in concrete technology. This is very beneficial since the depth that external water can penetrate is limited for any concrete, while internal curing water is dispersed throughout the depth of concrete. SAP, or super-absorbent polymers, is a type of material that can absorb up to 300 times its weight in water. Once absorbed, they do not immediately release it. Because it absorbs a considerable amount of water, super absorbent polymer (SAP) works well as an internal curing agent. SAP proves to be a better element in reducing early age shrinkage and significant increase in compressive strength.

Excessive amount of water added in the fresh concrete generally improves the workability of concrete while reducing the strength increasing the drying shrinkage of hardened concrete. The rate of water absorption into the concrete microstructure is greater than the rate of water absorption into the concrete from the surface. This hinders the conventional methods of curing of water from being successfully implemented in curing of concrete therefore we resort to alternative materials, such as lightweight aggregate or highly absorbent polymers, that can absorb, hold, and deliver water as needed while still fulfilling the purpose of aggregate.

Super-absorbent polymers (SAP) are a new form of concrete admixture that are utilised to provide more water resources to hardening concrete for internal curing. When added to the mix in a dry state, they absorb and store far more water than their own weight in a short period of time. This water absorption causes SAP to swell, resulting in an increase in its volume. SAP gradually releases the water it has absorbed, spreading itself throughout the concrete cracks and closing them. The water gel presented in concrete by SAP provides cushioning and lubricating in the concrete mass, which improves the workability and stability of the concrete.

In his findings, Jensen (2013) used superabsorbent polymers as an additive to his concrete. His research focused on strength of concrete and shrinkage. He came to the conclusion that concrete shrinkage owing to water loss to the environment causes cracking in both the plastic and hardened stages. Slowing down the water loss can effectively reduce this form of cracking. The use of super-absorbent polymers has the ability to reduce the cracking in concrete.

1.1 Literature review

According to Dudziak and Mechtcherine's [1] research, additional internal curing water absorbed by the SAP was required to compensate for the moisture in concrete since the SAP in concrete absorbed moisture in the mixture and reduced the slump of the concrete.

[2] S.Rajeswari et al., This study explains how a super absorbent polymer may collect a large amount of liquid from its surroundings and keep it in its structure without disintegrating. The polymers are added to the cement at a rate of 0-0.6 wt%. M 30 grade of concrete was designed with an internal curing agent as Super Absorbent Polymer ranging from 0.1 to 0.4 percent by weight of cement, and the features of self-curing concrete with the addition of 2% steel fibres by volume of concrete were investigated. According to the paper's finding the strength rises at varying proportions of polyethylene glycol, with 1 percent being optimal for M20 and M25 grades and 0.5 percent for M40 grade.

Snoeck and Schaubroeck [3] compared the performance of concrete with different kinds of SAP. The findings revealed that the water absorption rate and volume of SAP had a detrimental impact on concrete performance when the particle size was small. The loss in workability might be offset to some extent when internal curing water was absorbed by SAP. When water is released, however, SAP will escape the pores. The use of SAP absorbs additional internal curing water, leading to increase in porosity, which may have a detrimental impact on concrete strength. Although the swelling of SAP has an effect on the development of early pore structures, studies have shown that the water absorbed by the SAP will be progressively released when the relative humidity of the concrete drops. It will effectively reduce autogenous shrinkage and increase cementitious material hydration. As a result, concrete's strength may be improved.

[4] M.Srihari et al. According to this research, compressive, tensile, and flexure strength tests were performed at 7 and 28 days. Concrete is made with a mix that contains 0.5 percent PEG, 1 percent PEG, 1.5 percent PEG, 2 percent PEG, and 0.1 percent, 0.2, 0.3, and 0.4 percent SAP. The usual Super Absorbent Polymers are added to the cement at a rate of 0-0.6 wt%. Compressive, tensile, and flexural strength are all highest at 1percent PEG and 0.3 percent SAP, according to tests. Super absorbent polymer outperforms polyethylene glycol and is less expensive than PEG.

Ravindra D. Warkhade et al., [5] The paper deals with the use of SAP in concrete and studies the effect of SAP in concrete for the internal curing of a road. The super absorbent polymer has the ability to absorb a relatively large amount of water, these properties are found to be very useful and effective in plain concrete. There are various tests performed in this paper like test on cement, test on aggregate, test on concrete, workability of concrete, compressive strength of concrete. It has been noticed that super-absorbent polymer has been successfully used as an internal curing agent, which should help with total curing, which is required for developing strength, should be minimised. When 0.1 percent super absorbent polymer is added to concrete, the compressive strength produced in seven days rises by 11.0 percent over conventional concrete. The addition of SAP results very effective in reducing the cracking.

S. Dugane et al., [6] This research looks at all elements of using SAP in concrete, such as the impact of adding SAP on concrete behaviour, shrinkage, and strength, among other things. Various physical and chemical properties of SAP like appearance, ph, specific gravity, vapour pressure, melting point, boiling point etc are studied. The super absorbent polymer was added to the concrete at varying proportions of 0.5%, 1%, 2% of the weight of cement, at a water-cement ratio of 0.5. The desired slump value and compressive strength was obtained for conventional concrete at a 0.5 water-cement ratio. This study tried to focus on the most significant effect of addition of super-absorbent polymer to the concrete mixes. However, maximum gain in strength of concrete is found to depend upon the percentage of addition.

2. OBJECTIVES AND RESEARCH SIGNIFICANCE

This paper investigates the application of SAP as an internal curing agent in concrete. It is indicated by optimising the dosage of SAP, a trade-off can be reached to maintain a desired internal curing effect without seriously undermining the mechanical strength of concrete. The primary goal of this investigation is to reduce the efforts and cost needed for curing after the laying of fresh concrete on roads. This work will offer a fresh look on the application of SAP in concrete roads.

3. EXPERIMENTAL PROGRAM

3.1 Materials

Coarse aggregate (10mm) passing through 12.5mm, 10mm, 4.75mm, 2.36mm IS sieve and pan as specified specified by [IS:2386 (Part I)-1963]. The result of sieve analysis is shown in table 1.

Coarse aggregate (20mm) passing through 25mm, 20mm, 10mm, 4.75mm IS sieve and pan as specified specified by [IS:2386 (Part I)-1963]. The result of sieve analysis is shown in table 2.

Fine aggregate (Crushed Sand) passing through 10mm, 4.75mm, 2.36mm, 1.18mm, 600micron,300micron 150micron IS sieve and pan as specified specified by IS 383 -1970 [46]. The result of test is shown in table 3.

Cement: In all types of concrete mixes Portland cement conforming to IS 12269standard, was used. Fineness of cement by dry sieving. the result of test is shown in table 4.

Concrete- The concrete mix proportion was designed by IS:456-2000 method to achieve the strength of 40N/mm2, and the designed mix proportion was 1 : 1.65 : 2.92 by weight. The designed water cement ratio was 0.35 and the formulations of various mixtures were listed in Table 5.

Tap water was used as mixing water and internal curing water.

SAP (Super-absorbent Polymer): A white sugar-like powder was employed. It is also called as an ionic polyacrylamide.

3.2 Testing program

Standard Cubes of dimensions 150x150x150 mm confirming to IS10086 (1982) [43] were prepared and tested according to IS 516 (1959) [44] for determining 7, 28 and 90 days compressive strength of concrete for three mix with varying percentage of SAP and one set for conventional mixture. Three cubes each for identical mix along with different percentage of SAP i.e., 36 cubes were tested, and the average compressive strength was noted.

Standard cylinders 150 x 300mm length confirming to IS 10086 [43] were prepared and tested at a curing age of 7, 28 and 90 days as per IS 5816 (1999) [45]. for determining split tensile strength of concrete, three cylinders each for identical mix along with different percentage of SAP i.e., 36 cubes were tested, and the average split tensile strength was noted.

To determine the flexure strength of concrete, 36 beams of standard size (150 x150 x700 mm) were cast and tested at a curing age of 7, 28 and 90 days according to IS 516 (1959) [44]. The beam specimens were tested under two-point loading 200mm apart to ensure pure flexure between points of loading using the universal testing machine.

Slump cone test - The workability of the fresh concrete was measured by slump cone test, time ranged from immediate after mixing, 30min and 60min, as per IS 1199(1959). The internal surface of the mould is cleaned and applied a coat of oil then the mould is filled in four layers. The tamping rod is used to tamp each layer 25 times. After the top layer is fully filled the concrete is struck off the trowel. Then the mould is removed from the concrete immediately by raising it in the vertical direction. The difference in the layer between the height of mould and that of the highest point of the subsiding concrete is measured. This difference in height in mm is the slump of the concrete. The slump loss of the SAP substituted fresh concrete are given in Table 6 and explained the effect of SAP on the workability of the fresh concrete.

4 Results

4.1 Materials

Coarse aggregate (10mm) passing through 12.5mm, 10mm, 4.75mm, 2.36mm IS sieve and pan.

Table -1: Sieve analysis (Part A)Test Result I (weight taken = 2000 gms)

Sieve Size	Wt in gms Retained	Wt Retained %	Cummulative % Wt Reatined	% Passing	Limit as per IS:2386
12.5mm	20	1.00	1.00	99.00	100
10mm	212	10.60	11.60	88.40	85-100
4.75mm	1586	79.3	90.90	9.10	0-20
2.36mm	165	8.25	99.15	0.85	0-5
Pan	15	0.75	99.90	0	
Total	1998	99.90			

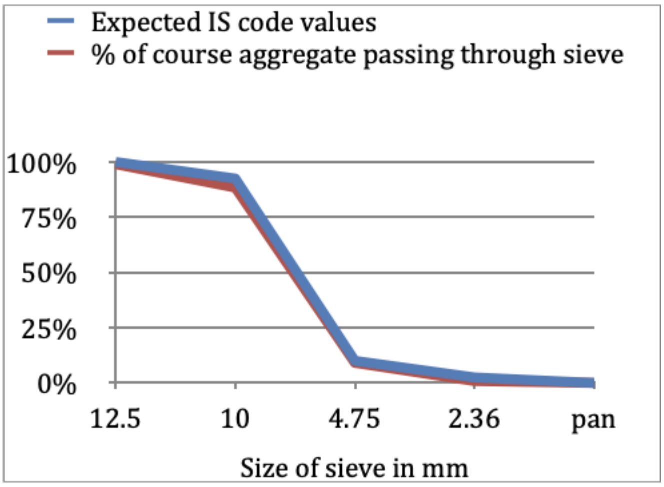

Chart -1: Gradation Curve For the natural fine aggregates.

Diagram-1: Standard IS sieves.

2) Coarse aggregate(20mm) passing through 25mm, 20mm, 10mm, 4.75mm IS sieve and pan

Table -2: Sieve analysis (Part B) Test Result (weight taken = 2000 gms)

Sieve Size	*Wt in gms Retained*	*Wt Retained %*	*Cummulative % Wt Retained*	*% Passing*	*Limit as per IS 383*
25mm	0	0.00	0.00	100.00	100

20mm	299	14.95	14.95	85.05	85-100
10mm	1584	79.20	94.15	5.85	0-20
4.75mm	98	4.90	99.05	0.95	0-5
Pan	19	0.95	100	0	
Total	2000	100			

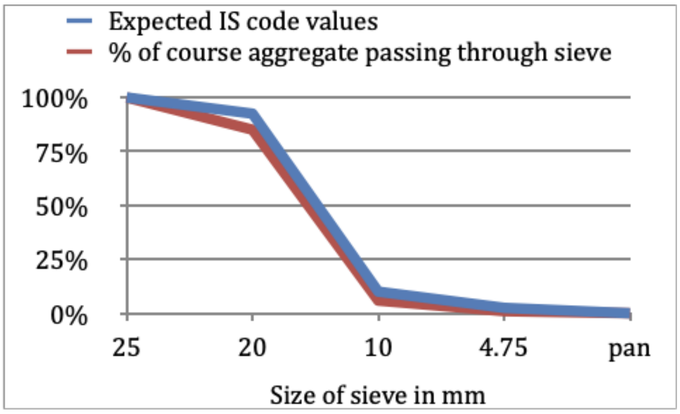

Chart -2: Gradation Curve For the coarse aggregates.

3) Fine aggregate (Crushed Sand) passing through 10mm, 4.75mm, 2.36mm, 1.18mm, 600micron, 300micron, 150micron IS sieve and pan.

Table -3: Fine aggregate (Crushed Sand) Test Result (weight taken = 1000 gms)

Sieve Size	*Wt in gms retained*	*Wt retained %*	*Cummulative % wt retained*	*%passing*	*Limit as per IS 383 Zone I*	*Zone II*
10mm	0	0.0	0.00	100.00	100	100
4.75mm	73	7.30	7.30	92.70	90-100	90-100
2.36mm	245	24.50	31.80	68.20	60-95	75-100
1.18mm	203	20.30	52.10	47.90	30-70	55-90
600micron	184	18.40	70.50	29.50	15-34	35-59
300micron	152	15.20	85.70	14.30	5-20	8-30
150micron	138	13.80	99.5	0.50	0-20	0-20
Pan	5	0.50	100	0.00		
Total	1000	100				

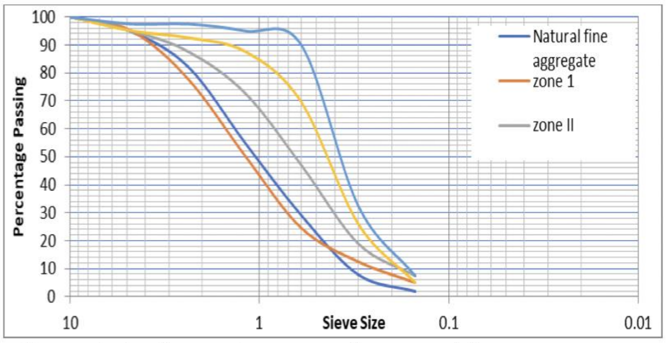

Chart -3: Gradation Curve For the natural fine aggregates

4) Fineness of cement by dry sieving

Table -4: Fineness of cement Test Result (weight in grams)

Sr.No.	*Description*	*Test-1*	*Test-2*
A	Weight of cement	500	200
B	Weight retained on 90 micron sieve	7.00	6.00
C	Fineness of cement (%)R1=(B/A)100	1.40	3.00
	Fineness of cement (%) R0=(R1+R2)/2	Avg. 2.20	

5) Concrete

The concrete mix proportion was designed by IS method to achieve the strength of 40N/mm2, and the designed mix proportion was 1:1.65:2.92 by weight. The designed water cement ratio was 0.35 and the formulations of various mixtures were listed in Table 5.

Table -5: Mix Proportion

Cement	400 gm
Water	160 gm
Fine Aggregate	660 gm
Coarse Aggregate 20mm	701 gm
Coarse Aggregate 10mm	467 gm
Admixture 0.6% by wt of cement	2.4 gm

Table -6: Concrete Mixture Proportions

Mixture	*Control Mixture*	*SAP 45*	*SAP 67.5*	*SAP 90*
W/c Ratio	0.35	0.35	0.35	0.35
Water (kg/m^3)	186	186	186	186
Cement (kg/m^3)	465	465	465	465
Sand (kg/m^3)	603	488.7	431.55	374.54
Course Agg. (kg/m^3)	1086	1086	1086	1086
Internal Curing Water (kg/m^3)	0	45	67.5	90
SAP (kg/m^3)	-	1.05	1.50	2.00

Mix ratio of the materials used for 1metre-cube as per the code IS 10262:2009

4.2 Test Results

1) Slump cone test

Slump cone test for workability (readings in mm)

Table -7: Slump cone test readings

Mixture Designation	*Immediate After Mixing*	*After 30 Minutes*	*After 60 Minutes*
CM	119	84	54
SAP45	88	53	11
SAP67.5	53	20	0
SAP90	33	0	0

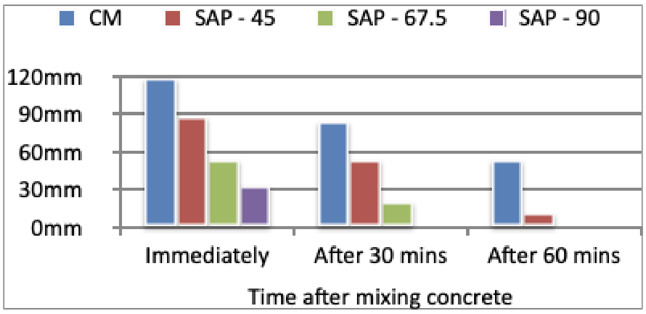

Chart -4: Slump loss value of concrete for all mixtures

2) Compressive strength

Table -8: Compressive strength of all mixtures

Mixture Designation	*Compressive strength (N/mm^2)*		
	7 Days	28 Days	90 Days
CM	28.64	38.72	40.45
SAP 45	36.55	52.12	54.78
SAP 67.5	31.25	50.22	51.18
SAP 90	30.95	46.82	48.09

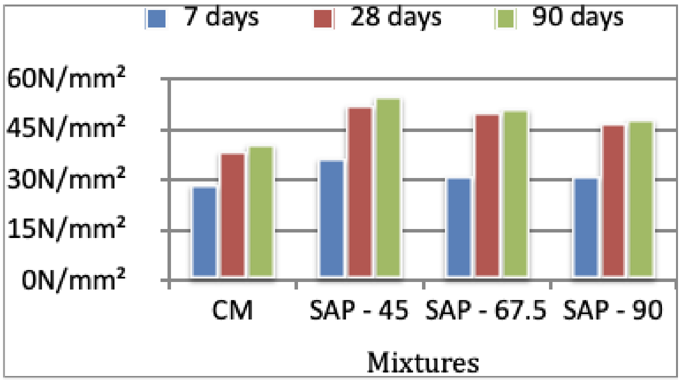

Chart -5: Compressive strength of concrete for all mixtures

3) Split Tensile and Flexural strength

Table -9: Split tensile and flexural strength of all mixtures

Mixture Designation	*Split Tensile Strength (N/mm^2)*		*Flexural Strength (N/mm^2)*	
	7 Days	28 Days	7 Days	28 Days
CM	3.72	5.02	2.68	3.98
SAP 45	3.95	5.18	3.41	4.81

SAP 67.5	3.88	5.22	3.14	4.48
SAP 90	3.45	4.78	3.00	4.33

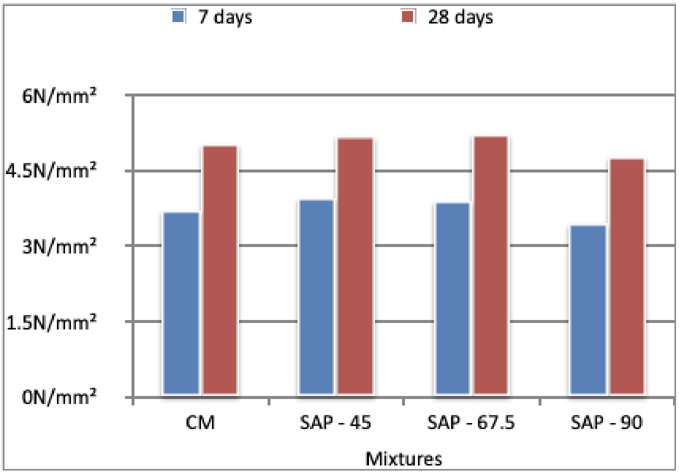

Chart -6: Split tensile strength of all mixtures

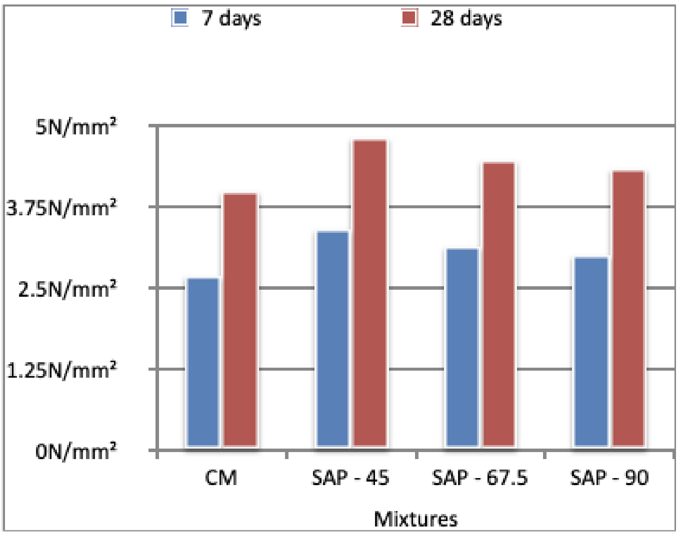

Chart -7: Flexural strength of all mixtures

5. CONCLUSIONS

1) The workability of the concrete was observed to decrease with an increase in the SAP substitution rate and the poor workability was observed for the mixture of SAP 67.5 and SAP 90 when compared to the other mixture.

2) At an early stage, the compressive strength of the SAP-containing mixture is neither comparable to nor significantly lower than that of the control mixture, and the SAP contribution can be clearly distinguished at later ages.

3) Substituting SAP reduces autogenous shrinkage, and the concrete's compressive strength improves with age.

4) Mixtures SAP 45, SAP 67.5, SAP 90 enhanced their compressive strength by 35.42%, 26.52%, and 18.88% when compared to the conventional mixture.

5) Mixtures SAP 45, SAP 67.5, SAP 90 enhanced their flexural strength by 20.85%, 12.56%, and 8.79% when compared to the conventional mixture.

REFERENCES

1. Viktor Mechtcherine, Lukasz Dudziak,"Internal curing by super absorbent polymers (SAP) – effects on material properties of self-compacting fibre-reinforced high performance concrete," International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation, 2006, pp. 87 - 96.

2. D. Snoeck and D. Schaubroeck, "Construction and Building Materials," V. 72, 15 December 2014, pp. 148-157.

3. M.Srihari, B.Karthick, "Experimental study on behaviour of concrete using self curing agents," International Journal of Engineering Sciences & Research Technology, May, 2016, pp 443-449.

4. Jensen, O. M., and Hansen, P. F., "Water-Entrained Cement-Based Materials I. Principles and Theoretical Background," Cement and Concrete Research, V. 31, 2001, pp. 647-654.

5. Ravindra D. Warkhade, Mahesh S. Varpe2, Vikas S.Dhangar, Varsha S.Dalvi, Prof.S.G.Upadhyay, "Use of SAP in concrete," International Journal of Advance Research in Science and Engineering, V. 5, March 2016, pp. 424-429.

6. Dugane S. , Langhe G., Erande Satyam, Jawak V., Ashwini Salunkhe, "Analysis of Effect of Internal Curing with Super Absorbent Polymer (SAP), IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Volume 16, Issue 3 Ser. IV (May. - June. 2019), PP 60-62

7. Bentur, A., Igarashi, S., and Kovler, K., "Prevention of Autogenous Shrinkage in High-Strength Concrete by Internal Curing using Wet Lightweight Aggregates," Cement and Concrete Research, V. 31, 2001, pp. 1587-1591.

8. Kovler, K., and Zhutovsky, S., "Overview and Future Trends of Shrinkage Research," Materials and Structures, V. 39, 2006, pp. 827-847.

9. Jensen, O. M., and Lura, P., "Techniques and Materials for Internal Water Curing of Concrete," Materials and Structures, V. 39, 2006, pp. 817-825.

10. Lura, P.; Durand, F.; and Jensen, O. M., "Autogenous Strain of Cement Pastes with Super-Absorbent Polymers,"

Volume Changes of Hardening Concrete: Testing and Mitigation, Lyngby, Denmark, 2006, pp. 57-65.

11. Igarashi, S., and Watanabe, A., "Experimental Study on Prevention of Autogenous Deformation by Internal Curing using Super-Absorbent Polymer Particles," Volume Changes of Hardening Concrete: Testing and Mitigation, Lyngby, Denmark, 2006, pp. 77-80.

12. Bentz, D. P.; and Snyder, K. A., "Protected Paste Volume in Concrete Extension to Internal Curing Using Saturated Lightweight Fine Aggregate," Cement and Concrete Research, V. 29, 1999, pp. 1863-1867.

13. Wang, F. Z.; Zhou, Y. F.; Liu, Z. C.; and Hu, S. G., "Internal Relative Humidity and Autogenous Shrinkage of Low Water/Binder Ratio Concrete," International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation, Lyngby, Denmark, 2006, pp. 51-55.

14. Shin-ichi Igarashi, Akio Watanabe [2006], "Experimental study on prevention of autogenous deformation by internal curing using super-absorbent polymer particles", International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation, pp.77 - 86

15. M. Wyrzykowski, P. Lura, F. Pesavento, D. Gawin, Modeling of water migration during internal curing with superabsorbent polymers, J. Mater. Civ. Eng., 24 (2012) 1006-1016.

16. K. Kovler, O. Jensen (Eds.), Report rep041: Internal curing of concrete: State-of-the-art report of RILEM Technical Committee 196-ICC, RILEM State-of-the-Art Reports, 2007.

17. S. Weber, H.W. Reinhardt, A New Generation of High Performance Concrete: Concrete with Autogenous Curing, Adv. Cem. Based Mater., 6 (1997) 59-68.

18. A. Bentur, S.-i. Igarashi, K. Kovler, Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates, Cem. Concr. Res., 31 (2001) 1587-1591.

19. O.M. Jensen, P.F. Hansen, Water-entrained cement-based materials: I. Principles and theoretical background, Cem. Concr. Res., 31 (2001) 647-654.

20. O. Jensen, P. Lura, Techniques and materials for internal water curing of concrete, Mater. Struct., 39(2006) 817-825.

21. V. Mechtcherine, M. Gorges, C. Schroefl, A. Assmann, W. Brameshuber, A.B. Ribeiro, D. Cusson, J.Custodio, E.F. da Silva, K. Ichimiya, S. Igarashi, A. Klemm, K. Kovler, A.N.D. Lopez, P. Lura, T. Nguyen,H.W. Reinhardt, R.D. Toledo, J. Weiss, M. Wyrzykowski, G. Ye, S. Zhutovsky, Effect of internal curing by using superabsorbent polymers (SAP) on autogenous shrinkage and other properties of a high-performance fine-grained concrete: results of a RILEM round- robin test, Mater. Struct., 47 (2014) 541-562.

22. M.T. Hasholt, M.H.S. Jespersen, O.M. Jensen, Mechanical properties of concrete with SAP. Part I:Development of compressive strength, in: O.M. Jensen, M.T. Hasholt, S. Laustsen (Eds.), Use of superabsorbent polymers and other new additives in concrete, RILEM Publications SARL, Lyngby (Denmark), 2010, pp. 117-126. RILEM Publications SARL

23. S. Zhutovsky, K. Kovler, Effect of internal curing on durability- related properties of high performance concrete, Cem. Concr. Res., 42 (2012) 20-26.

24. V. Mechtcherine, H.W. Reinhardt (Eds.), Application of Super Absorbent Polymers (SAP) in Concrete Construction. State-of- the-Art Report Prepared by Technical Committee 225-SAP, Springer 2012.

25. C. SchrÃfl, V. Mechtcherine, M. Gorges, Relation between the molecular structure and the efficiency of superabsorbent polymers (SAP) as concrete admixture to mitigate autogenous shrinkage, Cem. Concr. Res.,42 (2012) 865-873.

26. M.T. Hasholt, O.M. Jensen, K. Kovler, S. Zhutovsky, Can superabsorent polymers mitigate autogenous shrinkage of internally cured concrete without compromising the strength?, Constr. Build. Mater., 31 (2012)226-230.

27. N. Van Tuan, G. Ye, K. Van Breugel, O. Copuroglu, Hydration and microstructure of ultra high performance concrete incorporating rice husk ash, Cem. Concr. Res., 41 (2011) 1104- 1111.

28. G. Ye, N. Van Tuan, H. Huang, Rice Husk Ash as smart material to mitigate autogenous shrinkage in high (ultra-high) performance concrete, Third International Conference on Sustainable Construction Materials and Technologies, Kyoto, Japan, 2013.

29. V. Mechtcherine, L. Dudziak, S. Hempel, Internal curing to reduce cracking potential of Ultra High Performance Concrete by means Super Absorbent Polymers, Proceedings of 2nd International