EVALUATING THE MECHANICAL PROPERTIES OF CONCRETE BY UTILIZING WASTE DIAPER POLYMER

Yeasir Arafat Mim[1], Susmita Samonta[2], Md. Tarif Aziz[3], Md. Abul Hasan[4]

[1] *Undergraduate student, Southern University Bangladesh, Bangladesh,*
e-mail: mdyeasirarafat258@gmail.com
[2] *Undergraduate student, Southern University Bangladesh, Bangladesh,*
e-mail: susmi636@gmail.com
[3] *Lecturer, Southern University Bangladesh, Bangladesh,*
e-mail: tarifctg98@gmail.com
[4] *Assistant professor, Southern University Bangladesh, Bangladesh,*
e-mail: hasancuet90@gmail.com

***Corresponding Author**

ABSTRACT

It is generally acknowledged that, after water, concrete is the most frequently employed substance on earth. It is anticipated that the median annual consumption of concrete amounts to roughly one ton for every individual inhabiting the earth. Several researchers have investigated the implementation of fly ash (FA), rice husk ash (RHA), ladle furnace slag (LFS), silica fume (SF), superabsorbent polymer (SAP), recycled fibers, and a variety of other materials in concrete as a partial replacement to enhance its workability and mechanical qualities while making it more environmentally friendly. On the contrary, improper damping of waste baby diapers contribute significantly to landfilling and contaminate the natural surroundings by releasing hazardous chemical compounds and microplastics. Therefore, the consequences of utilizing superabsorbent polymers (SAP) from diapers as a sustainable resource are investigated in this research. In addition to integrating a superplasticizer to improve the workability of the concrete, silica fume is typically utilized to further improve its strength. In order to make comparison among numerous experimental data involving compressive strength, split tensile strength and flexural strength tests, a total of 72 specimens were constructed. The specimens comprises 6 distinct ratios (0%, 0.1%, 0.3%, 0.5%, 0.7%, and 1%) of SAP. In this study, both water curing and air curing at 28 days curing period were employed to assess the compressive strength of concrete, which are two ordinary types of curing operations. The addition of 0.5% SAP to the concrete mixture yields a noteworthy result for compressive strength (36.11 MPa), when cured in a water tank. In case of air curing, 0.1% incorporation of SAP in concrete shows the optimum result of compressive strength (37.76 MPa). On top of that, the use of SAP in concrete substantially improves the results of flexural strength and split-tensile strength tests after 28 days curing period. Following a similar trend of compressive strength result in air curing, 0.1% inclusion of SAP also gives peak value (8.2 MPa) in terms of flexural strength. In split-tensile test, 0.3% replacement of SAP offers preeminent result among all percentages. However, high dosage of SAP addition in concrete represent a downward trend on all mechanical strength properties, which is due to generation of excess macro voids in concrete samples.

Keywords: *Concrete, Superabsorbent polymer, Superplasticizer, Silica fume, Mechanical strength.*

1. INTRODUCTION

In recent years, several materials are being used in concrete for enhancing workability, improving the mechanical properties, also preventing drying shrinkage crack and leakage through the cracks (Mohamad et al., 2017; Tsuji et al., 1998, 1999). To accelerate the hydration process for improving the mechanical strength and workability, most researchers suggest using an internal curing agent as an additive to concrete (Chindasiriphan et al., 2020; Mohamad et al., 2021). Super-absorbent polymer (SAP) is one of the most effective material used as an internal curing agent and self-healing additive because SAP can absorb a large amount of water/fluid relative to their own mass and thus SAP could effectively expedite the w/c ratio and hydration process of concrete mix. Previous studies have demonstrated that the incorporation of a super-absorbent polymer as an admixture leads to an enhancement in mechanical strength (Bentz et al., 2002; Gao et al., 1997). The principle applications include the use of SAP as an internal curing admixture to mitigate self-desiccation, to reduce autogenous shrinkage in low w/c ratio environment and induce self-sealing/healing of cracks, as a consequent improving the mechanical properties of concrete (Jensen and Hansen, 2001, 2002; Wong, 2018).Waste diaper has major negative impact on environment as it is responsible for 2% to 7% global solid wastes production (Arena et al., 2016). Super-absorbent polymer is one of the key ingredients in baby diapers. Thus, SAP from waste baby diapers can be used in concrete, which can increase concrete's mechanical properties (Mohamad et al., 2017, 2021). In this study, concrete's compressive strength, flexural strength and tensile strength are evaluated.

2. METHODOLOGY

2.1 MATERIALS

The materials employed in this study **Fig 1** encompass super-absorbent polymer (SAP), silica fume, polycarboxylate ether, Ordinary Portland cement (OPC), coarse aggregate, and fine aggregate. SAP was collected from waste baby diapers. Silica fume, which is a by-product of the smelting process in the silicon and ferrosilicon industry. A superplasticizer called polycarboxylate ether used as a water reducing agent. Sylhet sand was used as fine aggregate and 20mm downgraded stone chips were used as a coarse aggregate. Particle size distribution of fine and coarse aggregate were showed in **Fig 2**. The research was carried out by making 72 specimens of 6 different batches to verify the mechanical properties (compressive strength, split-tensile strength, flexural strength tests) of concrete. Two different curing method (air curing and water curing) was carried out to check the variation in compressive strength data. The mix design was based on the ACI 211.1-91 standard. Mix proportions used for each batch are shown in **Table 1.**

Cement

Sand

Stone chips

Super-absorbent polymer Silica fume Superplasticizer

Fig 1: Materials used in this study

Table 1: Mix proportion

Sl. No.	Cement	Fine Aggregate	Coarse Aggregate	Water	Silica Fume	Super plasticizer	Super-absorbent Polymer	
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m	%	kg/m^3
1	404	779	1052	149.5	0	4.04	0	0
2	363.22	778.15	1050.89	149.32	40	4.04	0.1	2.39
3	362.45	776.44	1048.67	149.01	40.27	4.03	0.3	7.17
4	361.68	774.73	1046.45	148.69	40.19	4.02	0.5	11.95
5	360.91	773.03	1044.24	148.38	40.10	4.01	0.7	16.72
6	359.76	770.47	1040.91	147.9	39.97	4.00	1	23.89

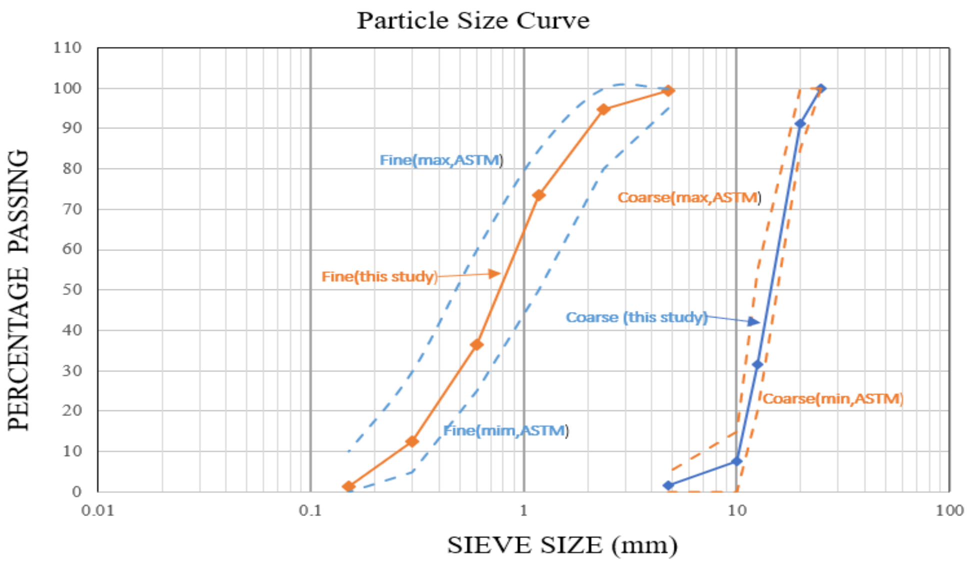


Fig 2: Particle size distribution curve of fine and coarse aggregate.

2.1.1 Superabsorbent Polymer

In this research, Superabsorbent polymer was collected from 0-2 years infant diaper (only urine contained diaper) and no mechanical device was used for the separation of SAP from waste diapers. The separation process was accomplished manually as shown in **Fig 3**. Superabsorbent polymer was collected from Waste diapers by cutting them sidewise using scissor. While cutting diaper or collecting SAP using hand gloves & face mask is mandatory for safety purpose. **Fig 4** shows the 3D morphology of waste diaper.

Urine contains some chemicals, such as urea, creatinine, uric acid, etc., and pathogens. Used diapers polymers pH is around 8 (Mohamad et al., 2019) and concrete has a pH of about 13 (Behnood et al., 2016), which means it produces an extremely alkaline atmosphere. The result of the high alkalinity is the destruction of all viruses, bacteria, and pathogens (Farrell et al., 1974; Karimi et al., 2020; Randall et al., 2016).

(a) (b)

Fig 3: Superabsorbent polymer collected from used diaper

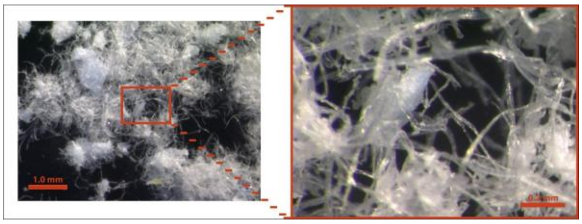


Fig 4: Morphology of shredded waste diapers under an optical microscope (Karimi et al.)

2.2 Mixing Procedure

For this study , the hand mixing technique was used in accordance with Bangladesh's preferred procedure, which complies with C192/C192M-19 for control specimen. Appropriate amount of cement, sand and silica fume were mixed thoroughly. After that, coarse aggregates were being mixed uniformly. Finally, in order to produce concrete, water that had been combined with superplasticizer was then introduced to the dry mixture. In case of SAP mix concrete, all procedures were same, but for uniform mixing, presoaked SAP was thoroughly mixed with coarse aggregates.

2.3 Test Detail

2.3.1 Slump (workability) test

Slump test was carried out according to ASTM-C143 to determine the workability of concrete. This test is carried out to further identify the effectiveness of the selected w/cm ratio. A sample of freshly mixed concrete is put into a cone-shaped mold (100 x 200 x 300 mm) and pressed down with a rod. The mold is lifted, and the concrete is left to settle. The slump of the concrete is the vertical distance between the original and new position of the center of the top surface of the concrete.

2.3.2 Mechanicsl strength tests

For evaluating mechanical properties of concrete three tests, which were compressive strength test, split-tensile strength test, flexure strength test, were conducted according to ASTM-C39, ASTM-C78/C78M and ASTM-C496/C496 respectively. A (100×100×100) mm cube molds showed in **Fig 5(a)** were used to perform compressive strength test for a curing period of 28 days. Two different curing method which are air curing and water curing, were adopted to demonstrate the variation in compressive strength. Flexural strength test of concrete was conducted with prismatic cubic concrete beams of (100×100×450) mm sizes as shown in **Fig 5(c)**. To operate split-tensile strength test, according to ASTM-C496, cylindrical specimen of (150×300) mm sizes as shown in **Fig 5(b)** were used. Both the flexural strength test and the split-tensile strength test were conducted after placing the specimens to the water-tank curing procedure for a duration of 28 days. Failure patterns of all test specimens are shown in **Fig 6.**

(a) (b) (c)

Fig 5: SAP incorporated specimens tests (a) Compressive strength, (b) Split-tensile strength, (c) Flexural strength

(a) (b) (c)

Fig 6: Fracture patterns of one of the samples (a) Compression, (b) Split-tensile, (c) Flexure

3. RESULT AND DISCUSSION

3.1 Workability

Concrete workability stands for the fundamental property of concrete that has just been mixed that governs its ability to be blended, applied, set, and completed in a consistent and simple method. The w/c ratio has a substantial impact on the workability of concrete and is directly proportional to that property. In this investigation, the incorporation of 1% SAP into concrete increased its workability by 12.2%. **Fig 7** represents the linear increase in workability as the SAP dosage increases in concrete. Addition of SAP in concrete changed the workability and rheological properties of concrete (Jensen and Hansen, 2002). (Mohamad et al., 2017) found an increasing result in workability after combining SAP with concrete.

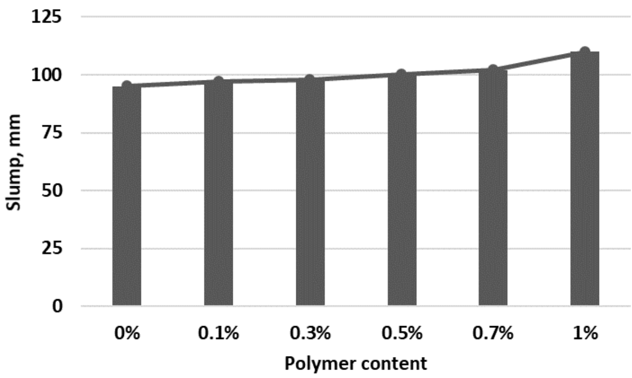
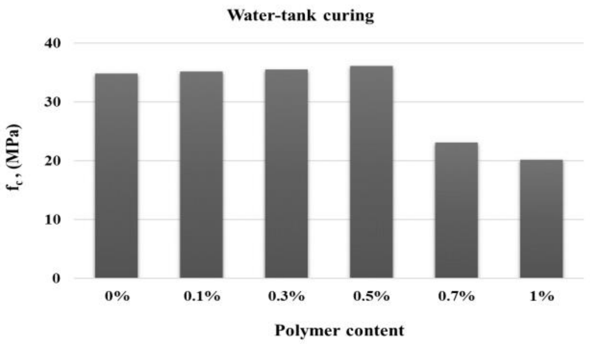


Fig 7: Slump of SAP mixed concrete

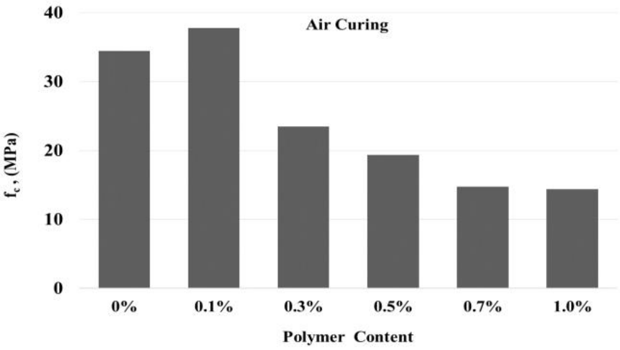
3.2 Compressive Strength.

Fig 8(a) represents the 28 days compressive strength of all 18 cubes of six different batches (control, 0.1%, 0.3%, 0.5%, 0.7% & 1%). For each batch the average of 3 concrete specimens were used in determining the result. From **table 2**, it is found that 0.5% inclusion of SAP with concrete gives promising result for compressive strength of 36.11 MPa, whereas the control concrete specimen attains a compressive strength of 34.83 MPa. With the incorporation of 0.1% & 0.3% SAP there was a slight increase in compressive strength which are 35.20 MPa & 35.57 MPa respectively. Beyond 0.5% addition of SAP in concrete, there is a rapid decrease in the compressive strength and 1% replacement of SAP shows the lowest compressive strength among all percentages (20.21 MPa). **Fig 8(b)** represents the 28 days compressive strength of specimens which were being cured in air at room temperature 25±2ºc. The highest strength was found in 0.1% mix proportion with strength of 37.76 MPa. The compressive strength of control concrete for air curing was found to be almost as same as water tank curing (34.47 MPa). However, beyond 0.1% inclusion of SAP in concrete, the compressive strength followed a descending trend where 0.3%, 0.5%, 0.7% & 1% replacement of SAP gives compressive strength of 23.50 MPa, 19.39 MPa, 14.73 MPa & 14.39 MPa respectively.

The variation of compressive strength for different percentages are because the overall effects depend on several factors. Firstly, addition of SAP improves the hydration, reduce autogenous shrinkage-induced cracking which is responsible for increasing the strength relative to the control concrete. Secondly when SAP releases absorbed water for further hydration, it shrinks & produce macro voids which leads to a decrease in strength. Therefore, incorporation of high dosage of SAP in concrete could lead to major reduction in compressive strength of concrete due to the formation of excess macro voids (Jensen and Hansen, 2002.; Hasholt et al., 2012; Igarashi and Watanabe, 2006).



(a)



(b)

Fig 8: Compressive Strength at 28 days (a) Water-tank curing, (b) Air curing

3.3 Flexure strength test

From **Fig 9**, the optimum value of flexural strength is found for 0.1% SAP incorporation (8.2 MPa) followed by control mix of flexural strength of 7.82 MPa. However, addition of SAP more than 0.1%, a negative trend in flexural strength was observed. All other results are shown in **table 2**. Dang et al., 2018 also observed that the addition of SAP in a low volume increases the flexural strength, nevertheless, by increasing the volume of SAP in concrete leads to reduction in strength. This strength reduction is because, pre-absorbed SAP formed quite a few detrimental holes in concrete, which is responsible for decrease in strength.

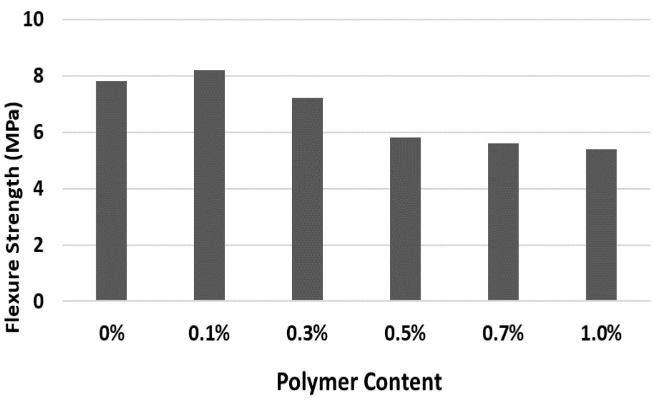


Fig 9: Flexural strength test at 28 days

3.4 Split-tensile strength test

Fig 10 is the graphical representation of the tensile strength of concrete specimen by replacing the volume of concrete with different percentages of SAP. From the graph, a positive trend is observed up to the mix proportion of 0.3%. SAP percentages of 0%, 0.1% and 0.3% gave the split-tensile strength of 1.1, 1.15 and 1.2 MPa respectively. However, as similar to compressive and flexural strength, further increase in the SAP percentage adversely affect the tensile strength of concrete as shown in **table 2**. The tensile strength of concrete increases with the incorporation of SAP for the action of alleviating the shrinkage-actuated cracking, however including large volume of SAP might be responsible for generating excess amount of macro voids which tends to produce micro cracks in concrete, consequently, reduce the tensile strength of concrete. Early researchers (Beushausen et al., 2014; Beushausen & Gillmer, 2014; Lam and Hooton, 2005) found an improvement in tensile strength at postliminary age. But several studies also show a negative effect on tensile strength of concrete (Esteves et al., 2007; Mechtcherine et al., 2006).

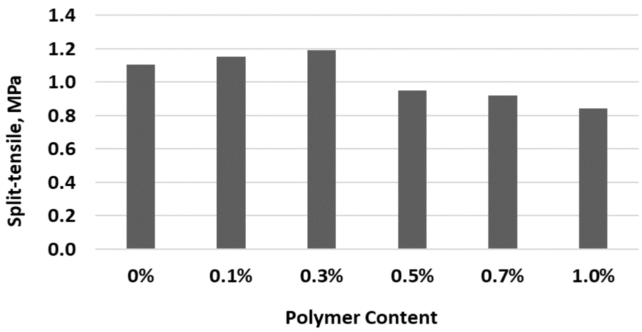


Fig 10: Split-tensile strength at 28 days

Table 2: Test result of all mechanical properties

		Mix proportion of SAP					
		0%	0.1%	0.3%	0.5%	0.7%	1%
Test	**Curing**	MPa					
Compression	Water-tank	34.83	35.20	35.57	36.11	23.13	20.11
Compression	Air	34.47	37.76	23.50	19.39	14.72	14.39
Flexure	Water-tank	7.82	8.20	7.21	5.81	5.59	5.38
Split-tensile	Water-tank	1.1	1.2	1.2	0.9	0.9	0.8

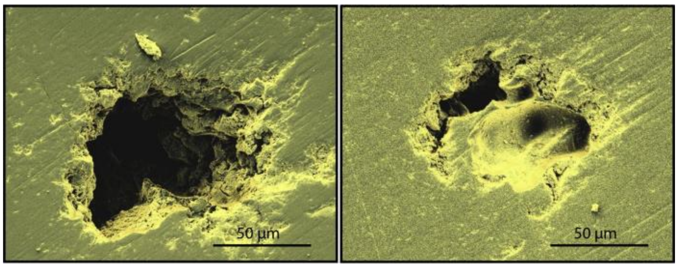


Fig 11: Morphology of the macropores developed by SAP inside hardened cement grouts (Karimi et al.)

4. CONCLUSIONS

1. Workability has increased by incorporation of super-absorbent polymer in concrete.
2. Compressive strength of concrete has improved by adding super-absorbent polymer in both water curing in tank and air curing. In water-tank curing and air curing, the peak values of compressive strength was found at 0.5% and 0.1% of SAP incorporations, respectively. In both curing methods, the lowest strength was found in mix proportion of 1%.
3. The optimum result in flexural strength test was found in 0.1% SAP inclusion, following the similar trend of compressive strength in air curing.
4. In split-tensile strength test, 0.3% incorporation of SAP give maximum value among all percentages.
5. Overall studies summarize that, including high dosage of SAP in concrete can lead to reduction in strength of concrete due to presence of excess macro voids when SAP volume decreases concrete with internal water release. However, 0.1% of SAP addition shows promising result in all types of tests.

ACKNOWLEDGEMENTS

The authors are expressing appreciation to Dzignscape Consultants Ltd., ABC Construction Chemical Company Ltd., NGS Cement Industry Ltd., Aerial Properties Limited, Console Construction Chemicals & Solution, for their unconditional supports by providing materials and equipment. Authors also show their humble gratitude to Concrete Lab of Civil Engineering Department of Southern University Bangladesh for vital support with necessary instruments and equipment.

REFERENCES

Arena, U., Ardolino, F., & Di Gregorio, F. (2016). Technological, environmental and social aspects of a recycling process of post-consumer absorbent hygiene products. Journal of Cleaner Production, 127, 289–301. https://doi.org/10.1016/j.jclepro.2016.03.164

Behnood, A., Van Tittelboom, K., & De Belie, N. (2016). Methods for measuring pH in concrete: A review. In Construction and Building Materials (Vol. 105, pp. 176–188). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2015.12.032

Bentz, D. P., Geiker, M. R., & Jensen, O. M. (2002). On the mitigating of early age cracking. In International Seminar on Self-desiccation and Its Importance in Concrete Technology Lund University.

Beushausen, H., & Gillmer, M. (2014). The use of superabsorbent polymers to reduce cracking of bonded mortar overlays. Cement and Concrete Composites, 52, 1–8. https://doi.org/10.1016/j.cemconcomp.2014.03.009

Beushausen, H., Gillmer, M., & Alexander, M. (2014). The influence of superabsorbent polymers on strength and durability properties of blended cement mortars. Cement and Concrete Composites, 52, 73–80. https://doi.org/10.1016/j.cemconcomp.2014.03.008

Chindasiriphan, P., Yokota, H., & Pimpakan, P. (2020). Effect of fly ash and superabsorbent polymer on concrete self-healing ability. Construction and Building Materials, 233. https://doi.org/10.1016/j.conbuildmat.2019.116975

Dang, J., Zhao, J., Miao, W., & Du, Z. (2018). Effect of superabsorbent polymer on the shrinkage and crack resistance of concrete at early age. Iranian Polymer Journal (English Edition), 27(5), 349–358. https://doi.org/10.1007/s13726-018-0615-8

Esteves, L.P., Cachim, P., Ferreira, V.M. (2007). Mechanical properties of cement mortars with superabsorbent polymers. In: Grosse, C.U. (eds) Advances in Construction Materials 2007. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-72448-3_45

Farrell, J. B., Smith, J. E., & Hathaway, S. W. (1974). Water Environment Federation Lime Stabilization of Primary Sludges. In Dean Source: Journal (Water Pollution Control Federation) (Vol. 46, Issue 1). http://www.jstor.orgURL:http://www.jstor.org/stable/25038098

Gao, D., Heimann, R. B., & Alexandertll, S. D. B. (1997). Box-Behnken design applied to study the strengthening of aluminate concrete modified by a superabsorbent polymer/clay composite. In Advances in Cement Research (Vol. 9, Issue 35).

Hasholt, M. T., Jensen, O. M., Kovler, K., & Zhutovsky, S. (2012). Can superabsorent polymers mitigate autogenous shrinkage of internally cured concrete without compromising the strength? Construction and Building Materials, 31, 226–230. https://doi.org/10.1016/j.conbuildmat.2011.12.062

Igarashi, S. I., Watanabe, A., Jensen, O. M., Lura, P., & Kovler, K. (2006, August). Experimental study on prevention of autogenous deformation by internal curing using super-absorbent polymer particles. In International RILEM conference on volume changes of hardening concrete: testing and mitigation (Vol. 100, pp. 77-86). Paris, France: RILEM Publications SARL.

Jensen, O. M., & Hansen, P. F. (2001). Water-entrained cement-based materials: I. Principles and theoretical background. Cement and concrete research, 31(4), 647-654.

Jensen, O. M., & Hansen, P. F. (2002). Water-entrained cement-based materials: II. Experimental observations. Cement and concrete research, 32(6), 973-978.

Karimi, H., Yu, Q. L., & Brouwers, H. J. H. (2020). Valorization of waste baby diapers in concrete. Resources, Conservation and Recycling, 153. https://doi.org/10.1016/j.resconrec.2019.104548

Mechtcherine, V., Dudziak, L., Schulze, J., & Staehr, H. (2006, August). Internal curing by super absorbent polymers (SAP)–Effects on material properties of self-compacting fibre-reinforced high performance concrete. In Int RILEM Conf on Volume Changes of Hardening Concrete: Testing and Mitigation, Lyngby, Denmark (pp. 87-96).

Mohamad, D., Beddu, S., Ibrahim, K. S., Zainoddin, M., & Sapuan, W. K. M. (2021). Comparison of different curing method for mechanical properties of self-curing agent using diapers polymer. AIP Conference Proceedings, 2339. https://doi.org/10.1063/5.0044593

Mohamad, D., Beddu, S., Sadon, S. N., Sheng, H. W., Ismail, I. N., & Sapuan, W. K. M. (2019). Study of physical properties and environmental monitoring for diapers polymer. AIP Conference Proceedings, 2129. https://doi.org/10.1063/1.5118019

Mohamad, D., Beddu, S., Nabihah Sadon, S., Liyana Mohd Kamal, N., Itam, Z., Mohamad, K., & Mohd Sapua, W. (2017). Self-curing Concrete using Baby Diapers Polymer. Indian Journal of Science and Technology, 10(4). https://doi.org/10.17485/ijst/2017/v10i4/110895

Randall, D. G., Krähenbühl, M., Köpping, I., Larsen, T. A., & Udert, K. M. (2016). A novel approach for stabilizing fresh urine by calcium hydroxide addition. Water Research, 95, 361–369. https://doi.org/10.1016/j.watres.2016.03.007

Tsuji, M., Okuyama, A., Enoki, K., & Suksawang, S. (1998). Development of new concrete admixture preventing from leakage of water through cracks. JCA Proc. of Cement & Concrete (Japan Cement Association), 52, 418-423.

Tsuji, M., Shitama, K., & Isobe, D. (1999). Basic Studies on Simplified Curing Technique, and Prevention of Initial Cracking and Leakage of Water through Cracks of Concrete by Applying Superabsorbent Polymers as New Concrete Admixture.

Wong, H. S. (2018). Concrete with superabsorbent polymer. In Eco-efficient Repair and Rehabilitation of Concrete Infrastructures (pp. 467–499). Elsevier Inc. https://doi.org/10.1016/B978-0-08-102181-1.00017-4