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The Effects of Superabsorbent Polymer (SAP) on Concrete in Marine Environment

Opeyemi Joshua[1], Olatokunbo M. Ofuyatan[2], Ayobami A. Busari[2], Isaac I. Akinwumi[2], Olawuyi, J. Babatunde[3], David O. Nduka[1] and Ibitayo A. Oladipupo[1]

[1]Department of Building Technology, Covenant University, Nigeria

[2]Department of Civil Engineering, Covenant University, Nigeria

[3]Department of Building, Federal University of Technology, Minna. Nigeria

Abstract

The quest for high strength concrete (HSC) has given rise to the use of several blends/additives with cement like silica fumes, fly ash and granulated blast furnace slag. One of the major techniques employed in achieving HSC is lower water/cement (w/c) ratio. One major additive used to achieve very low w/c ratio is the superabsorbent polymer (SAP) with superplasticizers. SAP which is applicable in HSC can hold water in concrete and gradually release it for curing for optimal strength development where external curing water cannot easily access. The very high-water absorbent property of SAP is the desired characteristics in HSC applications, but when it is exposed to sodium chloride (NaCl) salt, it rapidly losses its absorbent property and hence, the ability to improve strength in concrete. The major solute in marine water is NaCl at varying concentrations. This study aims to assess the effects of the NaCl in the marine environment on the SAP within the concrete and its effect on the concrete strength. Normal-strength class concrete was used in this study and cured in marine water, this is to allow for better curing-water (with dissolved NaCl) ingress into the concrete to magnify the effect. Concrete mix-design to attain a target strength of 30MPa was mixed and cast into 100mm cube mold. The control was cast and cured in fresh and marine water, the test concrete cubes were mixed with SAP and cured in marine and fresh water. Superplasticizers were used in all the mixes. Result shows that concrete cast with SAP required more water for good workability but the ones cured in the marine water had significant increased strength than the ones cured in fresh water. More significant strength difference was observed with the SAP concrete cubes cured in fresh and marine waters. This study concludes that there is a significant interaction between the SAP and the marine water. It is recommended that microstructural studies be performed to study the salt-SAP interaction that resulted in reduced strength.

1.0 Introduction

In this twenty-first century, building and structures needs to be bigger and higher to meet the increasing demands of man, and in consequence, there is need for higher strength of most common building and structural materials like concrete and steel. This has led researchers to develop additives and admixtures that could be blended with cement to achieve very high strength concrete. Such blends include pozzolans like Granulated Blast Furnace Slag (GBFS), Silica Fumes (SF) and Fly Ash (FA); admixtures like plasticizers and Super Absorbent polymers (SAP) (Joshua, 2018). According to Nduka et. al. (2018), there is a rising awareness amongst construction professional in the use of SAP in concrete works. Researches are ongoing on how to optimize SAP in concrete strength.

Internal curing (IC) is a promising technique of maintaining the internal temperature and relative humidity of a concrete section. Internal curing is accomplished by dispersing materials that have the capacity to absorb and desorb water during the plastic and hardened conditions of concrete respectively (Tu *at al* 2019). The distributed materials provide additional internal water to the cement gel furthering hydration process in cementitious products. Two popular materials, light weight aggregate (LWA) and superabsorbent polymer (SAP) have been widely used by practitioners and researchers in meeting internal curing in concrete section. SAP are cross-linked polymers that can absorb and desorb large amount of water that can be utilized for a number of applications in concrete technology. An important feature of SAP is its swelling rate and capacity to be altered depending on the polymer size, type and chemical composition (Jensen, & Hansen, 2001). They describe SAP as a smart material capable of changing its properties in reaction to an external influence in a controlled manner. Sun *et al*. (2019) inferred that the swelling ratio of SAP in deionized water can be greater than 500 g/g, but it can reduce to about 10 - 20 g/g in a typical concrete pore solution. The swollen SAP work by forming a barrier to flow and gradually releases absorbed water when the surrounding relative humidity falls.

Aside the use of SAP in concrete applications, notable use has been witnessed in personal hygiene products (diapers), biomedical (bandages), pharmaceuticals (drug delivery), agricultural (soil conditioning), waste solidification, meat packaging and water blocking tapes for undersea water cables (Sun *et al.,* 2019). In concrete technology use, SAP are mainly utilized as internal curing agent to reduce autogenous shrinkage in low-water-cement ratio mixes, rheological control, frost protection and self-healing. See state-of-the-art report on the application of SAP in concrete published by RILEM STAR-225 (2012). Benefits of SAP over other types of internal curing agent like LWA lies in the small amount of SAP capable of providing internal curing water, improve fresh and mechanical properties of concrete. It could serve as air entraining material to increase air content in concrete matrix leading to increased freeze-thaw resistances. The water absorption rate can be also analytically designed. The merit of SAP as internal curing agent as posit by Jensen and Hensen (2001) include mitigation self-desiccation, limiting cracks, increase hydration and durability and reduction of permeability. They also noted that the inclusion of SAP to cementitious matrix brings about improved tensile-stain and toughness of the composite concrete.

However, the larger particle size of SAP may create a larger volume of pores in cement base material after desorption of water (Olawuyi and Boshoff, 2017). They inferred that mechanical properties of concrete with SAP inclusion experiences low early compressive strength. Also, they reported that fresh property like workability is affected due to high water absorption of SAP and further affect the mechanical properties. Dry SAP equally affects the rheological behaviors of fresh concrete by increasing the plastic viscosity. Senff *et al.* (2015) also observed that SAP presence in concrete and mortar mixes can cause separation and grinding of particle due to aggregate during mixing. Notwithstanding the negative influences of SAP in concrete mixtures, empirical studies and analytical models have been devised by researchers in overcoming SAP content flaws culminating in vast use in literature and demonstrated projects.

Although, it has been seen from available literatures that SAP application in concrete technology is majorly used in high strength concrete with low water cement ratio less 0.4. Consequently, issues of concern like difficulty in curing vertical members, inaccessible locations in buildings, poor workmanship when external curing methods are used and scarcity of water (Nduka, Ameh, Joshua and Ojelabi, 2018) calls for an innovative curing method like internal curing method using SAP in addressing the challenges in normal strength concrete structures. Mousa *et al.* (2015) experimentally tested the inclusion of polyethylene glycol and light weight aggregate at varying percentages in determining the physical properties of self-cured concrete. Their results showed that polyethylene glycol effectively improved properties of conventional concrete of 0.5 water-binder ratio. Bashandy (2015) also incorporated polyethylene glycol SAP as internal curing agent in concrete of water-binder ratio of 0.5 in evaluating the performance of self-cured concrete at elevated temperatures. Their results showed that self-curing with SAP can be effective in withstanding elevated temperature using air cooling method. Manzur, Iffat & Noor (2015) found that concrete internally cured with sodium polyacrylate SAP performed better in terms of both strength and durability when compared to control specimen without SAP in the design mixtures. Their study evaluated the efficiency of sodium polyacrylate improved durability under adverse curing condition. Additionally, Deepika et al. (2016) applied SAP as internal curing agent in M40 concrete in evaluating the mechanical properties of the tested samples. It was revealed that that 1% of SAP addition by weight of the binder was optimum for improved strength in tested concrete without compromising workability of the mixes.

When water and SAP are mixed, semisolid gels are formed called hydrogels (Sultana et al, 2018). The water is locked within the hydrogel and is gradually released as an internal curing agent within the concrete when the internal moisture within the concrete diminishes. One of the envisaged problems that could affect the use of SAP in concrete is the behavior water-SAP hydrogel in the presence of salts like Sodium Chloride (NaCl), Calcium Chloride ($CaCl_2$) and Aluminum Chloride ($AlCl_3$), all of which are present in sea water (Department of Energy (DOE), 1994). These salts posses the ability to reverse the formation of the hydrogels back to water in its original phase state. The dissolution of these hydrogels is described in Pourjavadi et al (2008) and Sultana (2018) as reducing swelling rates of the hydrogels and their studies identified salinity and PH as a major factor that reverse the hydrogel formation. This dissolution of the hydrogel negates the principle and process of internal curing ability of SAP in concrete. This study intends to find the effect of marine water in concrete, firstly in normal strength concrete and subsequently on high strength concrete (HSC). Normal strength concrete permits greater percolation or ingress of water than in the HSC.

2.0 Materials and Method

2.1 Materials

The materials used in this study were Dangote brand of Portland cement CEM II 42.5N, river sharp sand fine aggregate obtained locally, 19mm quarry crushed coarse aggregate, SAP with particle size less than 600 µm [0.024 in.] labelled FLOSET CC 27 and borehole water sourced locally within the Covenant University premises. The marine water was gotten from the Bar beach at the Lagos Island.

2.2 Methods

Sieve analysis was performed on the fine and coarse aggregates to determine their gradation. The coarse aggregate used is a uniformly graded 19mm size.

A C40 concrete mix was designed in accordance to BRE (1988) and BS EN 206-1:2000 with cement content of 480kg/m^3 of concrete. Four sets of C40 concrete cubes were mixed and cast in 100mm cube molds in triplicates. The constituents for the various samples in as shown in Table 1.

Table 1: Mix Constituents of the Concrete Specimen

Constituents	Reference Mixes (kg/m^3)			
	M1	M2	M3	M4
water	144	144	192	192
Cement II 42.5N	480	480	480	480
Fine Aggregate (River dredged sharp sand)	500	500	500	500
Coarse aggregate (19mm max. size)	1000	1000	1000	100
SAP (<600µm FLOSET CC 27)	-	-	0.96	0.96
Super plasticizers CONPLAST SP 432MS	7.2	7.2	7.2	7.2
W/C Ratio	30%	30%	35%	35%
Curing medium	Fresh water	Marine water	Fresh water	Marine water

Slum test values in all cases were insignificantly low, less than 5mm in all cases

Specimen concrete M1 and M3 are controls and were cured in normal water while M2 and M4 were cast with and cured in marine water to observe the effect the sodium chloride concentration will have on the SAP concrete.

3.0 Results and Discussion

3.1 Aggregates Gradation Test

The gradation test done is the sieve analysis.

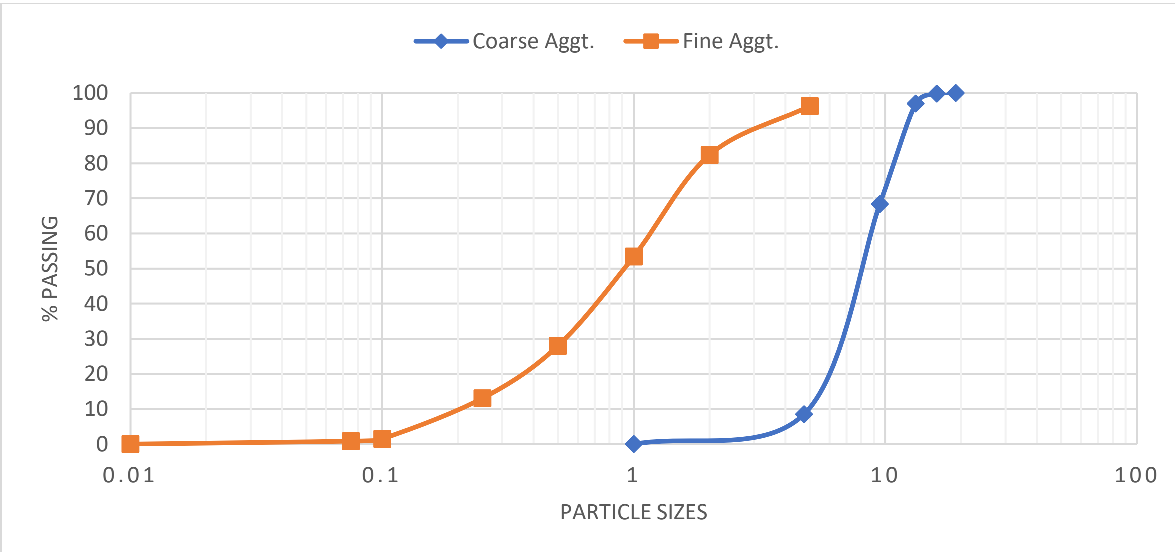

Fig 1: Sieve Analysis of the Fine and Coarse Aggregate

From the curves in Fig 1 and according to Holtz and Kovacs (1981), the fine aggregate has a coefficient of Uniformity (CU) and Coefficient of Curvature (CC) of six (6) and one (1) respectively, hence the sand is well graded. The coarse aggregate has a CU of 1.8 and CC of 0.9, hence, poorly graded. This is expected because the coarse aggregate is predominantly of uniform particle size.

3.2 Compressive Strength Test Analysis

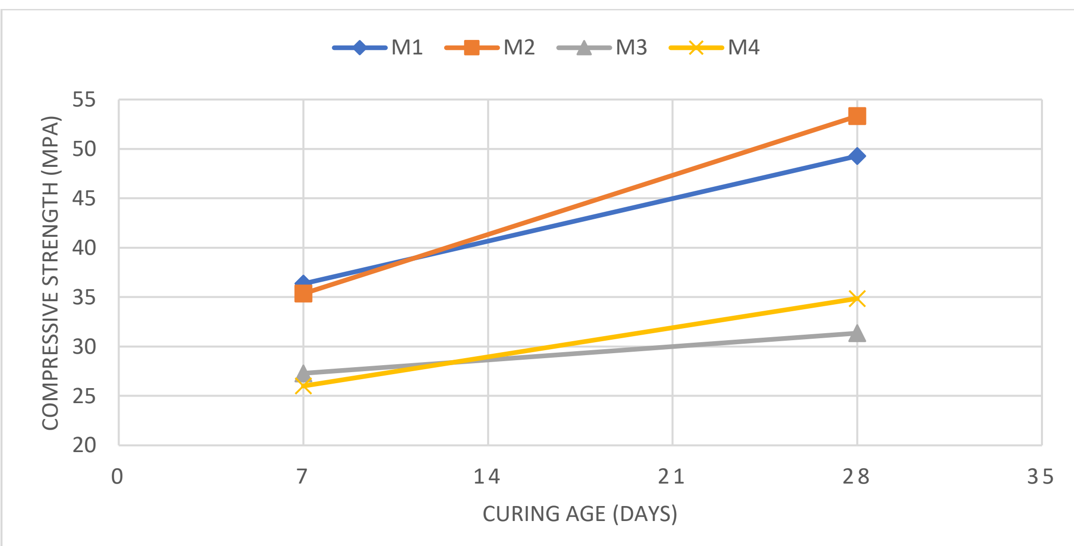

Fig 2: Compressive Strengths of Test Cubes

From the compressive strength test values in Fig 2, it was observed that all samples cured in marine water initially has lower 7-day strengths than those cured in fresh waters but later developed significantly better 28-day strength than the concrete cubes cured in the fresh waters. Olutogbe and Amusan (2014) also observed that concrete cast and cured in sea water had better strength than the ones cast and cured in fresh water. Fresh concrete mixed with SAP needed more water content to achieve similar workability as the ones without SAP, hence, higher water/cement ratio as observed generally in the use of SAP. Concrete with SAP had a very significant lower 28-day strength than ones cured in fresh water.

4.0 Conclusion and Recommendation

4.1 Conclusion

- The fine and coarse aggregates used in this study satisfies the provisions of BS EN 206-1:2013 and BS EN 12620:2002$^{+A12008}$ for aggregates to be used in concrete production. The sand is well graded and the coarse aggregate is uniformly graded as shown in Fig 1.
- The fresh concrete mix with SAP required more water content than the mix without SAP. Hence, workable consistence was reached at 30% w/c ratio and 35% with the SAP concrete.
- There is a significant strength reduction with the normal strength SAP concrete compared with the non-SAP concrete at 28-day curing age. Though studies show that SAP concrete developed improved strength in high strength concrete (HSC). SAP might not be applicable in normal strength concrete.
- The SAP concrete appeared to be moister after demoulding compared with the concrete without SAP.

4.2 Recommendation

This study does not fully encourage the use of SAP in normal strength concrete till some further studies as observing the strength development for 56 days and over, since most study on SAP's strength development is observed till 56 days or later, it is therefore recommended that this same study be observed till 90 days. Rilem STAR-225 (2012) report on SAP also conclude that observation for higher strength should be at later curing ages as most early age reports lower strength in relation to controls. The salts in marine water might be responsible for the highly reduced strength in the SAP concrete by disrupting the internal curing mechanism. The STAR-225 (2012) report records about 16% strength reduction for about the same level of replacement in this study, but this study on the averaged observed about 35% (Fig 2) strength reduction with SAP with marine water. The salt in the marine water is suspected to have influence the further strength reduction. Microstructural study is therefore recommended to observe the interaction of salt in the internal curing mechanism. SAP in normal strength concrete is discouraged by this study till some other tested parameters can justify its use.

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References

1. Bashandy, A. A. (2015). Performance of self-curing concrete at elevated temperatures. *Indian Journal of Engineering and Materials Sciences 22(1):93-104*
2. 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.

3. BS EN 12620:2002 +A1 (2008). Aggregates for Concrete. British Standard Institute. London.
4. BS EN 206-1 (2000). Cement - Specification, Performance, Production and Conformity. British Standard Institute, London.
5. Deepika, M., Saranya, R., Rajakamari, R., and Kalaiselvan, L.S. (2016). Experimental investigation of usage of polyethylene glycol as self-curing. *Journal of Engineering, Scientific Research and Application,* 2, (2), 2455- 3962
6. Department of Energy (DOE). (1994) Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water; version 2, A. G. Dickson & C. Goyet, eds., ORNL/CDIAC-74.
7. Holtz R. D. and Kovacs W. D., (1981). *An Introduction to Geotechnical Engineering*. Prentice Hall Englewood Cliffs, New Jersey 07632
8. Jensen, O. M. (2013). Use of Superabsorbent Polymers in Concrete: An overview of the possibilities offered by using these smart materials as concrete admixtures. *Concrete international*, 2-6.
9. 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.
10. Joshua, O., Matawal, D. S., Olusola, K. O., Ogunro, S., & Lawal, R. B. (2018). Development of a fully pozzolanic binder for sustainable construction: whole cement replacement in concrete applications. *International Journal of Civil Engineering and Technology*, *9*(1), 1-12.
11. Manzur, T., Iffat, S., & Noor, M. A. (2015). Efficiency of sodium polyacrylate to improve durability of concrete under adverse curing condition. *Advances in Materials Science and Engineering*, *2015*.
12. Mousa, M. I., Mahdy, M. G., Abdel-Reheem, A. H., & Yehia, A. Z. (2015). Physical properties of self-curing concrete (SCUC). *HBRC Journal*, *11*(2), 167-175.Lee, H. X. D., Wong, H. S., & Buenfeld, N. R. (2016). Self-sealing of cracks in concrete using superabsorbent polymers. *Cement and Concrete Research*, *79*, 194-208.
13. Nduka, D. O., Ameh, J., Joshua, O. and Ojelabi, R. (2018). Awareness and Benefits of Self-Curing Concrete in Construction Projects: Builders and Civil Engineers Perceptions. *Buildings*, *8*(8), 109.
14. Olawuyi, B. J. and Boshoff, W. P. (2017). Influence of SAP content and curing age on air void distribution of high-performance concrete using 3D volume analysis. *Construction and Building Materials*, *135*, 580-589.
15. Olutoge, F. A. and Amusan, G. M. (2014). The Effect of Sea Water on Compressive Strength of Concrete. International journal of engineering science and invention. 3(7), 23-31.
16. Pourjavadi, A., Kurdtabar, M. and Ghasemzadeh, H. (2008). Salt- and pH-Resisting Collagen-based Highly Porous Hydrogel*. Polymer Journal, 40(2), 94–103*
17. Rilem Report STAR 225-SAP (2012). Application of superabsorbent polymers (SAP) in Concrete Construction. Eds. Mechtcherine, V. and Reinhardt, H. Springer Dordrecht Heidelberg London New York.
18. Salma Sultana, Md. Saifur Rahaman, Shah Md. Marzuk Hasnine. Effect of Salinity on Swelling Behaviors of Superwater Absorbent Hydrogel Prepared from Carboxymethyl cellulose/Acrylamide Blends by Gamma Radiation. *American Journal of Applied and Industrial Chemistry.* Vol. 2, No. 2, 2018, pp. 20-26. doi: 10.11648/j.ajaic.20180202.13
19. Senff, L., Modolo, R. C. E., Ascensão, G., Hotza, D., Ferreira, V. M., & Labrincha, J. A. (2015). Development of mortars containing superabsorbent polymer. *Construction and Building Materials*, *95*, 575-584.
20. Sun, B., Wu, H., Song, W., Li, Z., & Yu, J. (2019). Design methodology and mechanical properties of Superabsorbent Polymer (SAP) cement-based materials. *Construction and Building Materials*, *204*, 440-449.
21. Tu, W., Zhu, Y., Fang, G., Wang, X. and Zhang, M. (2019). Internal curing of alkali-activated fly ash-slag pastes using superabsorbent polymer. *Cement and Concrete Research*, *116*, 179-190.