SELF-SEALING OF CRACKS IN CONCRETE USING SUPERABSORBENT POLYMER

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Abstract: Researchers tried almost every conceivable material to be mixed in concrete to alter some of its properties. To this end, the study proposes a model to predict changes in the amount of water runoff through cracks over time when spherical SAPs in superabsorbent material exhibit rapid swelling by absorbing the first water ingress after the occurrence of cracks. In this research superabsorbent polymer (SAP) is were used as an admixture to improve its water tightness properties especially in concrete tanks, aeration basins and retaining structures. The concrete tries to seal the leak by blocking the water path by semi-solid gels. This gel is the product of the interaction of the superabsorbent polymer with water. Several samples were prepared to study the effect of the superabsorbent polymer on the concrete mechanical properties, durability and on the concrete capability to block the water flow. Concrete cubes, concrete beams and concrete cylindrical samples were prepared to study the concrete strength of concrete mixed with superabsorbent polymer. Also concrete special type of short cylindrical samples were prepared to study the concrete ability to block the water flow. These cylindrical samples were intentionally broken into two approximately equal pieces to create an induced artificial crack. The artificially cracked samples were subjected to falling head water pressure to study the concrete ability to stop the water flow though the induced concrete crack. In this research work percentage of sodium polyacrylate are taken as 0.1, 0.2 1% and 2% by weight of cement. At end of the study result showed that the SAP also provides additional voids in the concrete mass so these voids affect the compressive strength of the concrete strength negatively. Transverse test of concrete beam and splitting tensile strength of cylinder showed that it is decrease with respect to increase the SAP % in concrete mix. The plain concrete sample has a very large water flow value and almost constant. The flow rate decreases with time. This applies for all of the SAP samples, but the one with high percentage showed faster decrease in water flow rate with time.

***Index Terms* - Concrete, Self-sealing, Cracks, Superabsorbent Polymer, Sodium Polyacrylate, Mechanical Property.**

I. INTRODUCTION

Concrete is likely to crack when exposed to structural loading or non-structural factors such as thermal effects, shrinkage and physiochemical reactions. As per the principle of structural design, concrete cracks in tension zone. Cracking causes seepage and affects water tightness, a serious serviceability requirement for many structures such as basements, retaining walls, reservoirs, dams, tunnels, pipelines and waste repositories. Cracks also act as pathways for aggressive agents, thereby accelerating deterioration mechanisms. Therefore, cracks not only affect water tightness, but also long-term durability and mechanical properties of concrete structures. So that we have to identify the reason behind the crack development. Causes of crack in concrete due to Excess water in the mix that means, Settlement, Drying Shrinkage, Improper strength concrete poured on the job and incorrect selection of cement and other things is Crack most often occur due to lack of expansion and contraction joints. So on provide proper joint bonding and we have to take care about the control joints. And so we have to reduce the flow of water penetration in cracks by selecting proper sealing agent in concrete subjected to certain water pressure. Cracks may seal when exposed to water, but this is usually limited to narrow cracks dependent on many conditions such as mix composition, hydraulic pressure and temperature. However, special measures (e.g. external liners and pre-stressing) will be required if no leakage is permitted. Methods such as surface coating, resin injection and integral water resisting admixtures are also often used to prevent leakage, but are not always effective, for example where there is significant movement, e.g. ground subsidence. Coatings deteriorate and require maintenance or reapplication. For successful application in civil engineering structures, new materials need to satisfy many criteria including affordability, availability, robustness, durability, performance across a range of exposure environments, chemically inertness and low toxicology. Superabsorbent polymer (SAP) is a promising class of materials that potentially meets these criteria and Application of SAP to improve frost resistance, SAP for mitigation of autogenous shrinkage and resist the deterioration. Superabsorbent polymers, also known as hydrogels, are cross-linked polymers that have the ability to absorb a disproportionately large amount of liquid, expanding to form an insoluble gel. A unique characteristic of SAP is that its swelling rate and capacity can be altered depending on the polymer type and properties of the liquid including composition, temperature and pressure. For example, the swelling ratio of SAP in deionized water can be greater than 500 g/g, but it drops to about 10–20 g/g in typical concrete pore solution. The swollen gel forms a barrier to flow and it gradually releases absorbed water when the surrounding humidity drops.

II. SELF-SEALING AND MATERIALS

Self-Sealing is the ability to stop the flow of water by automatically closing cracks. If concrete can self-seal, blocking penetrations, the material becomes its own waterproofing barrier. This stands in contrast to more-conventional means of waterproofing, which usually involve adding waterproofing admixture to increase the swelling capacity to stop water flow.

Water resisting admixtures are generally divided into solid, crystalline and hydrophobic or water-repellent chemicals. Solids and hydrophobic waterproofing admixtures are not considered effective in crack blocking. Some crystalline type admixture may seal very fine cracks, but only by reacting with unreacted cement and moisture to form crystalline products. Advance in materials science have led to the development of a range of smart adaptive materials that heal themselves when cracks develop and this is use for many purposes.

Superabsorbent polymer (Sodium Polyacrylate, Polyacrylate/Polyacrylamide Copolymer , Hydrogel, Expanded polymer balls and Others) a SAP may absorb 300 times its weight (from 30 to 60 times its own volume) and can become up to 99.9% liquid. In this research using sodium polyacrylate as a super absorbent polymer is used and it is very effective polymer in concrete. It has high swelling rate. Superabsorbent polymers, also known as hydrogels, are cross-linked polymers that have the ability to absorb a disproportionately large amount of liquid, expanding to form an insoluble gel. A unique characteristic of SAP is that it's swelling rate and capacity can be altered depending.

Figure 1 Sodium polyacrylate before and after absorbing water

Water-Swelling Rubber Particles is self-Sealing Cementitious Materials. In this, the application of water-swelling rubber particles for providing the cracked concrete a self-sealing function was developed.

Carboxylic acid waterproofing Admixture for self-sealing watertight concretes. Fumaric acid-based waterproofing admixture improves concrete water tightness.

Brittle glass fibers or capsules containing adhesives which is used for self-healing in concrete.

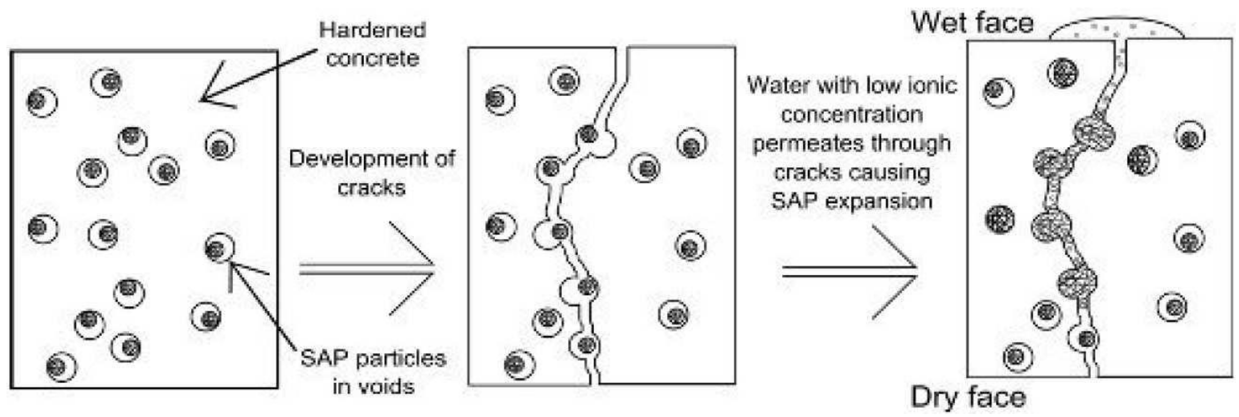
Carbon fiber composite grout used in under flowing conditions to raise the sealing efficiency (SE) and dynamic flowing resistance of slurry, carbon fiber was added into the grout and a new grout for flowing water environmental was provided

III. INDUCING CRACK

This study proposed a new method for inducing crack was induced at the centre of each sample by using the loading device Pressure was applied through a T-section placed at the tip of each side groove of the sample. The applied pressure was gradually increased until a single through crack was produced. The distance between the tips of each side groove i.e. the crack breadth was 30 mm. the size of the special type of mould has 100mm diameter and 150mm height and the distance between two grooves is 30mm. The cracked sample was then briefly taken apart and reassembled to ensure that a complete through crack was produced. A silicone rubber seal attached to a side grooves plate assembled into the sample. The assembled sample was held together using two stainless-steel hose clamps. The width of the crack was adjusted by adjusting the clamps while tightening the hose clamps reduces crack width.

IV. CRACK SEALING MECHANISM

Concrete is batched, the mix water reaches a very high pH (~12.5–13) and ionic concentration (~150–700 mmol/L) within minutes in contact with cement because of rapid dissolution of the cement compounds releasing ions including Ca^{2+}, K^{+}, Na^{+}, OH^{-} and SO_4^{2-}. As such, SAP that is added during batching will initially swell at a much reduced capacity compared with SAP in freshwater. Calcium ions in the mix water forms a bidentate complex with the acrylates of the SAP, which further limits its swelling. The initial swelling is also confined by the mixing and compaction processes. As cement hydrates and concrete self-desiccates, the SAP gradually releases its absorbed water and shrinks, leaving behind voids of tens to hundreds of microns in size in the cement paste (Fig. a). These voids can be viewed as macro-defects, and so cracks that form during the service life of the concrete structure are likely to propagate through them (Fig. b). The SAP lies dormant in the microstructure until a crack occurs through the SAP voids, exposing the polymer to the external environment. When the concrete is then subjected to wetting, ingress of water triggers the SAP to swell again. External fluids such as precipitation and groundwater have much lower ionic concentration compared to concrete pore solution and so the re-swelling of SAP will increase significantly. The reduced physical confinement will also increase the re-swelling capacity of the SAP. The swollen SAP forms a soft gel that expands beyond the void and into the crack, subsequently slowing down or preventing further flow (Fig. c).



(a) SAP is added to concrete during Batching, initial swelling (S_1) is confined. As concrete hardens, the SAP shrinks and Lies dormant in the microstructure.

(b) Subsequent cracking propagates Through SAP voids, exposing the polymer.

(c) Ingress of water causes SAP to swell (S_2), expanding into crack and restriction further flow.

Figure 2 Sealing mechanism of crack by using SAP

V. Inducing Crack

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VI. Effect of SAP on Mechanical Properties of Concrete

Two types of samples were prepared; samples for strength tests and samples for water flow tests. The strength test samples were used to test the concrete in compression, transverse, and split tensile test. Five different percentages of the SAP were used; 0%, 0.10%, 0.20% 1%, and 2% by weight of cement. The 0% sample is used as a control sample in order to study the effect of adding SAP to the concrete mix. 6 samples for each percentage were casted. Three of them were used for 7 days test and another three for 28 days for compressive strength, transverse strength and tensile strength. Fig. 3 shows the effect of the SAP on the compressive strength of the concrete

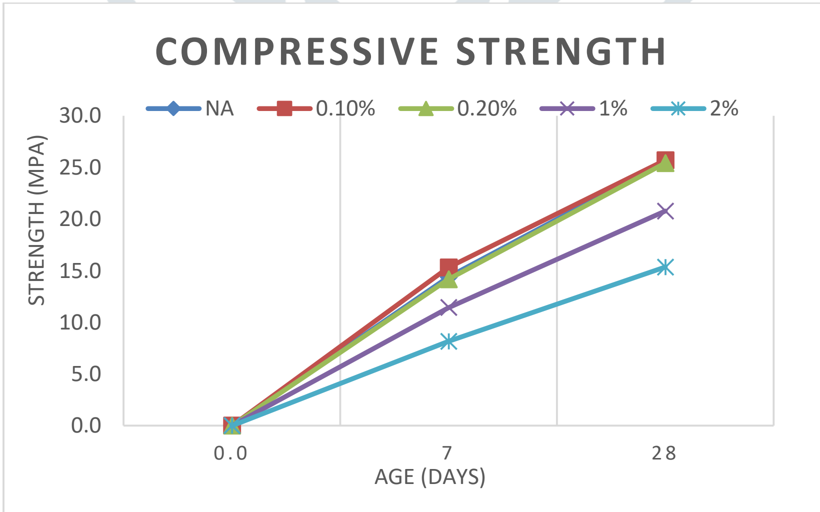

Figure 3 Compressive strength of concrete cubes mixed with SAP

The 0.10% SAP samples performed well compared to the other samples. The increase in the SAP quantity beyond the 0.10 % has negative effect on the compressive strength of the concrete. This is believed to be due to the excessive voids in the concrete solid mass generated by the SAP gel. Fig. 4 shows the effect of the SAP on the transverse strength of the concrete.

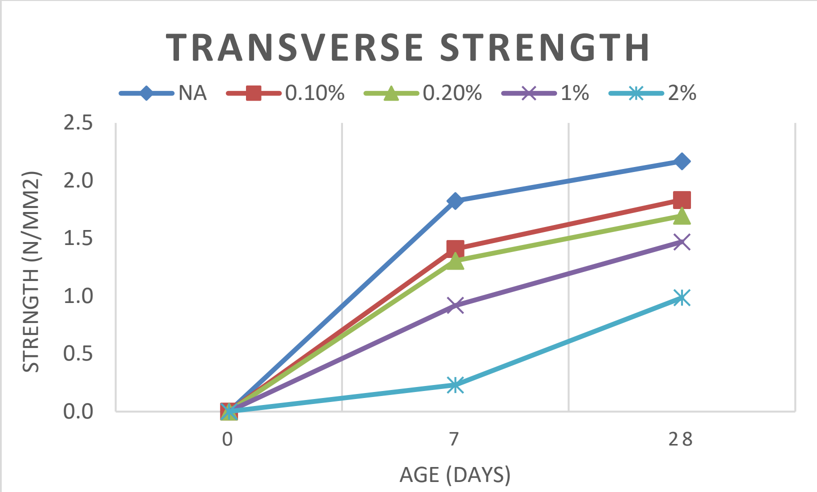

Figure 4 Transverse strength of concrete beams mixed with SAP

SAP also provides additional voids in the concrete mass so these voids affect the transverse strength of the concrete negatively and so strength decrease with respect to increase the SAP percentage. Transverse strength get maximum at 0% SAP and minimum at 2% SAP. Tables 1 shows the effect of tensile strength on concrete. Also tensile strength of concrete get maximum at 0% SAP and so on decreasing with respect to increasing SAP %.

Table 1 Transverse strength of concrete cylinder mixed with SAP

(Mpa)	**NA**	**0.10%**	**0.20%**	**1%**	**2%**
28 days	2.213	2.140	2.033	1.717	1.280

VII. WATER FLOW TEST

The samples of the water flow test are of cylindrical shape. Its height is 150 mm, and its diameter is 100 mm. The objective of the test is study of the concrete to decreasing the water flow through an induced artificial crack. Each water flow sample is broken into almost two equal parts, then these parts are put together again. The assembled sample represents a crack in the concrete of 150 mm depth, and width of 30 mm. 10 samples were prepared. For each percentage two samples were tested. The amount of SAP used in this study 0%, 0.1%, 0.2%, 1% and 2% by weight of Portland cement. The effect of increasing the amount of SAP mixed in the concrete mix is also the focus of this study. These samples were tested after 28 days curing. The first sample tested was the one with 0% of SAP. This sample is used as a control sample. Fig. 5 shows the drawing of a typical water flow sample.


Figure 5 Water flow sample

This procedure is standardized to make sure all samples were subjected to similar conditions. Special set-up was used to produce the water flow samples. A silicone rubber seal attached to a side grooves plate assembled into the sample. The assembled sample was held together using two stainless-steel hose clamps. The water flow sample is placed back in its mould, and then placed in a steel hose clamps. The Sample is then placed in the testing chamber in such way that the water has no path to flow but to flow though the concrete sample and in particular through the concrete crack. Water pressure is applied at the top side of the water flow sample. The samples were subjected to falling head water pressure. Test set up for the water flow test shown in fig 6.

Figure 6 Set-up for water flow test

The rate of water flowing through the concrete is 15 ml/min and it is set by using IV pipe. The smaller the amount of water flowing through the concrete sample the better water tightness capability, and the better sealing capability of concrete mixed with SAP. The water discharge can be determined by below equation.

$$Q_{SAP} = \frac{V}{t}$$

Where;
QSAP= water flow rate through the concrete sample in ml/min
V = volume of water flowing through the sample in millilitre
t = time measured in minutes.

VIII. TEST RESULTS

This study focused on the effect of the SAP on the concrete in terms of strength and in terms of sealing capability. Several SAP percentages were used to study the effect of the increase of SAP on the targeted concrete property. The water flow though the concrete samples were subjected to falling head water pressure. The broken concrete sample is put together in the same mould, then placed under falling head water pressure.

The falling head test is conducted in a very similar way. The water pressure started at 135 cm of water pressure at all the time. The flow of the water is measured in terms of water flow discharge in millilitre per minute, where the volume of water is measured per unit time. The first sample tested was the plain concrete sample. The water flow was almost at a constant rate ranges from 125 ml to 148 ml per 15min. The tendency is that the flow rate increases with time but at a very small rate. Within the time constraint of this test, the increase in the flow rate of the plain sample was not significant. Fig. 7 shows the flow rate of the three SAP concrete samples of 0.10 %, 0.20%, 1% and 2% by weight of Portland concrete. The plain concrete sample has a very large water flow value and almost constant to be included in this figure. The other four samples showed significant changes in flow rates. The flow rate decrease with time. This applies for all of the SAP samples, but the one with high percentage showed faster decrease in water flow rate with time. For other cases where the concrete sealing property is needed, higher percentage of SAP could be used.

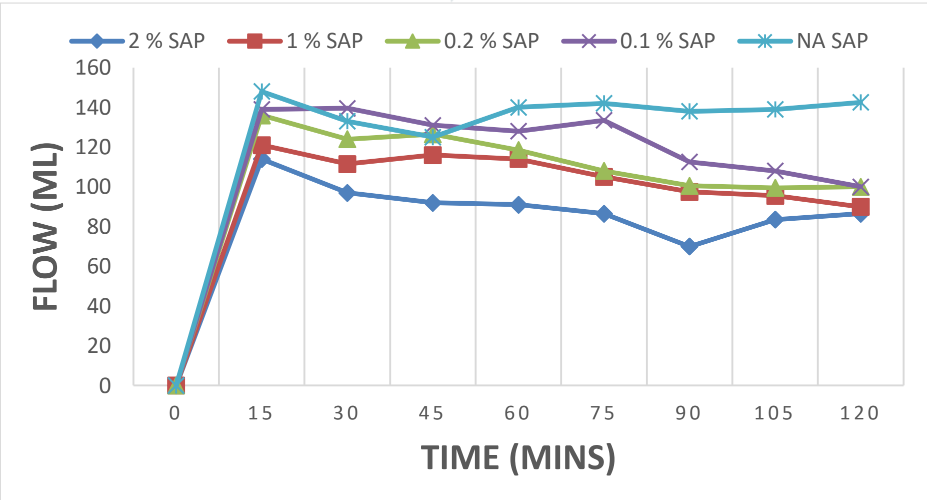

Figure 7 Effect of amount of the amount of SAP on water flow rate

IX. Conclusion

The super absorbent polymer has a significant effect on the behaviour of concrete in its two stages, fresh concrete and hardened concrete. The penetration water reduces with the increase in the amount of the super absorbent polymer added to the concrete mix.

The SAP also provides the concrete with internal curing by releasing water slowly with time inside the concrete mass. This internal curing helps increase the concrete strength especially in areas where it is difficult to cure the concrete with water. The SAP absorbs water up to 150 times of its own weight and coverts it into gel. This gel expands with water, and occupies spaces and cavities in the concrete mass. This property can be utilized to seal the concrete cracks, and to stop the leaks in the cracked concrete structures subjected to water pressure.

There is an optimum value 0.1%SAP to be added to the concrete as an admixture get the maximum compressive strength of concrete. The increase beyond the 0.1% optimum amount will affect the concrete strength negatively.

In transverse test of concrete beam and splitting tensile strength of cylinder showed that it is minimum at 2% and so on it is decrease with respect to increase the SAP % in concrete mix.

In water flowing through cracks test the plain concrete sample has a very large water flow value and almost constant. But the samples of 2% SAP content was able to stop the water flow sooner when subjected to certain water pressure with respect to sample of 0.1% SAP. So on increase in the amount of SAP added to the concrete mix improves the concrete sealing capability and it is capability decrease with respect to decreasing SAP amount in concrete.

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