Self-sealing concrete mortar, concrete mortar mixed with super absorbent polymer

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Abstract. Researchers tried almost every conceivable material to be mixed in concrete to alter some of its properties. In this research superabsorbent polymer is 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 have been prepared to study the effect of the superabsorbent polymer on the concrete strength, and on the concrete capability to block the water flow. Concrete cubes, concrete beams, and concrete tension samples were prepared to study the concrete strength of concrete mixed with superabsorbent polymer. Also concrete 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 crack. The artificially cracked samples are then subjected to water pressure to study the concrete ability to stop the water flow through the induced concrete crack. Two kinds of water pressure are used in this research; the constant head, and the falling head.

1 Introduction

There are several applications of the superabsorbent polymer (SAP) are available commercially. One of the most known use of the SAP is in some agricultural applications. The SAP absorbs water at very high rate and releases it slowly with time. This property is very useful for plants that needs constant supply of water. Other application of this product is in the baby diaper products. It is used for its capacity to absorb water and to convert it into gel. This property is very useful for any application that requires to retain water in a semi-solid form. When the SAP is subjected to drying process, it loses the water slowly, and eventually go back to its crystal dry form.

It has been long struggle to improve the properties of concrete by adding all kinds of admixtures. Mixing super absorbent polymer with concrete not only improves its water tightness capability, but it also provides the concrete with internal curing moisture it needs to improve its strength. This property is very useful in cases where curing of concrete is

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difficult. The fresh concrete plasticity and consistency change as well. This property is yet to be further explored. This self-sealing property of concrete can also be used in any tank or container that holds and retains any kind of liquid. The super absorbent polymer absorbs water at a rate of 300 to 500 times its own weight, in a process transforming the polymer dry powered into gel. Samples of different amount of superabsorbent polymer were prepared to study the effect of the increase of the superabsorbent polymer on the concrete strength and on the concrete water tightness capability.

The concrete is mixed with SAP at different percentages to study its effect on the concrete properties. Several samples of different SAP quantities are prepared. Samples of 0% SAP are also prepared to be used as control samples. The amount of SAP used in this study is expressed as a percentage by weight of the Portland cement. This percentage ranges from 0% to 0.3% by weight of Portland cement. Previous study by the author showed that the concrete is very sensitive to the SAP amount.

Normal weight concrete is produced by mixing Portland cement, aggregate, and water at moderate temperature. The mixing proportion is the key to good quality durable concrete. The quality of aggregates is very important factor to be considered when targeting quality concrete. The aggregate forms approximately 70% of the total mass of the hardened concrete. Portland cement is the most expensive ingredient, and the most important ingredient. It is the binding agent that starts its binding function the moment the water is added to the mix. The chemical reaction is triggered by the water, and continues with time. There two major well distinguished stages in the fresh concrete phase; the initial setting and the final setting. The water plays significant role in the concrete quality, and it is the cheapest ingredient. In the normal strength concrete, where ingredients are mixed without the help of any admixtures, the water is added at a rate of almost twice as much as needed for the chemical reaction. The excess water beyond the amount needed for the chemical reaction plays a negative role in the concrete. It increases the drying shrinkage, and increases the potential to propagate cracks in the mass of the hardened concrete. The water is necessary for concrete workability, and for the chemical reaction, but its amount must be under control. Nowadays, several admixtures are used to reduce the negative effect of the excess water on the hardened concrete without jeopardizing the concrete workability. Water / cement ratio became a significant parameter to be considered in the concrete mix design.

In this study, SAP is the only admixture used. The SAP starts absorbing water within minutes, and converts it into gel. Several masses of gel are then mixed with the rest of the concrete ingredient. These masses will release water slowly giving the chemical reaction the water it needs with time. This process has a great positive effect on the concrete final product. Unfortunately, the gel occupies large volume in the concrete mass. When the gel loses the water, it shrinks leaving large voids in the concrete mass. These voids play role in reducing the concrete strength.

AlNasra studied the effect of adding SAP on the concrete insulation property [1]. He proved that the SAP has the potential to save energy by improving the concrete insulation property. He showed that the increase in the SAP quantity added to the concrete mix increases the insulation degree of the hardened concrete.

The effect of the SAP on the concrete shrinkage was studied by several researchers. Also the effect on the SAP on the concrete strength is also investigated [2]. It is proven that the SAP has a significant role in increasing the concrete shrinkage. The loss of water with time increases the concrete shrinkage. Autogenous type of shrinkage is also studied in concrete [3]. The studies showed the uncontrolled shrinkage leads to concrete cracking. This can be of great challenge when high strength concrete is considered. The SAP played a role reducing the built-up stresses responsible of generating cracks in concrete during the process of restrained hardening of high performance concrete [4].

Al-Nasra used special kind of SAP called Sodium Polyacrylates in concrete as an admixture [5]. His study focused on optimizing the amount of SAP to be mixed in concrete. The optimizing process focused on the concrete strength as the main parameter. Several samples of different sizes were used. AlNasra concluded that approximately 0.11 percent of SAP by weight of Portland cement is the most effective percentage. This small percentage has little effect on reducing the concrete strength due to generating extra voids.

Excess amount of SAP added to the concrete mix increases the potential of generating cracks and weakens the concrete. Several studies suggested that the potential use of SAP as crack healing agent [6]. When concrete cracks it exposes larger surface areas to unfriendly chemicals. These unfriendly chemical accelerates the concrete deterioration from the inside. The super absorbent polymer helps in protecting the concrete by expanding and swelling in the face of the unfriendly chemicals, reducing the exposed concrete areas and limiting the access of these unfriendly chemicals to the concrete.

Al-Nasra, and Daoud studied the plasticity of concrete mixed with SAP [7]. The gel forming SAP changes the texture of the fresh concrete. They showed that adding SAP changes the concrete workability, plasticity, and consistency. They also concluded that a relatively small amount of SAP has the capability to make substantial changes in the behaviour of the fresh concrete.

2 Super absorbent polymer

The super absorbent polymer is composed of charged long chains of polymer. It contains multiple and repeated cross linked chains. These chains of polymer have the capability of absorbing water up to 500 times its own weight. Fig. 1 shows an actual picture of the super absorbent polymer used in this study. The figure shows the polymer before absorbing water, and the polymer after absorbing water in the amount of approximately 500 times its own weight. It can be noticed from this figure that the polymers took well distinguished crystal look alike shape. The ruler shows the scale in inches, reflecting the actual size of the super absorbent polymer used in this study.

Fig. 1. The super absorbent polymer before and after absorbing water.

This type of super absorbent polymer has been used widely in many commercial products mainly for its great ability to absorb water or liquid several hundred times its own weight. This property found its way into many agricultural applications. It is usually mixed with soil forming small water reservoirs. These reservoirs release water slowly with time. The constant supply of water keeps the plants and flowers fresh.

3 Concrete strength

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, tension, and flexure. Only one mould is used to produce water flow test samples. Four different percentages of the SAP were used; 0%, 0.10%, 0.20%, and 0.30%. The 0% sample is used as a control sample in order to study the effect of adding SAP to the concrete mix. Table 1 shows the concrete ingredients used in this study. The water/cement ratio is taken in this study as 0.5. The dimensions of the compression cubes are 5 cm X 5 cm, while the dimensions for the beam samples are 5 cm X 5 cm X 21 cm. Direct tension samples were also prepared.

Table 1. Concrete ingredients used.

Sample ID	Sand (gm)	Cement (gm)	SAP (gm)
Plain	400	200	0.0
0.10%SAP	400	200	0.20
0.20%SAP	400	200	0.40
0.30-SAP	400	200	0.60

Fig. 2 shows the effect of the SAP on the compressive strength of the concrete. The strength of concrete increases with time at a rate decreases with time. This applies for all of the samples within the time of the test. The percentage of SAP used has a substantial effect on the compressive strength. 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. 2. Compressive strength of concrete cubes mixed with SAP.

The fresh concrete mixed with SAP showed little or no shiny surface. The shiny surface is the result of concrete bleeding. Also the fresh concrete of samples mixed with SAP showed a different texture and colour compared to the plain concrete samples. Gel like firm texture became more visible with the increase in the amount of the SAP added to the concrete mix.

Fig. 3 shows the test set up of the compression cubes. Fig. 4 shows the direct tension test. The direct tension concrete samples are called dog bone samples due to its shape. Fig. 5 shows the flexural beam test set up. The test results of the direct tension samples were very close to each other. The same can be said about the flexural beam samples. The inaccuracy of the testing is larger than the difference between samples results. The size of the samples also played significant role in making the test inconclusive. However, the general trend of the results seems to enforce the trend of the compression samples.

Fig. 3. Compression test set up.

Fig. 4. Direct tension test set up.

Fig. 5. Flexural test set up.

4 Water flow test

The samples of the water flow test are of cylindrical shape. Its height is 10 mm, and its diameter is 35 mm. The objective of the test is study the ability of the concrete to block 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 10 mm depth, and width of 35 mm. Four groups of samples were prepared. Each of different SAP percentage. The amount of SAP used in this study ranges from 0% to 0.3% 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. The first sample tested was the one with 0% of SAP. This sample is used as a control sample.

Fig. 6 shows the drawing of a typical water flow sample. The induced crack is a results of applying flexural stress at the middle of the cylinder. This procedure is standardized to make sure all samples were subjected to similar conditions. Special mould was used to produce the water flow samples. The mould is basically a rubber ring of the inside dimensions of 10 mm in height, and 35 mm in diameter. The same mould is used again during testing to hold the broken pieces together.

Fig. 6. Typical water flow concrete sample.

The fresh concrete is poured into a rubber mould of 10 mm height and 35 mm inside dimensions. The concrete top is levelled and smoothened. The fresh sample was then covered in plastic sheets to maintain moisture in the concrete sample. The sample is then cured by

submerging it in water bath for additional 6 days. The sample is then removed from the water bath and left to dry for additional 7 days. The water flow test started on the day 14. On day 14 all samples were broken into approximately identical two pieces. Fig. 7 shows one of the samples which is broken into two pieces. Fig. 8 shows the same sample ready to be tested. The water flow sample is placed back in its mould, and then placed in a steel casing. The steel casing is then placed in the testing chamber in such way that the water has no path to flow but to flow through the concrete sample and in particular through the concrete crack.

Fig. 7. Typical water flow concrete sample with induced crack.

Fig. 8. Prepared water flow sample in the testing chamber.

Water pressure is applied at the top side of the water flow sample. The samples were subjected to both constant water pressure (constant head) and decreasing water pressure (falling head). These two different types of pressure are used in this experiment to study the effect of the water pressure on the sealing capability of concrete. The amount of water flowing through the concrete is then measured. This amount is indicative to the concrete sealing capability. 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 equation 1.

$$Q_{SAP} = \frac{V_w}{t} \tag{1}$$

Where;

Q_{SAP} = water flow rate through the concrete sample in ml/min
 V_w = volume of water flowing through the sample in millilitre
 t = time measured in minutes.

Fig. 9 shows the test set up for the water flow test. The same set up is used for both the falling head experiments, and the constant head experiments. The sample is cased inside the testing chamber, and subjected to water pressure at the top side only. The perimeter of the sample is sealed by epoxy to prevent any water flow through the sides.

Fig. 9. Test set up for falling head and constant head tests.

5 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 experiments took several months to reach to distinctive conclusions. The water flow though the concrete samples were subjected to both constant head water pressure and falling head water pressure.

The constant head test is conducted over several months around the clock. The broken concrete sample is put together in the same mould, then placed in water pressure chamber. The sample is subjected to 105 cm water pressure at all the time. Constant supply of water is provided to maintain the water at the same level in order to maintain constant water pressure. 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 26.8 ml/min to 29.2 ml/min. 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. 10 shows the flow rate of the three SAP concrete samples of 0.10 %, 0.20%, and 0.30 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 three 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. Eventually the water flow stops. The water flow through the sample with high SAP content stopped sooner compared to the one with low SAP content. Fig. 11 shows the stoppage time as it is related to the amount of SAP used in the concrete mix. The curve depicts high nonlinearity relationship. The stopping time is very sensitive to the amount of SAP used. For cases where the concrete sealing property is needed, higher percentage of SAP could be used. Equation 2 shows the relationship between the water flow stopping time and the amount of the SAP used in the concrete mix. This relationship is derived for this particular case, and can't be extrapolated or interpolated to match any other case.

Fig. 10. Water flow rate at constant head water pressure.

Fig. 11. Effect of SAP quantity on the water flow stoppage time.

$$t_{st} = 960 e^{-8.6 \eta}$$

(2)

Where,
 t_{st} = the water flow stoppage time in minutes
 η = super absorbent polymer amount expressed in terms of percentage by weight of the Portland cement

The falling head test is conducted in a very similar way. The water pressure started at 105 cm of water pressure and ended, in many cases, few centimetre above the sample level. The total volume of water flow is measured in this case. The plain concrete sample showed large water flow at the very beginning and trickled down to few drops at the end when the water pressure approaches the zero mark. Fig. 12 shows only the plain concrete sample and the 0.10% SAP sample. Showing the other two on this figure will make the figure clustered and difficult to read. Fig. 13 shows the effect of the amount of SAP on the water flow rate. The increase in the SAP amount in the concrete mix decreases the water flow rate and improves

the chances of the concrete to seal cracks. The water pressure has also significant effect on the water flow. The increase in the water pressure increases the water flow rate, which is expected conclusion. This study used low water pressure range.

Fig. 12. Effect of SAP quantity on the water flow rate.

Fig. 13. Effect of the amount of SAP on the water flow rate.

6 Conclusions

The super absorbent polymer has a significant effect on the behaviour of concrete in its two stages, fresh concrete and hardened concrete. The texture of the concrete changes substantially, while the plasticity of the concrete improves. The bleeding water reduces with the increase in the amount of the super absorbent polymer added to the concrete mix. There is an optimum value of SAP to be added to the concrete as an admixture as far as the concrete strength is concern. The increase beyond this optimum amount will affect the concrete strength negatively. 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 500 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. The increase in the amount of SAP added to the concrete mix improves the concrete sealing capability. This property is demonstrated by the ability of the cracked water flow concrete samples to stop the water flow. The crack is induced artificially

in the water flow concrete samples. These water flow samples are then subjected to water pressure of constant value and of decreasing value. The samples of high SAP content was able to stop the water flow sooner when subjected to certain water pressure.

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