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STUDY OF THE ABILITY OF CRACKED CONCRETE TO BLOCK WATER FLOW, CONCRETE MIXED WITH SUPER ABSORBENT POLYMER

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ABSTRACT

Concrete properties can be altered substantially by adding super absorbent polymer to the concrete mix. The modified concrete has the ability to absorb large amount of water and converts it into gel. This gel provides the concrete with the constant supply of water which is needed for internal curing process, at the same time occupies extra space in the concrete mass. This study targets the property of the modified concrete that helps blocking the water flow through the concrete mass by filling the voids and cracks with the produced gel. Several concrete samples of varying super absorbent polymer content that ranges from 0% to 0.3% are prepared. The water tightness samples are of cylindrical shape. Each of these samples is broken, identically, into approximately two pieces. The water tightness test will focus on the ability of the modified concrete to block the water flow thought the induced concrete crack. These samples will be subjected to both; constant water pressure – constant head, and varying water pressure - falling head. New device is developed to study the ability of the concrete to block the water flow subjected to certain water pressure. The effect of the amount of the added super absorbent polymer on the concrete water tightness will be presented. Several other samples are also prepared to study the effect of the super absorbent polymer on the concrete compressive and tensile strength. Concrete cubes and beams made of the same concrete mix as the water tightness samples are tested. The effect of superabsorbent polymer on the fresh concrete will also be discussed in this study including the concrete workability stability, and plasticity.

Keywords: concrete curing, concrete strength, water blockage, super absorbent polymer, water tightness.

INTRODUCTION

The super absorbent polymer (SAP) has been utilized extensively in many commercial products for its ability to absorb large amount of water. The absorbed water will be converted into gel that has the ability to release the water back slowly with time. This product is used in planting flowers to provide constant supply of water released to the roots. There are many applications of this product. In this study this product is used in the concrete mix. The superabsorbent polymer absorbs the water in the concrete mix and converts it into gel. The volume of the gel increases with the increase in the amount of water absorbed. The expansion in volume has the tendency to clog the water pathways in the concrete mass, and consequently improving its water tightness properties. This study focuses on the water tightness of the cracked concrete, and the ability of the SAP to block the water flow though the concrete cracks. Several concrete samples were prepared to study the effect of the amount of SAP on the properties of the final concrete product. A relatively small amount of SAP, mostly less than one present of the total weight of cement used in the concrete mix, is proven to be very effective. One of the samples is prepared with no additive of any kind (0% SAP). This sample is used as a control sample, and used to study the effect of adding SAP to the mix. The amount of SAP used in this study as admixture in the concrete mix ranges from 0% to 0.3% of the total weight of the Portland cement.

Concrete is produced mainly by mixing water, cement, and aggregates. Portland cement is the most common cement used in the concrete mix. The amount of water used in the concrete mix in proportion to the amount of cement used plays significant role on the quality and durability of the hardened concrete. The increase in the amount of water, in general, improves the workability, reduces the strength on concrete, and increases the amount of the concrete drying shrinkage. The excessive water used in the concrete mix leaves voids in the concrete mass. The amount of water added to the fresh concrete is one of the most important key factors that affect the concrete properties, including water tightness, durability, and strength. The water is an essential ingredient needed for the hydration process in the fresh concrete and for the curing process in the hardened concrete at its early stages. Different admixtures were used to reduce the amount of water demand in the fresh concrete without jeopardizing the workability. Water reducer admixtures were used extensively in the ready mix plants. The most useful amount of water is the one that is needed for the hydration process. Any amount beyond this amount is not desirable, when it comes to the concrete quality and durability of the hardened concrete.

The superabsorbent polymer plays a significant role in the concrete mix. The added super absorbent polymer to the concrete mix absorbs water and converts it into gels to be released later for the curing process. There is also an optimum amount of SAP to be used in the concrete mix. Excessive amount of SAP added to the concrete mix produces excessive voids in the mass of the concrete. These excessive voids reduces the concrete strength at the same time helps in protecting the concrete from the hydraulic pressure generated by the freezing thawing process, osmotic pressure, or any generated pressure in the concrete mass. An optimum amount of the SAP must be determined in order to balance between

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benefit of the internal curing and the loss of strength due to the excessive voids.

There several types of superabsorbent polymers. The most effective is the one that has high absorbing rate. Some of the direct effects of the SAP on the concrete product is concrete strength and concrete shrinkage Jensen (2013). The SAP used in the concrete mix increases the concrete shrinkage, which in turn make the concrete susceptible to cracking. This shrinkage is mainly due to the loss of water over time. This type of cracking can effectively be mitigated by slowing down the water loss. Jensen and Hensen (2001) studied the autogenous shrinkage phenomena in concrete. They concluded that the autogenous shrinkage may lead to cracking and affect concrete strength and durability, which is also, can be considered as technological challenge of high performance concrete. Addition of superabsorbent polymer in the ultra-high-performance concrete can be used to control the autogenous shrinkage. They also conducted tests that show that the shrinkage reduction due to superabsorbent polymer is related to a corresponding increase in the internal relative humidity of the cement paste. In addition, the use of superabsorbent polymer in concrete resulted in a reduction or elimination of stress build-up and related cracking during restrained hardening of these high-performance cementitious systems (Jensen and Hensen 2002).

Al-Nasra (2013) studied the use of Sodium Polyacrylates as SAP in concrete. His study focused on determining the optimum amount of SAP to be added to the concrete in order to maximize the strength and durability of concrete. Several concrete samples were used. Some of the samples used were 6 in. x 12 in. cylinders. Other samples of smaller size made of concrete mortars were also used. Al-Nasra concluded in his study that the optimum amount of SAP is 0.11 percent of cement by weight, which he showed to be the most effective amount to be used in concrete.

Some of the water added to the concrete mix will convert into gel. The rest will enter directly into the chemical hydration process. The gel produced by the superabsorbent polymers shrinks during the hydration process leaving voids in the concrete similar to the voids created by adding air entrainment agent to the concrete. The air bubbles left in the concrete are critical to absorb the hydraulic pressure due the water freezing. Water expands upon freezing about ten percent in volume generating hydraulic pressure in the concrete that has the potential to cause the concrete to crack. Providing voids in the concrete absorb the hydraulic pressure and provide addition space for the water to expand. The same can be said about the osmotic pressure in the concrete. The osmotic pressure is usually generated due to the difference in salt concentration in two adjacent water media. This difference in salt concentration can be created by adding de-icer to the concrete top surface, for the purpose of melting the ice on the concrete. Also these voids can be useful to absorb other kinds of internal pressures in concrete including alkali reactivity pressure.

Adding superabsorbent polymer to the concrete mix in excessive amount produces cracks in the concrete mass. SAP has the potential to seal concrete cracks too. Snoeck *et al* (2012) studied the use of superabsorbent polymers as a crack sealing and crack healing mechanism in cementitious materials. Their research focused on the use of the superabsorbent polymer to seal concrete cracks. As concrete cracks due to its low tensile strength and as harmful unfriendly chemicals may migrate into these cracks, the durability of concrete is endangered if no proper treatment or manual repair is applied. The first stage focused on hindering the fluid flow by swelling of superabsorbent polymers after they are exposed to a humid environment. The increase in the gel volume due to the absorbed water plays useful role in sealing concrete cracks. The sealing capacity was measured by means of water permeability tests and through visualization of permeability tests by neutron radiography. They also concluded that the use of superabsorbent polymers is able to seal cracks and thus allow a recovery in water-tightness as a decrease in permeability is noticed. The second stage focused on healing of small cracks by the use of fiber reinforced cementitious materials that have the ability to restore the mechanical properties. These mechanical properties were analyzed by four-point-bending tests and the crack closure was microscopically monitored. Cracks close through the combination of further hydration of unhydrated cement particles, precipitation of calcium carbonate and activation of the pozzolanic reaction of fly ash. Also they concluded that the desorption of superabsorbent polymers triggers healing in the vicinity of crack faces and cracks up to 130 μm were able to close completely in wet/dry cycles due to the precipitation of calcium carbonate.

Concrete curing is an essential part of producing quality concrete. The chemical reaction needs sustained supply of water after the final setting to improve the bonding strength in the concrete mass. Traditionally the curing process involves adding water to the hardened concrete for at least one week after removing the forms. To keep constant supply of water for the curing process, plastic sheets used to cover the concrete members in order to prevent or reduce water evaporation. Proper non-interrupted curing is proved to improve the concrete strength, the concrete durability, and the resistance to freezing - thawing cycles, the resistance to concrete shrinkage. Traditionally, the concrete is cured by adding water on the concrete surface externally. The SAP plays significant role in providing water within the concrete mass internally. The SAP holds the water for longer period of time, and releases it slowly in a process seems to be very useful in the curing process. This is extremely useful in the concrete members that are difficult to provide with constant water supply for about a week. An example of the concrete members that has the potential to benefit from this property is the concrete columns. Concrete columns are, commonly, vertical members that are difficult to retain water for longer period of time. SAP has the potential to improve the concrete column strength by

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providing feasible alternative to the curing process of these members.

Al-Nasra and Daoud (2013) studied adding SAP to the concrete mix to improve the fresh concrete plasticity. The SAP when added to the concrete mix absorbs water and converts it into gel. This gel alters the fresh concrete workability, consistency, and plasticity. They concluded that small amount of SAP was able to make significant difference in the fresh concrete behaviour.

SUPER ABSORBENT POLYMER

The super absorbent polymer used in this study is Sodium Polyacrylate, also known as water-lock, which is a sodium salt of polyacrylic acid with the chemical formula $[-CH_2\text{-}CH(COONa)\text{-}]_n$ and broad application in consumer products. It has the ability to absorb as much as 200 to 300 times its mass in water. Sodium polyacrylate is an ionicpolyelectrolytes with negatively charged carboxylic groups in the main chain. Figure-1 shows the composition of the sodium polyacrylate.

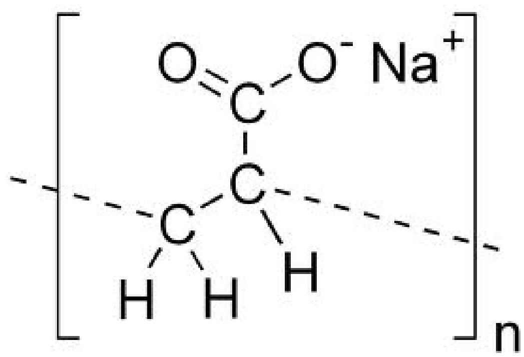

Figure-1. Sodium polyacrylate chemical compound.

Sodium polyacrylate is a chemical polymer that is widely used in a variety of consumer products for its ability to absorb several hundred times its mass in water. Sodium polyacrylate is made up of multiple chains of acrylate compounds that possess a positive anionic charge, which attracts water-based molecules to combine with it, making sodium polyacrylate a super-absorbent compound. Sodium polyacrylate is used extensively in the agricultural industry and is infused in the soil of many potted plants to help them retain moisture, behaving as a type of water reservoir. Florists commonly use sodium polyacrylate to help keep flowers fresh.

CONCRETE STRENGTH

Several concrete samples were prepared. The samples were grouped into two main categories. The first group is related to the concrete strength in compression, tension and flexure. The second group is related to the water tightness tests, to study the concrete ability to block water. The samples were prepared with three different super absorbent polymer content expressed in terms of percentage of the amount of Portland cement used by weight. The percentages used in this study of the SAP added to the concrete mix are 0.10%, and 0.20%, and 0.30% respectively. Plain concrete samples were also prepared with 0% SAP in order to compare results, and use as control sample. The same batch of each different sample is used for both strength test, as well as the water sealing test. Table-1 shows the concrete ingredients used. The ratio of sand to cement was taken to be 2, with water - cement ratio of 0.5. Figure-2 shows the moulds used in this experiment. The cubes are of 5 cm side length, and the beams are of 21 cm length with cross sectional area of 5x5 cm^2. Dog bone samples were also used in this study for direct tension test.

Table-1. Ingredients used.

Sample ID	**Sand** (gm)	**Cement** (gm)	**SAP** (gm)
Plain	200	100	0.0
0.10%SAP	200	100	0.10
0.20%SAP	200	100	0.20
0.30-SAP	200	100	0.30

Figure-2. The concrete strength moulds used in this study.

Mixing the concrete ingredients with some percentage of SAP changes the fresh concrete properties. The more SAP used in the mix the more plastic the mix will be. The increase in the amount of SAP in the mix shifts the behaviour of the fresh concrete to a gel like mix at the same time gives darker colour to the fresh mix. The control samples (the samples with 0% SAP) showed shiny surface, as expected from the concrete bleeding process, before the final setting of the concrete mix, while the samples mixed with SAP showed little to no shiny surface in the fresh concrete stage. The increase in the amount of SAP used in the mix reduces the visibility of the bleeding shiny surface of the fresh concrete. .

Figure-3 shows the results of the compressive strength of concrete cubes mixed with SAP compared with the control sample of plain concrete. These results are of cubes that were not cured in the lab. The compressive strength of the samples with SAP improved with time at a

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faster rate than the plain concrete samples, especially for low SAP content. Internal curing is believed to have positive effect on the concrete compressive strength. The increase in the SAP content in the concrete mix increases the void content in the hardened concrete mass. This increase in the void content in the hardened concrete mass is believed to be the main reason for the decrease in the concrete compressive strength at high SAP content. Figure-4 shows the experimental set up of the compression sample. The results of the direct tension tests shows an average strength of plain concrete of 0.88 kN while the samples with SAP shoed and average strength of 0.91 kN. These results are taken as an average of three samples. The direct tension test was conducted on the 14th day. The flexural beam tests showed similar pattern, with a very slight change in flexural strength of less than 5%.

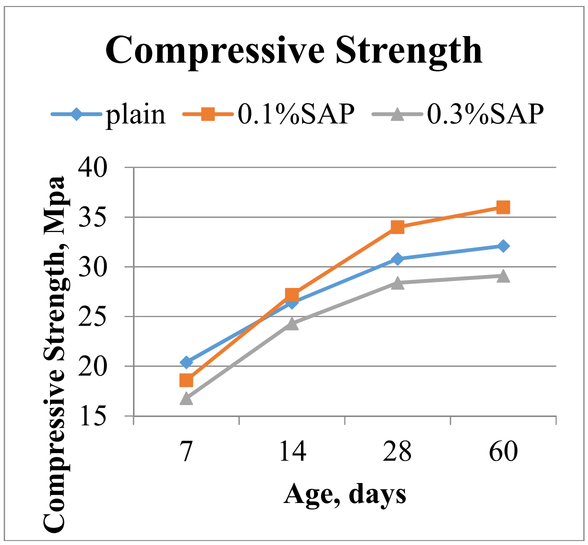

Figure-3. Compressive strength of concrete cubes mixed with SAP compared with plain concrete.

Figure-4. Cube compression test.

WATER FLOW TEST

Four samples were prepared. Each of cylindrical shape of 35 mm in diameter and 10 mm thickness. The purpose of this test is to study the concrete ability to block water. This property is very useful to prevent water leakage in water tanks, and nitrification basins. The water tightness property of concrete is studied under constant water pressure, as well as under variable water pressure. The focus is to study the effect and the ability of SAP to stop the water flow through the concrete mass. Several samples of increasing SAP content were prepared to study the effect of adding SAP to the concrete mix. The results were compared with the control sample, a sample mixed with 0% of SAP.

Concrete are often subjected to forces that cause the concrete to crack. Water can flow throw the concrete cracks causing additional damage to the concrete. The water flow through the concrete mass can erode the concrete from the inside, and ultimately accelerate the concrete failure. This study focused on preparing samples with the intention to study the concrete water tightness, as well as the concrete ability to block the water flow. Stopping the water flow through the concrete protects the concrete and prolong the life of the concrete structures. Sealing concrete cracks temporarily, using SAP, has the potential of sealing the concrete cracks permanently by accumulating fine particles of some kind of cementitious value in the concrete cracks. These particles include calcium carbonate, calcium hydro-oxide, and some Portland cement. The amount used in this study is mostly above the optimum amount found by Al-Nasra (Al-Nasra 2013).

Figure-5 shows a typical sample of cylindrical shape. The diameter is kept 35 mm for all water tightness tests. Also the thickness is kept 10 mm. Special moulds were prepared in the lab, and were used to produce water tightness test samples. The moulds are basically rubber ring of 10 mm height. Fresh concrete is poured into the small moulds. The surfaces were smoothen out. The samples were left to dry for one week, then removed from the moulds. Each water tightness sample is broken into two pieces, by subjecting each sample to flexural and bending stresses. The intention is to break each sample in the middle along the diameter producing two identical pieces as shown in Figure-6. The samples were put again in the mould as shown in Figure-7. A sealant is used to seal the gaps between the mould and the concrete sample. This is to prevent any unwanted water flow at contact surface between the mould and the concrete sample, and force the water to flow only through the concrete sample. For the plain concrete sample the water will flow faster through the concrete crack. The samples prepared with SAP will try to seal the crack by absorbing the water and expanding into the crack. This phenomena is studied in light of changing the water pressure. The higher the water pressure, the more sealing forces needed to prevent the water flow through the concrete sample and the concrete crack.

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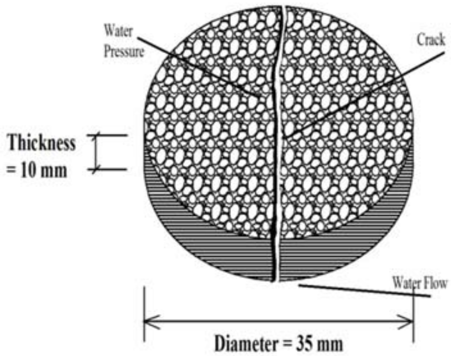

Figure-5. Identical water tightness concrete sample.

Figure-6. Typical water tightness concrete sample with induced crack.

Figure-7. Preparing the water tightness sample for the test.

The water tightness samples were subjected to two kinds of water pressure; falling head, and constant head. The first set of the water tightness samples was subjected to falling head water pressure. In this test the water pressure decreases due to the increase in the water flow through the concrete sample. The second set of water tightness samples was subjected to constant water pressure. In this test the water flowing through the concrete sample is replaced by an inflow of water.The value water discharge though the concrete sample can be calculated using the following formula:

$$Q=V/t$$

Where;

Q = water flow rate in ml/min
V = volume of water passing through the sample in millilitre
t = the measured time.

Figure-8 shows the experimental test set up for both constant head and falling head tests. The samples were confined in a chamber and tight sealed at the perimeter, which is the contact surface between the concrete sample and the rubber mould.

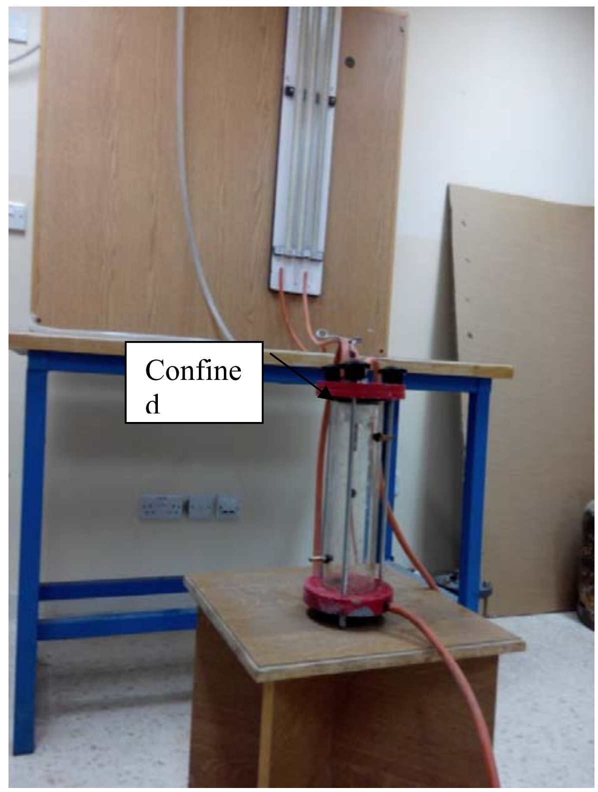

Figure-8. Test set up for falling head and constant head tests.

TEST RESULTS

The test focused on measuring the water flow through the concrete sample. The ability of SAP to block the water flow is the main objective of this experiment. The actual test took several weeks and months for some samples, especially the ones with low SAP content. The samples were subjected to both constant water pressure as well as variable water pressure. The water flow through the concrete sample is measured with time. The water discharge is measured in terms of ml/min. Each experiment was conducted over days and in some cases weeks and months. The water discharge through the concrete water tightness samples is proven to sensitive to the time. Short term readings showed higher sensitively to the time than the long term readings during the course of the test. Short term readings were taken at the beginning of the experiment in terms of minutes to focus on the changing rate of flow, then these readings were taken over several hours and later over several days, weeks and months. The test was even extended, especially with the samples of high SAP content, beyond the stoppage time. The stoppage time is the time at which the water stops flowing through the concrete sample and the water discharge remains zero for several days and weeks. The plain concrete samples have no stoppage time, since the water kept flowing at almost constant rate. The plain concrete samples showed even a slight increase in the water flow with time when subject to constant water pressure. The samples prepared with SAP were able to slow down the water flow through the concrete sample and ultimately stopping the water flow. The samples mixed with high percentage of SAP showed stronger trend in stopping the water flow. This proved the sensitivity of the concrete sealing property to the amount of SAP used in the concrete mic. The time required to stop the water flow through the concrete sample changes with the amount of SAP used in the concrete mix. The increase in the amount of SAP in the concrete mix the sooner the stooping time will be. There is direct correlation between the stoppage time and the amount of SAP used in the concrete mix.

Table-2 shows readings of the water flow through the concrete sample with time when the samples were subjected to the falling head test. The water flow in the sample made of plain concrete (0% SAP, which is the control sample) decreases due to the drop in the water pressure. Initially the samples were subjected to 103 cm water pressure, which deceases with time due to the water flow. The sample made with 0.10% SAP in the concrete mix, showed a rapid decrease in the water flow due the fast drop in the water pressure and the effect of the SAP in the concrete mass. The water eventually stopped flowing through the concrete sample for this particular test sample after 233 hours (9.7 days). It was observed that the water flow slowed down very rapidly and trickled down over several days until it reached to a complete stoppage at 59 cm water pressure.

The samples prepared with 0.30% SAP exhibited stronger capability to block the water flow in comparison with the samples prepared with 0.10% SAP, and 0.2% SAP. The water flow in the samples prepared with 0.30% SAP initially was similar to the other samples prepared with some SAP content, but soon the samples showed higher capability to stop the water flow. This can be explained by time needed for the SAP to absorb the water and expand in the concrete crack. Even though it was possible to create an identical crack in the concrete sample, the test results were consistent. The samples prepared with 0.30% SAP were able to stop the water flow in 1.2 hours at water pressure 101 cm of water column. The samples made with SAP showed the ability to retain water under relatively high pressure compared with the samples of plain concrete. The sample made with 0.3% SAP kept a sustained constant water pressure after the blockage time. Figure-9 shows the water flow in (ml/min). The rate of flow in the plain concrete samples was relatively high compared with the samples prepared with SAP. The effect of the increase in the amount of SAP mixed with concrete is illustrated in Figure-9 under falling head pressure. The higher the SAP content in the concrete mix the better water blocking capability will be.

Table-2. Falling head summarized results.

Time, min	Falling head, Water Flow, ml/min			
	Plain concrete	0.10% SAP	0.20% SAP	0.30% SAP
0	0	0	0	0
5.5	100	6	6.2	5.4
15.25	195	13.5	11.03	6.6
34	300	22.5	15.5	7
73.1	360	52.5	19.6	7
158.25	385	82.5	22.1	7
246.5	405	120	22.7	7

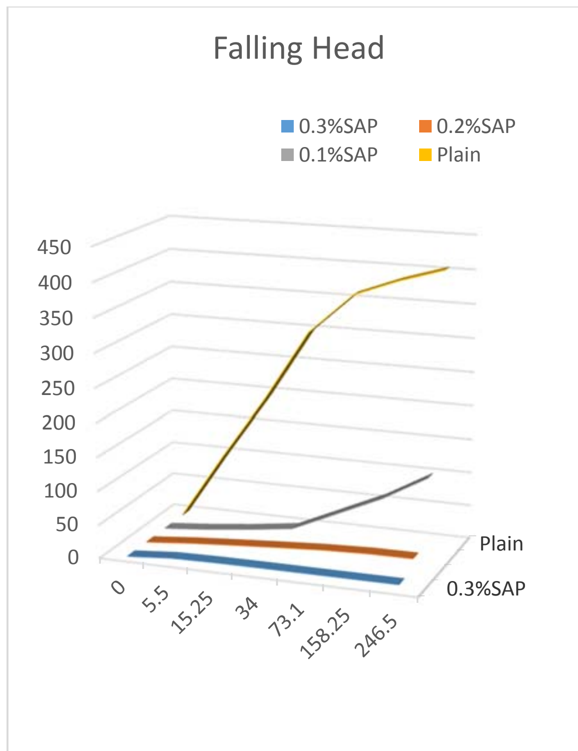

Figure-9. Falling head water flow with time.

The samples of the same concrete mix were then tested under constant pressure. The main focus is to study the effect of the amount SAP in the concrete mix on concrete water tightness capability. The water pressure is maintained constant at 103 cm of water pressure column. Table-3 shows a partial list of the results. The water flow in the plain concrete samples (samples prepared with 0% SAP) exhibited almost a continuous and a constant water flow in a value hovering around 27 ml/min. This flow increased slightly with time due to the internal erosion of the concrete sample. The samples prepared with 0.10% SAP showed fast drop in the water flow rate. The flow rate in those samples eventually trickled down to a minimum, few drops per hour in about 25 days. The samples prepared with 0.30% SAP showed an improved water blocking capability. The water flow stopped completely in about 72.2 hours (3 days). Figure-10 shows the effect of the amount of SAP used in the concrete mix on the water flow rate under constant pressure.

Table-3. Constant head summarized results.

Time, hrs	Constant head, Water Flow, ml/min			
	Plain concrete	0.10% SAP	0.20% SAP	0.30% SAP
0	27.3	1.7	1.4	1.133
12	27	0.82	0.52	0.35
24	26.9	0.64	0.32	0.123
48	26.8	0.53	0.21	0.045
72	28.5	0.43	0.15	0
144	29.2	0.31	0.08	0

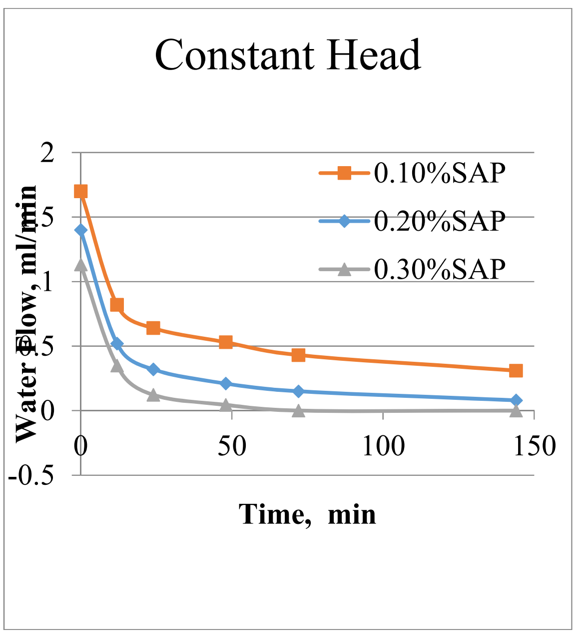

Figure-10. The effect of SAP on the water flow rate under constant head pressure.

CONCLUSIONS

Adding a relatively small amount of the super absorbent polymer, SAP, in the concrete mix makes a substantial difference in the concrete behavior. This effect can be seen in both stages of concrete; the fresh concrete stage and the hardened concrete stage. The increasing future use of super absorbent polymer in the concrete has real promising potential to improve desired concrete properties including strength, plasticity, stability and water tightness. The concrete mixed with SAP makes the concrete more plastic and improves its workability and stability. Also it has the potential to make the concrete as self sealing concrete. The concrete water blocking capability is improved substantially with the increase in the SAP content in the concrete mix as shown by the test results. All of the tested water tightness samples were broken into two separate pieces in a process of inducing an artificial concrete cracks. Test results showed that the SAP was able to block the water flow through the induced concrete cracks at a relatively low percentage of SAP. The samples with 0.30% of SAP were able to block the water flow in about 72 hours. The concrete mixed with SAP exhibited a capability to block the water flow due to the continuous expansion of the formed gel. Excess amount of SAP added to the concrete mix creates more voids in the concrete mass. Excess voids in the concrete mass have the potential of reducing the concrete strength. Well determined optimum amount of SAP should be considered in the concrete mix design. On the other hand, adding SAP to the concrete mix creates voids in the concrete mass in the form of get. The gel produced by the SAP provides soft cushioning around the aggregates of different sizes, a property that might help in improving the concrete mix stability. Adding SAP also changes the colour and the texture of the concrete mixed, producing lighter colour and softer plastic mix. It was also observed that the shiny water surface during the fresh concrete stage is becoming less visible with the increase of the amount of SAP in the mix due to transforming the excess water in fresh concrete into gel.

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