Fresh and Hardened Properties of Superabsorbent Polymer Concrete

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Abstract: ***Superabsorbent polymers(SAP) have the ability to absorb large quantity of water and store it inside its body and then release the water when drought happen depending on this mechanism this polymers had been used in concrete to obtain some benefits, The most important of use it to minimize shrinkage that caused due to losing of water by providing internal moisture, this problem can be overcome, It is also used to improve curing (internal curing agent),enhancing freezing and thawing resistance and reduce permeability, This corresponds to effect on the concrete strength negatively or positively depending on the method of use. The aim of this research is to reach the optimum addition ratio of SAP to mortar concrete which gives the best strength results(where three different addition ratios of SAP were used 0.1 , 0.4, and 0.7% by weight of cement), as well as to make a simulation of the curing at site work, two different methods of curing were used, first one was immersed samples in water for one week and Then leave it in the normal atmosphere for the next 21 days and the second method was sealed curing by nylon bags for 28 days, And also test the effect of SAP on the workability of mixtures.***

Keywords: Sodium Polyacrylate, internal curing, concrete strength, workability

1. Introduction

Concrete is one of the most important materials used in the construction work because of the availability of its materials, cost is moderate and easy to work, Therefore, research and development attempts are constantly carried out on the concreteto improve its properties, increase strength and durability and overcome the negative aspects. Water considered as an essential component in concrete and an important element in the processes of mixing, curing, hydration and hardening, but when not added water accurately or when added it more than the required quantity a significant weakness in the properties of concrete will happen, on the other hand, when controlling the water working mechanism in concrete, it is possible to obtain a significant improvement in properties, This can be done by using some additives such as superabsorbent polymers (SAP) that have the ability to arrange water behavior inside the concrete.

Super absorbent polymer are white granules Made in different sizes (the type used in this research have size ranges approximately 100 µm) have ability to absorb water within them at a rate up to 300 gm/gm and swell to be like a gel shape, when drought happen (SAP) begin to release water gradually and shrink back to their first shape (see figure 1).

The amount of water absorbed by (SAP) is affected by the purity of the water itself. When the purity of water be high, ability of polymers to absorb will increase, For example, absorption of distilled water is higher than tap water and tap water higher than sea water and so on. When using this material with concrete components can be as an internal water tanks filled up at mixing and lose it moisture during drought. (SAP) can be used as a method of internal curing by adding additional water during mixing (internal curing agent), also It can be used without adding water as a retaining agent where can organize the process of hydration (retaining agent).

Figure 1: Dry (SAP) in the left cup. The right cup after adding some water

Based on properties that mentioned above , (SAP) can improve a range of concrete properties, such as reducing shrinkage by providing internal moisture to compensate the loss of moisture due to the process of cement hydration, reduce permeability of hardened concrete by interception the entry of water to concrete body depending on the mechanism of SAP swelling when it absorbed water, where the size of polymers will increase due to swelling so the cracks will be closed and prevent the flowing of water as in (Figure 2), also one of the benefits of this type of polymer is improve the resistance of concrete to freezing and thawing by providing very small voids caused by swelling of SAP particles after absorption some of mixing water and then the particles will shrink when drought happen leaving small voids can absorb the stress resulting from the cycles of freezing and thawing, In other words, it can operate with the same mechanism of air entraining(air entraining is one of additives of concrete which have the ability to increase concrete resistance against the cycles of freezing and thawing), therefore SAP can be considered as one of the multifunctional concrete additives.

In this paper, the focus will be on the effect of SAP on the workability, compressive and tensile strength of the mortar concrete samples. There will be two independent types of curing (water curing for one week and sealed curing by nylon bags for 28 days)

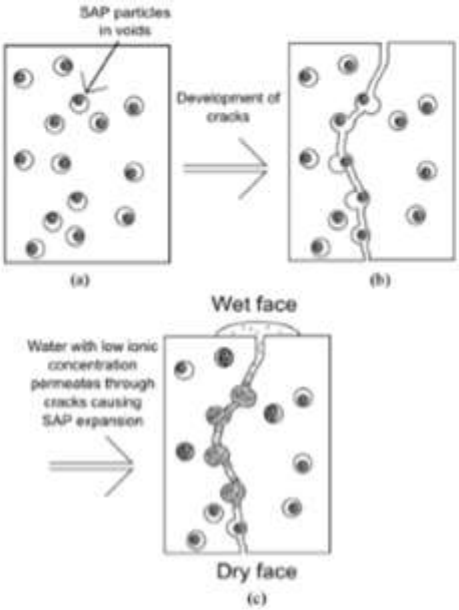

Figure 2: SAP as water blocker[13]

2. Review of Literature

Pierard,et.al studied the compressive strength of concrete contain superabsorbent polymers with two different quantity of SAP addition (0.3% - 0.6%) to the mass of cement with extra water (2% - 4%) to cement mass the test samples were cured at 20°C and 98%(RH) till 28 days, Pierard concluded that there is a decreased in the compressive strength at age of one week , at the age of 28 days the reduction in the strength was lowering to 7% and 13% for SAP quantity 0.3 % , 0.6%

Alnasra (2013) studied the effect of adding sodium polyacrylate (SAP) to concrete mortar as an internal curing agent on the strength , after conducted a sundry experiments and select the optimum quantity to enhance concrete strength. The researcher found that 0.11% of SAP to cement mass (without extra water) it was the optimum quantity that leads to improved concrete strength.

Bentz et.al checked the strength of two types of mortars samples with SAP and without. SAP content 0.4% relative to cement weight ,w/c ratio was = 0.35 the compressive strength at age of one week show some reduction in SAP samples compared with normal mortar 53 MPa _ 57 MPa. atage of 28 days the situation had been changed the SAP concrete mortar samples gave results in compressive strength higher than the normal samples 73 MPa _ 61 MPa respectively

Esteves et.al test the effect of adding SAP to the concrete mortar and studied its effect on concrete properties. 0.2 % of SAP relative to cement mass with some extra water (5% to cement mass) were used, half of samples were cured at 95 % RH and the others cured at 30 % RH. at the age of 28 days the SAP samples that cured at 95 % RH showed a 20 % decline in the results of compressive strength compared with reference samples(without SAP). At 30 % RH the decline in strength result was only 5 %.

Hareendran et.al (2014) tested the compressive strength of six different mortar samples with different quantity of superabsorbent polymer 0, 0.2, 0.25, 0.3, 0.35, and 0.4% to cement mass with some extra water (relatively every one kilogram of SAP corresponds to 45 liters of extra water).after 28 days, the addition 0.35% of SAP gave the highest value in the compressive test even higher than the reference mixture.

Igrashi and Watanabe studied the properties concrete mortars contain SAP and compared it with normal mortars samples. The polymer used is white powder in spherical granular shape whose diameter 200 µm, the researchers found that with increment of SAP quantity compressive strength results was reduced as shown in Table (8.2) according to Igrashi and Watanabe The lowering of strength is due to using SAP with large particles size and also due to addition extra water.

Table 1: Result of compressive strength of concrete with different amount of SAP [6]

SAP, %	w_e/c	Compressive strength, MPa 7 days	28 days
0	0	86.3	97.4
0.35	0.045	78.0	94.2
0.70	0.09	67.0	76.1

Mechtcherine et al examined the compressive strength of some SAP mortars with low water content w/c = 0.22, with different SAP quantities (0%(ref)-0.3%-0.6%)to cement weight additional water was added to compensate the lowering of workability. It was observed that there is a reduction in the results of the compressive strength at the age of one week, the decrease was 12% and 30% for 0.3% and 0.6% of SAP content At the age of 28, there was no reduction in the strength of the mixture containing 0.3% SAP compared to the reference mixture While the decrease in the strength of the mixture containing 0.6% SAP reach to 20%

3. Experimental Works

Six different mixtures were performed to conduct this experiment as shown in (table 1) and (table 2) , three different quantities of SAP((0.1-0.4-0.7)%to cement weight) were added to the concrete mortar mixtures with addition of water and without (except mixture which contain 0.1% of SAP did not add extra water to it because there was no significant effect on the workability), also reference mixtures was performed to compared the results.All samples were cured in two different ways(water curing for one week after that putted out for open curing until the age of 28 days - sealed curing by nylon sealing bags for 28 days), the aim of this types of curing is to make a simulations of site working and also to see the effect of SAP on curing)

Table 2: Mixtures materials (water curing)

No.	Mix Symbol	W/c ratio	SAP % by weight of cement	SP % by weight of cement
1	RW	0.485	-	0.6
2	0.1_SW	0.485	0.1	0.7
3	0.4_SW	0.485	0.4	1
4	0.7_SW	0.485	0.7	1.4
5	0.4_SW+0.06	0.485+0.06=0.545	0.4	0.6
6	0.7_SW+0.1	0.485 +0.1=0.585	0.7	0.6

Table 3: Mixtures materials (sealed curing)

No.	Mix Symbol	W/c ratio	SAP % by weight of cement	SP % by weight of cement
1	RS	0.485	-	0.6
2	0.1_SS	0.485	0.1	0.7
3	0.4_SS	0.485	0.4	1
4	0.7_SS	0.485	0.7	1.4
5	0.4_SS+0.06	0.485+0.06=0.545	0.4	0.6
6	0.7_SS+0.1	0.485 +0.1=0.585	0.7	0.6

4. Materials

Cement:
Ordinary Portland cement (type 1), commercially named (mas)

Superabsorbentpolymers
Sodium Polyacrylate used in the experiments as a superabsorbent polymers with chemical formula [-CH2-CH(COONa)-]n produced by Scompany for Chemicals. Table (4) shows the properties of this type see table 4

Table 4: Properties of Sodium Polyacrylate

Properties	Technical description
Appearance	Granular Powder
color	white
odor	odorless
Absorption Capacity in distilled water	280g/g
Fusion point	390°F
Bulk density	700 kg/m³
Solubility in Water Insoluble	Insoluble
Stability	Stable, but moisture sensitive
Chemical Name:	Sodium polyacrylate
Molecular Formula	$(C_3H_3NaO_2)n$
pH	4.9-6.5
Possibility of Hazardous Reactions	Will not occur

* According to manufacturer (SOCO COMPANY)

Water
Tap water was used in all parts of this experiment mixing, curing and washing

Fine aggregate
Natural sand was used from locally quarries. Conforming to IQ standards No.45/1985, with Grading zone II

Superplasticizer (SP):
The additive used for this job has commercially name (Sika ViscoCrete).This type is Conform to the specification of the standard ASTM C494-04.

Curing
Two different ways of curing were used for each mixture (water curing for one week after that putted out for open curing till the samples became 28 days old - sealed curing by nylon sealing bags for 28 days), the aim of this types of curing is to make a simulations to site working and also to see the efficiency of SAP as an internal curing agent also to see the ability of the polymers to improve cement hydration. See fig3

Figure 3: Types of curing

5. Flow Test

All mixtures included in this study were subjected to the flow test in accordance with specifications ASTM C1437-03.(Flow rate must be maintained =110±5 according to the specification see fig 4)Where the importance of the test is to evaluate the effect of SAP on the workability of the mixtures and the extent of the need for superplasticizer or water to maintain theproper rheology (The amount of superplasticizer is changed if the SAP is used as a retaining agent see (fig 5)and the amount of water is changed if used as an internal curing agent).Also, through this test, the amount of water absorbed by SAP is determined and thus the quantity of water added to the mixture for internal curing is determined without any surplus. When water is added to the mixture, the superplasticizer ratio remains the same quantity used in the reference mixture

Figure 4: flow test

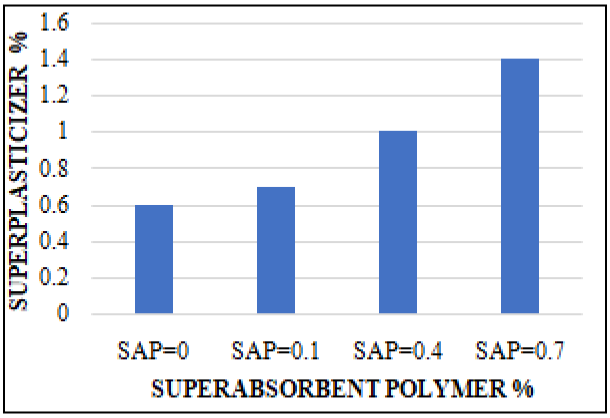

Figure 5: Relationship between SUPERPLASTICIZER and SAP (when used SAP as a retaining agent)

6. Compressive Strength

Each mortar mixture was test in three ages 7, 14, and 28 days and for each one average of three readings was calculated(total samples were made for this test =108) for all types of curing. All test steps were conducted according to the specification standard ASTM C109/C 109M-05, Molds with dimensions (50 * 50 * 50) mm were used,

`From Tables 5 and 6 it is easy to note that the addition ratio of 0.4% of SAP gives the best results whether by adding water(SAPused as internal curing agent) or without adding water(SAP used as retaining agent)

When comparing the mixture (0.4_SW) which contain 0.4% SAP to cement weight with the reference mixture (RW), Noted that there is an increment in the strength up to 20% for the age of 28 days, The same situation happen but with a lesser degrees when comparing the reference mixture RS (sealed curing) with the mixture (0.4_SS) without extra water and with sealed curing. This indicates that the polymers have improved the cement's hydration by releasing the water regularly.

Also when compared the mixture(0.4_SW+0.06)which containing 0.4% of the polymer and an extra water(w/c=0.485+0.06) for internal curing with the reference mixtures (RW), there is no decrease in strength This indicates that all extra water is absorbed by the SAP and used in the internal curing.

As for the addition of 0.7% some negative things were appeared, including the great impact on the workability and increased need for superplasticizer, Also, when reading the results there was no improvement in the strength when used the SAP as a retaining agent, but on the contrary, there was a decline in the result at the age of one week. When using 0.7% of SAP with extra water(internal curing agent) sharp drop in the strength results was appeared in both ways of curing reached to 30%, The negative results in this addition are due to the increase in the amount of gaps.

Table 5: Compressive strength for samples cured with water for one week

No.	Mix Symbol	7 days (MPa)	14 days (MPa)	28 days (MPa)
1	RW	18	21.5	25
2	0.1_SW	19	23.4	27
3	0.4_SW	21.5	26.3	30
4	0.7_SW	17.35	22.5	26
5	0.4_SW+0.06	18.1	20	24
6	0.7_SW+0.1	13.3	15.3	17

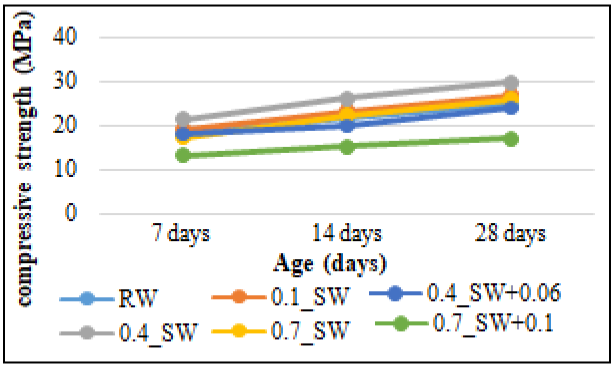

Figure 6: Compressive strength of samples cured by water

Table 6: Compressive strength for samples cured by sealed curing method for 28 days

No.	Mix Symbol	7 days (MPa)	14 days (MPa)	28 days (MPa)
1	RS	16.5	19.3	23.2
2	0.1_SS	17.3	21.6	25
3	0.4_SS	19.9	22	26.8
4	0.7_SS	17	18.8	24
5	0.4_SS+0.06	16	18.2	22
6	0.7_SS+0.1	13.5	15	15.7

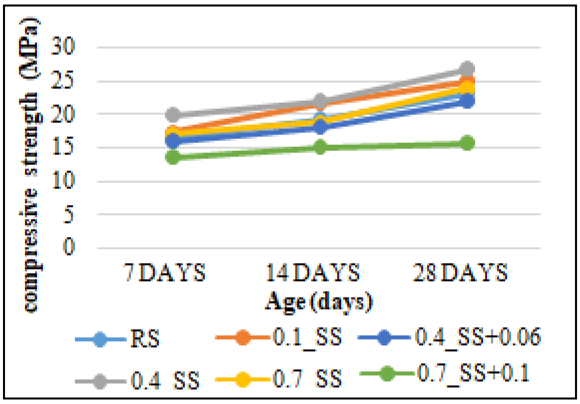

Figure 7: Compressive strength of samples cured by sealed curing method

Tensile Strength

Six mixtures, as in (table 2) and (table 3), were prepared for direct tensile test, three ages and two curing methods, and for each age average of three samples was obtained (108 samples were made for this test). The purpose of this test is to reach the optimam addition quantity as well as to know the effect of SAP on the mechanical properties of the concrete. from fig 8 , fig 9 , table 7 and table 8 can be observe that the mixtures containing 0.1% of the SAP with sealed curing did not give a significant change in strength result,., unlike 0.1% results with water curing Which demonstrated good results in this test. On the other hand, the addition of 0.4% gives a clear increment in the tensile strength results when SAP used as a retaining agent in both curing methods Specially samples that cured by water Which gave the highest results , also there is no drop in the tensile strength when SAP used as an internal curing agent(with extra water).

When the SAP quantity was increased to 0.7%, the test show not good and irregular results in both curing methods

Generally, When comparing the results of the tensile strength test with the results of the compressive strength test, it is observed that the rate of improvement of the strength in the tensile test higher than the improvement rate in the compressive test.The only explanation for this conclusion is that since SAP considered a shrinkage reducer due to its ability to compensate the loss of moistures so the cracks will be reduced in the concrete and as is known, the failure in the tension related to the existence of cracks.

Table 7: Result of tensile strength for samples cured with water for one week

No.	Mix Symbol	7 days (MPa)	14 days (MPa)	28 days (MPa)
1	RW	1.9	2.2	2.81
2	0.1_SW	2	2.4	3
3	0.4_SW	3.1	3.42	3.9
4	0.7_SW	1.784	2.4	2.74
5	0.4_SW+0.06	1.84	2.27	2.9
6	0.7_SW+0.1	1.21	1.38	1.61

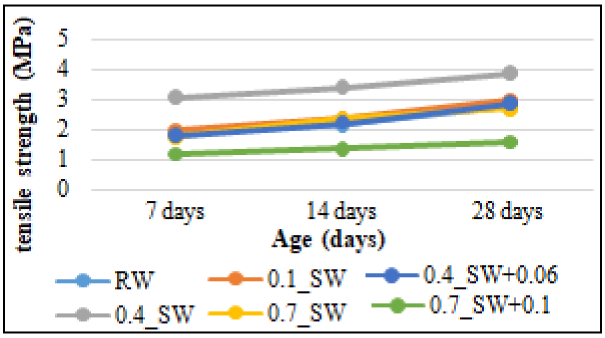

Figure 8: Tensile strength of samples cured by water

Table 8: Result of tensile strength for samples cured with sealed curing for 28 days

No.	Mix Symbol	7 days (MPa)	14 days (MPa)	28 days (MPa)
1	RS	1.71	2.1	2.61
2	0.1_SS	1.8	2.2	2.72
3	0.4_SS	2.35	2.81	3.2
4	0.7_SS	2.5	2.57	3
5	0.4_SS+0.06	1.58	1.87	2.3
6	0.7_SS+0.1	1.27	1.3	1.8

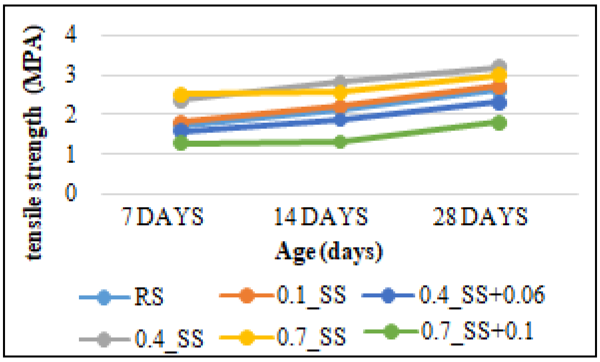

Figure 9: Tensile strength of samples cured by sealed curing

7. Scanning Electron Microscope (SEM)

Is a super zoom depiction used to microstructure investigations for the materials.two samples were tested by (SEM) the reference mixture (RW) and the mixture that contain 0.4% of SAP to cement weight (0.4-SW). Through the images in Figure 10 and Figure 11 were observed that there are a spherical voids are a places of the swelling SAP due to water absorption, also in the images of the sample that contains SAP can be noticed that the percentage of capillary voids is lower than the normal mixture This indicates to improved the hydration process due to exist the polymers.(see figures 10-11-12)

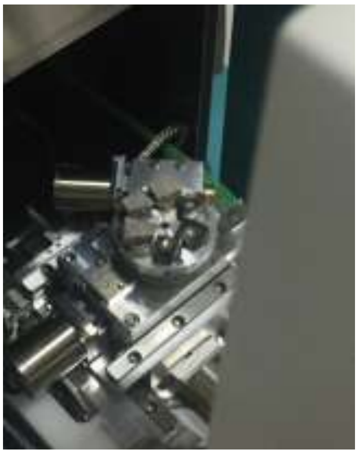

Figure 10: Samples inside SEM device

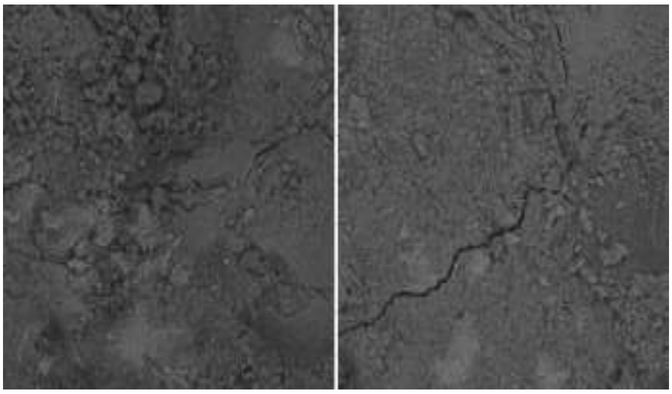

Figure 11: Two images of reference mixture (RW)

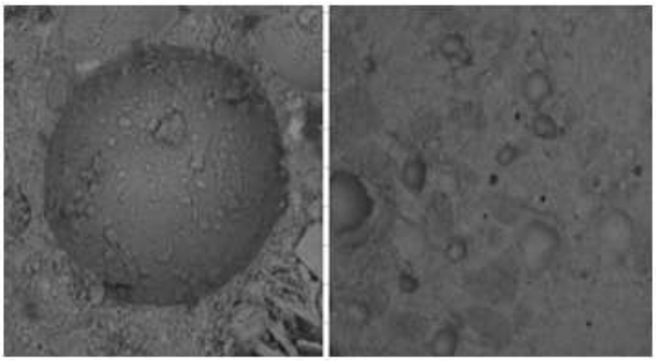

Figure 12: Two images of SAP mixture (0.4_SW)

8. Conclusions

The main findings of this research are as follows:

- Any quantity of SAP addition will effect on the concrete workability, where additional water or superplasticizer should be added for this reason. When the amount of SAP is high, the mixture will take a harsh textures and the dealing with it will be difficult.
- Through the flow test, the quantity of water that absorbed by the SAP wasdetermined, in other words, the amount of extra water that should be added to the mixture was known by making several trial mixtures.
- The use of this type of polymer as an internal curing agent is not considered a curing method in itself, but an auxiliary factor(adding SAP to concrete does not mean neglecting the normal water curing) where the samples that cured by water for one week gave higher result in strength than samples that cured by nylon bags sealing.
- Use SAP as a retaining agent (without adding extra water) improves the concrete hydration.
- After studying previous research in this field, 100 µm was selected as the size of the SAP granules so that the gaps caused by swelling the polymer are not large and did not negatively affect the strength.
- The addition of 0.4% gave the best results in the compressive strength and tensile strength tests. When the SAP used as a retaining agent (without adding extra water), the strength results improved by 20% compared to the reference mixture.
- The results of strength were not reduced when the SAP used as an internal curing agent (with adding extra water) with the ratio 0.4% to cement weight (can take advantage of The other polymer properties when it used in this way for example reduce shrinkage, increase resistance of freezing and thawing and reduce permeability without decreasing the strength of the concrete by using the ratio of polymers = 0.4% to cement weight and with granular size = 100µm.
- The increase in the quantity of SAP addition ratio is not desirable as in the rate of 0.7%, where the results are followed by a decline in strength due to increased areas of weakness(voids) in addition to the problems of workability.
- SAP change the pore structure of the concrete and transform the gaps from a network of connected capillary voids to separated spherical voids.

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