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Performance of super-absorbent polymer as an internal curing agent for self-compacting concrete

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Abstract. Internal curing agent by using super-absorbent polymer was present in this study, its effect on the properties of self-compacting concrete was evaluated .The SAP content in the concrete mix was 0.5 % by weight of cement. Three procedures for curing were adopted; curing in water, curing in water and air and curing in polyethylene sealed bags. Fresh concrete tests conducted to assess the self-compactability of the produced concrete. Moreover, compressive and splitting strength tests were carried out. The testing program had been extended to the age of 90 days.The use of super-absorbent polymer did not affect the fresh state characteristics of the studied SCC and achieved an increase in both compressive and tensile strengths as compared to the reference concrete mix.

1 Introduction

Okamura [1] defined Self-Compacting Concrete (SCC) as concrete that is able to flux in the interior of the formwork, flow in a natural manner and then pass through the reinforcing bars and other obstacles under the action of its own weight .In order to achieve the required flowability, high strength concrete and low water to cementitious materials ratio (w/cm), high-range water reducer (HRWR) admixtures are essential [2]. Self-desiccation will arise with mixtures having low water-cementitious materials ratios (w/cm) [3].The aim of internal curing is to prevent self-desiccation and the accompanying autogenous stresses and strains that may lead to early age cracking by maintaining saturated conditions within a hydrated cement paste

The efficiency of internal curing, preserve saturated conditions within a hydrating cement paste in order to avoid self-desiccation and the accompanying autogenous stresses and strains that may lead to early age cracking.

depending on the measurement of a wide sets of performance properties like restrained shrinkage internal relative humidity, restrained shrinkage and creep, degree of hydration, and compressive strength development ,the efficiency has been estimated for the internal curing for example by using saturated lightweight aggregates (LWA) or super-absorbent polymers (SAP) [4-7].

Super-absorbent polymers (SAP) are generally white sugar-like hygroscopic materials also SAP are hydrophilic networks that can absorb and retain large amounts of water or aqueous solutions. [8]. Super-absorbent polymers made from partially neutralized, lightly cross-linked poly (acrylic acid) are proved to give the best performance versus cost ratio. Dried polymers are milled in to granular white solids while in water they swell to a rubbery gel that in some cases can be up to 99% water. These polymers are manufactured at low solids levels for both quality and economic reasons [9]. Very efficient internal water curing can be ensured by using SAP, which is defined as "incorporation of a curing agent serving as an internal reservoir of water, gradually releasing it as the concrete dries out [10]. From a strength point of view, there are two opposite effects for the addition of SAPs to concrete, first it generates voids in the concrete and thus reduces strength;second enhances the degree of hydration due to the internal water curing provided by the SAP and that way increases the strength. Water-cement ratio (w/c), the maturity of the concrete, and the amount of SAP addition determines which of these two effects is dominant depends on the water-cement ratio (w/c), the maturity of the concrete, and the amount of SAP addition. The total effect seems to be described well with existing models, such as the gel-space ratio concept. In particular, at a high w/c (more than 0.45), also there is very little effect on hydration through the addition of SAP which generally reduces compressive strength. At a low w/c (less than 0.45), SAP addition may increase the compressive strength [11].

2 Material and Experimental work

2.1 Materials

Cement: In all types of concrete mixes Portland cement conforming to IQS No. 5/1984- type I [12], was used . Tables 1and 2 show the chemical and physical properties of the cement

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Table 1. Chemical properties of cement

Compound composition	Abbre-viation	Percent by weight	Limit of IQS No.5/1984
Lime	CaO	62.02	-
Silica	SiO_2	21.13	-
Alumina	Al_2O_3	5.33	-
Iron oxide	Fe_2O_3	3.07	-
Magnesia	MgO	1.71	≤ 2.85%
Sulfate	SO_3	2.65	≤ 5%
Loss on ignition	L.O.I	4	≤ 4%
Insoluble residue	I.R	1.04	≤ 1.5
Lime saturation factor	L.S.F	0.88	0.66-1.02
Main compounds % by weight			
Compounds	Abbreviation	Percent by weight	
Tri calcium silicate	C_3S	44	
Di calcium silicate	C_2S	27.6	
Tri calcium laminate	C_3A	8.9	
Tetra calcium alumino ferrite	C_4AF	9.3	

Table 2. Physical properties of cement

Physical properties	**Limits of cement**	**Limits of IQS No. 5/1984**
Fineness m2/kg	340.2	≥ 230
Initial setting time (h:min)	1:40	≥ 00:45
Final setting time (h:min)	4:15	≤ 10:00
Compressive strength(Mpa)		
3 days	33	≥ 15
7 days	39	≥ 23

Table 3. Gradation of fine aggregate

Sieve size (mm)	**Percentage passing %**	**Limit of IQS No.45/1980, zone(2)**
10	100	100
4.75	90	90-100
2.36	74.5	75-90
1.18	63	55-90
0.6	44.4	35-55
0.3	14.8	8-30
0.15	3	0-10
Sulfite % (SO3)	0.047	≤ 0.5%

Table 4. Gradation of coarse aggregate

Sieve size(mm)	**Percentage passing %**	**Limit of Iraqi specification NO. (45/1984)**
20	100	100
10	37	30-60
5	2.8	0-10
Sulfite content	0.07	≥0.1%

Fine aggregate: Natural sand conforming to IQS No.45/1984- Zone 2 was used [13]. Table (3) shows the gradation of the used sand and its main properties.

Coarse aggregate: 20 mm maximum size of crushed river gravel was used, conforming to Iraqi specification to IQS No.45/1984 [13], and was shown in Table (4).

Silica fume: Silica fume (exported from Elkem material company) is a highly reactive material used in this research as Pozzolanic materials to produce SCC. Silica fume conforms to the ASTM 1240 [14]. Physical and chemical properties for this by-product are listed in Table 5and 6.

Limestone powder (LSP): Limestone powder (locally known as Al-Gubra). It has been used as filler for concrete production for many years. It was added as 9 % replacement by weight of cementitious materials to enhance the workability of SCC mixes. Chemical properties for this material are listed in Table 7.

High Range Water Reducing Admixture:

Superplasticizer known commercially as (BETONAC®-1030) was used. It conforms to the ASTM C 494- type G. SCC (self-compacting/ consolidating) concrete was produced by designing high efficiency acrylic copolymer-based superplasticizer, with extremely high levels of workability without segregation. The SP content in the concrete mixes was 8.750 Kg/m3. Its properties (as claimed by the manufacturer) are listed in Table 8.

Crushed Brick: Pieces of clay bricks, conforming to IQS No.25/1984-Class B [15], was used. The water absorption for this brick was about 21.16%.The brick was crushed and graded as the grading curve of sand (Zone 2). It was used by two percentages (15 and 20) % as a partial volumetric replacement of sand. Before using the crushed brick in the mix, it was soaked in water for (24) hours to bring the particles to saturated condition.

Super-absorbent Polymer, SAP: Commercial SAP, white sugar-like was used. It is described as an ionic polyacrylamide and used efficiently in agriculture to reduce watering intervals. SAPs has the ability to gain and preserve aqueous solutions up to several hundred times of its own weight as can be seen in Figure 1. It was added (0.5%) by weight of cement. The dry particle of SAP carefully mixed with sand before adding the mixing water.

Table 5. Physical and Chemical Properties of Silica Fume

Compound composition	**Percent by weight**	**Limit of ASTM C1240**
Loss on ignition	2.14	≤6
SiO_2	93.47	≥85
Al_2O_3	2.15	
Fe_2O_3	0.65	
SO_3	Nil	
Total	99.79	

Table 6. Physical properties of Silica Fume

Physical properties	**results**	**Requirement of ASTM C1240**
Retaining on sieve 45μm,%	6	≤10
strength activity index	125	≥105

Table 7. Chemical Properties of LSP

Compound composition	Percent by weight
Loss on ignition	43
SiO_2	1.83
Al_2O_3 and Fe_2O_3	0.63
SO_3	0.2
MgO	0.58
CaO	53.71

Table 8. Properties of HRWR

Chemical content	Polycarboxylate based
Color, appearance	transparence
pH	7.5 at 20◦c
Density	1.108 g/ml

Fig. 1. (**a**) Dry SAP powder and (**b**) swollen SAP.

3 Concrete Mix Proportions

For the production of SCC, the mix proportioning should be performed so that the predefined properties of the fresh concrete are reached. The total powder content was 500kg/m^3, consisting of cement 405kg/m^3, silica fume 50kg/m^{3}and limestone powder 45kg/m^3. The fine and coarse aggregate contents were (880 and 900) kg/m^3 respectively. Water content was 172 kg/m^3 for reference mix (R) and for mixes containing crushed brick (B 15 and B 20%). Meanwhile the mix containing 0.5% SAP had 173 kg/m^3 of water. According to these proportions, the reference mix yielded 60 MPa compressive strength at 28 days. The concrete was mixed using a drum mixer of 50 L capacity. Mixing procedure followed the laboratory procedure outlined by Emborg [16] as follows: Fine aggregate was added to the mixer with 1/3 of water and mixed for 1-minute following that, the powder mixture of cement, limestone and Silica fume was added. After that, the coarse aggregate was added with the last 1/3mixing water and 1/3 of superplasticizer, and mixing for 1.5 minutes; then, the remaining 2/3 of the superplasticizer was added and mixed for 1.5 minutes; the mixture was then discharged and cast in moulds.

Curing Procedures

After the demoulding of specimens, three methods of curing were used. The first one was by immersing specimens in tap water until the time of testing (water-cured). The second method was by curing the specimens in water for 7 days and then the specimens were put in a wetted burlap bags and all covered with plastic sheet (moist-cured). The last method was by curing the specimens in water for 7 days and then left in laboratory conditions (air-cured).

4 Experimental Program

The fresh SCC tests include; the slump flow, L-box. The tests were conducted according to the standard methods cited by international literature [17] and the results were recorded.

Tests for hardened concrete were; compressive strength B.S 1881: Part 116 [18], splitting tensile strength (ASTM C496) [19] and ultrasonic pulse velocity (ASTM C597) [20]. The compressive strength test was done cubes at 7, 28 and 90 days curing age. The splitting strength and UPV tests were done on cylinders at the age of 90 days.

5 Results and Discussion

5.1 Fresh SCC

Desired fresh properties of SCC include suitable flowability, good passing and filling abilities, isolation resistance and stability, which are achieved by properly proportioning the constituent materials and related admixtures. Table 9 shows the results of fresh SCC tests. The tested concrete has proven itself to have self-compactability.

Table 9. Fresh Tests results for all fresh mixes.

Mix	Details of replacement	Slump flow		L – Box H1/ H2
		D(mm)	T_{500}(sec)	
Ref	No replacement	650	5	1
B15%	15 % brick by wt of sand	705	4.5	1
B20%	20% brick by wt. of sand	700	3.5	1
SAP0.5%	0.5 % SAP by wt. of cement	700	4.5	1

Fig. 2. (a) **Slump flow** (b) **L – Box**

Table 10. Compressive strength results

Mix Description	Curing method	Compressive strength, N/mm²		
		7 days	28 days	90 days
Ref	Water cured	34	60	66
	Moist cured	-	58	67
	Air cured	-	62	64
B15%	Water cured	33.4	55	63
	Moist cured	-	56	68
	Air cured	-	59	64
B20%	Water cured	31	58.2	65
	Moist cured	-	60.7	69.2
	Air cured	-	62	69
SAP0.5%	Water cured	35.4	59	69
	Moist cured	-	61	71
	Air cured	-	66	73

5.2 Hardened SCC

There is continuous increase in strength for all concrete specimens with the increasing of curing age as can be seen in Table 10, which is attributed to the increase of the bond strength between the concrete ingredients and the continuous hydration process which increased the dense hydrated calcium silicate in concrete with increased curing age.

Results also showed that the compressive strength of SCC increased by curing with water or moisture, however using internal curing enhancing this increment especially at later ages.

For water-cured specimens, the Ref mix always showed higher strength except the case of mix SAP.5% at 90 days curing age.The change in compressive strength at 28 days is -8, -3, and -2 for mixes B15%, B20% and SAP.5% respectively. This change for 90 days is -5, -2 and +4 % for mixes B15%, B20% and SAP.5%.

For moist and air curing procedures, the mixes B20% and SAP.5% showed their best enhancement for compressive strength. There were increments in strength for 28 and 90 days. At 28 days the change in strength is +5 and +5 % for moist-curing and is 0 and +7% for air-curing for mixes B20% and SAP.5% respectively. At 90 days these figures change to +3 and +6% for moist-curing and +8 and +14% for air-curing for mixes B20% and SAP.5% respectively. It could be concluded that when there is a lack in curing water the internal curing by SAP is the best solution for this problem.

The improvement of the interfacial transition zone, raise hydration because of internal curing, and absence of shrinkage-induced microcracking will enhanced in strength. During mixing a 0.5% SAP addition permits an active control of geometric and thermodynamic properties of the water phase. The water is free in the formed SAP inclusions , and the initially added SAP particles governed the size and shape of the inclusions [21].The moisture can be seen clearly in SAP-concrete at early ages of curing (7days-broken cube), Figure 4.

Results of splitting tests of air-cured SCC showed the importance of using internal curing. The splitting strength increased by about 14%, 47% and 40% in B15%, B20% and SAP0.5%, respectively as compared to the reference mix. An enhancement was also observed in the Ultrasonic Pulse Velocity test and modulus of elasticity due to the high density of internally cured SCC concrete mixes.

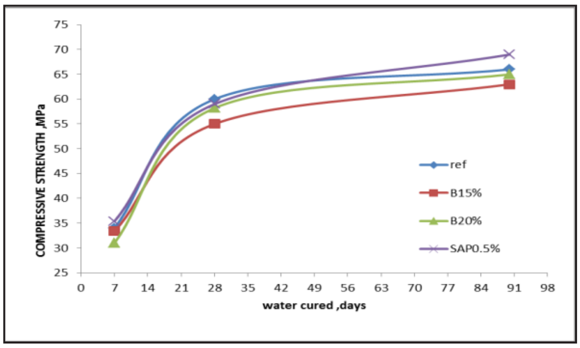

Fig.3. Compressive strength for all concrete mixes cured by water

Fig. 4. Moisture in concrete due to SAP additio**n**

Table 11. Splitting Strength, UPV, Density and Modulus of Elastisity

Concrete Mixes	Splitting strength (MPa) 90 days	Ultrasonic Pulse Velocity 90 days	Density kg/m3	Modulus of elasticity GPa
Ref	2.5	4.47	2358.7	47.13
B15%	2.86	4.37	2368.4	45.229
B20%	3.69	4.545	2334.5	48.223
SAP0.5%	3.5	4.545	2361.4	48.779

6 Conclusions

Based on the obtained results, the followings conclusions can be drawn:

1. Saturated Crushed brick has no adverse effect on self-compactability tests of fresh SCC. SAP concrete needed a small addition of water due to high water absorption capacity of the SAP.
2. The replacement of fine aggregate by 20% crushed brick as internal curing material caused better enhancement in mechanical properties (strengths) of SCC than the case of 15% replacement.
3. The compressive strength of HPC containing 0.5% SAP yielded higher strength than HPC mixtures with or without saturated crushed brick.
4. Increments in splitting strength by about (14 and 47) % were achieved due to adopting internal curing by 15% and 20% of crushed brick and 40% in SAP concrete.
5. Application of internal curing, results in higher ultrasonic pulse velocity values and density when compared with the normally cured concrete.
6. The most important benefit of using SAP as an internal curing is when the concrete is produced in hot weather; an increase in compressive strength by about 14% was achieved due to the application of internal curing by SAP for concrete left in air.

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