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Investigation of Performance of concrete under water

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ABSTRACT: Many construction sites are found to pour concrete in aqua media especially in raft foundations, and marine projects docks and piers. Many of these applications of underwater concreting suffered from deterioration due to the poor quality of the placed concrete and to lack of controlled in placement. The ongoing concept is that in aqua media it is favourable to use dry mixes and the cement will satisfy its demands from the surrounding media.

In this testing program, we were trying to monitor the performance of various concrete mixes visually through dropping of concrete in a transparent fiber tube filled with water. We were also trying to investigate the effect of pouring height, type of aggregates and different w/c on the physical and mechanical properties of concrete cast under water and document the degree of deterioration at different circumstances.

Introduction: When devising a technique of placing concrete under water, the quality of the concrete must be ensured. The first consideration must be to avoid segregation of the mix; the simplest remedy for this is not to drop the concrete through the water. *Malhotra el al. (2008).*Techniques such as termite and pumping are based on the principle of piping the concrete through the water and thus eliminating mixing with the water and segregation. Over the past few years, additives have been developed to prevent the segregation of concrete, which has given greater freedom in the development of placing techniques. *Gareth et al. (2000). Kamal et al. (2001). Michael et al. (2008).*

The concrete/water interface is a zone of contaminated, weak material and therefore of no structural value. *Scott et al (1995), Sonebi & Khayat (2001). Robinson & Basheer (2008).*If this weakened material becomes entrained into the heart of the pour, weakening of the structure will occur. The aim, when placing concrete under water is to minimize the surface area of concrete in direct contact with the water, and to avoid agitation of the exposed surface. Consequently, the ideal method of placing concrete would be to inject the fresh concrete into the heart of the concrete already deposited, which would leave the weakened outer layer as a skin over the pour. Unfortunately this is not the case in many underdeveloped countries, where drum mixers are used instead. The concrete must be of sufficient workability to allow the pressure of the added concrete to cause displacement of the placed concrete. It is not practical, or advisable, to use compaction equipment, such as vibrators, under water. The agitation caused by compaction and screening may cause the inclusion of water and layers of detritus into the body of the mix. It is, therefore, of importance to use a concrete that has a workability to allow self-compaction and, if possible, be self-leveling. Great care must be taken when working under conditions where high water velocities are found, as cement and fines will be removed from the surface of the pour.

Testing program:

The first phase in the testing program focused on monitoring the flow rate of the various components of concrete individually. The procedure depends on dropping Coarse aggregate and fine aggregate and cement in a transparent fiber glass tube 2.25 meters in height and 10 cm in diameter and monitoring the flow rate for each component with an accuracy of 0.01 seconds. The second phase focused on investigation of the effect of the pouring height (,0 cm from the surface of water (Aqua), 30cm(Aqua). Results were compared with reference specimens cast in (Air),also the effect of w/c (0.6-0.65-0.7) was considered. See Fig (1and 2). Types of aggregates were also considered in this study (crushed stone & natural gravel). A total of 72 cubes standard concrete specimens (150*150*150) mm and 72 standard beams (100*100*500) were cast in various conditions. A polypropylene fiber container with a height of 1.2 meter and a diameter of 1.00 meter was used to simulate casting in site. Fig (3- 4) shows the process of pouring concrete. After 24 hours the specimens were placed in basins filled with fresh water for curing. Concrete specimens were left for testing after 7 and 28 days for their compressive and flexure strength characteristics. Each sub-group was tested for its slump value and then weighed individually in a saturated condition, wet surface dry condition to determine the absorption capacity. Also ultrasonic and Schmidt hammer tests were performed on the concrete specimens before they were tested for their compressive and flexural strength. (See Table 1).

Table 1 phase one with w/c=0.6, 0.65 and 0.7

Group	Type of Aggregate	W/C	Water Level cm	Cement Kg/m^3	F.Agg Kg/m^3	C.Agg Kg/m^3
Gn (1-1)	Natural	0.6	Air	350	650	1200
Gn (1-2)	Natural	0.6	0	350	650	1200
Gn (1-3)	Natural	0.6	30	350	650	1200
Gn(1-4)	Natural	0.65	Air	350	650	1200
Gn(1- 5)	Natural	0.65	0	350	650	1200
Gn(1- 6)	Natural	0.65	30	350	650	1200
Gn (1-7)	Natural	0,7	Air	350	650	1200
Gn (1-8)	Natural	0.7	0	350	650	1200
Gn(1- 9)	Natural	0.7	30	350	650	1200
Gc(2-1)	Crushed	0.6	Air	350	650	1200
Gc(2-2)	Crushed	0.6	0	350	650	1200
Gc(2-3)	Crushed	0.6	30	350	650	1200
Gc(2-4)	Crushed	0.65	Air	350	650	1200
Gc(2-5)	Crushed	0.65	0	350	650	1200
Gc(2-6)	Crushed	0.65	30	350	650	1200
Gc(2-7)	Crushed	0,7	Air	350	650	1200
Gc(2-8)	Crushed	0.7	0	350	650	1200
Gc(2-9)	Crushed	0.7	30	350	650	1200

Fig 1 Test Setup showing test tube filled with water and sedimentation process of cement paste (Phase I)

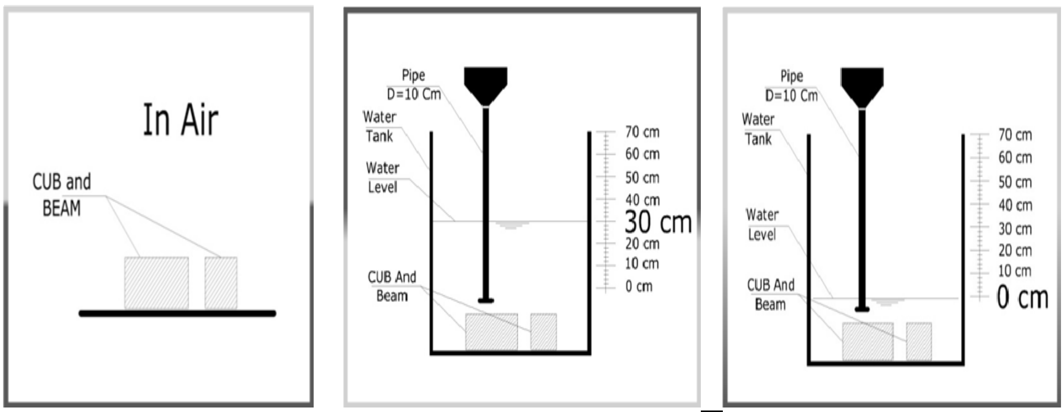

Fig 2 A Schematic Diagram showing method of casting concrete. Phase 2

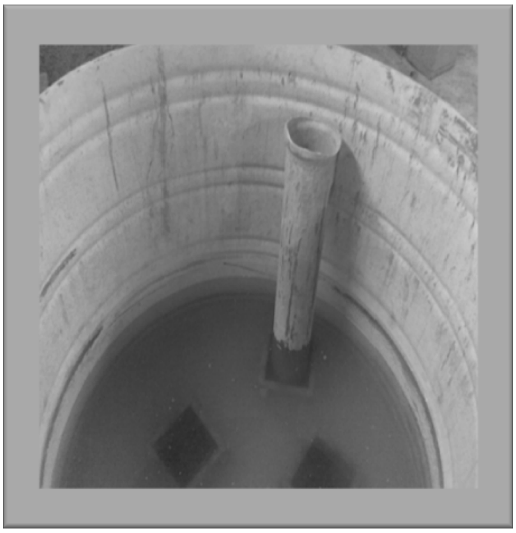

Fig 3 Method of casting Concrete

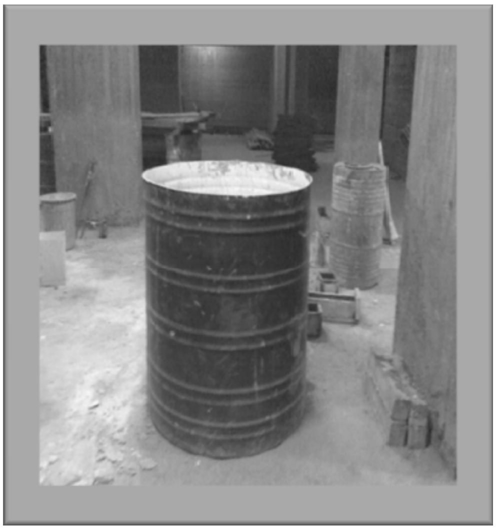

Fig 4 Container for Casting Concrete

Results and Discussion

In what follows a review of the flow rate results, slump test, density, compressive and flexural strength results, ultra-sonic pulse velocity, and Schmidt hammer results, discussed in detail.

Phase I Performance of concrete componenets under water:

Table 2 Sample Flow Rate in water

Retained on Seive Size	Sample 1 Flow Rate in m/sec.	Sample 2 Flow Rate m/sec.	Sample 3Flow Rate in m/sec.	Sample 4 Flow Rate in m/sec.	Average Rate in m/sec.
3.375	1.14	1.39	1.24	1.58	1.337
2.5	1.59	1.66	1.455	1.415	1.53
1.9	1.78	1.49	1.54	1.75	1.64
1.3	1.865	1.905	1.94	1.9	1.9
1.0	2.62	2.24	2.42	2.335	2.4
0.9	2.905	2.94	2.63	2.38	2.714
0.475	3.115	2.435	3.1	2.965	2.904
0.236	3.82	3.62	3.395	2.925	3.44
0.118	4.44	4.965	4.79	5.04	4.808
0.06	6.62	6.56	6.72	7.09	6.747
Passing from 0.06	9.38	9.585	9.36	9.925	9.56

It was noted that the smaller the particle size, the slower the rate of descend of the particle, which indicates the natural tendency of water to separate the components of concrete. This lead us to believe that, concrete components in dry concrete mixes tend to separate from each other in aqua media very easily and after a very short time. Wet concrete mixes tend to maintain cohesiveness for longer duration which in turn reflects on better compressive and flexural strength characteristics. See Table (2).

The slump test results

The slump test was performed within 2-3 minutes after mixing the concrete. All specimens were tested under the same environmental conditions. The general trend indicates that, for all groups as the w/c ratio increases the slump value increases. This is attributed to the fact that as w/c ratio increases; more water is available in the concrete mix to achieve better workability which reflects directly on the slump value. It was also noted that, natural aggregate results is higher slump value compared to crushed stone. This may be attributed to the fact that the small and smooth surface of the natural aggregate play a very important role in improving the workability of concrete. Meanwhile the sharp edges in the crushed stone interlock with each other resulting in poor workability and lower levels of slump value. Except in groups with w/c 0.7, where the quantity of water eliminates the interlock effect in crushed stone. In that case, the slump values for natural aggregate and crushed stone reach the same level. See fig (5).

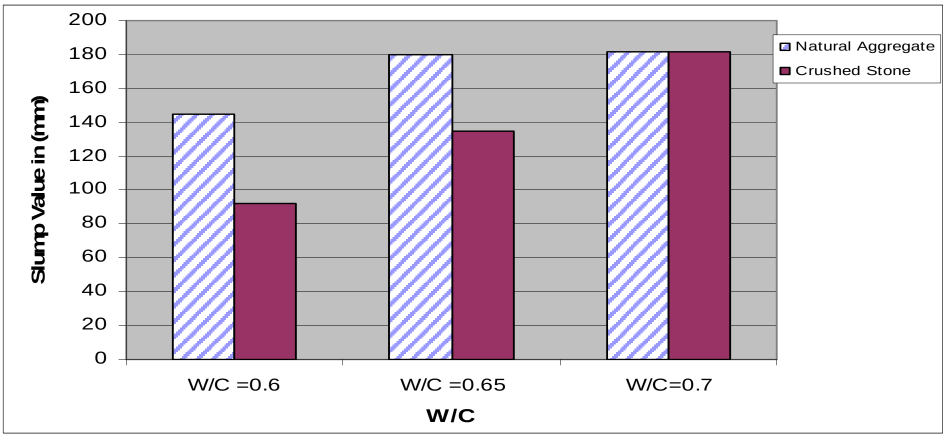

Fig 5 Average Slump Value for Natural Agg. And Crushed Stone

Density of cubes

Natural gravel

The general trend indicates that as the w/c ratio increases the bulk density shows slight decrease in density; that was for specimens cast in air. It was also noted that specimens cast in air gave higher density than specimens cast in water. It should be noted that specimens with w/c 0.6 cast in water, gave the weakest results regarding the bulk density; meanwhile specimens with w/c ratio 0.65 gave the highest values for bulk density. See Table (3). This indicates that, harsh specimens with low w/c ratio tend to flocculate and engulf large quantities of water resulting in large amount of voids in concrete, which lead to very low density. The wet concrete mix tends to make the concrete more cohesive and compact; when it is submerged in water it tends to maintain that level of cohesion minimizing the amount of water that could penetrate the concrete mix during casting. Meanwhile for subgroups with water cement ratio w/c 0.7, the mix itself includes higher quantities of water resulted in lower bulk density, and lower Cohesiveness compared to specimens with w/c 0.65.

Crushed stone

The same trend observed in natural aggregate was noted in crushed stone specimens. And it was noted that crushed stone gave lower density values, compared to natural aggregate. That was attributed to sharp edges in crushed stone which led to interlock with each other resulting in harsh specimens, this further enhances reduction in workability, resulting in large amount of voids in concrete which lead to lower density values. It was noted that the performance of specimens of w/c ratio 0.6 that was submerged in water was very close to the performance of specimens with w/c ratio 0.7, having low density compared to specimens with w/c 0.65. For specimens with w/c ratio 0.6 the case of low density took place due to segregation of concrete components which by the way was more evident in crushed stone than natural aggregate. For specimens with w/c ratio 0.7, low density was observed due to higher water content compared to specimens with w/c 0.65. See Table (3).

Table 3 Average cube weight for Natural gravel and Crushed Stone

Spec. Code	W/C	Water Level	Avg.Cube wt.(S.S.D) Natural Gravel (Kg)	Avg.Cube wt.(Bulk) Natural Gravel (Kg)	Specimen code	Avg.Cube wt.(S.S.D) Crushed Stone (Kg)	Avg.Cube wt.(Bulk) Crushed Stone (Kg)
Gn (1-1)	0.6	Air	8.246	7.676	Gc(2-1)	7.980	7.568
Gn (1-2)	0.6	0	7.920	7.450	Gc(2-2)	7.510	7.235
Gn (1-3)	0.6	30	7.690	7.223	Gc(2-3)	7.1	6.775
Gn(1-4)	0.65	Air	8.203	7.600	Gc(2-4)	8.106	7.834
Gn(1- 5)	0.65	0	8.003	7.290	Gc(2-5)	7.820	7.468
Gn(1- 6)	0.65	30	7.923	7.090	Gc(2-6)	7.600	7.200
Gn (1-7)	0,7	Air	7.953	7.470	Gc(2-7)	7.723	7.513
Gn (1-8)	0.7	0	7.813	7.250	Gc(2-8)	7.453	7.288
Gn(1- 9)	0.7	30	7.653	7.050	Gc(2-9)	7.203	6.966

Compressive strength of cube after 7 and 28 days:

Natural gravel: The general trend indicates that, for all groups specimens cast in air gave the highest compressive strength values compared to the specimens cast in water at level 0 cm and level 30 cm. Segregation, and up lift force of water, reduced compaction. Also separation of cement in water occurred while pouring concrete in water. See Fig (6 and 7). For specimens cast in water it was noted that specimens with w/c 0.65 gave the highest compressive strength values compared to specimens with w/c 0.6 and 0.7after 28days

Crushed stone: The same trend observed in natural aggregate was noted in crushed stone. And it was also noted that specimens with w/c ratio 0.6 gave the weakest values compared to specimens with w/c ratio 0.65 which gave the highest values. For all groups it was observed that as the height of pouring concrete increases compressive strength decreases. For all groups it was noted that specimens cast in air gave better results by 49% to 63% for natural aggregate and gave better results by 52% to 67% in crushed stone after 28 days.

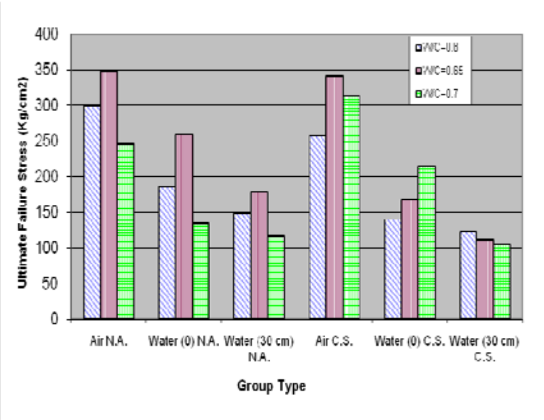

Fig 6 Compressive strength of after 7 days

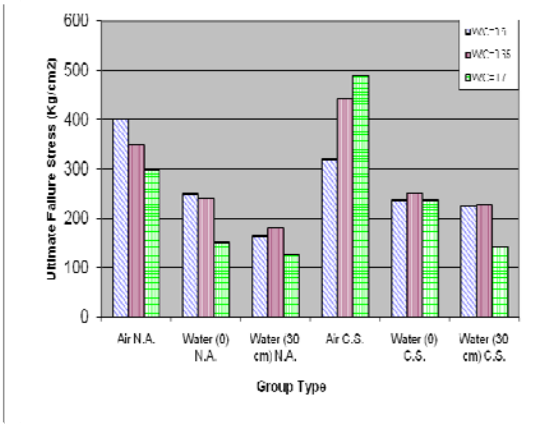

Fig 7 Compressive strength after 28 days

Flexural strength Results: In case of natural aggregate and crushed stone: The general trend in natural aggregate and crushed stone indicates that the specimens cast in air gave the highest flexure values compared to specimens cast in water at level 0 and level 30 cm. It was observed that as the level of pouring concrete increase flexure strength decreases. For all groups it was noted that specimens cast in air gave better results by 47% to 71% for Natural Aggregate and gave better results by 49% to 62% in Crushed Stone after 28 days. See fig (8).

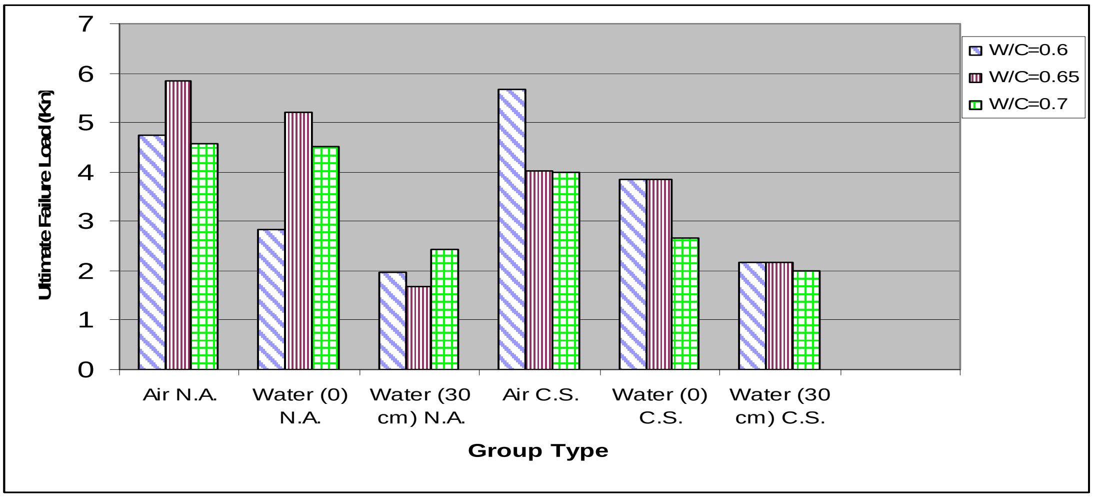

Fig 8 Flexure strength of beams after 28days

Ultra-sonic test: In case of natural aggregate and crushed stone: It was observed that as the voids in concrete increase ultrasonic phase time increases. Specimens cast in air with highest compressive strength gave short time in micro second (high velocity). This was observed in all groups in natural aggregate and crushed stone and this is in agreement with compressive strength. For all groups it was noted that specimens cast in air gave better results by 5.3% to 7.9% for natural aggregate and gave shorter time (high velocity) results by 6.5% to 7% in case of crushed stone. See Fig (9)

Schmidt hammer : In case of natural aggregate and crushed stone: It was observed that specimens cast in air gave highest rebound values followed by specimens cast at level 0 than specimens cast at level 30 cm. For all groups it was noted that specimens cast in air gave better results by 16% to 29% for natural aggregate and gave better results by 27.6% to 39.6% in Crushed Stone. (See Fig 10).

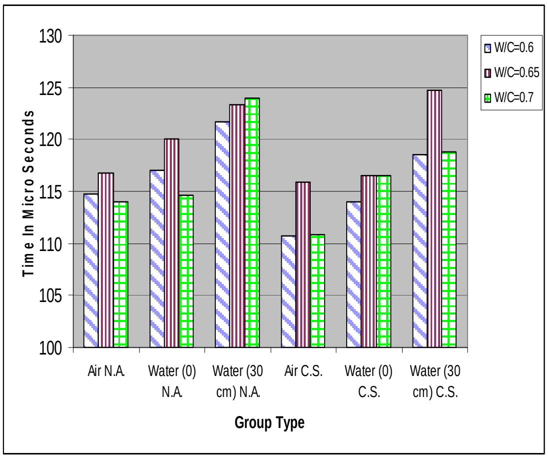

Fig 9 Ultrasonic Pulse velocity for natural aggregate and crushed stone

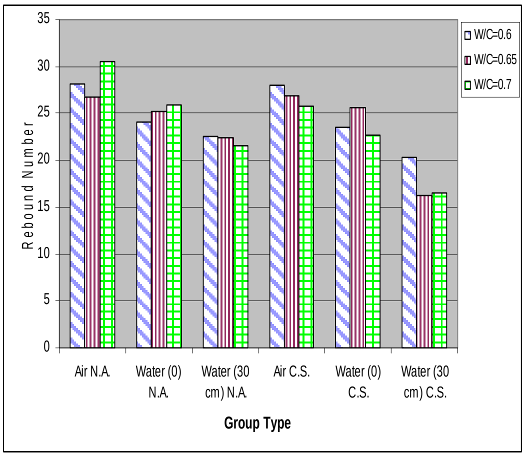

Fig 10 Schmidt hammer results for natural aggregate and crushed stone

CONCLUSIONS: In this study we reviewed the main points, concluded from the experimental testing on the physical and mechanical properties of concrete cast in air and submerged in water.

1-For natural aggregate and crushed stone, it was observed that as w/c ratio increases the slump value increases, although natural aggregate gave higher results compared to crushed stone.

2-It was observed that specimens with w/c ratio 0.65 gave the highest density compared to specimens with w/c ratio 0.6 and 0.7, that was clear in specimens with crushed stone.

3-Specimens cast in air gave better results regarding compressive strength after 28 days, by 49% to 63% for natural aggregate. They also gave better results by 52% to 67% in Crushed Stone, compared to specimens cast in water.

4-It was also observed that drop height of concrete, as well as type of aggregate, play a very important factor on compressive strength.

5- Contrary to on going beliefs dry mixes in water enhance deterioration of concrete.

6-Flexure for specimens cast in air gave better results than flexure specimens cast in water.

7-Ultrasonic pulse velocity and Schmidt hammer shows compatibility with results obtained from compressive strength

Recommendations: It is recommended that further investigations using the same technique of casting with set accelerators and self compacting concrete may be of interest. It is also recommended to mix concrete & delay casting for 15 minutes to achieve better cohesiveness.

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