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EFFECT OF HYDROSTATIC WATER PRESSURE ON PERFORMANCE OF SELF-COMPACTING CONCRETE PLACED UNDERWATER

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ABSTRACT

This study has focused on investigation of effect of hydrostatic pressure on the properties of underwater self-compacting concrete. In this research, 30 mixes of self-compacting concrete have been prepared with six groups. The first three groups contain AWA (Anti Washot Admixture), while the second groups made without AWA. The main parameters explored in this research were: silica fume, limestone powder and rice husk ash as a cement replacement content with 0% and 1% anti washout admixture and different water depth (10 ,20, 30 ,40 and 50 m). Washout loss was found by using either the CRD C61 test method or a newly developed device for simulation of increased hydrostatic pressure on the concrete/water interface. Good correlations were investigating between the standard washout loss determined according to CRD C61 and simulated threshold water head and corresponding maximum washout loss.

KEYWORDS

Hydrostatic pressure; Washout loss; Compressive strength; Antiwashout; Undwater concrete

1. INTRODUCTION

Underwater concrete (UWC) is kind of high performance concrete that used since of the beginning of last century and until now and used in constructions under water especially in foundations of bridges, the high performance concrete is widely used in high loaded members and for more durable structures and also in structures that subjected to severe conditions. Recently when concrete structures in harbors, bridges, and marine constructions have become larger in use, needing of anti washout underwater concretes to achieve correct underwater placement has become greater. The major requirements for the anti washout underwater concretes are anti washout or segregation resistance, flow ability, self-leveling ability, and bleeding control. The anti washout underwater concretes are produced by the addition of anti washout polymeric admixtures. Anti washout. Because of the excellent resistance of underwater concrete, it can be used under both salty and fresh water. Decrease of the strength of UWC can be attributed by several factors such as wash out of the cement paste particles by the water, the grow of water–binder ratio, aggregate segregation during the cast of concrete, hydrostatic pressure of water, erosion of concrete surfaces and insufficient consolidation of the components. Small number of investigations on the influence of hydrostatic pressure on UWC properties are caused by the necessity of construction of the special testing stands. They are, generally, pressure tanks of special structure, enabling investigation on very small samples of concrete or mortar. Several methods of test are used for the ‘evaluation of washout loss of UWC are available in the literature (Hughes, 1961; Khayat, 1991; Yurugi et al., 1995). The most commonly used test is CRD C61 (US ACE, 1989). This research project was undertaken to evaluate the effect of increased hydrostatic pressure and mixture parameters on washout loss and residual compressive strength of UWC. Washout loss was determined using either the CRD C61 test method or a special air pressurised tube that can simulate deep placements down to 50 m below the water surface. As well as seek to establish a relationship between washout loss and residual compressive strength determined using the same concrete samples that were used for measuring washout loss.

2. EXPERIMENTAL PROGRAM

2.1. Experimental Program

Cement: a sulphate resistance cement (type v) has been used. The results of the test demonstrate that the used cement fulfills the Iraqi requirements (IQS No.5/ 1984). The specific gravity and fineness are 2.96, and 3100 cm^2/gm, respectively.

Fine Aggregate: it has been brought from Al- Najaf region as natural sand to be used in all mixes in this study. The specific gravity of fine aggregate was 2.56; the absorption was 1.5%, and the fineness modulus was2.12 in this study.

Coarse Aggregate using irregular shape coarse aggregate with fineness modulus of 6.05. The coarse aggregate was having maximum size of 20 mm. The specific gravity was 2.61 in this research with absorption of 1%.

Anti washout admixtures (AWA): it is known as Flocrete which is a powder with brown color used as anti washout admixture for the underwater placement of concrete and grout.

Superplasticizer (SP): using polycarboxylated SP in this study free with density of 1.1 gram/cm3 and used as percentages of cement content.

Water: Tap water from Najaf water supply is used for both mixing and curing of concrete.

Silica fume (SF): a grey silica fume was used in this study that confirming ASTM requirements with specific gravity of 2.2.

Limestone Powder (LSP): based on ACI 237, the size of particles less than 0.125 mm was utilized to rise both of workability and density of the self-compacted concrete. The LSP sieve through a sieve No. 100 (125mm) and specific gravity is 2.25.

Rice Husk Ash (RHA): The Rice Hush Ash (RHA) used in this study was from Al – najaf city Farms in Iraq and burned in temperature of 550 centigrade and for two hours (Al-kadhi, 2002).

2.2. Mix proportion

The proportion of concrete mixes are summarized in Table 1. The self-compacting AWA concrete incorporated high contents of cementitious material to limit aggregate volume, hence enhancing flow characteristics in restricted area. For all the mixes, the water to binder ratio was constant. The concrete was designed according to ACI 237, 2007 guidelines.

As summarized in Table 2 and Table 3 six concrete test series were investigation in this study. The objective of the first three series test was the evaluation of wash out loss and residual strength of concrete mixtures made with 10% silica fume, 20% rice husk ash and 20% lime stone powder replacement by weight of cement materials without any addition of AWA, while the second three test series contain AWA at dosage 1% kg/100 kg of cement which represent high dosage to evaluate the effect of AWA on wash out and residual strength.

Table 1. Mix proportion of investigated concrete

Materials	10% SF	20% LSP	20% RHA
Cement (kg/m3)	427.5	380	380
Sand (kg/m3)	768	768	768
Gravel (kg/m3)	835	835	835
LSP (kg/m3)	__	95	__
Silica Fume (kg/m3)	47.5	__	__
Rice Husk Ash (kg/m3)	__	__	95
Water (kg/m3)	214	214	214
w/cm	0.45	0.45	0.45
AWA%	1	1	1
SP %	3	3	3

Table 2. Concrete mix designations for CRD C61 method.

Mix Symbol		
10% SF	20% RHA	20% LSP
M-S-AWA 0%	M-RHA-AWA 0%	M-L-AWA 0%
M-S-AWA 1.0%	M-RHA-AWA 1.0%	M-L-AWA1. 0%

Table 3. Concrete mix designations for pressurized Steel tube.

2.3. Mixing, casting, and curing of concrete

All samples were mixed in drum mixer. The mixing of concrete consists making both sand and coarse aggregate homogeneous, then introducing half of the mixing water followed by the cementitious materials. The remaining water, SP, and AWA were then introduced, and the concrete was mixed for 3 min. following 2 min of rest, the mixing was remixed for 2 additional minutes.

Mix Symbol			
10% SF	**20% RHA**	**20% LSP**	**Pressure head (bar)**
M1-S-AWA 0%	M11-RHA-AWA 0%	M21-L-AWA 0%	1
M2-S-AWA 0%	M12-RHA-AWA 0%	M22-L-AWA 0%	2
M3-S-AWA 0%	M13-RHA-AWA 0%	M23-L-AWA 0%	3
M4-S-AWA 0%	M14-RHA-AWA 0%	M24-L-AWA 0%	4
M5-S-AWA 0%	M15-RHA-AWA 0%	M25-L-AWA 0%	5
M6-S-AWA 1.0%	M16-RHA-AWA 1.0%	M26-L-AWA 1.0%	1
M7-S-AWA 1.0%	M17-RHA-AWA 1.0%	M27-L-AWA 1.0%	2
M8-S-AWA 1.0%	M18-RHA-AWA 1.0%	M28-L-AWA 1.0%	3
M9-S-AWA 1.0%	M19-RHA-AWA 1.0%	M29-L-AWA 1.0%	4
M10-S-AWA 1.0%	M20-RHA-AWA 1.0%	M30-L-AWA 1 .0%	5

All steel molds were prepared for mixing by putting oil along the interior surfaces of the mold to prevent adhesion with concrete after hardening. Immediately after measuring W3 (using the CRD C61) or W (using the pressurized tube), the fresh concrete sample was transferred to a clean container and covered by a wet burlap. Thus, another fresh sample of approximately 3 kg was taken from the same batch, subjected to similar W testing, and then stored in the same container again. This process was recurred four times to get a total mass of approximately 10 kg (taking into account the material lost because of washout), which was then rigorously mixed for the use in strength determination. It is important to notice that the time required to complete the four cycles of washout testing should not exceed 20 to 25 minutes, however; slump-flow loss thresholds were determined to be less than 25 or 40 mm (Assaad and Issa, 2011). The underwater strength was determined by casting concrete that determined immediately after wash out test into 100 x 100 mm cubes for compressive strength. These results were compared to strengths determined on specimens cast in air. The specimens were leaved in molds for 48 hrs then cured in water until the time of testing.

2.4. Testing procedure

Fresh state testing for concrete is part of this study and it is important to investigate the effect of dosage of AWA on the fresh properties of SCC. The first performance characteristics of SCC are filling ability, passing ability, stability and washout resistance. Many tests were used in this works such as slump flow test, J-ring test, column segregation test and finally washout test. Two test methods have been used to determine the resistance of freshly mixed concrete to washing out. The same specimens after washout test were tested during this experimental works to find the compressive strength of specimens cast in air and under water.

2.4.1. Slump flow test and T50 cm test

A sample of freshly mixed concrete is put in a slump mold in one lift and not consolidated by means of mechanical or commotion. The mold is left and the concrete is allowed to spread. After the concrete stops spreading, the average of two diameters measured perpendicular to each other of the resulting spread is reported as the slump flow of the concrete. In addition, the person performing the test measures the time it takes, in second T50, for any part of the outer edge of the concrete spread to reach a diameter of 500mm from the time of the mold is first lifted. The used apparatus and test procedure as described in the ACI 237, 2007.

2.4.2. J-ring test

Sample of fresh mix concrete is put in a slump mold that is concentric with the J-ring in one lift without tamping or vibration. The mold is raised and the concrete is then allowed to move through J-ring, which contains steel ring assembly consist reinforce bar and subside. The diameter of the concrete is measured in two directions approximately perpendicular to each other. The average of the two diameters is reported as the J-ring flow of the concrete, the difference between the slump flow and J-ring flow indicates the passing ability of the concrete. The used apparatus and test procedure as described in the ACI 237, 2007.

2.4.3. Column segregation test

Column segregation test evaluates the stability of the concrete mix by quantify the segregation of aggregates. This test consists of filling a 26 in (610mm) high column with concrete. The concrete is allowed to sit 15 minutes after placing it. Each section removed individually, the concrete from the top and bottom section is washed over a No.4 (4.75mm) sieve, and the retained aggregate is weighed. A non-segregation mixture will have consistent aggregate mass distribution between the top and bottom section. A segregation mixture will have a higher concentration of aggregate in the lower section. The used apparatus and test procedure as described in the ACI 237, 2007.

2.4.4. Washout test

CRD C61 method

This test is used for determine the ability of freshly mixed concrete to resistance washing out in water. According to US Army Corps of Engineering Standards (CRD-C 61-89A), the test composed of calculating the amount of cement paste lost of a fresh concrete sample after three drops through a determined column of water. A fresh concrete sample measuring 2,000 ± 20 g is placed in a perforated basket measuring 130 mm in diameter and 120 mm height. The basket is made of 1.4 mm thick sheet metal with 3 mm staggered holes, spaced 5 mm apart. Once the basket is filled with concrete, it is covered and tapped gently, then excess mortar is removed from the outside surface. The basket is fallen freely through a closed ended pipe filled with 1.7 m of clear water. After 15 secs at the bottom of the tube, the sample is retrieved in 5 secs and allowed to drain for 2 min before measuring its weight. The test is repeated three times for fluid concretes, and the calculated cumulative weight loss is reported as a percentage of the initial sample weight.

Washout, or loss of mass of the sample, expressed as a percentage of the initial mass of the sample is given by the following formula (CRD-C 61-89A):

$$D = (Mi - Mf)/ Mi \times 100 \qquad 1$$

Where:

D: washout, %.

Mi: mass of sample before initial test.

Mf: mass of sample after each test

Pressurized Steel Column Method

The second method is the pressurized air tube which used to determine washout resistance by simulation at different water heads. The testing procedure involved filling the column with water at 1m and dropping a fresh concrete sample in a perforated basket (similar to that used in CRD C61) to the bottom of the tube. The top cover was then tightly closed and an overhead air pressure introduced to simulate different water heads. Air pressure was monitored using dial gage of range (0-12) bar, as shown in Fig. 1.

Fig. 1. Pressurized steel column

The steps used to simulate washout of UWC were as follows:

1. Subjected a sample of around 4 kg to free-fall to the bottom of the tube.
2. After closing top cover of the tube to prevent air leakage during pressure application, apply air pressure gradually until reaching the desired water head.
3. Keeping the desired pressure applied for 1 min.
4. Opening the air valve to release the pressure, and measure washout loss W.

Immediately after measuring W3 (using CRD C61) or W (using the pressurized tube), the same fresh concrete sample was then homogenized manually and placed in (100 *100) mm cubes to determine the corresponding compressive strength after curing in water for 28 days.

3. RESULTS AND DISCUSSION

3.1. Results of slump flow

Slumps flow for Non AWA concrete s mixes are 700mm for mixes contain silica fume, 750 mm for mixes contain lime stone powder and 760mm for mixes contain rice husk ash, while slumps flow for AWA concrete mixes are 500 mm for mixes contain silica fume, 515 mm for mixes contain lime stone powder and 500mm for mixes contain rice husk ash.

As indicated in Table 4, by increasing of AWA dosage leads to decreasing slump flow due to cohesion increment of concrete and that lead to reduce the washout of the fine particles of cement and and fine particles of sand of the fresh concrete when it cast under water.

Using of AWA decreased the slump flow by 29.3%, 33.3% and 34.2 % for concrete mixes contain silica fume, lime stone powder and rice husk ash respectively.

The highest slump flow was obtained for concrete mixes contain lime stone powder. Lime stone powder gives more workability than silica fume by (6.67 - 2.9) % and more than rice husk ash by (12 - 2.9) % for mixes with (0 - 1%) AWA.

T50 values increased when used AWA. For example, when used 1% AWA T50 increased from (2.6, 2.1 and 2 sec) for non AWA concrete mixes to (45, 25 and 58 sec) for 1% AWA mixes contain silica fume, lime stone powder and rice husk ash, respectively.

Table 4. Results of slump flow tests.

Mix Symbol	S. Flow, mm	T50, sec
M1-S-AWA 0%	700	2.6
M2-S-AWA 1%	500	46
M3-LSP-AWA 0%	750	2.1
M4-LSP-AWA 1.0%	515	25
M5-RHA-AWA 0%	660	2
M6-RHA-AWA 1%	500	58

3.2. J-Ring results

The J-ring test was used in this study to assess the passing ability of the mixes. According to (ACI 237, 2007), the difference between the slump flow and J-ring flow gives an indication to the degree to which the passing of SCC through the reinforced bars is limited. So the difference of less than or equal to 50mm represents good passing ability. The test results are summarized in Table 5.

The increasing AWA concentration from 0 to 1.0% reduced j-ring flow from 650 to 500mm,705 to 515 and from 610 to 495 for concrete mixes made with silica fume, lime stone powder and rice husk ash respectively with 3 l / 100 kg of cementitious material.

3.3. Column segregation test

Column segregation test is used for knowing stability of the concrete mix by finding quantity of aggregates that segregate when it cast in deep water using high fluid concrete. S represented the values of the segregation of the concrete mixes in the study.

As indicated in Table 6, result demonstrates that coalition of an AWA reduces the segregation. of the mixes of concrete made with silica fume, limestone powder and rice husk ash, the segregation resistance results varied between 8.5% and 0, 13.5% to 0 and 9.8% to 0, respectively.

Table 5. Results of J-Ring tests

Mix Symbol	J-ring, mm	Difference, mm
M1-S-AWA 0%	650	50
M2-S-AWA 1%	500	0
M3-LSP-AWA 0%	705	45
M4-LSP-AWA 1.0%	515	0
M5-RHA-AWA 0%	610	45
M6-RHA-AWA 1%	495	5

Table 6. Results of column segregation test

Mix Symbol	Segregation (%)
M1-S-AWA 0%	8.5
M2-S-AWA 1%	0.0
M3-LSP-AWA 0%	13.5
M4-LSP-AWA 1.0%	0.0
M5-RHA-AWA 0%	9.8
M6-RHA-AWA 1%	0.0

3.4. Results of Washout Mass Loss Test

Washout test issued for calculating the resistance of fresh mixes of concrete to washing out in water. As shown in Table 7 and Table 8, W3 represented the values of standard washout mass loss confirm to CRD C61 for underwater concrete while W represented the washout mass loss determined by pressurized air tube.

Table 7. Results of the washout mass loss test determined by CRD C61

Mix Symbol	Weight Loss (W3%)
M1-S-AWA 0%	18.9
M2-S-AWA 1%	8.20
M3-LSP-AWA 0%	32.8
M4-LSP-AWA 1.0%	10.0
M5-RHA-AWA 0%	39.0
M6-RHA-AWA 1%	12.6

Table 8. Results of washout mass loss test determined by pressurized air tube

Mix Symbol	Water Depth, (m)	Weight Loss, (W%)
M1-S-AWA 0%	10	6.6
	20	7.6
	30	8.7
	40	9.8
	50	15.5
M2- S -AWA 1%	10	1.6
	20	2.9
	30	3.6
	40	4.1
	50	6.5
M3-LSP-AWA 0%	10	7.7
	20	9.8
	30	12
	40	15.8
	50	20.2
M4-LSP-AWA 1.0%	10	2.1
	20	3.4
	30	3.8
	40	5
	50	7.2
M5-RHA-AWA 0%	10	8.3
	20	11.1
	30	16
	40	20
	50	28
M6-RHA-AWA 1%	10	3
	20	4.1
	30	4.5
	40	6.2
	50	8.6

It is clearly from tables that antiwashout concrete that have usage of AWA reduced more significantly the loss of mass by washout than concrete that don't use AWA. For example, it found that the concrete mixes made with silica fume and and SP with dosage of 0.01 kg, increasing AWA percentage from 0 % to 1%, leads to decrease the loss of mass by washout by 56.6%. These values were 69.5% and 67.7% for concrete mixes made with Lime stone powder and Rice husk ash respectively. This illustrates the ability of the long chain AWA polymers to develop the degree of water retention by adsorbing onto cement grains along with water, hence reducing washout loss (Assad et al., 2010).

The substitution of 10% cement by silica fume resulted in reduction in washout loss. Silica fume concrete with (0-1) % AWA dosage shows better washout resistance compared with similar concrete made with limestone powder and Rice husk ash by (42.4 – 18) % and (51.5 - 35) %, respectively.

The increase in air pressure gradually over the submerged plastic concrete sample that simulated the increase in water head leads to W increase. For example, in the case of silica fume mix with AWA 0%, W increase from 6.6 to 9.8 when the overhead pressure increased from 1 to 4 bar corresponding to 10 to 40 m of water head. This clearly indicates that at the casting point washout is directly dependent on water depth as shown in Fig. 2 and Fig. 3. For example, when use 1% AWA by weight of cement, the weight loss decreased from 15.5% to 6.5 % respectively, at overhead pressure corresponding to water head 50 m, which indicate that washout is dependent on water depth at the certain point.

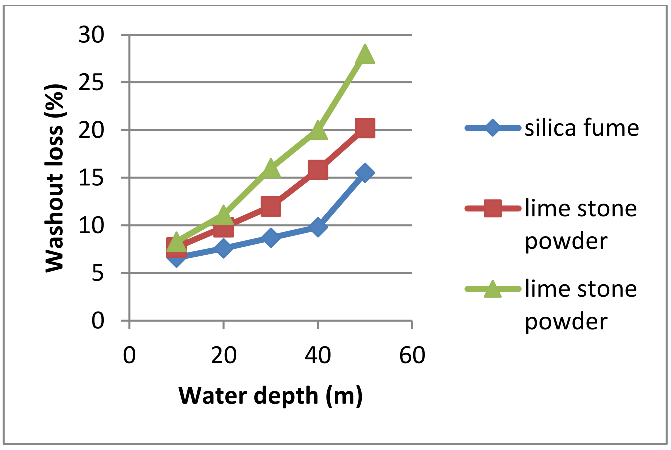

Fig. 2. Relationship between water depth and washout loss without AWA

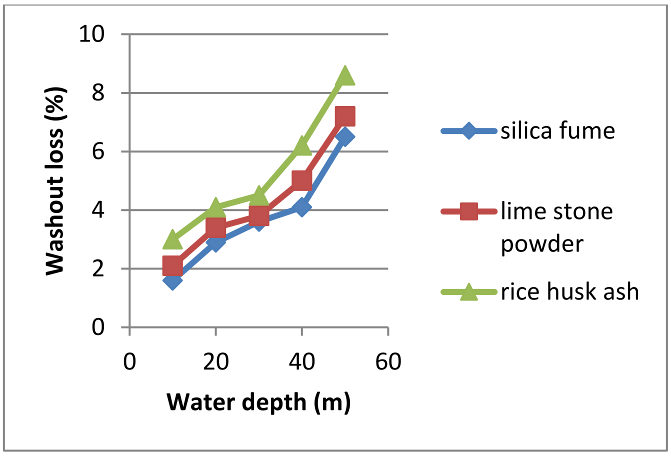

Fig. 3. Relationship between water depth and washout loss with AWA

The result showed that concrete mixes contain silica fume had lowest washout loss compared with mixes contain lime stone powder and rice husk ash. For example, at overhead pressure (4 bar) and 0% AWA the washout loss of mix contain silica fume was 9.8. This value was 15.8 % and 20% for mixes contain lime stone powder and rice husk ash, respectively.

The variations of weight loss determined by CRD-C61 with respect to the threshold water head and the corresponding weight loss determined by simulation are plotted in Fig. 4. Concrete with a lower weight loss can be casted at a deeper water depth or higher threshold depth

The increase in H for UWC mixtures exhibiting lower W3 values can be attributed to the fact that this category of mixtures possesses a more cohesive concrete/water interface, thus leading to better resistance against increased overhead water pressure (Assaad et al., 2009).

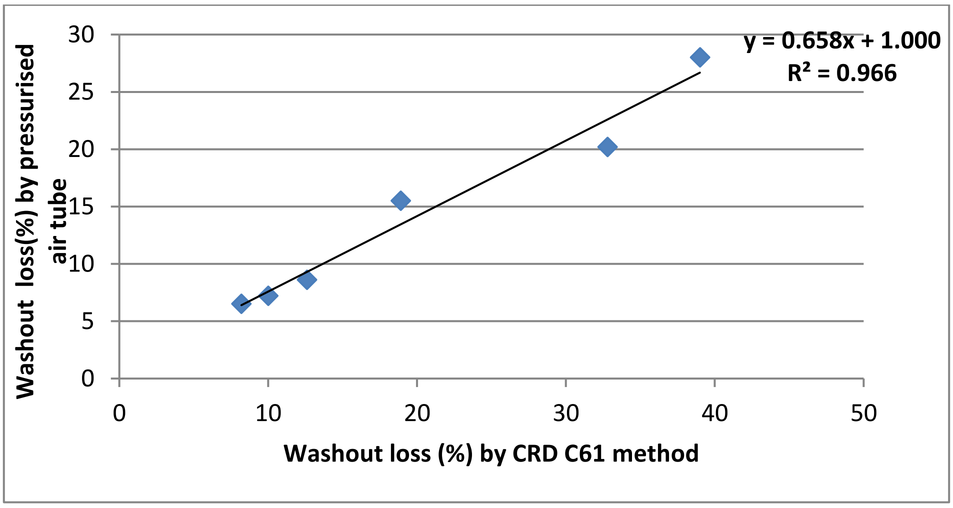

Fig. 4. Relation between standard washout loss W3 and washout characteristics determined by pressurized air tube

3.5. Compressive strength results

The mechanical properties of underwater concrete have been investigated in terms of compressive strength at 28 days. The compressive strength of all tests were determined by using cubic specimens with dimensions of 100*100*100 mm and using the same concrete that determined after washout test. The residual strength (in%) was calculated as the ratio of the reference compressive strength determined in dry conditions minus the strength determined using the sample taken after washout measurement, divided by the reference strength in dry conditions. Compressive strength for reference mix tested in 28 days and casted above water (in air), for cube cast underwater (fc uw) and The residual strength (in%) with various water pressure, concentration of AWA (0 and 1) %, for cement replacement by weight by silica fume, lime stone powder and rice husk ash and for Pressurized air tube and CRD C61 test in Table 9 and Table 10, respectively.

The concrete compressive strength of test specimens casted in the air is generally greater than that of cast underwater. This also agrees with the results given in Table 9 and 10. This could be attributed to the contamination of fresh concrete resulting from water erosion. Generally, compressive strength of test specimens made in air (casting in air) is lowered by using of the amount of AWA. This is due to the amount of AWA increased that can lead to an increase in air-entrainment that will tend to lower the compressive strength (Heniegal, 2012). For mix made with Silica fume, Lime stone powder and Rice husk ash, as a result of using (0% -1%) of AWA of by weight of cement, the compressive strength of the concrete specimens cast in air reduced from (41 to 39.5), (39 to 37.5) and from (32 to 30.5) N/mm2 respectively. furthermore, compressive strength of test specimens made in water (concrete after washout) increased by an increase of the amount of AWA. For example, due to changing AWA of (0% - 1%) by weight of cement, the compressive strength of the concrete was from (16 to 33.8), (9.5 to 31.8) and (7.3 to 25.6) at water depth 50 m for concrete mix made with Silica fume, Lime stone powder and Rice husk ash, respectively.

The relationship between washout loss determined using either CRD C61 or the pressurised air tube and residual strength is plotted in Fig. 5 and 6 for all tested UWC mixtures.

Table 9. Results of fc for pressurized air tube

Mix Symbol	Water Depth (m)	fc Air (MPa)	fc uw (MPa)	The Residual Strength (%)
M1-S-AWA 0%	10	41	30.5	74.4
	20	41	27	65.8
	30	41	23.9	58.3
	40	41	20.1	49
	50	41	16	39
M2- S -AWA 1%	10	39.5	38.5	97.5
	20	39.5	37.3	94.4
	30	39.5	36.4	92.1
	40	39.5	35	88.6
	50	39.5	33.8	85.5
M3-LSP-AWA 0%	10	39	19.8	50.7
	20	39	13.4	34.3
	30	39	12.8	32.8
	40	39	12	30.7
	50	39	9.5	25.6
M4-LSP-AWA 1.0%	10	37.5	35	93.3
	20	37.5	34.2	91.2
	30	37.5	33.3	88.8
	40	37.5	32	85.3
	50	37.5	30.1	80.2
M5-RHA-AWA 0%	10	32	15.6	48.7
	20	32	11.6	36.3
	30	32	11.2	35
	40	32	9.8	30.6
	50	32	7.3	22.8
M6-RHA-AWA 1%	10	30.5	28.6	93.8
	20	30.5	27.8	91.1
	30	30.5	27	88.5
	40	30.5	26.2	85.9
	50	30.5	25.6	83.9

Table 10. Results of 28 days compressive strength for CRD C61 test

Mix Symbol	fc Air (MPa)	fc uw (MPa)	The Residual Strength (%)
M1-S-AWA 0%	41.0	12.5	30.50
M2-S-AWA 1%	39.5	30.8	78.00
M3-LSP-AWA 0%	39.0	8.5	21.80
M4-LSP-AWA 1.0%	37.5	30.5	81.30
M5-RHA-AWA 0%	32.0	6.8	21.25
M6-RHA-AWA 1%	30.5	22	72.10

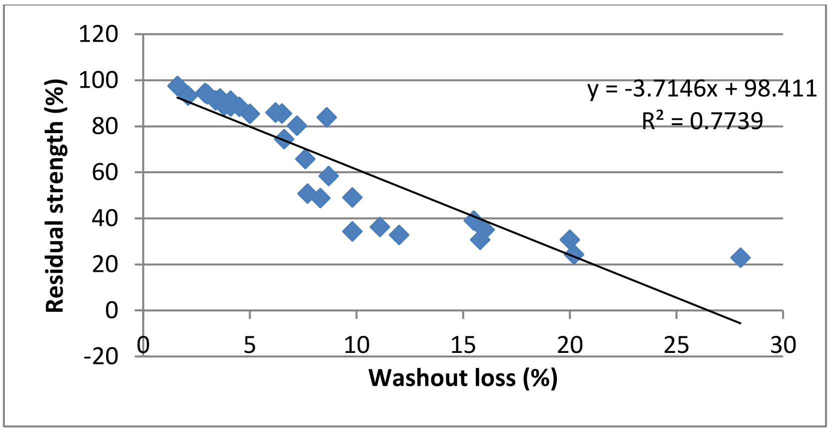

Fig. 5. Relationship between washout loss determined by CRD C61 method and Residual strength

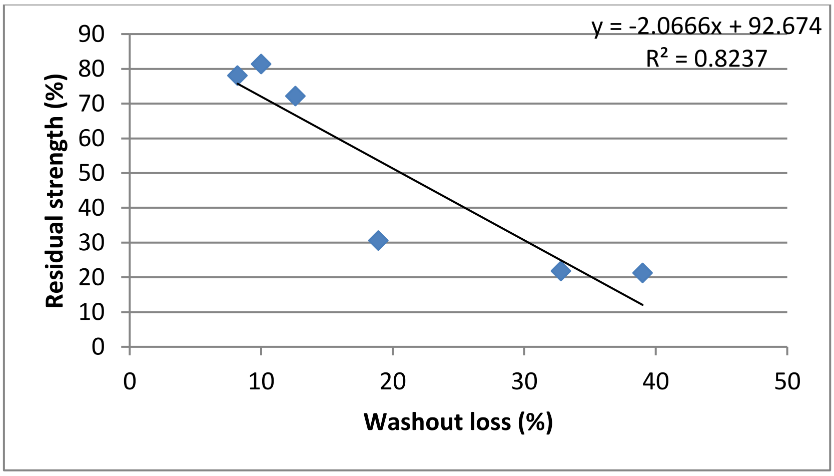

Fig. 6. Relationship between washout loss determined by pressurized air tube method and Residual strength

Loss in strength is found to increase for mixtures exhibiting increased washout losses for mixes with and without AWA as shown in Figs. 7 and 8. For example, when washout loss increased from 1.6 to 8.7 and 15.5%, the residual compressive strength decreased from approximately 97.5 to 58.3 and 39 % respectively. As already indicated, this can be attributed to the relative loss of cement paste and infiltration of water into the concrete. It can thus be stated that hardened UWC properties are governed by the washout loss that occurs during the casting process. Depending on the allowable loss in strength, both the CRD C61 test method and the pressurised air tube method can be used to estimate maximum washout loss and corresponding residual compressive strength.

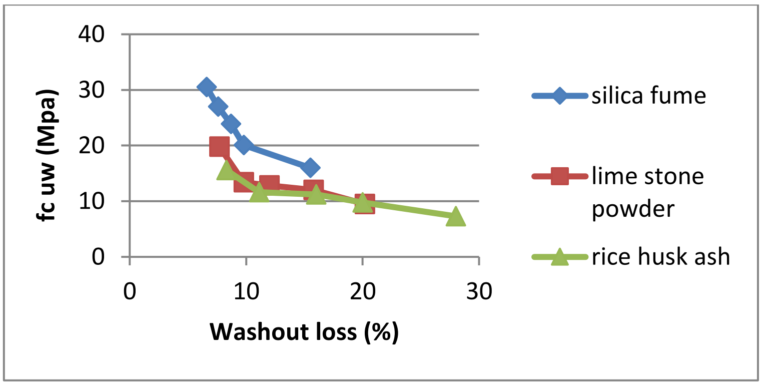

Fig. 7. Relationship between washout loss and under water compressive strength without AWA

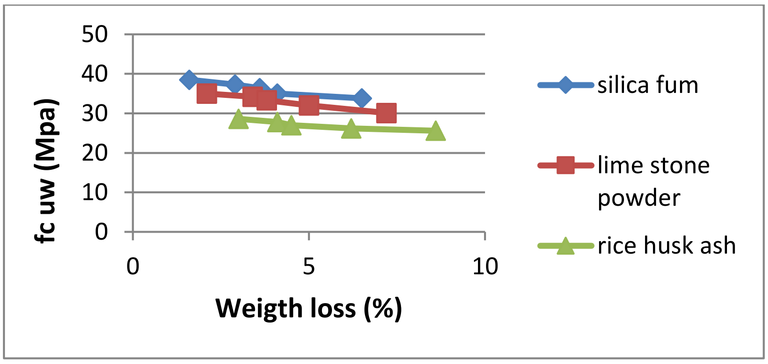

Fig. 8. Relationship between washout loss and under water compressive strength with AWA

The silica fume concrete with and without AWA dosage exhibit better compressive strength and residual compressive strength compared with similar concrete made with limestone powder and rice husk ash. The silica fume concrete gives more underwater compressive strength when the dosage of AWA (0 – 1) % than limestone powder and rice husk ash by (40.6-10.95) % and (54.4-24.24) %, respectively.

4. CONCLUSIONS

The main conclusions and limitations come up with this study could be summarized as following:

1. For non AWA mixes contain silica fume, lime stone powder and rice husk ash, slump flow were 700, 750 and 660 respectively. Whereas; for similar concrete mixes contain 1% AWA, slump flow was 500, 515 and 500 respectively.

2. T50 values increased with the increase in dosage of AWA from 0% to 1%. For concrete mixes contain silica fume, the T50 results varied between (2.6 to 46) sec. These values were 2.1 to 25 sec and 2 to 58 sec for concrete mixes made with limestone powder and rice husk ash, respectively.

3. For concrete containing silica fume (without AWA), limestone powder and rice husk ash, J-ring values were 650,705, and 610 mm respectively. While for similar concrete mixes contain AWA, J-ring values were 500, 515 and mm, respectively.

4. The mixes that made with limestone powder had higher slump flow compared with similar mixes made with silica fume and rice husk ash by (6.67- 2.91) % and (12 - 2.91) % respectively. When increasing AWA from (0-1) %. as well as higher J-ring values by (7.8 - 2.9) % and (13.47 - 3.9) % respectively.

5. AWA is used to reduce separation of concrete constituents is especially advantageous when casting deep lifts using high fluid concretes. For non AWA concrete mixes contain silica fume limestone powder and rice husk ash, segregation resistance values were 8.5, 13.5, and 9.8 % respectively. While segregation resistance was eliminated for similar concrete mixes contain AWA.

6. The washout resistance of underwater concrete can be significantly enhanced by using 1% AWA concentration despite the additional SP dosage necessary to maintain high consistency and self-consolidated. For concrete mixes made with silica fume, increasing AWA dosage from 0% to 1% decreases the standard washout mass loss by 58%% respectively. These values were 64.35% and 69.28% respectively, for similar concrete mixes containing limestone powder and rice husk ash.

7. Silica fume concrete contains (0-1) % percentage of AWA behaves better in washout resistance compared with similar concrete made with limestone powder and rice husk ash by (42.4- 18) % and (51.5 - 34.9) % respectively.

8. Washout loss of UWC increased with increase in water depth. AS a result of changing water depth from (10 to 50) m which corresponding overhead pressure from (1 - 5) bar, the weight

loss increase by 57.4%, 61.9% and 70.3 % for concrete mixes contain silica fume, lime stone powder and rice husk ash respectively.

9.Good correlations were obtained between the standard washout loss determined according to CRD C61 and the simulated threshold water head and corresponding maximum washout loss.

10. By increasing AWA dosage from 0% to 1%, for mixes that contain silica fume, the compressive strength of concrete cast in water increment in this case was found 52.6%. These values were 68.4% and 71.5% respectively for similar mixture made with limestone powder and rice husk ash respectively.

11. The silica fume mixes give more compressive strength than limestone powder and rice husk ask mixes by (40.6 - 10.95) % and (54.4 - 24.24) %, respectively, for AWA dosages from (0 - 1) %. As well as the maximum relative compressive strength is 97.5% and for concrete with 10% silica fume containing 1% AWA at 10 m depth of water.

12. Residual compressive strength was look like proportional to washout loss determined using either the CRD C61 test method or the pressurized air tube, for washout loss 1.6%, 12% and 28% the corresponding residual strength were 97.5%, 30.7% and 22.8%, respectively.

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